



Reliability Analysis of a Distribution Network Using ETAP Software

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ABSTRACT

The reliability of a distribution network is important to both electricity providers as well as consumers. This is even more so when the consumer consist of sensitive loads like hospital equipment as is the case with Delta State University Teaching Hospital (DELSUTH). Making use of data collected between February 2021 to January 2022 the reliability of the Delta State University Teaching Hospital (DELSUTH) 7.5 MVA, 33/11 kVA distribution network has been analyzed, on a sub-station by substation basis using the ETAP 16.0 software. Distribution system data as well as reliability data from DELSUTH has been used to model the network using ETAP 16.0 and to run reliability analysis on the network. Also analytical methods have been used to validate the ETAP 16.0 results for reliability based on interruption frequency and duration. Comparing the results obtained with the IEEE standard 1366 of 2011 it is seen that while most distribution substations of the DELSUTH network appear to meet up the IEEE standard in terms of interruption frequency (SAIFI) they however fall short of the standard in terms of duration of interruption (SAIDI)

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INTRODUCTION

The reliability of an electric power network is a very important subject. This is so because society as it were today has come to depend heavily on electric power supply whether it be in domestic, commercial or industrial capacity (Cruz, Alvarez, Al-Sumaiti, & Rivera, 2020). Also, when a distribution network is reliable it becomes beneficial to both power providers and consumers. A reliable distribution network is beneficial to the power provider as there is less downtime due to equipment failure or malfunction which means less is spent on equipment repairs and income from energy sale is increased (Amakiri & Oshevire, 2020). On the other hand a reliable network is beneficial to the power consumer as it means more value for money spent on purchase of power whether for commercial or domestic application.

The reliability of an electrical power network has to do with the ability of the network to provide a steady, uninterrupted and good quality power to all categories of consumers whether industrial, commercial or domestic. In other words reliability has to do with frequency and duration of power outages experienced on the network. From the foregoing therefore, a

power system with fewer and shorter downtimes will be considered more reliable compared to a power system with more downtimes. It is also worthy of notice that while the system could be seen as reliable based on frequency of interruption it might not be reliable in terms of duration of interruption. This is why the reliability analysis has to be done both on the basis of interruption frequency as well as duration (Antikainen, Repo, Verho, & Järventausta, 2009).

Since a power system is divided into generation, transmission and distribution the overall reliability of the power system depends on the reliability of these separate parts (Onohaebi.s.o & Omorogiuwa, 2014). Since each part of the power system contain several components which enable it function properly the reliability of each part of the power system would depend on the reliability of the individual components making up that part. For proper evaluation of the reliability of a network or any particular component on the network reliability data must be available (Gono, Krátký, & Rusek, 2012). This reliability data should provide information about the frequency of failure as well as duration of failures experienced. The

accuracy of the reliability analysis will depend on the quality of data that is available to the engineer. This therefore shows the importance of reliability records to the reliability analysis procedure.

Generally, reliability analysis on any power system can be done in three levels (figure 1) known as hierarchical levels (HL) (Amakiri & Oshevire, 2020). The first level of analysis is

known as hierarchical level 1 (HL1). The HL1 is concerned about whether or not the generated power is sufficient for the load. The second level of analysis is known as hierarchical level 2 (HL2). The HL2 covers the reliability of both the generation and transmission systems. The third level of reliability study is the hierarchical level 3 (HL3) which covers the entire power system from generation to distribution.

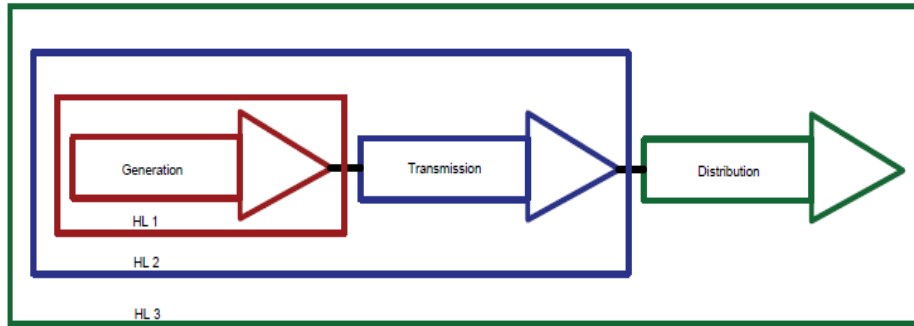


Figure 1. Hierarchical levels of reliability analysis

Several indices exist for power system reliability analysis. These indices are the system average interruption duration index (SAIDI) and system average interruption frequency index (SAIFI) (Niu, Wang, Pan, Peng, & Liu, 2021). While the SAIDI measures reliability by the duration of power outage experienced on the system SAIFI analyses reliability by measuring the frequency of power interruption experienced on the network. Other indices include customer average interruption index (CAIDI), average service availability index (ASA) and average service unavailability index (ASUI).

In practice these reliability indices can be evaluated using simple load point indices such as average failure rate (λ_p), annual outage duration (μ_p), average outage duration (ν_p), mean time before failure (MTBF) and mean time to repair (MTTR). Equations 1 to 5 present expressions for evaluating the simple load point indices, while reliability indices SAIDI, SAIFI, CAIDI, ASAI and ASUI are evaluated using equations 6 to 10 (Gana, Dalyop, & Mustapha, 2020).

$$\text{Average failure rate } (\lambda_p) = \frac{\sum F}{T} \text{ int./yr} \quad 1$$

Where F represents failure frequency and T represents time in hours.

$$\text{Annual outage duration } (\mu_p) = \frac{\sum T\Delta x}{T} \text{ hrs/yr} \quad 2$$

Where $T\Delta x$ represents down time at any particular load point.

$$\text{Average outage duration } (\nu_p) = \frac{\mu_p}{\lambda_p} \text{ hrs/int.} \quad 3$$

$$\text{Mean time to failure (MTTF)} = \sum \frac{T}{F} \quad 4$$

$$\text{Mean time to repair (MTTR)} = \sum \frac{T\Delta x}{F} \quad 5$$

$$SAIFI = \frac{\text{total number of customer interruptions}}{\text{total number of connected customers}} = \frac{\sum(\lambda_p N_i)}{\sum N_T} \quad \text{int/cust.} \quad 6$$

Where N_T and N_i represents number of consumers on load point and duration of individual interruptions

$$SAIDI = \frac{\text{total duration of customer interruptions}}{\text{total number of connected customers}} = \frac{\sum(\mu_p N_i)}{\sum N_T} \quad \text{hrs/cust.} \quad 7$$

$$CAIDI = \frac{\text{total duration of all interruptions}}{\text{total number of all interruptions}} = \frac{\sum(\mu_p N_i)}{\sum(\lambda_p N_i)} = \frac{SAIDI}{SAIFI} \quad \text{hrs/int.} \quad 8$$

$$ASAI = \frac{\text{total duration of availability}}{\text{total hours of demand}} = \frac{8760 \sum N_T - \sum(\mu_p N_i)}{8760 \sum N_T} \quad 9$$

$$ASUI = 1 - ASAI \quad 10$$

To underscore the importance of reliability of a distribution network some countries have set up a reward and penalization scheme depending on whether or not the reliability standards are met by distribution companies (Sadeghian, Nazari-Heris, Abapour, Taheri, & Zare, 2019). In (Escalera, Hayes, & Prodanović, 2018) some techniques for improvement of reliability such as distributed generation, energy storage, demand response, electric vehicles, automation of protective devices and microgrids have been discussed.

The purpose of this paper therefore is to analyze the Delta State University Teaching Hospital (DELSUTH) 7.5 MVA 33/11 kV distribution network on a substation by substation basis with a view to ascertain its level of reliability.

MATERIALS AND METHOD

Materials

The materials used in this research are data collected from the DELSUTH 7.5 MVA

33/11 kVA distribution network and ETAP 16.0 power system simulation software. Data gathered, over a 1 year period (February 2021 to January 2022) from the DELSUTH distribution network daily logs have been used to model the network in ETAP 16.0 software simulation environment. The ETAP simulation software has also been used to run a reliability analysis on the network.

Network Description

The Delta State University Teaching Hospital (DELSUTH) is located on Otefe road, Oghara in Ethiopia west local government area of Delta State, Nigeria. Power to the facility is supplied through the DELSUTH 7.5 MVA, 33/11kv injection substation which receives power from Transmission Company of Nigeria (TCN), 2x30 MVA, 132/ 33kv transmission substation sited near Sapele town in Delta State. Figure 2. presents a photo view of DELSUTH 7.5MVA, 33/11 injection Substation.



Fig.2. DELSUTH 7.5MVA, 33/11 injection Substation.



The various load centers in the DELSUTH distribution network are supplied through thirteen 11/0.415 kV distribution transformers which are fed from two separate feeders attached to the 7.5 MVA 33/11 kV injection substation. While feeder 1 feeds nine of these 11/0.415 kV distribution transformer

feeder 2 has four 11/0.415 kV distribution transformers on it. Figure 3 presents the single line diagram model of the DELSUTH distribution network in ETAP software environment while table 1 presents the different distribution transformers along with some system data.

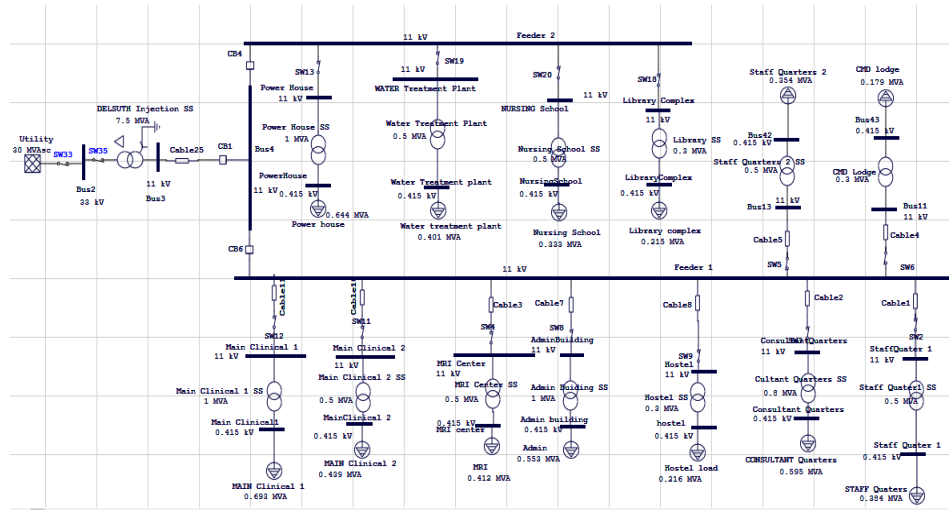


Fig. 3. DELSUTH distribution network in ETAP software environment

Table 1. Distribution transformers on feeders 1 and 2 with some accompanying data

SN	LOAD POINT ID	TRANSFORMER RATING (KVA)	NUMBER OF CONSUMERS	FAILURE FREQUENCY	ANNUAL UPTIME (HRS)	ANNUAL DOWNTIME (HRS)
FEEDER 1						
1	Main clinical 1	1000	5622	112	6894	1639
2	Main clinical 2	500	3987	158	7367	1065
3	MRI center	500	520	138	5387	3371
4	Admin building	1000	580	120	6327	2433
5	Hostel	300	1896	89	4994	3766
6	Consultant qtrs	300	89	210	7024	1736
7	Staff quarters 1	500	320	101	6902	1858
8	Staff quarters 2	500	350	183	6099	2661
9	CMD lodge	300	50	96	5602	3158
FEEDER 2						
1	Power house	1000	150	39	6235	2525
2	Water treatment plant	500	50	46	7899	861
3	Nursing school	500	1983	174	4239	4521
4	Library complex	300	568	250	6710	2050

Method

The method that has been adopted in the research is to evaluate the reliability indices of the distribution network using ETAP reliability analysis tool (Figure 4). The distribution network data displayed in table 1 has been used to

model the distribution network and to compute the indices for the different load points using equations 1 to 5. The values of the computed indices are presented in table 2. These computed simple load indices values are then used to compute the system reliability indices

namely SAIFI, SAIDI, CAIDI. These system reliability indices are presented in table 3. The calculated reliability indices and ETAP simulation results are compared with IEEE

standards to determine if they meet up to the standards. Calculated and simulated results are presented in the results section.



Fig. 4. Research method implementation

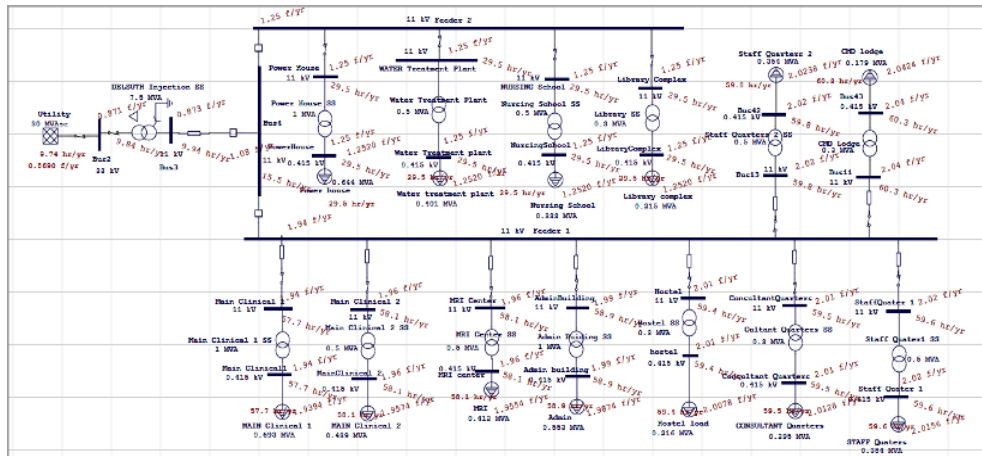


Fig. 5. ETAP reliability tool interface

ETAP 16.0 has been used to model the injection substation and distribution network including the different load centers feeding from the injection substation. ETAP 16.0 possesses a comprehensive reliability tool. The interface for the reliability analysis study case is shown in figure 5.

The results of the calculations and simulations made in the previous section are presented here. The results of simple load point reliability indices λ_p , μ_p and ν_p are presented in table 2 while the results of the calculations of the system reliability indices SAIFI, SAIDI and CAIDI are presented in table 3. The results of the ETAP reliability analysis simulation is presented in table 4 and table 5 compares the simulation results with IEEE standards.

RESULTS AND DISCUSSION
Results

Table 2. Load point reliability indices

S/N	LOAD POINT ID	AVERAGE FAILURE RATE (λ_p) (INT./YR)	ANNUAL OUTAGE DURATION (μ_p) (HR/YR)	AVERAGE OUTAGE DURATION (ν_p) (HRS/INT)
1	Main clinical 1	0.013	0.864	67.554
2	Main clinical 2	0.018	0.159	8.816
3	MRI center	0.016	0.385	24.428
4	Admin building	0.014	0.278	20.275
5	Hostel	0.010	0.430	42.315
6	Consultant quarters	0.024	0.198	8.267
7	Staff quarters 1	0.012	0.212	18.396
8	Staff quarters 2	0.021	0.304	14.541
9	CMD lodge	0.011	0.361	32.896



10	Power house	0.004	0.288	64.744
11	Water treatment plant	0.005	0.098	18.717
12	Nursing school	0.020	0.516	25.983
13	Library complex	0.029	0.234	8.200

Table 3. System reliability indices for the distribution substations

SN	DISTRIBUTION SUBSTATION ID	SAIFI (INT/CUST)	SAIDI (HRS/CUST)	CAIDI (HRS/INT)
1	Main clinical 1	0.017	1.162	67.554
2	Main clinical 2	0.006	0.056	8.816
3	MRI center	0.102	2.495	24.428
4	Admin building	0.057	1.165	20.275
5	Hostel	0.020	0.854	42.315
6	Consultant quarters	0.468	3.865	8.267
7	Staff quarters 1	0.067	1.232	18.396
8	Staff quarters 2	0.159	2.309	14.541
9	CMD lodge	0.692	22.769	32.896
10	Power house	0.075	4.852	64.744
11	Water treatment plant	0.090	1.693	18.717
12	Nursing school	0.045	1.177	25.983
13	Library complex	0.103	0.845	8.200

Table 3. ETAP simulation results

SN	LOAD POINT ID	AVERAGE FAILURE RATE (λ_p) (INT./YR)	ANNUAL OUTAGE DURATION (μ_p) (HR/YR)	AVERAGE OUTAGE DURATION (γ_p) (HRS/INT)
1	Main clinical 1	0.043	1.964	45.67
2	Main clinical 2	0.038	0.359	9.45
3	MRI center	0.026	0.695	26.73
4	Admin building	0.034	0.678	19.94
5	Hostel	0.04	1.87	46.75
6	Consultant quarters	0.021	0.2	9.52
7	Staff quarters 1	0.014	0.21	15.00
8	Staff quarters 2	0.023	0.3	13.04
9	CMD lodge	0.025	0.81	32.40
10	Power house	0.008	0.498	62.25
11	Water treatment plant	0.01	0.18	18.00
12	Nursing school	0.09	1.916	21.29
13	Library complex	0.024	0.231	9.63

Table 4. Comparing system reliability indices with IEEE standards

SN	DISTRIBUTION SUBSTATION ID/IEEE STANDARD	SAIFI (INT/CUST)	SAIDI (HRS/CUST)	CAIDI (HRS/INT)
1	IEEE standard 1366	0.6 – 0.75	1.5	1.36
2	Main clinical 1	0.017	1.162	67.554
3	Main clinical 2	0.006	0.056	8.816
4	MRI center	0.102	2.495	24.428
5	Admin building	0.057	1.165	20.275
6	Hostel	0.020	0.854	42.315



7	Consultant quarters	0.468	3.865	8.267
8	Staff quarters 1	0.067	1.232	18.396
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10	CMD lodge	0.692	22.769	32.896
11	Power house	0.075	4.852	64.744
12	Water treatment plant	0.090	1.693	18.717
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14	Library complex	0.103	0.845	8.200

The bar chart illustrations of figures 6, 7 and 8 also represent the reliability indices for the DELSUTH distribution network. While figure 6 represent the simple load point reliability

indices figure 7 represents the system reliability indices and figure 8 represents a comparison between the calculated and simulated results.

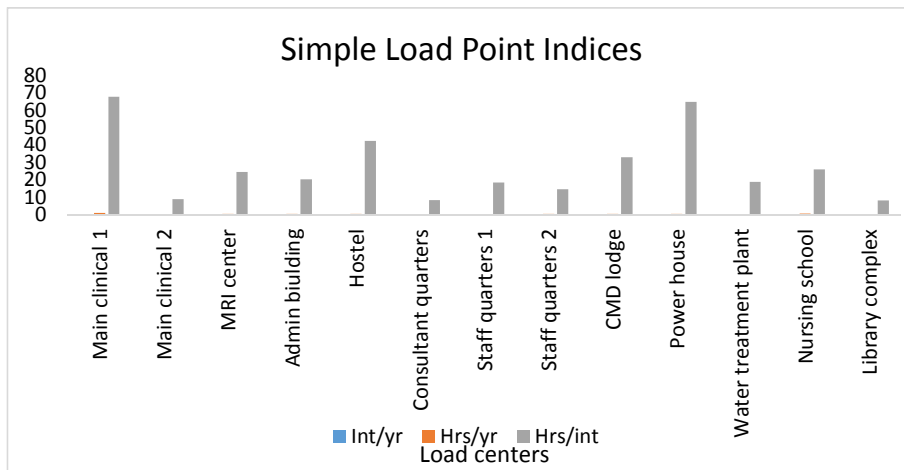


Fig. 6. Bar chart representation of simple load point reliability indices

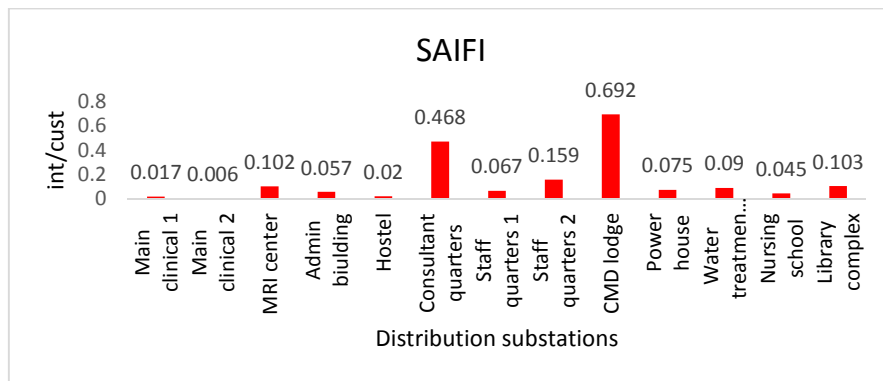


Fig. 7. Bar chart representation of SAIFI.

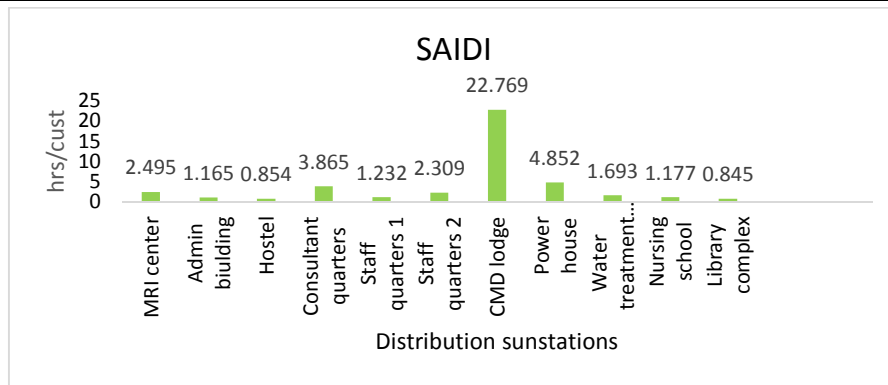


Fig. 8. Bar chart representation of SAIDI values

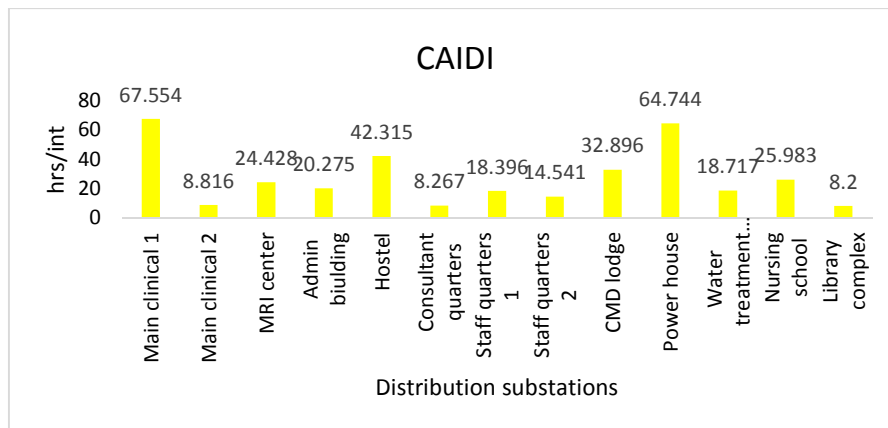


Fig. 9. Bar chart representation of CAIDI values for different substations.

DISCUSSION

Due to the importance of the reliability of the distribution system and for the purpose of a uniform platform the IEEE came up with a benchmark as stated in the IEEE standards 1366 of 2011. From the IEEE standards 1366 of 2011 reliability indices for a system should not go beyond certain limits as presented in table 4. Now comparing the results obtained from this research with the IEEE standards it is seen that while the system as performed reasonably well with regards to some of the indices the system has fallen short going by other indices. Also while some distribution substations have performed well over the 1 year period some others have not performed so well.

From table 3 and figure 7 it is seen that main clinical 1 has the lowest SAIFI value of 0.006 interruptions/customer while CMD lodge has the highest SAIFI value of 0.692 interruptions/customer. Table 3 and figure 8 also show that hostel distribution substation has

the lowest SAIDI value of 0.854 hrs/customer while CMD lodge has the highest value of 22.769 hrs/customer. With regards to CAIDI values table 3 and figure 9 reveal that main clinical 1 has the highest value of 67.554 hrs/interruption while library complex has the lowest figure of 8.2 hrs/interruption.

CONCLUSIONS

In general, the reliability of the power system is a measure of the probability of the system to carry out its functions as expected for the duration and operations capabilities required of it. In this research the reliability of DELSUTH 7.5 MVA, 33/11 kVA distribution system has been analyzed in terms of frequency (SAIFI) and duration (SAIDI) of power outages experienced by the various load points being fed from the different distribution substations.

By making reference to table 4 and comparing the results obtained for the various



indices with IEEE standard 1366 of 2011 its seen that all but one (CMD lodge) of the SAIFI values fall outside the desired range of values. Considering the values obtained for SAIDI and comparing with the IEEE standards seven out of the thirteen distribution substations fall within range while the other six fall out of acceptable range. Looking at the values obtained for CAIDI all substations are seen to be out of range.

From the foregoing therefore it can be concluded that while some substations can be considered reliable in terms of one index they are found to be unreliable in terms of other indices. In general while the distribution system appears reliable in terms of interruption frequency (SAIFI) it is not reliable in terms of duration of interruption (CAIDI).

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