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Original Research Article

Reliability Indices of Electric Power Distribution System in Ilorin, Nigeria

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ABSTRACT

The failure probability and epileptic power supply is a pointer to the reality that there is a need for reliability studies and fault evaluation of the electric power system in Nigeria. The recent blackout faced in the country has paralyzed many activities and has destroyed many industrial processes. Therefore, it is worth considering reliability assessments as it provides an opportunity to incorporate the cost or losses incurred by the utility customer as a result of a power failure and this must be considered in planning and operating practices. The reliability assessment and estimation of indices were carried out on selected 11 kV injection substations feeders in Ilorin, Nigeria. Using the analytical method and network reduction technique, the substation reliability was analyzed based on recorded outage data. Results show the low level of reliability of power supply to customers on the feeder, the failure rate is quite on the high side and a low system average interruption frequency index was recorded on most feeders. The overall system availability shows that the system needs improvement and quick response to network failure.

1. INTRODUCTION

Electricity supply in Nigeria today is known for its inadequate, epileptic and unreliable nature. Indeed, the government has been making a significant effort for improvement, but the result is still far from the expected. To ensure a constant supply of power, a huge amount of money is required to increase generation, transmission capacities, and distribution networks. Hence, the maintenance of the existing network becomes a necessity. Due to this fact, there is an urgent need for fault evaluation and reliability studies of the electric power system in Nigeria. The electric power distribution substations are the most critical part of a power system because the power equipment in the distribution substation connects the consumers to the power grid (Awosope, 2014; Eminoglu and Uyan, 2016).

The distribution system reliability evaluation considers the ability of the distribution system to transfer energy from bulk supply points (transmission stations and local generation points) to customer loads (Eminoglu and Uyan, 2016). Generation, transmission and distribution are the three subsystems of an electric power system. A substation reliability assessment evaluates the effect of these aspects on the service continuity of the main power system connected to the substation (Zapata et al., 2010). With an increasing demand for electricity supply, the distribution companies have to achieve an acceptable level of reliability, quality, and safety at an economic price in order to guarantee improved electricity delivery and maintain consumer loyalty (Franklin and Adegboyega, 2014).

Reliability analysis helps to answer questions relating to whether the network is reliable enough, the component that fails less and which part of the system requires more financial commitment to better the system operations (Akintola et al., 2017). Some of the basic indices that have been used to assess the reliability performance are system average interruption frequency index (SAIFI), system average interruption duration index (SAIDI), customer average interruption duration index (CAIDI), average service availability index (ASAI) and the average service unavailability index (ASUI) (Cepin, 2011; Okorie et al., 2015; Braide, 2018).

SAIFI shows how often an average customer faces a sustained interruption over a predefined time period. SAIDI shows the total duration of any interruption for an average customer during a predefined time period and is generally measured in customer minutes or customer hours of interruption. CAIDI gives the mean values of the time that is necessary to restore the service provided whenever there is an outage. CAIFI shows the average frequency of sustained interruptions for customers who are experiencing sustained interruptions, and the customer is counted once without considering the number of times. ASAI shows the fraction of time (usually in percentage) in which a customer receives power during the defined reporting period. Failure rate, annual unavailability, and average outage duration are the basic indices associated with system load points (Jibril and Ekundayo, 2013; Anthony, 2014; Braide, 2018).

Reliability analyses have been performed on other networks within the country, hence the need to conduct similar research in Ilorin, Kwara State. Adegboye and Dawal (2012) assessed and discussed the reliability performance and faults that impact a typical 11kV feeder in the Southern part of Kaduna City. The feeders were assessed by analyzing the data obtained from the supply authority. Two major faults were identified, and they are earth fault and overcurrent faults. Similarly, Franklin and Adegboyega (2014) assessed the reliability of the power distribution system in Nigeria using the Ekpoma network, Edo, as a case study. Earth fault, supply failure, planned outage for maintenance, and load shedding were identified to be the possible causes for interruptions on the feeders. This was also reported by Akintola et al., (2017). The study further showed that heat during the dry season and windstorms in the rainy season were factors that could increase the failure rate of the feeders.

Thus, this study aims to investigate the reliability indices in the distribution system of some parts of Ilorin, Kwara State. Available and established methodologies found in the literature will be adopted in the analysis.

2. METHODOLOGY

The methodologies in the investigation of the reliability indices in the distribution system of some parts of Ilorin, Kwara State are presented in this section. These assessments cover a period of twelve months of data (Jan. – Dec. 2017) and data were obtained from the distribution substations authority. By collecting information on the past performance of a system, valuable insight was provided into the reliability profile of the existing system.

2.1. Network Structure

The reliability of a system depends on the component of the system and the duration of operations. Hence, the reliability of the selected network relies on the interconnection and setting of the system. The basic distribution network model on which this study was carried out forms an integral part of a basic distribution network and they are mostly referred to as injection substation or control rooms. The layout of the substations is described in Table 1.

Table 1: The Name of each injection substation and their feeders

S/No	Names of injection substations	Voltage level (kV)	Number and transformer rating (MVA)	Name of feeders
1	Agba-Dam	33/11	2x15	Tanke
				Sabo-Oke
				Agba
				Basin
				Govt. House
2	I.T.C	33/11	2x15	Babaode
				M.M
3	Gaa-Imam	33/11	1x7.5	Kilanko
4	Asa-Dam	33/11	2x15	Ganmo
				Asa Water Works
				Irewolede

2.2. Reliability Indices

The system reliability indices are the failure rate, reliability, mean time between failures (MTBF), mean time to failures (MTTR), failure probability and availability while the customer based reliability indices include the SAIDI, SAIFI, CAIDI, ASAI and ASUI (Akintola and Awosope, 2017). Failure rate (λ) represents the frequency at which the substation feeders fails over a period of time and can be expressed as in Equation (1).

$$\lambda = \frac{\text{Number of Outages a feeder}}{\text{Total time feeder is in operation}} \quad (1)$$

MTBF is one of the basic ways of measuring the reliability of repairable components in a power system. It is the expected unit of time between the occurrences of two consecutive failures for repairable systems and it is expressed as in Equation (2).

$$MTBF = \frac{Total\ operating\ hours}{number\ of\ failures} = \frac{1}{\lambda} \quad (2)$$

MTTR is the average time it takes to identify the location of a failure and to repair that failure, thereby restoring the component into normal operation. It describes the average time for which a component is out of service due to fault before it is restored to normal operation. It is expressed as in Equation (3).

$$MTTR = \frac{Total\ maintenace\ time}{Total\ number\ of\ outages} \quad (3)$$

Equation (4) is the system reliability over a given time *t*.

$$Reliability, R(t) = e^{-\lambda t} \quad (4)$$

Availability *A(t)* is the measure of the duration for which the component is in operation at any time. It deals with the duration for which the system is fully operational for its specific function. It is expressed as in Equation (5).

$$A(t) = \frac{MTBF}{MTBF+MTTR} \tag{5}$$

SAIDI is defined as the average interruption duration for customers served during a specified time period. The unit is "minutes". This index helps the utility to report for how many minutes customers would have been out of service if all customers were out at one time. It is expressed as in Equation (6).

$$SAIDI = \frac{Total\ operating\ hours}{Number\ of\ failure} \tag{6}$$

SAIFI is defined as the average number of times that a customer is interrupted during a specified time period. The resulting unit is "interruptions per customer". It is expressed as in Equation (7).

$$SAIFI = \frac{Frequency\ of\ outage}{Number\ of\ customers\ supplied} \tag{7}$$

CAIDI is defined as the average length of an interruption, weighted by the number of customers affected, for customers interrupted during a specific time period. The index enables utilities to report the average duration of a customer outage for those customers affected. It is expressed as in Equation (8).

$$CAIDI = \frac{Sum\ of\ interruption\ duration}{Total\ number\ of\ cutomer\ interrupted} \tag{8}$$

ASAI is a measure of the average availability of the distribution system that serves customers. It is usually represented in percentages. It is expressed as in Equation (9).

$$ASAI = \frac{Customer\ hours\ service\ availability}{Customer\ of\ hours\ demanded} \tag{9}$$

ASUI provides the fraction of time customers are without electricity throughout the predefined interval of time and it is expressed as in Equation (10).

$$ASUI = \frac{Duration\ of\ outages\ in\ hours}{Total\ hours\ demanded} \tag{10}$$

3. RESULTS AND DISCUSSION

The results presented in this section details the reliability analysis of the studied distribution network Ilorin. The data collected from the selected substation was used to estimate the reliability indices of the feeders and the customer reliability indices of the system.

Figure 1 presents the number of interruptions on a feeder for the whole year. Most of the feeders show an outage of above 300 in a year with Ganmo having the highest. The cause of outage depends on geographical locations of the area. From the data of 2017, the major causes of outages in the system were evaluated and presented in Table 2.

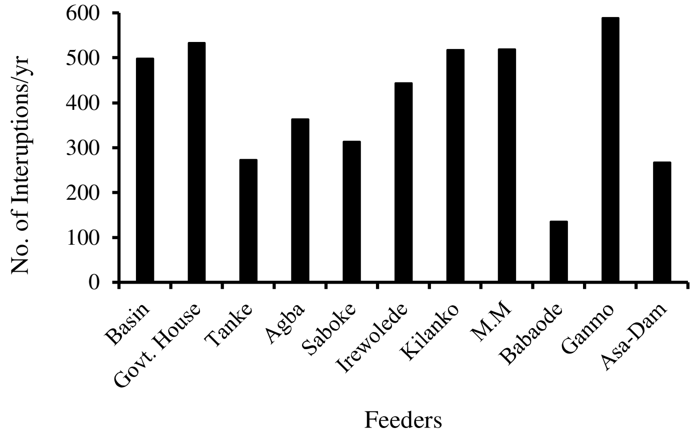

Figure 1: Feeders interruption per year

It is understood that most of the outages that occur were caused by transformer limitation, leading to load shedding in most of the distribution substations. It was also discovered that most of these outages are during the peak period when the demand is very high. Failure of the transformers, being a major contributor to the loss of supply to customers can be a result of the overloading of the transformer. This is as a result of the number of customers' loads being served or internal faults due to mechanical faults or to aging.

Table 2: Sources of interruptions

Causes	Transformer limitation	Component failure	Forced outage	Insulation defectives	Birds and trees
Numbers	2341	76	629	628	932

From the data, it could be noted that failure of components like a relay, circuit breaker, isolator failure as well as forced outages caused by earth fault, overcurrent and tripping on 33kv lines also serve as sources of outages in distribution station.

From Figure 2, it is understood that the failure rate on most feeders is very high except that of M.M feeder that is slightly better as compared to others. The frequency of interruption presented in the form of MTBF in Figure 3 implies that most feeders fail in less than 15,000 hrs. In Figure 4, the reliability of all the feeders were very low, hence customers derive low satisfaction from the supply authority. The MTTR of Figure 5 shows that the response to maintenance requires improvement. All the feeders have above 1000 hrs between interruptions.

SAIDI provides information about the average time that the customers are disconnected. The IEEE standard 1366-2003 which gives a value of 1.5 hrs. for North American Utility. Though North America has sufficient power generation and robust system security. From Figure 6, the feeders with the lowest SAIDI value implies that the causes of interruption were quickly identified, and the faults were early cleared. The feeders with the highest values were not quickly cleared and have a delay in their restoration. The feeders with the lowest SAIDI values are Basin, Tanke, Agba, Ganmo, and Babaode while feeders with the highest are Asa-dam, Kilanko, Saboke, and Govt. House.

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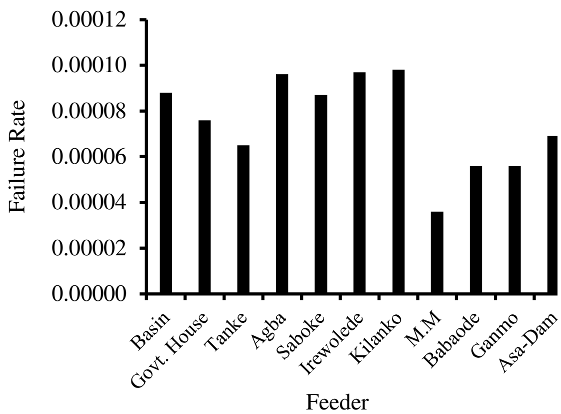


Figure 2: Annual failure rate

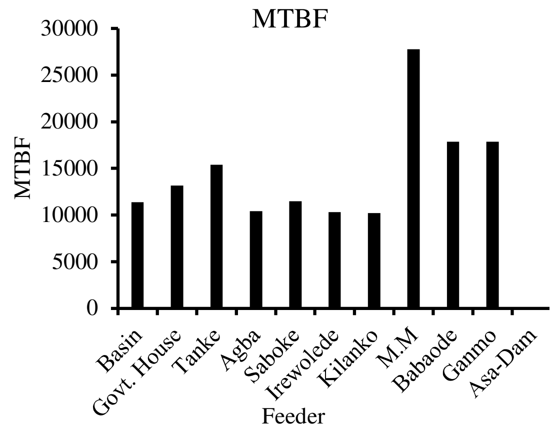


Figure 3: Annual MTBF

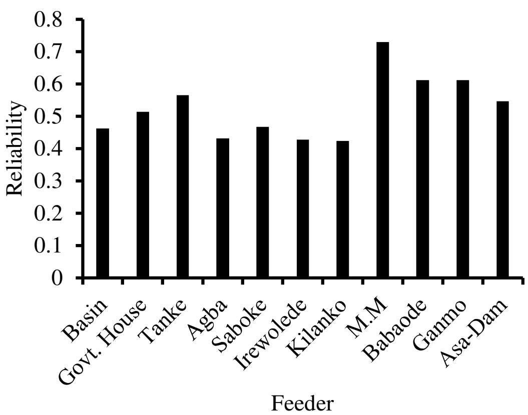


Figure 4: Annual reliability

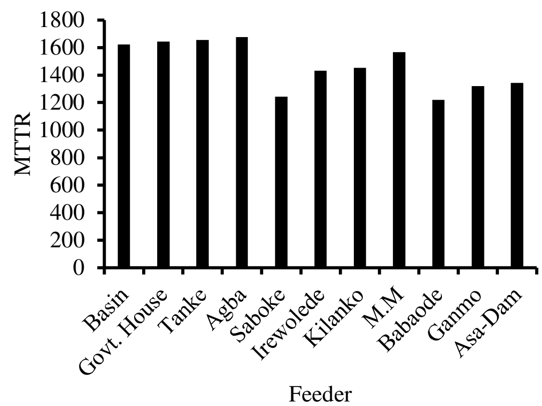


Figure 5: Annual MTTR

SAIFI measures the units of interruption per customer. It is the average number of interruptions that a customer would experience. According to IEEE Standard 1366-1998, the median value is approximately 1.10 interruptions per customer. Considering Figure 7, almost all the feeders in each substation except the Asa-dam substation have a very low value of SAIFI for the year. This means that the frequency of interruptions spread across the year is low.

CAIDI gives the average outage duration that any given customer would experience. CAIDI is also being viewed as the average restoration time. According to the IEEE standard 1366-1998 median value for North American utilities is approximately 1.36 hrs. As shown in Figure 8, a CAIDI value for Basin 11kV feeder is 6.97 which implies that it takes 6.97 hrs./day to restore power supply whenever there is an interruption. This is far greater than the IEEE standard which shows that the feeder is less reliable. Similar behavior is noticed on Govt. House feeder with 12.7 hrs./day, Tanke with 10.7 hrs./day, Sabo-Oke with 16.3 hrs./day, Irewolede with 10.1hrs/day, Kilanko with 10.5 hrs./day, M.M. with 9.5 hrs./day, Babaode with 13.3 hrs./day, Ganmo feeder with 8.52 hrs./day and Asa-dam feeder with 16.05 hrs./day.

The ASAI values plotted in Figure 9 shows that the availability of the system is very low. It is very clear that all the substations have worse and low performance and needs improvement in order to increase its reliability indices. Operators need to increase their efforts in reducing the length and duration of outages in order to improve the availability. However, it is important to note that the frequency of interruption, SAIFI is high which implies that the substation has a value of SAIFI but needs to work on reducing the duration of the outages, SAIDI and CAIDI. The main challenge, therefore, is that the substation needs to intensify efforts in reducing the length or duration of outages in order to improve the availability.

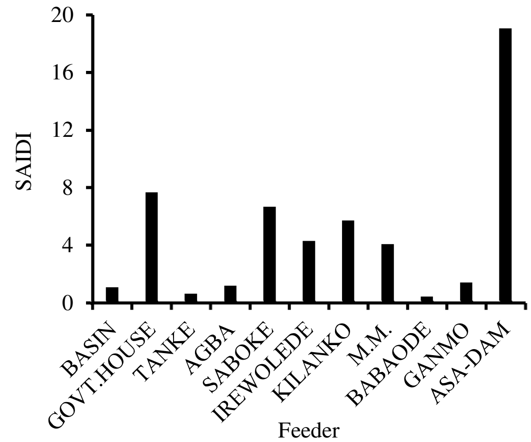


Figure 6: Annual SAIDI on all the feeders

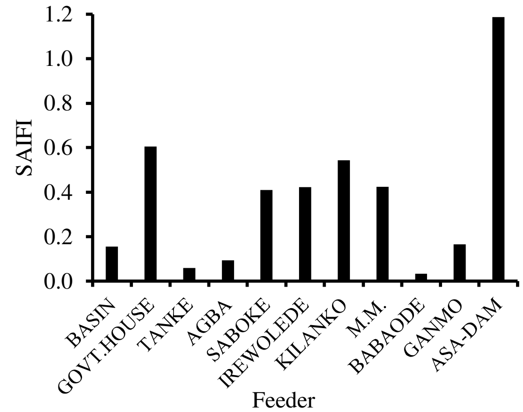


Figure 7: Annual SAIFI on all the feeders

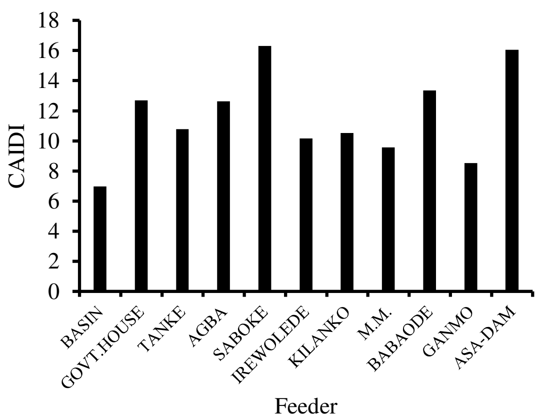
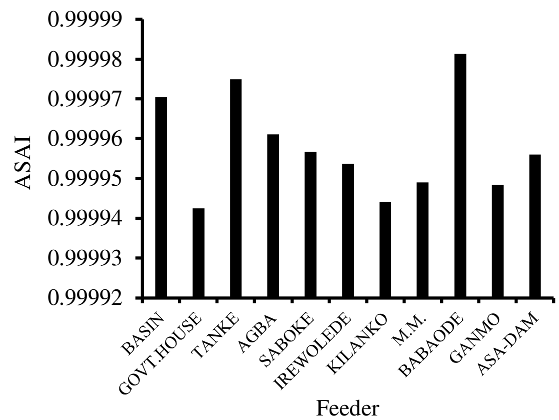


Figure 8: Annual CAIDI



Figures 9: Annual ASAI

4. CONCLUSION

The reliability assessment of selected feeders in Ilorin has been considered. All four injection substations were put into consideration. The supply of electric power in the study network is seen as less reliable. It is characterized by a large number of faults. The duration of outages or interruption of the power supply is also very high in the area. It was observed that high fault frequency affected the failure rates and reduces the reliability of the power system in the distribution area. Based on the analysis carried out, it is shown that the outage duration has more impact on the system availability than the frequency of outage. The overall reliability of the distribution system showed that the substation performance is low for the distribution system in the study network as compared to the IEEE standard benchmark. It is recommended that the distribution company in charge should replace all the obsolete equipment with new ones, to reconstruct and amend some of their network construction especially the one that passes through the forest, maintenance should be the order of the day in the distribution network, keep and publish the accurate record of interruptions such that it shows the causes and durations as these will really help to carry out research work.

5. CONFLICT OF INTEREST

There is no conflict of interest associated with this work.

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