NIPES Journal of Science and Technology Research 3(3) 2021 pp. 148-161 pISSN-2682-5821, eISSN-2682-5821

NIPES

Journal of Science and Technology Research

Journal homepage: www.nipesjournals.org.ng

Load Point Reliability Study of 33kV Feeders in Central Part of Edo State, Nigeria

E. A. Omoroghomwan[1*], S.O. Igbinovia[1], F. O. Odiase[1]

[1]Department Of Electrical/Electronic Engineering, Faculty of Engineering, University of Benin, Benin City, Edo State, Nigeria.
*Corresponding Author: efosaarnoldomoroghomwan@gmail.com

Article Info

Received 04 July 2021
Revised 12 July 2021
Accepted 18 July 2021
Available online 31 August 2021

***Keywords*:**
Power system, IEEE, Nigeria Power Sector, Load Point Indices, Reliability, Failure Rate

https://doi.org/10.37933/nipes/3.3.2021.15

https://nipesjournals.org.ng

Abstract

Reliability is the chance that a given desirable event will occur at the very time it is required and expected to occur. The power system is expected to supply power continuously to the customers for their socio-economic purposes. The inability of the power system in Nigeria to meet up this requirement prompted a lot of scholars to embark on a reliability study of the system. However, the outage data used were found to only focus on forced outages thereby neglecting other unforced events in their works. In this study, all the outages on the 33kV feeders in the Irrua Transmission station were used to assess the performances of the system from 2015 to 2018 using the load point indices. The result showed that the failure rate is on the high side and the system reliability is depreciating with time. To turn things out for the better, it was suggested that PV cells should be introduced at strategic locations within the network. The introduction of reliability-centered maintenance techniques by the management could also go a long way in bringing about better performance. This study will help the management to appraise their performance which in turn will motivate them to do better.

1. Introduction

Reliability is the chance of a desired event occurring under specified circumstance(s). However, from engineering point of view, reliability can be defined as the probability that a system will perform required function under a given conditions for a stated period, usually a thousand hours or million hours [1]. The reliability of a system or equipment as defined by Iresome and Coombs [2] is the conditional probability at any given confidence level that the system or equipment will perform its intended function at a given age, for a specific length of time when used in the manner and purpose intended while operating under specific environment. However, Bhavaraju, et al., [3] defined reliability of an electric power system as the probability that the system will continuously deliver electricity to its consumers without compromise on the quality of the power being delivered. It is also simply a measure of whether users have electricity when it is needed [4]. Furthermore, according to IEEE as in [5], the definition of reliability is simply the ability of a system or component to perform its intended functions under stated conditions for a specified period of time. Power reliability can also be defined as the degree to which the performance of the elements in a bulk system result in electricity being delivered to customers within accepted standards and in the amount desired [6].

One of the major outcomes of the weaknesses in power sector is blackout. Power outages are unpalatable events for power users whether they were scheduled or unscheduled. The scheduled events are usually as a result of the need to carry out maintenance operations on the equipment, construction and consumer requests. Most often, customers are pre-informed of such outages in advance so they could make alternative arrangements for any critical activity that may require electric power. The unscheduled events may be as a result of oversights during installation or maintenance operations, component failures and faults. These have resulted in poor power availability to customers with its attendant negative effects [7]. Records have shown that the Nigeria national grid has suffered from many system collapses in the past resulting in partial or total blackouts in the country. In 2003 alone, there were total records of 53 incidents comprising 14 total and 39 partial cases [8].

On the international scene, the study by Wirfs-Brock [9] showed that power interruption events in the United States (U.S.) have increased on the average from 2.5 to 14.5 per month during 2000 – 2013. Also, overloading of power facilities in 2012 caused the collapse of Bina-Gwalior-Agra regional grids in India [10]. In a related development, system overloading also caused Tarbela and Mangla power stations in Pakistan to fail thereby causing blackout in some regions of the country [11]. Byrd and Matthewman [12] predicted that there is going to be an increase in power outages in the future. Literature has shown that about 80% of all the power interruptions experienced by customers do occur as a result of the weaknesses at the distribution level of the power supply chain [13]. Therefore, the distribution sub-sector has the lowest reliability status in the entire power system.

Different countries have tried in many ways to solve their power sector problems as much as they could in order to improve on the reliability of the system by adopting different methods. In Nigeria for instance, the Federal government has embarked on the building of new power plants and injection substations through the Nigeria Integrated Power Projects Schemes (NIPP). There are lot of reinforcement work being done on the existing power infrastructures while some radial transmission networks are being converted to ring circuits such as Oshogbo-Benin-Egbin-Ikeja West, Oshogbo-Benin-Abuja-Shiroro-Jebba, Onitsha-Alaoji-Afam-Ikot Ekpene-Enugu, and Shiroro-Abuja-Benin-Onitsha-Enugu-Makurdi-Jos-Kaduna links [14]. The government has also declared eligibility policy in line with the provisions of Section 27 of the Electric Power Sector Reform Act 2005 whereby eligible customers (those with load demand up to 2MW, or more) are permitted to buy power directly from a licensed operator (such as Generating Companies (GenCos) or Transmission Company (TransCo)) other than electricity distribution companies [15]. Other creative regulations are the Mini Grid and Meter Asset Providers (MAP) Regulations. These policies provide opportunities for independent power producers to supply power to communities whose power requirement is not more than 1MW and allows electric power customers to obtain meters from licensed meter distributors other than the distribution companies respectively [16], [17].

Some of the above-highlighted solutions have been adopted in many parts of the world. In the US for instance, the installed generation capacity is adequate enough to ensure that an average customer has access to about 3.33MW of electric power for use [18]. Also, a lot of system security improvement measure have been put in place through the deployment of smart power distribution facilities such as SCADA to regulate, monitor, control and operate the system more efficiently. There is also improved maintenance policies and techniques like condition-based monitoring (CBM) and reliability centered maintenance (RCM). All these have helped to improve system reliability [4], [19], [20], [21].

The major point of interest in distribution system reliability assessment is the rate of equipment failure and the general interruptions suffered by the customers [22]. Therefore, the health condition of all the components in any power system is pivotal to the performance of the network. This is because the flow of power requires that all the components should be healthy and energized (except standby) before electricity can get to customers.

The magnitudes of the major load point indices of any power system which include Availability, Failure Rate, Mean Time To Fail, Mean Time To Repair, and Mean Time Between Failures are very vital information for future system planning and designs. Their record may also assist in efficient operation, minimizes work hazard, helps in effective policy formulation and disbursement of aid and interventions when applicable and available. However, the information from existing works in Nigeria in this field have shown that they only considered outages that were caused by faults in their studies [23], [24], [25], [26], [27]. Literature has shown that there are other cases of outages beside faults. Such lapse has the capacity to significantly downplay the integrity of the obtained results. The major objective of this study is to close this gap by considering both forced and unforced outage events to present a factual report on the performance of the power system within the study environment.

1.1. Reliability Indices

In reliability considerations, the focus could be on the failure related characteristics of the components without consideration of the number of customers affected by the breakdown as defined by [5]. This can influence choice of equipment vendor(s)/manufacturer(s) to rely on for supply of components based on established reliability of products over time. This is sequel to the fact that the Utility Industry is to ensure that maintenance fund is spent wisely to meet customer expectations [28]. In this regard, some reliability indices which are mainly known as Load Point Indices (LPI) were developed to help in the evaluation of equipment failure events based on their frequency of occurrence. It is important to analyze the effect of probable equipment failure on overall performance of the power system. for instance, the impact of a failed injection substation power transformer on the entire system is different from that of a pin insulator failure. Results from these studies help to understand the system behavior and provides probable remedies for system abnormalities [29].

In this section, in order to study the reliability of the components in the system, the following indices shall be considered;

1. Failure Rate (λ)
2. Mean Time To Failure (MTTF)
3. Mean Time To Repair (MTTR)
4. Mean Time Between Failures (MTBF)
5. Availability (A)
6. Unavailability

1.1.1. Failure Rate, λ

This is the most fundamental index for reliability studies. It is a measure of rate of fault occurrence of a repairable equipment like an isolator or rate of failure of a non-repairable component like pin insulator. Hence there are two mathematical expressions for this index which depends on whether, it applies to repairable or non-repairable scenario. The mathematical Equation, which relates to non-repairable materials expresses failure rate as a percentage as presented in Equation 1.

$$(\%) = \frac{Number\ of\ units\ which\ failed\ x\ 100}{Number\ of\ units\ tested} \qquad 1$$

On the other hand, in the case of repairable pieces of equipment or systems (e.g., the power system), failure rate can be expressed as the number of failures per unit-hour for the period being investigated. This can be expressed mathematically as in Equation 2.

$$(N) = \frac{Number\ of\ times\ that\ failure\ occurred}{Number\ of\ unit{-}hour\ operation} \qquad 2$$

The unit of λ (N) is therefore failure per unit – hour however, there are also scenarios whereby the index is expressed as failure per thousand hours or failure per million hours [30]. It is important to note that high failure rate implies low system reliability [31].

1.1.2. Mean Time to Failure (MTTF)

Mean time to failure (MTTF) is used in measuring the average up-time of a piece of equipment or a system before any failure will occur. Therefore, it gives an idea of the time duration of which a piece of equipment or a system is available without any form of failure or fault [32]. For this research, the study area has series-connected distribution networks. This implies that the failure of any of the system component will result to an outage (system failure). Therefore, in this context, MTTF is an indication of the average healthy time of each circuit components before any breakdown occurs. The mathematical expression for MTTF is presented;

$$MTTF = \frac{Total\ system\ uptime\ hours}{Numbers\ of\ failures} \qquad 3$$

1.1.3. Mean Time To Repair (MTTR)

The meantime to repair is a reliability index which determines the average time within a given period that it takes to restore a faulty equipment back to its normal working condition or the average time it takes to restore a failed system back to operation. In the power system, this represents the average time taken to restore a feeder or circuit back to operation after outage events. MTTR of any item or system is usually dependent on the adopted designs, personnel operations proficiency and sometimes, the age of the component can be a factor. High value of MTTR indicates low reliability and poor maintainability [33].

The mathematical expression for MTTR is presented by Equation 4.

$$MTBF = \frac{Total\ system\ downtime\ hours}{Numbers\ of\ failures} \qquad 4$$

1.1.4. Mean Time Between Failures (MTBF)

Mean time between failures (MTBF) is a reliability index which helps to determine the average time between consecutive failures of a system or item during operations. This metric is based on items or systems that are repairable or renewable. The mathematical expression for MTBF is presented in Equation 5.

$$MTBF = \frac{Total\ system\ operating\ hours}{Numbers\ of\ failures} \qquad 5$$

Furthermore, Meantime between failures (MTBF) is the reciprocal of failure rate which indicates that higher values of MTBF indicates higher system stability in terms of performance. Also, MTBF is the sum of MTTR and MTTF as shown in the Figure 1 [32].

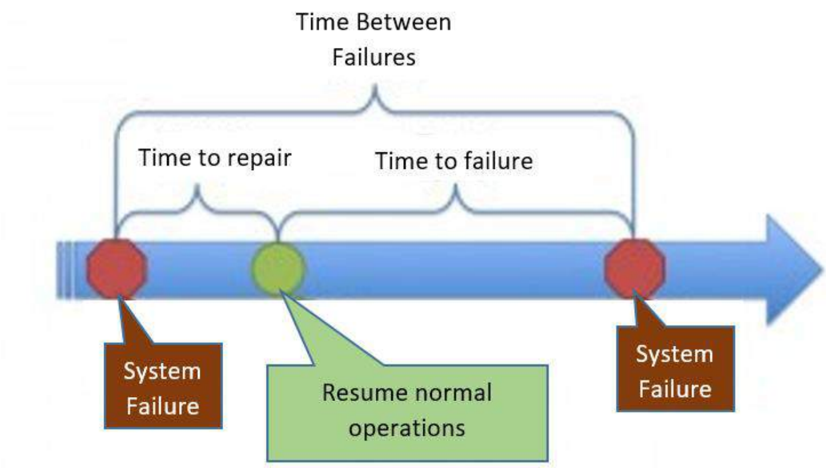

Figure 1: Differentiating between reliability metrics [32]

1.1.5. Availability (A)

Availability is one of the most important reliability metrics as it measures the level of operational effectiveness of a system or an equipment within a given time. This metric espouses the impacts of the maintainability and reliability of the system or items under investigation. In the availability evaluations, the downtimes due to logistics and administrative purposes are assumed to be insignificant [13]. The mathematical expression for Availability (A) is as presented in Equation 6.

$$Availability\ (A) = \frac{MTBF-MTTR}{MTBF} \quad 6$$

1.1.6. Unavailability (U)

Unavailability is a reliability index that represents the fraction of time that a system or an equipment was not able to perform the normal services due to failures. It can also be defined as the steady-state probability that a system was unable to meet with the operational requirements due to failures [5]. The mathematical Equation for unavailability is as presented;

$$Unavailability\ (U) = 1 - Availability \quad 7$$

Meaning,

$$Unavailability\ (U) = 1 - \frac{MTBF-MTTR}{MTBF} \quad 8$$

$$Unavailability\ (U) = \frac{MTTR}{MTBF} \quad 9$$

1.2. Related Works

Power system reliability has become a major research area in electrical engineering due to its direct relationship with the level of industrialization of a place. Different scholars have investigated the behavior of the power system in different parts of Nigeria at different times with the desire to add to existing knowledge on the subject. Their findings and suggestions have helped to define the tune and pace in the field on a local level.

Airoboman, et al., [23] investigated the reliability of the 33kV feeders that emanated from the Benin Transmission Station in Benin City and discovered that the feeders with short length and within the city and free from vegetational encroachment like GRA feeder are more reliable compared to the longer ones that passes through swampy and high vegetational terrain like Koko feeder. This work only considered interruptions due to faults in their analysis.

Etu, et al. [24] assessed the power reliability situation in Nigeria and the way forward by analyzing the data from the works of Okoronkwo and Nwagu [34]. In the work, the reliability of power supply in Nigeria was discovered to be very low and getting worse by the years based on the outcome of the analysis of fault records from Abakiliki and Enugu distribution power system from 2001 to 2003. It was observed that inadequate and erratic power supply is one of the biggest threats to the national development as only about 40% of the population has access to power supply from the grid leading to a situation of proliferation of inefficient mini generators. These have also caused stagnation in economic activities and decline in social comfort. The authors observed that the problems in the power sector in Nigeria includes exorbitant estimated bills, poor execution of power projects and gas shortage for power generating plants. However, the authors only considered interruptions due to faults while leaving out the other interruptions such as those caused by maintenance activities, load shedding and emergency operations.

Onime and Adegboyega [25] studied the power system reliability of Ekpoma distribution network by considering the fault data from PHCN for year 2012 on a monthly basis. The various reliability indices were determined using load point indices. However, apart from using only fault incidences in the analysis, the authors did not give any unit of measurement for their results.

Popoola, et al. [26] investigated the power system reliability in the south-western part of the nation by analyzing the inputs from the administered questionnaires to people in this region. The work scored the power system in the studied area very low in reliability and also noted that the reliability level does vary from state to state. However, the findings from reports such as this will suffer low acceptability due to the weakness in the applied methodology [35]. One, it was based on people's opinion as no instrument was used to measure whatever value of answers that were given. Secondly, individual differences and the emotional state of the respondents can affect their answers to questions. In addition, the method does not conform to international standard.

Adoghe, et al., [27] analyzed their equipment failure data-set of Abule Egba power distribution network in Lagos State from 2004 to 2008 in order to investigate the critical role assets maintenance plays in system reliability. The study adopted an advanced Reliability Centered Maintenance (RCM) methodology that is based on quantitative statistical analysis of components failure records as a tool for the identification of high-risk index equipment. With this approach, maintenance activities are more of proactive action during operations unlike the current situation whereby the utility companies are more on the reactive side with regard to component failure in the system. This method if fully explored could help to improve power system reliability in the Nigeria power industry.

A summarized review of the existing reliability studies in Nigeria is presented in Table 1. The presented results have helped to enhance the available knowledge in the studied areas with regard to the reliability in Nigeria. The major concern in these works is the observed deficiency in the data used as presented in the remarks and non-determination of all the load point indices in each of these works.

Table 1: Load Point indices of power distribution in different studied power system in Nigeria.

S/N	Literatures	Studied Area & Period	MTTF	MTTR	MTBF	Failure Rate	Availability	Remarks (details in literature review)
1	Airoboman, et al., (2017) [23]	Benin City (2011-2015)		39.046hrs/ 1.6 days	352.766hr / 14.7days	0.0414	0.8893	Only Considered faults. (Ikpoba Dam 33KV Feeder info for 2011)
2	Etu, et al., (2015) [24]	Enugu distribution networks (2001-2003)			7.36hrs	0.14		Values for 2002. Only Considered faults
3	Onime and Adegboyega (2014) [25]	Ekpoma (2012)			5.8275		0.6147	Only Considered faults. No unit of measurement. Values for Iruekpen feeder
4	Popoola, et al., (2011) [26]	South-West				1.55		Interruption data was based on questionnaire
5	Adoghe, et al., (2013) [27]	Lagos- Abule Egba (2004-2008)	2.06 days	6.67days			0.485	Only Considered faults. Values for Feeder 1, (2007)

2. Methodology

The data used for this study were obtained from the 33kV feeders in Irrua Transmission Station in Edo State, Nigeria. The concerned feeders include Ehor, Ubiaja, and Uzebba. These are the major 33kV feeders that supply power to the central part of Edo state, Nigeria. The period of the study covers four years (January 2015 to December 2018). Samples of the obtained raw outage data for Ehor, Ubiaja and Uzebba are presented in Tables 2, 3 and 4 respectively. The other information received from the obtained data is the duration of each outage. Also, record showed that the invents comprises outages as a result of faults, emergency operations, maintenance activities, load shedding and Transmission system failures.

Table 2: Sample of Power Interruption log of Ehor 33kV Feeder

FEEDER	DAY OUT	TIME OUT (HH:MM)	DURATION (HRS)	OUTATAGE CATEGORY
EHOR 33KV FDR	14-03-15	13:46	1.18	FAULT (BREAKDOWN)
EHOR 33KV FDR	17-03-15	16:44	1.77	LOAD SHEDDING (OUTAGE)
EHOR 33KV FDR	20-03-15	7:45	6.15	SUPPLY FAILURE (SYSTEM CO
EHOR 33KV FDR	20-04-15	13:36	2.90	SUPPLY FAILURE (SYSTEM CO
EHOR 33KV FDR	21-04-15	0:03	7.85	SUPPLY FAILURE (SYSTEM CO
EHOR 33KV FDR	22-04-15	18:53	23.22	FAULT (BREAKDOWN)
EHOR 33KV FDR	22-04-15	6:48	7.10	FAULT (BREAKDOWN)
EHOR 33KV FDR	22-04-15	16:25	1.35	LOAD SHEDDING (OUTAGE)
EHOR 33KV FDR	25-04-15	13:30	28.92	PLANNED (OUTAGE)
EHOR 33KV FDR	25-04-15	7:37	10.80	SUPPLY FAILURE (SYSTEM CO
EHOR 33KV FDR	26-04-15	2:22	13.25	FAULT (BREAKDOWN)
EHOR 33KV FDR	27-04-15	11:32	4.97	FAULT (BREAKDOWN)
EHOR 33KV FDR	28-04-15	12:42	2.97	SUPPLY FAILURE (SYSTEM CO
EHOR 33KV FDR	29-04-15	16:05	28.42	FAULT (BREAKDOWN)
EHOR 33KV FDR	30-04-15	12:18	29.35	SUPPLY FAILURE (SYSTEM CO
EHOR 33KV FDR	01-05-15	6:05	7.30	FAULT (BREAKDOWN)
EHOR 33KV FDR	01-05-15	23:45	0.78	SUPPLY FAILURE (SYSTEM CO
EHOR 33KV FDR	02-05-15	9:13	8.45	PLANNED (OUTAGE)
EHOR 33KV FDR	03-05-15	19:35	24.68	FAULT (BREAKDOWN)
EHOR 33KV FDR	03-05-15	10:22	3.62	FAULT (BREAKDOWN)
EHOR 33KV FDR	05-05-15	20:28	24.53	SUPPLY FAILURE (SYSTEM CO
EHOR 33KV FDR	05-05-15	5:35	9.03	FAULT (BREAKDOWN)
EHOR 33KV FDR	08-05-15	1:27	15.80	LOAD SHEDDING (OUTAGE)
EHOR 33KV FDR	09-05-15	17:54	3.35	FAULT (BREAKDOWN)

EHOR 33KV FDR	10-05-15	15:59	9.08	SUPPLY FAILURE (SYSTEM CO
EHOR 33KV FDR	10-05-15	10:17	3.62	PLANNED (OUTAGE)
EHOR 33KV FDR	10-05-15	6:10	1.97	FAULT (BREAKDOWN)
EHOR 33KV FDR	12-05-15	9:00	6.55	FAULT (BREAKDOWN)
EHOR 33KV FDR	13-05-15	14:35	2.43	FAULT (BREAKDOWN)
EHOR 33KV FDR	14-05-15	2:50	14.15	FAULT (BREAKDOWN)
EHOR 33KV FDR	15-05-15	8:42	5.38	FAULT (BREAKDOWN)
EHOR 33KV FDR	16-05-15	2:15	6.32	FAULT (BREAKDOWN)
EHOR 33KV FDR	17-05-15	16:49	2.92	FAULT (BREAKDOWN)
EHOR 33KV FDR	18-05-15	17:26	2.03	SUPPLY FAILURE (SYSTEM CO
EHOR 33KV FDR	18-05-15	13:06	2.42	SUPPLY FAILURE (SYSTEM CO
EHOR 33KV FDR	18-05-15	20:38	11.60	FAULT (BREAKDOWN)
EHOR 33KV FDR	19-05-15	21:32	9.85	FAULT (BREAKDOWN)
EHOR 33KV FDR	20-05-15	21:21	12.03	LOAD SHEDDING (OUTAGE)

Table 3: Sample of Power Interruption log of Ubiaja 33kV Feeder

FEEDER	DAY OUT	TIME OUT (HH:MM)	DURATION (HRS)	OUTATAGE CATEGORY
UBIAJA 33KV FDR	15-04-15	1:05	19.13	SUPPLY FAILURE (SYSTEM CO
UBIAJA 33KV FDR	16-04-15	11:12	9.22	SUPPLY FAILURE (SYSTEM CO
UBIAJA 33KV FDR	17-04-15	10:30	7.48	PLANNED (OUTAGE)
UBIAJA 33KV FDR	19-04-15	2:31	14.70	FAULT (BREAKDOWN)
UBIAJA 33KV FDR	21-04-15	0:03	5.65	SUPPLY FAILURE (SYSTEM CO
UBIAJA 33KV FDR	22-04-15	12:23	5.18	PLANNED (OUTAGE)
UBIAJA 33KV FDR	22-04-15	18:43	24.90	FAULT (BREAKDOWN)
UBIAJA 33KV FDR	23-04-15	1:39	2.85	EMERGENCY (OUTAGE)
UBIAJA 33KV FDR	23-04-15	7:50	4.82	SUPPLY FAILURE (SYSTEM CO
UBIAJA 33KV FDR	23-04-15	4:45	2.63	FAULT (BREAKDOWN)
UBIAJA 33KV FDR	24-04-15	11:25	6.63	PLANNED (OUTAGE)
UBIAJA 33KV FDR	24-04-15	22:55	8.20	FAULT (BREAKDOWN)
UBIAJA 33KV FDR	25-04-15	7:37	4.43	SUPPLY FAILURE (SYSTEM CO
UBIAJA 33KV FDR	25-04-15	13:04	1.47	SUPPLY FAILURE (SYSTEM CO
UBIAJA 33KV FDR	26-04-15	1:03	9.45	FAULT (BREAKDOWN)
UBIAJA 33KV FDR	28-04-15	12:42	2.97	SUPPLY FAILURE (SYSTEM CO
UBIAJA 33KV FDR	29-04-15	19:39	14.43	FAULT (BREAKDOWN)
UBIAJA 33KV FDR	30-04-15	12:18	29.18	SUPPLY FAILURE (SYSTEM CO
UBIAJA 33KV FDR	01-05-15	5:28	6.45	FAULT (BREAKDOWN)
UBIAJA 33KV FDR	01-05-15	23:45	2.53	SUPPLY FAILURE (SYSTEM CO
UBIAJA 33KV FDR	02-05-15	4:06	0.53	FAULT (BREAKDOWN)
UBIAJA 33KV FDR	02-05-15	9:27	0.70	SUPPLY FAILURE (SYSTEM CO
UBIAJA 33KV FDR	03-05-15	19:05	22.42	FAULT (BREAKDOWN)
UBIAJA 33KV FDR	05-05-15	20:28	24.53	SUPPLY FAILURE (SYSTEM CO
UBIAJA 33KV FDR	07-05-15	22:23	24.70	FAULT (BREAKDOWN)
UBIAJA 33KV FDR	08-05-15	1:27	9.73	LOAD SHEDDING (OUTAGE)
UBIAJA 33KV FDR	09-05-15	16:32	0.58	FAULT (BREAKDOWN)
UBIAJA 33KV FDR	10-05-15	15:59	8.45	SUPPLY FAILURE (SYSTEM CO
UBIAJA 33KV FDR	10-05-15	10:17	3.42	PLANNED (OUTAGE)
UBIAJA 33KV FDR	18-05-15	13:06	2.02	SUPPLY FAILURE (SYSTEM CO
UBIAJA 33KV FDR	18-05-15	22:12	5.53	FAULT (BREAKDOWN)
UBIAJA 33KV FDR	09-06-15	17:23	17.53	FAULT (BREAKDOWN)
UBIAJA 33KV FDR	11-06-15	16:29	4.93	LOAD SHEDDING (OUTAGE)
UBIAJA 33KV FDR	11-06-15	10:45	3.47	PLANNED (OUTAGE)

Table 4: Sample of Power Interruption log of Uzebba 33kV Feeder

FEEDER	DAY OUT	TIME OUT (HH:MM)	DURATION (HRS)	OUTATAGE CATEGORY
UZEBBA 33KV FDR	09-07-15	16:10	0.30	SUPPLY FAILURE (SYSTEM CO
UZEBBA 33KV FDR	09-07-15	20:26	0.15	SUPPLY FAILURE (SYSTEM CO
UZEBBA 33KV FDR	10-07-15	8:59	6.35	FAULT (BREAKDOWN)
UZEBBA 33KV FDR	10-07-15	7:50	0.67	SUPPLY FAILURE (SYSTEM CO
UZEBBA 33KV FDR	13-07-15	15:15	5.68	FAULT (BREAKDOWN)
UZEBBA 33KV FDR	14-07-15	11:55	8.45	PLANNED (OUTAGE)
UZEBBA 33KV FDR	15-07-15	9:05	0.60	FAULT (BREAKDOWN)
UZEBBA 33KV FDR	18-07-15	11:27	3.93	PLANNED (OUTAGE)
UZEBBA 33KV FDR	21-07-15	22:00	14.80	FAULT (BREAKDOWN)
UZEBBA 33KV FDR	21-07-15	19:33	1.72	SUPPLY FAILURE (SYSTEM CO
UZEBBA 33KV FDR	30-07-15	6:40	5.70	EMERGENCY (OUTAGE)
UZEBBA 33KV FDR	08-08-15	10:37	5.27	LOAD SHEDDING (OUTAGE)
UZEBBA 33KV FDR	10-08-15	18:20	19.70	SUPPLY FAILURE (SYSTEM CO
UZEBBA 33KV FDR	23-08-15	7:10	1.47	SUPPLY FAILURE (SYSTEM CO
UZEBBA 33KV FDR	24-08-15	9:59	4.77	FAULT (BREAKDOWN)
UZEBBA 33KV FDR	27-08-15	4:14	2.35	FAULT (BREAKDOWN)
UZEBBA 33KV FDR	01-09-15	20:48	12.90	FAULT (BREAKDOWN)
UZEBBA 33KV FDR	02-09-15	19:16	5.25	EMERGENCY (OUTAGE)

UZEBBA 33KV FDR	04-09-15	19:42	1.30	SUPPLY FAILURE (SYSTEM CO
UZEBBA 33KV FDR	04-09-15	19:08	0.40	FAULT (BREAKDOWN)
UZEBBA 33KV FDR	21-09-15	19:28	15.28	EMERGENCY (OUTAGE)
UZEBBA 33KV FDR	07-10-15	14:53	4.03	SUPPLY FAILURE (SYSTEM CO
UZEBBA 33KV FDR	08-10-15	11:28	0.87	FAULT (BREAKDOWN)
UZEBBA 33KV FDR	10-10-15	15:16	24.98	FAULT (BREAKDOWN)
UZEBBA 33KV FDR	11-10-15	22:45	7.48	FAULT (BREAKDOWN)
UZEBBA 33KV FDR	11-10-15	10:30	25.75	FAULT (BREAKDOWN)
UZEBBA 33KV FDR	14-10-15	14:42	25.70	SUPPLY FAILURE (SYSTEM CO
UZEBBA 33KV FDR	15-10-15	18:39	24.75	FAULT (BREAKDOWN)
UZEBBA 33KV FDR	23-10-15	14:52	1.22	PLANNED (OUTAGE)
UZEBBA 33KV FDR	25-10-15	20:42	12.88	FAULT (BREAKDOWN)
UZEBBA 33KV FDR	29-10-15	12:51	9.37	PLANNED (OUTAGE)
UZEBBA 33KV FDR	30-10-15	12:37	3.35	PLANNED (OUTAGE)
UZEBBA 33KV FDR	31-10-15	15:34	3.00	FAULT (BREAKDOWN)
UZEBBA 33KV FDR	31-10-15	13:13	0.28	SUPPLY FAILURE (SYSTEM CO

These events were collated and analyzed with the help of computer spreadsheet application. The load point indices such as failure rate, mean time to fail, etc of the various feeders were determined using Equation 10 to 15 according to Pham [36].

$$\boldsymbol{\lambda} = \frac{\sum \mathrm{F_{Oi}}}{\sum_{i=1}^{N} \mathrm{T_{OHi}} - \sum_{i=1}^{N} \mathrm{T_{DTi}}} \quad 10$$

$$\mathrm{MTTR} = \frac{\sum_{i=1}^{N} \mathrm{T_{DTi}}}{\sum \mathrm{F_{Oi}}} \quad 11$$

$$\mathrm{MTTF} = \frac{\sum_{i=1}^{N} \mathrm{T_{UTi}}}{\sum \mathrm{F_{Oi}}} \quad 12$$

$$\mathbf{MTBF} = \mathbf{MTTR} + \mathbf{MTTF} \quad 13$$

$$\mathbf{A} = \frac{\sum_{i=1}^{N} \mathbf{T_{UTi}}}{\sum_{i=1}^{N} \mathbf{T_{UTi}} + \sum_{i=1}^{N} \mathbf{T_{DTi}}} \quad 14$$

$$\mathbf{U} = \mathbf{1} - \frac{\sum_{i=1}^{N} \mathbf{T_{UTi}}}{\sum_{i=1}^{N} \mathbf{T_{UTi}} + \sum_{i=1}^{N} \mathbf{T_{DTi}}} \quad 15$$

Where

λ = Failure Rate
A = Availability
U = Unavailability
F_{Oi} = Failure occurrence of the feeder
T_{OHi} = Total operational hour
T_{DTi} = Total downtime of feeder
T_{UTi} = Total uptime of feeder

3. Results and Discussion

Reliability is the ability of an item to perform optimally at all required situations. This is not always obtainable due to failure of the system components owing to wear and tears over time. In Section 2 of this study, the reliability level of Ehor, Ubiaja and Uzebba feeders were assessed using the Load Point Indices (LPI) equations presented in equations 10 – 15. The obtained results which include outage frequency, down time, failure rate and availability, meantime to fail (MTTF), meantime to repair (MTTR) and mean time between failures (MTBF) are presented in Table 5. The total outages in Uromi Business Unit from 2015 to 2018 were found to be 4,520. The analyzed data showed that all the feeders experienced interruptions during the time under review (2015 - 2018). The feeder that has the best performance in this regard is the one with the lowest outages as illustrated in Table 5. Therefore, the best feeder is Uzebba with a total of 1,184 incidents followed by Ubiaja (1,543 incidents) and Ehor (1,793 incidents) as the worst. From the trend of events in Table 5, it is obvious that the interruption frequencies of all the feeders are increasing by the years. This implies depreciating reliability state of the power system in Uromi Business Unit and it corroborates the findings of earlier studies in the US [9], Benin City [37] and Enugu [24] and also agrees with the prediction of Byrd and Matthewman [12].

The down time represents the total duration (in hours) of all the outages experienced by the feeders. The feeder that has the best performance in this regard is the one with the lowest down time as illustrated in Table 5. The table shows that the feeder with the lowest outage duration for the period investigated is Ubiaja with a total of 11,009.27 hours followed by Ehor (11,100.72 hours) and Uzebba (11,572.63 hours) in that order.

The trends of event showed that the outage durations have increased over the years for all the feeders. Consequently, the total down time for all the feeders during the period of study showed that it is increasing by the years from 7,072.78 hours in 2015 to 9,834.80 hours in 2018.

The failure rate as presented shows the average number of outages experienced by the feeders on hourly basis annually. The feeder that has the best performance in this regard is the one with the lowest value as illustrated in Table 5. The record showed that the feeder with the lowest failure rate is Uzebba with an average value of 0.0338 failure per hour. The next feeder in terms of lowest failure rate is Ubiaja (0.0440) and then Ehor (0.0511).

Historical records showed that the failure rates are on the increase for all the feeders. Consequently, the total failure rate for the system increased from 0.1062 failures per hour in 2015 to 0.1559 failures per hour in 2018 and this trend agrees with the findings of Sambo et al. [38].

The presented feeder availability is the fractional duration (in hours) of power supply out of the total duration (in hours) of the years being considered. The feeder that has the best performance in this regard is the one with the highest percentage availability as illustrated in Table 5. It was observed that Ubiaja feeder has the highest availability of an average value of 68.60%, followed by Ehor (68.34%) and then Uzebba (67.00%).

Historical trend showed that the availability of all the feeders has reduced over the years such that on the average, the availability of electricity in the study area has reduced from 73.09% in 2015 to 62.58% in 2018.

The mean time to fail (MTTF) shows the average time (in hours) it takes for the feeder to experience outages during the period under study. The feeder that has the best performance in this regard is the one with the highest duration as illustrated in Table 5. It shows that the most stable feeder is Uzebba which stays for an average of 21.63 hours before failure. The other feeders in the order of stability are Ubiaja (15.75 hours) and Ehor (13.75 hours).

The table showed that the mean time to fail (MTTF) have reduced over the years for all the feeders. Hence the overall average value for MTTF of all the feeders reduced from 23.07 hours in 2015 to 12.40 hours in 2018.

Tables 5: Load point indices of the feeders

Feeders	Outages (Nos) 2015	2016	2017	2018	Total	Trend
Uzebba	201	339	280	364	1184	
Ubiaja	351	415	348	429	1543	
Ehor	378	426	416	573	1793	
Total	930	1180	1044	1366	4520	

Feeders	DownTime (Hrs) 2015	2016	2017	2018	Total	Trend
Ubiaja	2799.28	2570.72	2564.03	3075.23	11009.27	
Ehor	2895.30	2770.72	2275.10	3159.60	11100.72	
Uzebba	1378.20	3150.98	3443.48	3599.97	11572.63	
Total	7072.78	8492.42	8282.62	9834.80	33682.62	

Feeders	Failure Rate/Hr 2015	2016	2017	2018	Average	Trend
Uzebba	0.0229	0.0386	0.0320	0.0416	0.0338	
Ubiaja	0.0401	0.0472	0.0397	0.0490	0.0440	
Ehor	0.0432	0.0485	0.0475	0.0654	0.0511	
Total	0.1062	0.1343	0.1192	0.1559	0.1289	

Feeders	Availability (%) 2015	2016	2017	2018	Average	Trend
Ubiaja	68.04	70.73	70.73	64.89	68.60	
Ehor	66.95	68.46	74.03	63.93	68.34	
Uzebba	84.27	64.13	60.69	58.90	67.00	
Average	73.09	67.77	68.48	62.58	67.98	

Feeders	MTTF (Hrs) 2015	2016	2017	2018	Average	Trend
Uzebba	36.73	16.62	18.99	14.18	21.63	
Ubiaja	16.98	14.97	17.80	13.25	15.75	
Ehor	15.52	14.12	15.59	9.77	13.75	
Average	23.07	15.23	17.46	12.40	17.04	

Feeders	MTTR (Hrs) 2015	2016	2017	2018	Average	Trend
Ehor	7.66	6.50	5.47	5.51	6.29	
Ubiaja	7.98	6.19	7.37	7.17	7.18	
Uzebba	6.86	9.29	12.30	9.89	9.58	
Average	7.50	7.33	8.38	7.52	7.68	

Feeders	MTBF(Hrs) 2015	2016	2017	2018	Average	Trend
Uzebba	43.58	25.91	31.29	24.07	31.21	
Ubiaja	24.96	21.17	25.17	20.42	22.93	
Ehor	23.17	20.62	21.06	15.29	20.03	
Average	30.57	22.57	25.84	19.92	24.73	

The mean time to repair (MTTR) represents the average time (in hours) required to restore back supply in the advent of any failure experienced by the feeders. The feeder that has the best performance in this regard is the one with the lowest restoration time as illustrated in Table 5. From the table, it is obvious that Ehor has the lowest average restoration duration of 6.29 hours followed by Ubiaja (7.18 hours) and then Uzebba (9.58 hours).

From historical record shown in the table, it is obvious that the mean time to repair has reduced for over the years for Ehor and Ubiaja feeders but increased for Uzebba feeder. However, the overall mean time to restore value for the entire feeders remained fairly constant being 7.50 hours in 2015 and 7.52 hours in 2018.

The mean time between failures (MTBF) shows the average time between consecutive failure incidents of the feeders. The feeder that has the best performance in this regard is the one with the highest interval as illustrated in Table 5. Record shows that the feeder with the highest duration is Uzebba with an average value of 31.21 hours. The next is Ubiaja (22.93 hours) followed by Ehor (20.03 hours).

The table showed that the mean time between failures for all the feeders have reduced with time. Consequently, the average duration between consecutive failure events for all the feeders reduced from 30.57 hours in 2015 to 19.92 hours in 2018.

Earlier reports in this field of study from different scholars suffers from wide variation as earlier noticed in Table 1 [23]. [24], [25], [26], [27]. This has been attributed to the quality of data used. The only exception is that Onime and Adegboyega [25] presented availability of 62% for Iruekpen feeder which is close to the results in this study (67.98%). However, same study presented 5.8 hours for MTBF as against an average value of 24.73 hours presented in this study.

4. Conclusion

Power system reliability study is a systematic analysis method for optimizing system operations, maintenance, performance and planning. This study assessed the power system reliability of Ehor, Ubiaja and Uzebba 33kV feeders that radiated from Irrua transmission station in Edo State, Nigeria. All the major load point indices of power system were evaluated and the result showed that the failure rate and availability deteriorated while the mean time to repair remained a bit stable throughout the period of the study. Based on these findings, it is therefore suggested that the power system should be reinforced with alternative power distributed sources like photovoltaic infrastructures. The mini grid and eligibility customer policies of the government should be enforced. Also, the pace of response to outage should be improved by adopting reliability centered maintenance strategies.

Nomenclature

A	Availability
CBM	Condition-Based Monitoring
F_{Oi}	Failure occurrence of the feeder
GenCos	Generating Companies
LPI	Load Point Indices
MAP	Meter Asset Providers
MTBF	Mean Time Between Failures
MTTF	Mean Time To Failure
MTTR	Mean Time To Repair
NIPP	Nigeria Integrated Power Projects Schemes
RCM	Reliability Centered Maintenance
T_{DTi}	Total downtime of feeder
T_{OHi}	Total operational hour
TransCo	Transmission Company
T_{UTi}	Total uptime of feeder
U	Unavailability
US	United States
λ	Failure Rate

References

[1] Abdullahi, M. I., Akinsanmi, O., Muazu, M. B. and Jubril, Y. (2007). Reliability assessment of an electronic system: A case study of a British siren in Nigeria. J. Appl. Sci. Res., 3(1): 671 – 675.

[2] Ireson, W. G. and Coombs, C. F. (1988). A Handbook of Reliability Engineering and Management. 2nd ed. McGraw-Hill, New York, NY, USA, pp. 1-608.

[3] Bhavaraju, M. P., Billinton, R., Brown, R. E., Endrenyi, J., Li, W., Meliopoulos, A. P. and Singh, C. (2005). IEEE tutorial on electric delivery system reliability evaluation. IEEE Power Engineering Society General Meeting (PES). Publication 05TP175: 39-51.

[4] Wang, F. (2012). Reliability evaluation of substations subject to protection failures. Master of Science Thesis, Department of Electrical Engineering, Mathematics and Computer Science, Division of Electrical Power System, Delft University of Technology, Delft, the Netherlands.

[5] IEEE Standards 493-1990 (1990). Recommended practice for design of reliable industrial and commercial power system. IEEE, 54: 75 – 204.

[6] Kueck, J. D. (2004). Measurement practices for reliability and power quality. Tennessee: Oak Ridge National Laboratory, pp. 1-45.

[7] Oladipo, F. and Folorunso, O. T. (2014). The Nigerian Power System Till Date: A Review. International Journal of Advance Foundation and Research in Science and Engineering (IJAFRSE). 1(5): 20-33.

[8] Akinloye, B., Oshevire, P. and Epemu, A. (2016). Evaluation of system collapse incidences on the Nigeria power system. Journal of Multidisciplinary Engineering Science and Technology (JMEST), 3(1): 3707 – 3711.

[9] Wirfs-Brock J. (2014). Power Outage on the Rise Across the U.S., Inside Energy, Denver, CO, accessed Aug. 18, 2018, http://insideenergy.org/2014/08/18/power-outages-on-the-rise-across-the-u-s/

[10] Lai, L. L., Zhang, H. T., Lai, C. S., Xu, F. Y., and Mishra, S. (2013). Investigation on july 2012 indian blackout. Paper presented at the 2013 International Conference on Machine Learning and Cybernetics. Pp 1-6.

[11] Dawood, R. (2016). “Major breakdown leaves Pakistan power-less.” Daily Pakistan online Newspaper. Available at https://en.dailypakistan.com.pk/21-Jan-2016/major-breakdown-leaves-pakistan-power-less.

[12] Byrd, H. and Matthewman, S. (2014). Exergy and the city: the technology and sociology of power (failure). J Urban Technol, 21(3): 85 – 102.

[13] Billinton, R. and Allan, R. N. (1996). Reliability evaluation of power systems. 2nd ed. New York and London: Plenum Press, pp. 1 – 13.

[14] PSRP-Power Sector Recovery Program (2018). PSRP Power Sector Recovery Program Master Document: 2017 – 2021 Pp. 1-50 . Retrieved from http://mypower.ng/wp-content/uploads/2018/02/PSRP-Master-Document-January-2018.pdf

[15] IEA-International Energy Agency (2017). Nigerian Electricity Regulatory Commission Mini-Grid Regulation 2016. Retrieved from iea.org: https://www.iea.org/policiesandmeasu res/pams/nigeria/name-165004-en.php.

[16] Aigbomia, M. F. (2019). The NERC Mini-Grid Regulations and The Nigerian Mini_Grid Market: Opportunity For Investment. Retrieved from mondaq.com: https://www.mondaq.com/nigeria/renewables/781960/the-nerc-mini-grid-regulations-and-the-nigerian-minigrid-market-opportunity-for-investment.

[17] Amaza I. and Okwurionu C. (2018). The 2018 Meter Asset Provider Regulation – Problems And Prospects. Retrieved from mondaq.com: http://www.mondaq.com/Nigeria/x/687408/Oil+Gas+Electricity/The+2018+Meter+Asset+Provider+Regulation+Problems+And+Prospects

[18] Hines, P., Balasubramaniam, K. and Sanchez, E. C. (2009). Cascading failures in power grids. University of Vermont. pp. 1–7.

[19] Sultana, B., Mustafa, M., Sultana, U. and Bhatti, A. R. (2016). Review on reliability improvement and power loss reduction in distribution system via network reconfiguration. Renewable and Sustainable Energy Reviews. 66(0): 297-310.

[20] IEEE/PES-Task Force on Impact of Maintenance Strategy on Reliability of the Reliability, Risk and Probability Applications Subcommittee (2001). The Present Status of Maintenance Strategies and the Impact of Maintenance on Reliability. 16(4), 638-640.

[21] Dhend, M. H. (2015). Innovative scheme for smart grid distribution SCADA system. 1-6. 10.1109/IFEEC.2015.7361557.

[22] Akintola, A. A. (2017). Reliability evaluation of secondary distribution system in nigeria: a case study of Ayetoro 1 substation, Aguda, Lagos State. Master of Science Thesis, Department of Electrical and Information Engineering, Faculty of Engineering, Covenant University, Ota, Ogun State, Nigeria, pp. 1-78.

[23] Airoboman, A., Ogujor, E. and Okakwu, I. (2017). Reliability analysis of power system network: a case

study of transmission company of Nigeria, Benin City. IEEE PES-IAS Power Africa Conference. June 27-30. The Gimpa, Accra, Ghana. 99-104. DOI: 10.1109/PowerAfrica.2017.7991206.

[24] Etu, I. A., Ahmed, E. A. and Jack, K. E. (2015). Assessment of Nigeria's power situation and the way forward. International Journal of Latest Research in Engineering and Technology (IJLRET), 1(4): 23 – 31.

[25] Onime, F. and Adegboyega, G. A. (2014). Reliability analysis of power distribution system in Nigeria; a case study of Ekpoma network, Edo state. International Journal of Electronics and Electrical Engineering, 2(3): 175 – 182.

[26] Popoola, J. J., Akinlolu A. P. and Ale T. O. (2011). Reliability Worth Assessment of Electric Power Utility in Nigeria: Residential Customer Survey Results. Assumption University Journal, Thailand. 14(3): Pp. 217-224.

[27] Adoghe, U. A., Awosope, C. O. and Ekeh, J. C. (2013). Asset maintenance planning in electric power distribution network. Elsevier Journal of Electrical Power and Energy Systems, 47: 424 – 435.

[28] Layton, L. (2004). Electric System Reliability indices. Retrieved May, 22, 2018 from https://www.researchgate.net/file.PostFileLoader.html?id=57e7af1396b7e4d28151fe14&assetKey=AS%3A410161068953600%401474801427090

[29] Izuegbunam, F. I., Uba, I. S., Akwukwaegbu, I. O. and Dike, D. O. (2014). Reliability evaluation of Onitsha power distribution network via analytical technique and the impact of pv system. IOSR Journal of Electrical and Electronics Engineering (IOSR-JEEE), 9(3): 15 – 22.

[30] Heizer, J. and Render, B. (1988). Production and operation management strategies and tactics. Allyn and Bacon Incorporated, pp. 551 – 680.

[31] Megbowon, I. O. and Oyebisi, T. O. (2005). A reliability assessment of the south western transmission lines of the Nigerian National Grid. International Journal of Engineering and Engineering Technology, FUTAJEET 4(1): 17 – 22.

[32] Stephen (2011). Defining failure: What is MTTR, MTTF, and MTBF? Retrieved from fosketts.net: http://blog.fosketts.net/2011/07/06/defining-failure-mttr-mttf-mtbf/

[33] Dhillon, B. S., and Reiche, N. A. (1987). Reliability and maintainability Management. CBS Publication and Distribution, pp. 604 – 701.

[34] Okoronkwo, C. and Nwangwu, E. O. (2006). Distribution System Reliability Assessment of Enugu District of Power Holding Company of Nigeria (PHCN) for Three Years. Journal of Science and Engineering Development, 1(1): 27 – 38.

[35] Mbonu E. S., Okwu P. I., Inyiama H. C., and Okafor K. C. (2014). Reliability Evaluation of Power Distribution Companies in Nigeria, Leveraging ICT Based Framework for Unbiased Performance Evaluation. Proceedings of the IEEE. Pp.13-18. ISBN: 978-1-4799-4997-7.

[36] Pham H., (2006) "System Software Reliability" Springer First Edition Publisher. ISBN 978-1-85233-950-0.

[37] Ogujor, E. A. and Kuale P. (2007). "Using Reliability Indices-Markov Model in Electric Power Distribution Assessment" International Journal of Electrical and Power Engineering. Vol. 1 pp.418-420.

[38] Sambo, A. S., Garba, B., Zarma, I. H. and Gaji, M. M. (2010). Electricity Generation and the Present Challenges in the Nigerian Power Sector. Energy Commission of Nigeria, Abuja-Nigeria. 1-17.