Impact of Power Outages on the Reliability Assessment of Electrical Distribution System

Ganiyu Adedayo Ajenikoko[1*] & Bolarinwa Samson Adeleke[2]

[1]Department of Electronic & Electrical Engineering, Ladoke Akintola University of Technology, P.M.B. 4000, Ogbomoso, Nigeria

[2]Department of Electrical Engineering, The Ibarapa Polytechnic, Eruwa, Oyo State, Nigeria

[*]Email: *ajeedollar@gmail.com*

Abstract: An outage is a fault that occurs on electrical power systems. This fault may be permanent, brownout or a blackout. Reliability is the probability that a system will perform required functions under a given condition from a stated period. In reliability assessment of electrical distribution system, parameter indices such as Mean Time Between Failure (MTBF), Mean Time to Failure (MTTF), Mean Time to Repairs (MTTR), Availability (A) and Unavailability (U) were employed to establish the impact of power outages. Poor maintenance of Opebi distribution feeders made it to be relatively less reliable because many of the customers attached to this feeder experienced a prolonged period of darkness that lasted longer. This paper discusses the impact of power outages on the reliability assessment of electrical distribution systems. The outage data from selected feeders of Ikeja distribution systems were collected and analyzed using appropriate mathematical notations to compute their reliability indices. The results of the research paper show that Alagbole feeder of Ikeja distribution system recorded the highest failure rates of 0.0217 faults in 2015. This is due to the frequent occurrence of outages on the feeder leading to the highest energy loss and momentary loss to the utility management. The unreliable performance of some of the feeders is due to high forced outages. Olowu feeder of this distribution system recorded the least failure rate of 0.0102 faults in 2006 probably because most of the customer attached to the feeder experienced a little interruption which lasted for a short time period and was cleared promptly on time. Alagbole feeder also had the least mean-time-between failure of 45.9952 with General Hospital feeder emerging as having the highest mean-time-between failure of 99.8160 in 2013. The prominent failure of Alagbole distribution feeder was probably due to sudden switching of heavy equipment used. The availability of all the selected distribution feeders was lower than the IEEE standard of the Average System Availability Index (ASAI) as a result of inadequate maintenance actions carried out on most of the feeders.

Keyword: Outage, Reliability, Mean-Time-Between-Failure (MTBF), Mean-Time-To-Failure (MTTF), Mean-Time-To-Repair (MTTR), Availability, Failure Rate, Repair Rate.

I. INTRODUCTION

A power outage (also called a power cut, power blackout, power failure or a blackout) is a short-or long-term of the electric power to an area [2, 5 & 8]. There are many causes of power failures in an electricity network. Examples of these causes include faults at power stations, damage to electric transmission lines, substations or other parts of the distribution system, a short-circuit or the overloading of electricity mains [1, 3 & 6]]. Power failures are particularly critical at sites where the environment and public safety are at risk. Institutions such as hospitals, sewage treatment plants, mines and the like will usually have back-up power sources such as standby generator, which will automatically start up when electrical power is lost. Other critical systems, such as telecommunication, are also required to have emergency power. The battery room of telephone exchange usually has array of lead-acid batteries for back-up and also a socket for connecting a generator during extended outage period.

Type of Power System Outages

Power outages are categorized into three according to the duration and effect of the outage [11, 15 & 19].

i. A permanent fault is a massive loss of power typically caused by a fault on a power line. Power is automatically restored once the fault is cleared.

ii. A brownout is a drop-in voltage in an electrical power supply. The term brownout comes from the dimming experienced by lighting when the voltage sags. Brownouts can cause poor performance of equipment or even incorrect operation.

iii. A blackout is the total loss of power to an area and is the most severe form of power outage that can occur. Blackouts which result from or result in power stations tripping are particularly difficult to recover from quickly. Outages may last from a few minutes to a few weeks depending on the nature of the blackout and the configuration of the electrical networks.

Protection of Power Systems from Outages

In power supply networks, the power generation and electrical load (demand) must be monitored every second to avoid overloading of network components which can severely damage them. Protective relays and fuses are used to automatically detect overloads and to disconnect circuits at risk of damage. Under certain conditions, a network component shutting down can cause current fluctuations in neighboring segments of the network loading to a cascading failure of large section of the network. This may range from a building, to a block, to an entire city, to an entire electrical grid [16, 17, 20].

Restoration of Power after a Wide-Area Outage

Restoring power after a wide-area outage can be difficult, as power stations need to be brought back on-line. Normally, this is done with the help of power from the rest of the grid. In the total absence of grid power, a so-called 'black start' needs to be performed to bootstrap the power grid into operation. The means of doing so will depend on Local circumstances and operation policies, but typically, transmission utilities will establish localized power islands which are then coupled together progressively. To maintain supply frequencies within tolerable limits during this process, demand must be reconnected at the same pace that generation is restored, requiring close coordination between power stations, transmission and distribution organizations [4, 7, 9 & 10].

Mitigations of Power Outage Frequency

The mitigation of cascading failures has the following effects [12, 13, 14, 18]:

i. Increase critical number of failures causing blackouts: - Shown to decrease the frequency of smaller blackouts but increase that of larger blackouts.

ii. Increase individual power line maximum load: - Shown to increase the frequency of smaller blackouts and decrease that of large blackouts.

iii. Combination of increasing critical number and maximum load of lines: - Shown to have no significant effect on either size of blackout. The resulting minor reduction in the frequency of blackouts is projected not to worth the cost of the implementation.

iv. Increase the excess power available to the grid: - Shown to decrease the frequency of smaller blackouts but increase that of larger blackouts.

II. MATERIALS AND METHODS

Data were extracted from the daily tripping report of ten 33kV feeders supplying Ikeja distribution system. The monthly reliability indices were computed from the data collected at the station over the study period of ten years using appropriate reliability indices notations. For the purpose of this research paper, the mathematical notations of the following reliability indices were employed.

(a) Mean Time Between Failure (MTBF):- This is expressed as MTTF + MTTR

$$MTBF = MTTF + MTTR \quad (1)$$

(b) Mean Time to Failure (or Mean Up Time)

$$MTTF = \frac{SOH}{NF} \quad (2)$$

(c) Mean Time to Repair (or Mean Down Time)

$$MTTR = \frac{FOH}{NF} \quad (3)$$

(d) Availability

$$A = \frac{MTBF}{MTBF+MTTR} \quad (4)$$

(e) Failure Rate

(f) $$\lambda = \frac{1}{MTTF} \quad (5)$$

(g) Repair Rate

(h) $$\mu = \frac{1}{MTTR} \quad (6)$$

(i) Unavailability

(j) $$\bar{A} = \frac{\lambda}{\lambda+\gamma} = 1 - A \quad (7)$$

Where: NF is the number of times a unit, experiences forced outage.

FOH is the time in hours during which a unit or major equipment was unavailable or experience forced outage during operation due to fault.

SOH is the hours during which a unit or major equipment was deliberately taken out of service.

λ is the failure rate.

III. DISCUSSION OF RESULTS

Figure 1 shows the relationship between the failure rate and the names of the feeders. In 2006, Olowu feeder had a failure rate of 0.0102 faults per year while Opebi had a failure rate of 0.0157 faults per year in the 2007. Most of the feeders attached to Alagbole feeder failed frequently as a result of poor maintenance culture on these feeders compared to Olowu and Opebi Distribution feeders, this making Alagbole feeder to be relatively less reliable. Alagbole feeder of Ikeja distribution system had the highest failure rate of 0.0217 faults in 2005. This is due to the fact that most of the customers attached to this feeder experienced a prolonged period of darkness which persisted for a longer period of time before being cleared, this makes Alagbole feeder to be unreliable. Olowu feeder of Ikeja distribution system recorded the least failure rate of 0.0102 in 2006 due to the fact that most of the customers attached to this feeder experienced a little interruption which lasted for a short period of time before being cleared.

The graph illustrating the correlations between the repair rates and the feeders over ten years study period is shown in Figure 2. Olowu feeder of Ikeja distribution system recorded a repair rate of 0.03141 which appeared to be the least repair rate in this range in 2006. This suggests that most of the faults on this feeder were not promptly cleared in 2006 thus leaving most of the customers attached to the feeder in a period of total darkness over a period of time. In 2007, Opebi feeder had a repair rate of 0.0926 while Dopemu, Awuse, Medical and Mafoluku had repair rates of 0.1846, 0.1938, 0.2793 and 0.0418 respectively in 2008, 2009, 2010 and 2011. In addition, Oba-Akinjobi feeder, General Hospital feeder, 7-Up feeder and Alagbole feeders recorded rapair rates of 0.1793, 0.5126, 0.7132 and 0.0916 respectively in 2012, 2013, 2014 and 2015. In this case, Mafoluku recorded the least repair rate of 0.0418 in 2011 due to the fact that most of the customers attached to this feeder experienced a complete black-out which lasted for a longer period of time.

Figure 3 shows the graph of Mean Time Between Failure. In 2006, Olowu feeder of Ikeja distribution system recorded an MTBF of 97.6326 while Opebi had an MTBF of 63.7525 in 2007 representing about 20% decrease in MTBF as compared to Olowu distribution feeder in 2006. In 2008, Dopemu distribution feeder recorded an MTBF of 70.4805 unlike Awuse distribution feeder that recorded an MTBF of 74.2413 in 2009. Awuse distribution feeder had almost the same MTBF as that of Dopemu feeder in 2008. The MTBF of Mafoluku, Oba-Akinjobi, General Hospital, 7-Up and Alagbole distribution feeders are 63.6601, 91.5837, 99.8160, 58.6674 and 45.9952 respectively thus, ranking Alagbole distribution feeder as having the least MTBF. In this case, General Hospital feeder of Ikeja distribution feeder experienced the highest MTBF suggesting that a long period of time was taken before clearing the faults experienced by the customers attached to this distribution feeder.

The Mean Time To Repair graph of the distribution feeders is shown in Figure 4. Opebi distribution feeder recorded the least MTTR while Mafoluku distribution feeder recorded the highest MTTR. This is because it took a long period of time to clear all the faults experienced by the customers attached to Mafoluku distribution feeder as a result of the poor maintenance culture of the distribution feeder by the maintenance engineer. Olowu, Dopemu, Awuse, Medical, Oba-Akinjobi, General Hospital, 7-Up and Alagbole feeders recorded MTTR of 2.5962, 3.1329, 4.3238, 3.7142, 3.4271, 3.4858, 3.2845 and 3.6084 respectively in 2006, 2008, 2009, 2010, 2012, 2013, 2014 and 2015.

Olowu feeder of Ikeja distribution system recorded the highest availability of 97.4047 indicating that this feeder is the most reliable feeder of all the ten selected distribution feeders used in this research paper as illustrated in Figure 5. All the customers attached to this distribution feeder enjoyed a steady and uninterrupted power supply throughout the year 2006. This is partly due to the proper and prompt maintenance of the distribution feeders coupled with the replacement of aged equipment on the feeder. The only time when there was power interruption on this feeder was when there was a total black-out experienced by all customers attached to the distribution system feeder. This however lasted for just a very short period. The overall unavailability of this distribution feeder was 2.5958 in 2003 as illustrated in Figure 6.

Mafoluku feeder of Ikeja distribution system is less with an availability of 71.1112. Even though, this feeder was available to most of the customers attached to it, some of the customers still experienced a level of intermittent interruptions which were cleared as they occurred thus, rating this feeder to have an unavailability of 28.2888 as illustrated in Figure 6. Opebi, Dopemu, Awuse, Medical, Oba-Akinjobi, General Hospital, 7-Up and Alagbole feeders of Ikeja distribution system recorded availability values of 76.3565, 75.7441, 74.4966, 75.5771, 76.3929, 76.6256, 74.6983 and 72.7255 respectively. The unavailability levels of these eight feeders are as illustrated in Figure 6.

The Mean Time To Failures of the distribution feeders are shown in Figure 7. The outages on Oba-Akinjobi feeder was too prominent in 2012 making all the customers attached to this feeder to be in a period of total darkness in 2012 as compared to other distribution feeders. Thus, this feeder had a MTTF of 9.0976 in 2012. Olowu feeder recorded the least MTTF of 1.0921 in 2015 making the feeder to be reliable because the few outages on this feeder were for a short period of time. The MTTF of Alagbole, Opebi, Dopemu, Awuse, Medical, Mafoluku, General Hospital and Alagbole feeders are 3.116, 2.0914, 2.9217, 6.1821, 7.1721, 8.9124, 8.1491 and 8.9314 respectively.

Figure 8 shows the maintainability levels of the distribution feeders. Olowu feeder had the least maintainability of 0.0259 suggesting that Oluwu is the most available distribution feeder with an availability value of 97.4047 and unavailability value of 2.5953. Customers attached to this feeder enjoyed a steady power supply especially in 2006 where the outage recorded on this feeder was too minimal. Mafoluku distribution feeder had the highest maintainability value of 0.0829 ranking the feeder to be the least available feeder with availability and unavailability values of 71.7112 and 28.2888 respectively. A prominent level of outages was experienced by customers attached to this feeder especially in 2011 when the customers were put in a condition of total darkness (black-out) for a period of time. The maintainability levels of Opebi, Dopemu, Awuse, Medical, Oba-Akinjobi, General Hospital, 7-Up and Alagbole are also 0.0364, 0.0426, 0.0550, 0.0442, 0.0361, 0.0337, 0.0530 and 0.0727 respectively.

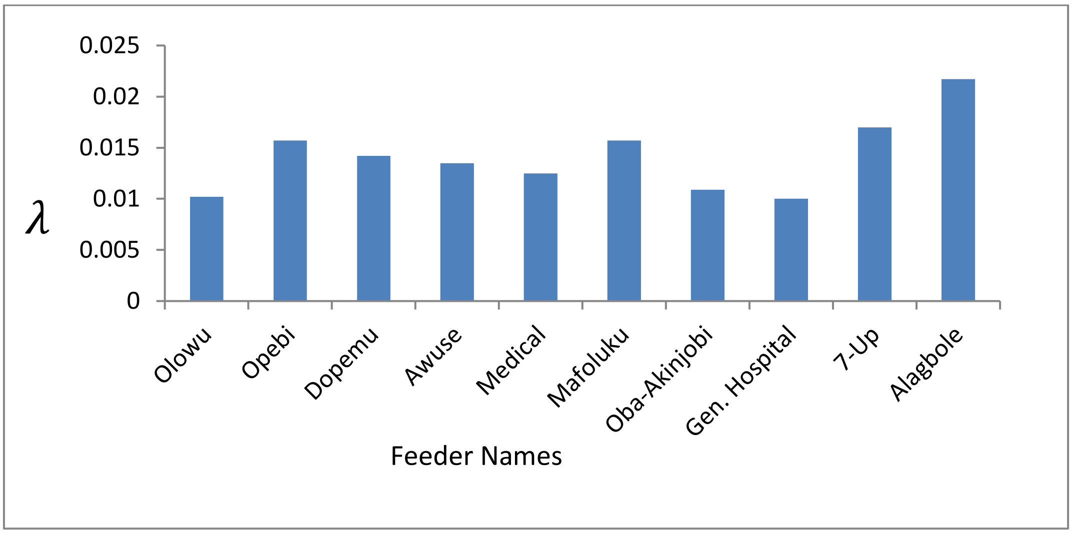

Figure 1: Failure Rate Graph for Ikeja distribution feeders

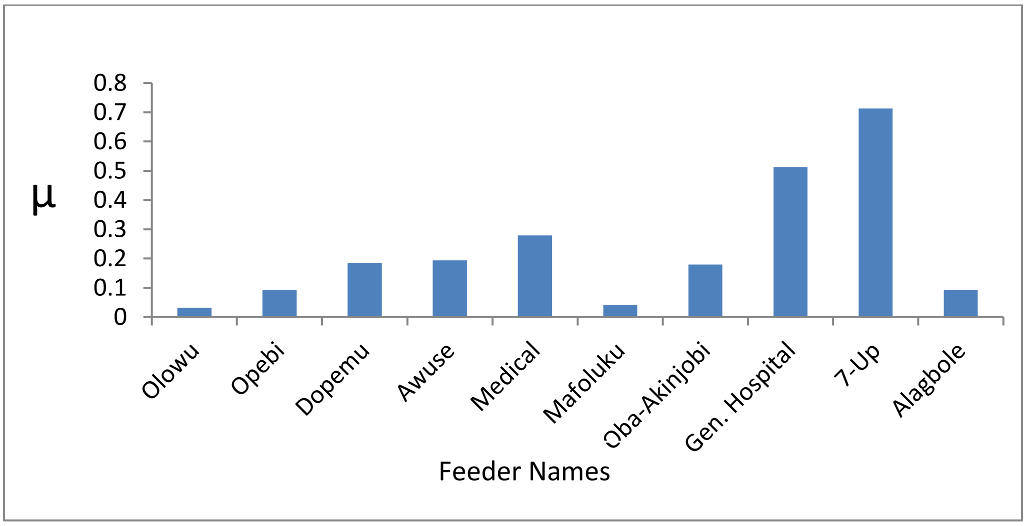

Figure 2: Repair Rate Graph for Ikeja distribution feeders

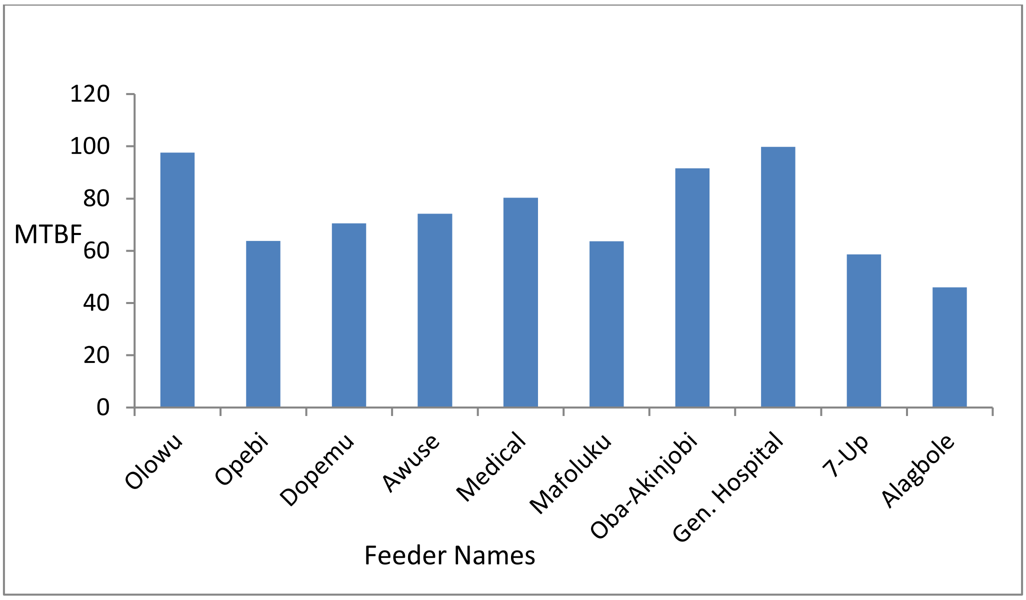

Figure 3: MTBF Graph for Ikeja distribution feeders

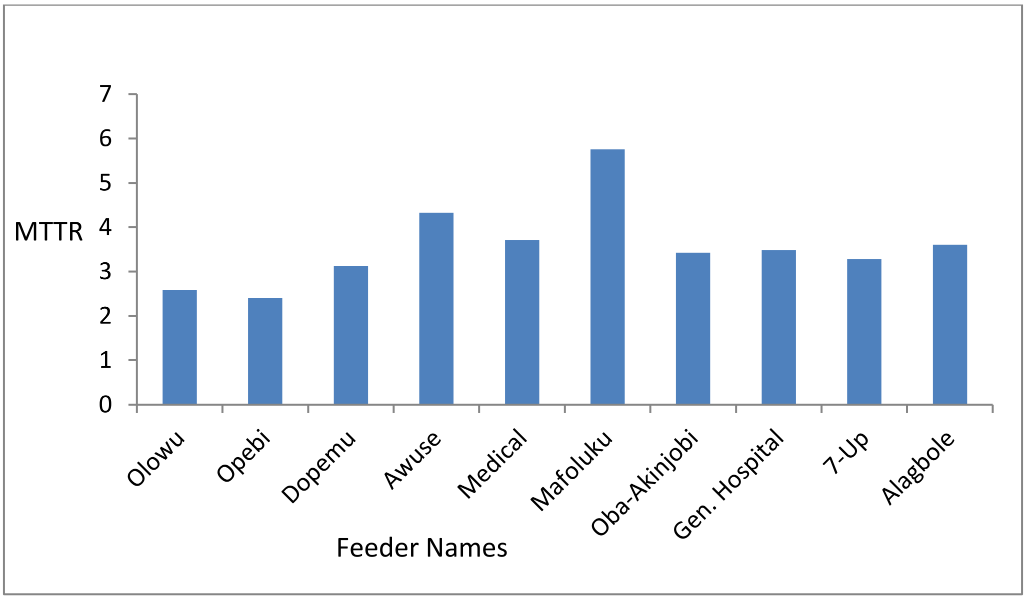

Figure 4: MTTR Graph for Ikeja distribution feeders

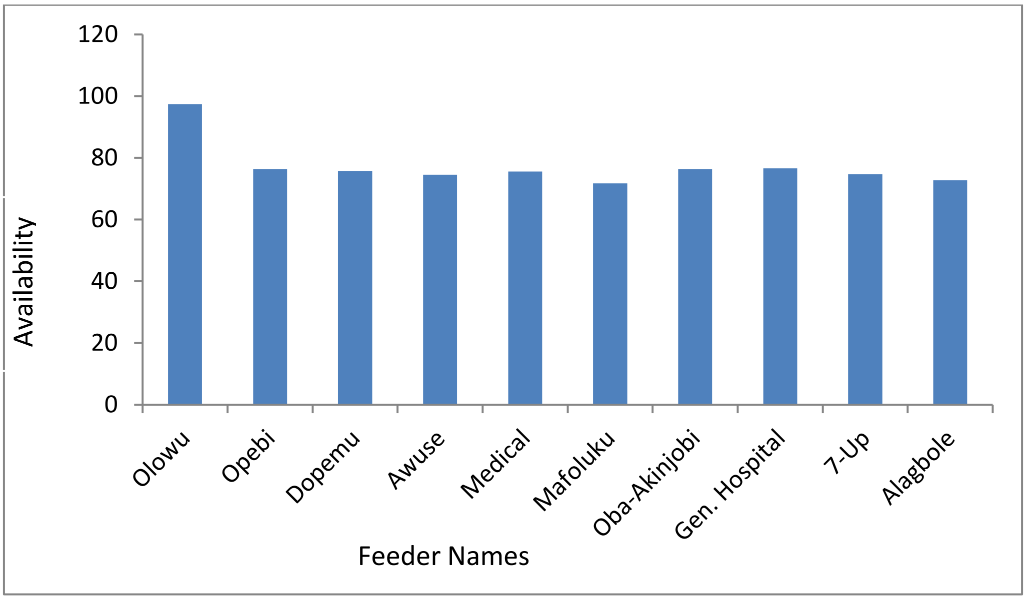

Figure 5: Availability Graph for Ikeja distribution feeders

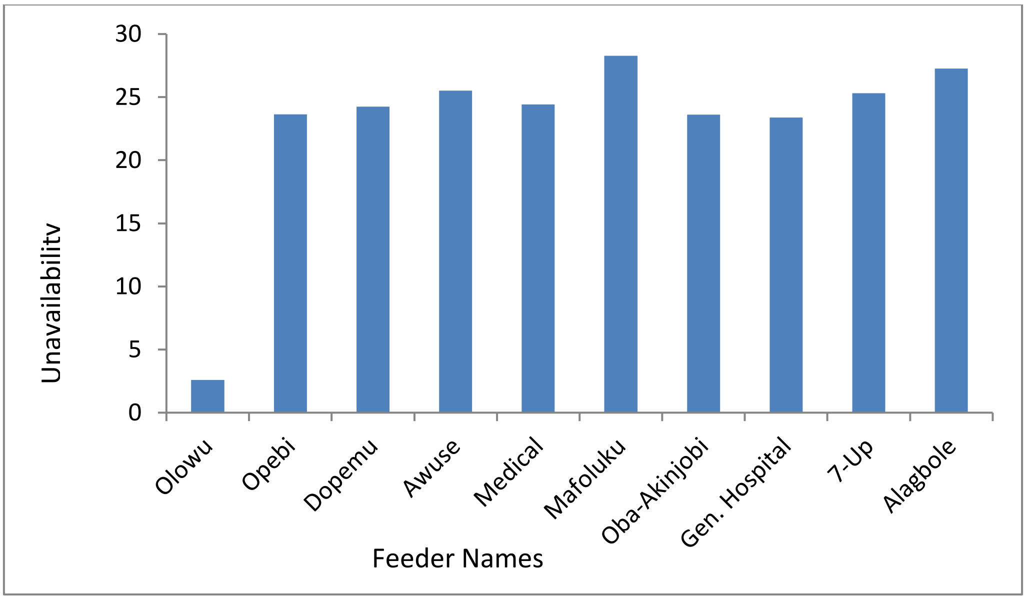

Figure 6: Unavailability Graph for Ikeja distribution feeders

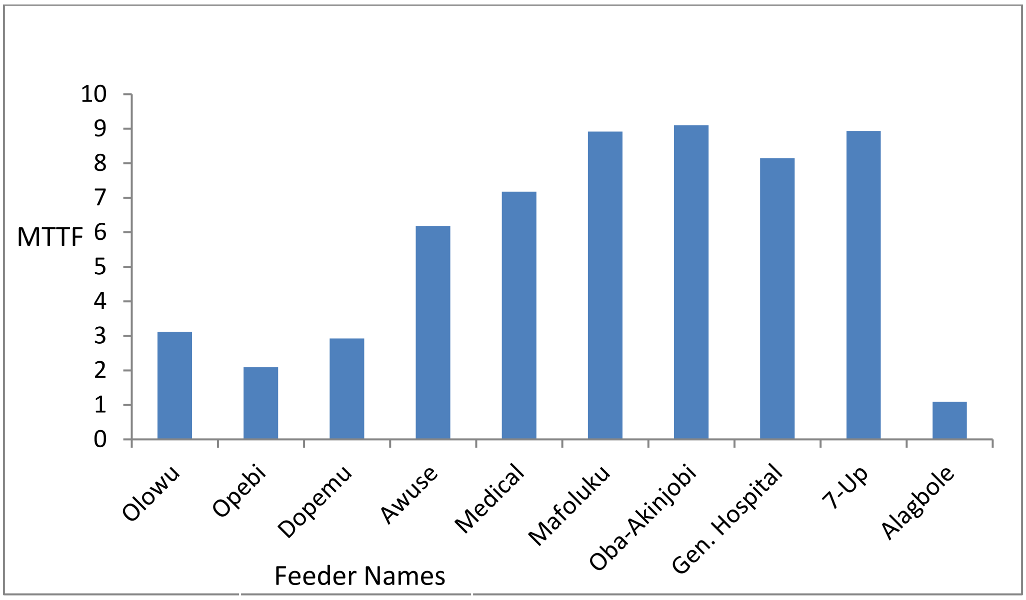

Figure 7: MTTF Graph for Ikeja distribution feeders

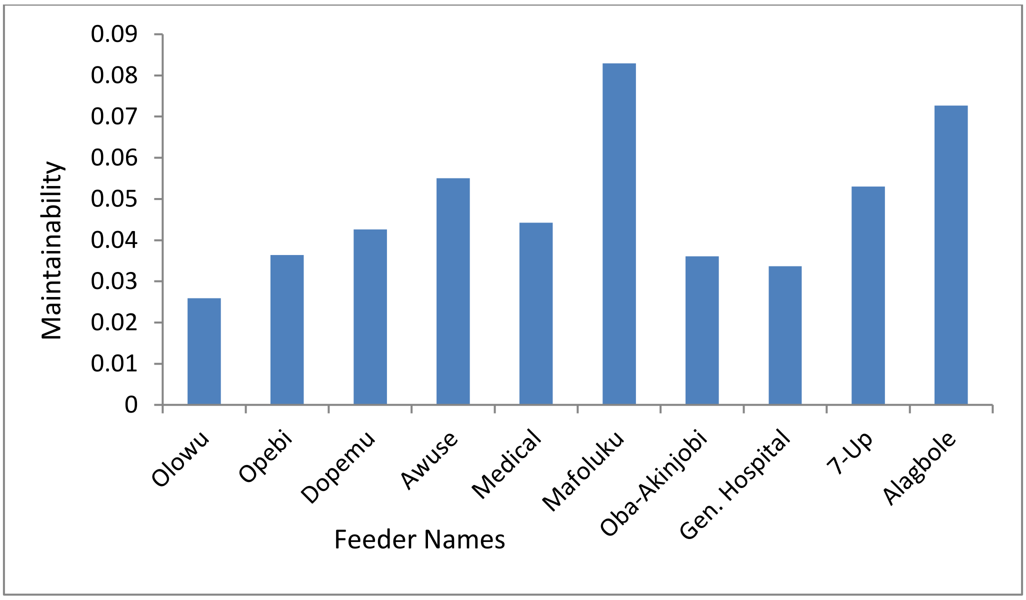

Figure 8: Maintainability Graph for Ikeja distribution feeders

IV. CONCLUSIONS

The impacts of outages on the reliability assessment of electrical power distribution systems have been presented. The study started with the computation of various reliability indices for the selected feeders of Ikeja distribution system- using appropriate mathematical notations. The results of the research paper showed that Alagbole feeder experienced the highest failure rate of 0.0217 faults in 2005 compared to other feeders in the system. General Hospital feeder had the least failure rate of 0.0100 faults per year in 2003 due to few outages experienced by the feeder thereby making it to be relatively reliable compared to Alagbole feeder. 7-Up feeder also had the highest failure rate of 0.7132 and least repair rate of 0.0314. Olowu feeder is the most reliable and available feeder with availability and an unavailability values of 97.4047 and 2.5953 respectively in 2006 because of the adequate maintenance culture on this feeder. This invariably gave rise to the feeder's maintainability value of 0.0259. The availability and unavailability values of Alagbole feeder in 2015 were 72.7255 and 27.2745 respectively with a maintainability value of 0.0727 in the same year. This is largely due to the prominent and frequent outages on this feeder, thus making the feeder to be relatively less reliable. Power outages have a greater impact on the reliability assessment of electrical distribution systems.

Conflict of Interest: The authors declare that they have no conflict of interest.

Ethical Statement: The authors declare that they have followed ethical responsibilities.

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