Evaluation of reliability of power distribution components: A case study of Sagamu Substation, Ogun State

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Global Journal of Engineering and Technology Advances, 2022, 10(01), 065–074

Publication history: Received on 01 December 2021; revised on 07 January 2022; accepted on 09 January 2022

Article DOI: <https://doi.org/10.30574/gjeta.2022.10.1.0180>

Abstract

Power system especially the distribution system which is the closest to the consumer is very fundamental and important to a nation's economy development and that was the reason this study titled "Evaluation of reliability of power system distribution components, a case study of Sagamu Substation, Ogun State" was carried out in response to the yawning of the consumer for reliable and stable power supply. It is indispensable to find means of shaping which component failure contributes most to the unavailability, outage or interruption of the distribution system, and how this unavailability essentially affects the customers. A year power outages data that caused as a result of failure on each of these components such as Switch gears, Supply lines (11Kv), Busbar, circuit breakers, Fuses, Switches, Outgoings feeders, Over current relays, Earth fault relays, Surge arresters, transformers e.t.c. were collected from Ibadan Electricity Distribution company (IBDEC), Sagamu Substation Zone, Ogun State and were typified in Table 1-11. The failure rate (f/yr) (λ) of transformer, switch gear, supply line (incoming), bus bars, circuit breakers, fuses, switches, outgoing feeder, over current relay, earth fault relay and surge arrester were evaluated as follows 0.0059, 0.0044, 0.0011, 0.6667, 0.0007, 0.0082, 0.0000, 0.0039, 0.0003, 0.0001 and 0.0000 respectively and others such as average outages time (hours), outages time hours and other basic reliability indices were calculated and illustrated in Table 12. Some of these failures were also represented in bar chart. This method relates reliability theory with the experience gained from statistics and practical knowledge of components failures and maintenance. The findings from this work revealed that fuses had the highest failure followed by transformers and the least was surge arresters and it was also discovered that the outages time was reduced during the December period. This approach can be applied to rural and urban distribution systems. This submission made reliability theory a powerful tool to assist distribution Engineers in solving difficult and complicated problems.

Keywords: Evaluation; Power; Components; Reliability; Distribution; Outages

1. Introduction

Power systems are made up of three stages which are generation, transmission and distribution. The last stage which is distribution delivers energy to different consumers such as residential, commercials and industrials consumers'. Regular, effective and stable power supply is fundamental to the economy development of any nation. A country that is experiencing elliptic power supply will definitely lags behind in her socio-economic activities. The power sector in Nigeria has her peculiar problem like every other segments of the economy. The problem in power sector is pronounced in the sense that it will affect both the common man and the rich and it also required in every sector of the economy [1]. In most distribution substation in Nigeria, overhead lines feed the substation and it also delivers electricity to customers

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while few make use of underground cables. The insulation material used in overhead lines and in underground cables is the main difference. Overhead lines are insulated by air which is an external factor and makes lines exposed to different environmental factors such as animals, weather etc. One of the advantages of overhead lines is that it is not easily affected by high currents because the conductors are able to cope with temperatures higher than normal. That notwithstanding, the reliability of overhead lines is still greatly affected by high currents in many ways [2]. Lightning is a natural phenomenon which affects distribution substation system by directly striking the power contacts and sometimes indirectly by striking objects in close range which induces a travelling voltage wave. Usually, direct strikes are almost impossible to be protected against in a distribution system. Lightning surge arrestors are used to protect distribution system equipment from damage that might result as a result of induced high voltage caused by direct strikes. Furthermore, the body of the transformer which is solidly grounded and the neutral serves as lightning arrester ensuring protection against lightning in the distribution substation. Poles are structural elements needed to implement overhead distribution designs. They are conspicuous and can be easily tampered with by vehicular accident or wind. The safety of electrical wires on poles is the major reliability concern. When wind blows, it affects both the pole itself and the conductors. Laminated woods and cast concretes are the two types of pole majorly used and the wooden type is gaining popularity due to the fact that it is cheaper. In many cases, there are new attachments placed on existing poles which may mean that the pole may no longer meet wind loading criteria. Distribution poles are needed to be inspected and replaced when deterioration has occurred. A circuit breaker is also known as the automatically operated electrical switch that functions when a fault detected by interrupting the current flow. There are various sizes of circuit breaker which are from small devices up to large switchgear that used to protect low current circuit until high voltage circuit [3]. There are many types of circuit breakers. Switchgear is combinations of electrical disconnect switches, fuses or circuit breakers used to control, protect and isolate electrical equipment. Switches are safe to open under normal load current (some switches are not safe to operate under normal or abnormal conditions), while protective devices are safe to open under fault current. Very important equipment may have completely redundant and independent protective systems, while a minor branch distribution line may have very simple low-cost protection. Fuses are most used in power distribution networks are the fuses. This is due to its low cost when compared to other protection devices and its satisfactory operation for one of the major problems of the distribution networks that refer to the over current from short circuits by contact of the cables between each other, the vegetation or to the ground, and among others. As a fuse-type protective device, it bases its operation on a metal link with specific characteristics of time versus current; when it reaches the maximum tolerable current, the heat melts the active element and releases the opening of circuit [4]. Preventive maintenance measures will have effect on reliability of the system by prolonging the lifetime of an asset and improving the condition of an asset [5]. Usually, preventive maintenance is the anticipation of failures and adoption of necessary preventive actions before they occur. The main objectives of preventive maintenance are to affect the work of inspection servicing and adjustment and to prevent failure of equipment during operation [6]. Reliability may also reduce the duration of power supply interruptions. Preventive maintenance activities could prevent the actual cause of the failure in the system. As a result, in cost- effective expenditure, Preventive maintenance should be employed where the reliability benefits outweigh the cost of implementing the Preventive maintenance [7]. Reliability of power system is the probability that a power system will meet the consumers' load requirements at any time [8]. Reliability of Power system can be explained as: The reliability of a System is the ability of the system to function satisfactorily under stated planned actions for a certain time frame [9] and [10]. The data collected from the selected substation is used to estimate the reliability of the components in the substation, the overall reliability of the substation and the customer reliability indices of the system.

The data collected from the selected substation is used to estimate the reliability of the components in the substation, the overall reliability of the substation and the customer reliability indices of the system.

2. Collection of Data

Power outages data recorded in the utility outage logbook were collected from the substation, the system here in Nigeria generally is too poor and lack intelligent devices that can alert or inform the distribution company whenever there is failure of any of the components or any form of interruption to the delivery of electricity to the customer. Outages due to scheduled maintenance and load shedding were not taken into consideration. This is so because scheduled outage or load shedding in the substation is intentional and cannot be attributed to any component failure which makes it hard for analysis to pin-point weak component if used. Data were collected from Sagamu distribution station for a period of a year with referencing to these components stated in the Table 1-11 below.

3. Reliability evaluation

Reliability is the measure or the probability that a product or service will perform properly under normal operating condition for a specified period of time. It is used as a measure of the system's success in providing its function properly [10] and [11]. The failure rate ($f(t)$) is calculated as

$$\frac{n_f}{n_o} = \lambda \quad (1)$$

Where, n_f is number of failures per year and n_o is total numbers of observation per year and

Reliability is given as,

$$R_t = e^{-\lambda t} \quad (2)$$

In reliability analysis, the arbitrary variable is the regularity time and so the usual function that is paramount suitable is the exponential distribution function due to the fact that it has only time as the independent variables [12]. Hence a constant hazard rate is often assumed and described the failure rate (λ). When a constant failure rate is presupposed, the reliability functions now turn out to be [13].

$$h(t) = \lambda \quad (3)$$

$$F(t) = 1 - e^{-\lambda t} \quad (4)$$

$$R(t) = 1 - F(t) = e^{-\lambda t} \quad (5)$$

$$f(t) = \frac{dF(t)}{dt} = \lambda e^{-\lambda t} \quad (6)$$

The above equations represented many fundamental reliability functions. Where:

$F(t)$ is the failure distribution (this is the probability of finding a healthy component in a failed state after time t).

$R(t)$ is the reliability function. This is defined as the probability of finding a healthy component in a healthy state after time t .

$f(t)$ is the failure density distribution and which implies the rate at which a component fails at time t

$H(t)$ is the Hazard rate is defined as the rate at which a component fails at time t given that it is healthy until time t .

λ = failure rate

t = time

• **MTBF: Mean Time between Failures:** This is the average time between two failures of the component. i.e.

$$MTBF = \frac{\text{Total System operating hours}}{\text{Number of failures}} \quad (7)$$

$$\text{Availability } (A) = \frac{MTBF - MTTR}{MTBF} \quad (8)$$

From these parameters, some other parameters can be derived (when assuming the negative exponential distribution)[14].

Table 1 Summary of Outage Frequency and Duration on Transformer

Month	No. of Outages	Outage Time (Hours)	Total Hour	Failure Rate(λ)
January	8	150	744	0.0108
February	9	50	696	0.0115
March	0	0	744	0.0000
April	6	50	720	0.0083
May	7	20	744	0.0094
June	5	40	720	0.0070
July	2	2	744	0.0027
August	7	3	744	0.0094
September	1	2	720	0.0014
October	2	4	744	0.0027
November	1	6	720	0.0013
December	4	5	744	0.0054
Total number of failures per year	52	232	8784	

Table 2 Summary of Outage Frequency and Duration on Switchgear

Month	No. of Outages	Outage Time (Hours)	Total Hour	Failure Rate(λ)
January	12	24	744	0.0161
February	14	18	696	0.0201
March	5	15	744	0.0067
April	0	0	720	0.0000
May	5	3	744	0.0067
June	0	0	720	0.0000
July	0	0	744	0.0000
August	0	0	744	0.0000
September	0	0	720	0.0000
October	0	0	744	0.0000
November	1	3	720	0.0014
December	2	4	744	0.0027
Total number of failures per year	39	232	8784	

Table 3 Summary of Outage Frequency and Duration on supply line (11KV)

Month	No. of Outages	Outage Time (Hours)	Total Hour	Failure Rate(λ)
January	1	10	744	0.0013
February	3	5	696	0.0043
March	1	2	744	0.0013
April	5	4	720	0.0069
May	0	0	744	0.0000
June	0	0	720	0.0000
July	0	0	744	0.0000
August	0	0	744	0.0000

September	0	0	720	0.0000
October	0	0	744	0.0000
November	0	0	720	0.0000
December	0	0	744	0.0000
Total number of failures per year	10	21	8784	

Table 4 Summary of Outage Frequency and Duration on Busbar

Month	No. of Outages	Outage Time (Hours)	Total Hours	Failure Rate(λ)
January	0	0	744	0.0000
February	0	0	696	0.0000
March	0	0	744	0.0000
April	1	5	720	0.0013
May	1	4	744	0.0013
June	1	3	720	0.0013
July	0	0	744	0.0000
August	2	6	744	0.0027
September	3	8	720	0.0042
October	0	0	744	0.0000
November	0	0	720	0.0000
December	0	0	744	0.0000
Total number of failures per year	8	26		

Table 5 Summary of Outage Frequency and Duration on circuit breakers

Month	No. of Outages	Outage Time (Hours)	Total Hours	Failure Rate(λ)
January	0	3	744	0.0000
February	1	5	696	0.0014
March	1	4	744	0.0013
April	0	0	720	0.0000
May	0	0	744	0.0000
June	0	0	720	0.0000
July	2	5	744	0.0027
August	1	5	744	0.0013
September	0	7	720	0.0000
October	0	0	744	0.0000
November	0	0	720	0.0000
December	1	7	744	0.0013
Total number of failures per year	6	36	8784	

Table 6 Summary of Outage Frequency and Duration on Fuses

Month	No. of Outages	Outage Time (Hours)	Total Hours	Failure Rate(λ)
January	5	7	744	0.0067
February	7	6	696	0.0100
March	9	5	744	0.0121
April	6	4	720	0.0083
May	3	2	744	0.0040
June	6	8	720	0.0083
July	2	7	744	0.0027
August	7	5	744	0.0094
September	7	3	720	0.0097
October	6	5	744	0.0081
November	9	7	720	0.0125
December	5	6	744	0.0067
Total number of failures per year	72	65	8784	

Table 7 Summary of Outage Frequency and Duration on Switches

Month	No. of Outages	Outage Time (Hours)	Total Hours	Failure Rate (λ)
January	0	0	744	0.0000
February	0	0	696	0.0000
March	1	5	744	0.0134
April	2	5	720	0.0028
May	0	0	744	0.0000
June	0	0	720	0.0000
July	0	0	744	0.0000
August	0	0	744	0.0000
September	0	0	720	0.0000
October	0	0	744	0.0000
November	0	0	720	0.0000
December	0	0	744	0.0000
Total number of failures per year	0	0	8784	

Table 8 Summary of Outage Frequency and Duration on Outgoing Feeders

Month	No. of Outages	Outage Time (Hours)	Total Hours	Failure Rate(λ)
January	2	26	744	0.0027
February	3	10	696	0.0043
March	4	14	744	0.0054
April	2	10	720	0.0027
May	4	12	744	0.0054
June	4	2	720	0.0056
July	3	4	744	0.0040
August	6	5	744	0.0081

September	2	2	720	0.0027
October	1	1	744	0.0013
November	3	1	720	0.0042
December	1	1	744	0.0013
Total number of failures per year	35	88	8784	

Table 9 Summary of Outage Frequency and Duration on over current relays

Month	No. of Outages	Outage Time (Hours)	Total Hours	Failure Rate (λ)
January	1	1	744	0.0013
February	0	0	696	0.0000
March	0	0	744	0.0000
April	0	0	720	0.0000
May	0	0	744	0.0000
June	1	2	720	0.0014
July	1	1	744	0.0013
August	0	0	744	0.0000
September	0	0	720	0.0000
October	0	0	744	0.0000
November	0	0	720	0.0000
December	0	0	744	0.0000
Total number of failures per year	3	4		

Table 10 Summary of Outage Frequency and Duration on Earth fault relay

Month	No. of Outages	Outage Time (Hours)	Total Hours	Failure Rate(λ)
January	0	0	744	0.0000
February	0	0	696	0.0000
March	0	0	744	0.0000
April	1	3	720	0.0013
May	0	0	744	0.0000
June	0	0	720	0.0000
July	0	0	744	0.0000
August	0	0	744	0.0000
September	0	0	720	0.0000
October	0	0	744	0.0000
November	0	0	720	0.0000
December	0	0	744	0.0000
Total number of failures per year		3	8784	

Table 11 Summary of Outage Frequency and Duration on Surge Arresters

Month	No. of Outages	Outage Time (Hours)	Total Hours	Failure Rate (λ)
January	0	0	744	0.0000
February	0	0	696	0.0000
March	0	0	744	0.0000
April	0	0	720	0.0000
May	0	0	744	0.0000
June	0	0	720	0.0000
July	0	0	744	0.0000
August	0	0	744	0.0000
September	0	0	720	0.0000
October	0	0	744	0.0000
November	0	0	720	0.0000
December	0	0	744	0.0000
Total number of failures per year	0	0	8784	

Table 12 Basic Reliability Indices on Each Component for the year under review

Components name	No. of the components	Failure Rate (λ) (yr)	Failure Rate (f/yr) (λ)	No. of Failures	Average Outage Time (Hours)	Outages time (hour)
Transformer	30	0.0699	0.0059	52	27.67	232
Switch gear	37	0.0537	0.0044	39	5.583	67
Supply line (Incoming)	20	0.0138	0.0011	10	1.75	21
Bus bars	3	0.0108	0.6667	8	2.167	26
Circuit Breakers	5	0.008	0.0007	6	3.000	36
Fuses	57	0.0985	0.0082	72	5.417	65
Switches	5	0.0162	0.0000	0	0.000	0
Outgoing feeder	40	0.0477	0.0039	35	7.333	88
Over current relay	2	0.004	0.0003	3	0.333	4
Earth fault relay	1	0.0013	0.0001	1	0.250	3
Surge Arrester	0	0.000	0.0000	0	0.000	0

Figure 1 Bar Chart representing the Number of the Components

Figure 2 Bar Chart representing the Number of failures that occurred on Component

Figure 3 Bar Chart representing the Failure Rate of Each Component

Figure 4 Bar chart representing the Average Outage Time (Hours) and outages time (hour)

4. Conclusion

Evaluation of reliability of power system distribution components was carried out using Sagamu as a case study, since power supply is very cogent to the development of a nation economy.

Power outages data that were occasioned as a result of failure on each of these components such as Switch gears, Supply line (11Kv), Busbar, circuit breakers, Fuses, Switches, Outgoings feeders, Over current relays, Earth fault relays, Surge arresters and transformers e.t.c. were collected from the distribution of Ibadan Electricity Distribution company, Sagamu Substation Zone, Ogun State and were typified in Table 1-11. The reliability indices were evaluated utilizing mathematical and statistical solutions such as the failure rate, Average outages time (hours) and outages time hours were calculated as some of basic reliability indices and were illustrated in Table 12 and some of these failures were also represented in bar charts with fuses has the highest failure followed by transformers and the least was surge arresters. The results were discussed and deduced so as to identify the component contributing most to unavailability and interruption of the system and also revealed the overall reliability of the substation and how this affected the consumers that were connected to the substation the result of the analysis illustrated that fuses failures contributed the highest power outages in the substation followed by the transformers and the switch gears. From the analysis carried out, it has been demonstrated that the frequency of outages affects system's reliability but the outage duration has more impacts on the system availability and reliability. The conclusion from this study demonstrated that it is advantageous to base the evaluation of reliability of power system distribution components decisions on tested, processed, investigated and analyzed outages data. This study could be used in planning of power system, assets management and extension and out rightly improve power supply and the components must be well maintained to prevent unplanned interruptions, concerted efforts should be put in place to see that when there is a component outage, the time duration is reduced in order to obtain more stable and reliable power supply and lastly suitable and constant inspection and maintenance of components by the Utility must be put in place to improve reliability of the substation.

Compliance with ethical standards

Acknowledgments

I would like to thank the Management of Ibadan Electricity Distribution Company for their support on the project and I also appreciate the contribution of my coauthor.

Disclosure of conflict of interest

No potential conflict of interest was reported by the authors.

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