International Journal of Electrical and Power Engineering 1 (4): 463-467, 2007

Fault Events Reduction in Electric Power Distribution Reliability Assessment Using Pareto Analysis

[1]E.A. Ogujor and [2]P.A. Kuale
[1]Department of Electrical and Electronics Engineering, University of Benin, Benin City,
Edo State, Nigeria
[2]Faculty of Engineering, Oleh Campus, Delta State University, Delta State, Nigeria

Abstract: Identification of the significant few faults in Electric Power Distribution Systems (EPDS) is very crucial in reliability assessment. This study presents the application of Pareto analysis in capturing the faults that, if attended to, will increase the reliability of Electric Power Distribution Systems. Historical power outage data in 2004 were collected from the monopolistic operator of the Nigerian power system, National Electric Power Authority-NEPA (now unbundled and called Power Holding Company of Nigeria, (PHCN) Plc) on the four feeders: Uselu, Ugbowo, Eguadaiken and FGGC Road feeders radiating from the 2×15 MVA transformers, 33/11kV Ugbowo injection substation were collected and analysed using Microsoft Access database. The substation serves about 17537 customers. The Pareto charts were then plotted using the line-column in two-axis of Microsoft Excel spreadsheet. The results obtained showed that attending to load shedding, load shedding and earth faults, load shedding and 33kV line failures, load shedding in the FGGC Road, Ugbowo, Uselu and Eguadaiken feeders will lead to reliability increase from 0.78879-093353, 0.69483-0.91959, 0.78797-0.94413 and 0.75938-0.93032, respectively. It is apparent that the reduction of load shedding as suggested by the analysis implies the need for the increase of Electric power generation in Nigeria to meet demand and system losses. The other faults that are not captured by this analysis will cost more to solve than the derivable benefits.

Key words: Pareto analysis, electric power, frequency, faults, reliability

INTRODUCTION

The comfort of modern day society can only be sustained by the availability of Electricity. Electric power is generated at far locations and transmitted through conductors over long distances to distribution centres close to consumers. There are various protective devices such as relays, circuit breakers, fuses, e.t.c to ensure that the customer receives electric power safely at all times. All the components from the generators through transformers and protective gears are prone to stochastic failures. An outage can occur due to equipment failures, animals, severe weather, vegetation, human factors (vandalisation, operators' faults, e.t.c), load shedding and some unknown factors (Ogujor, 2007). A Pareto chart is created using frequency of faults and cumulative percentage arranged in descending order. A bar chart of the frequency of fault events is plotted on the left hand and the cumulative percentage on the right hand. A trace of the 80% mark on your right hand of the Pareto chart is traced until it intercepts the cumulative frequency curve. All the fault events to the left of the point of interception are the significant few fault events that must be attended to.

The Nigeria distribution system as a developing one with horizontally distributed customers is characterised by very long radial circuits, under sized distribution conductors and high concentration of factors that impact reliability (Ogujor, 2007). These factors that lead to power outages do not impact on Electric Distribution at the same degree. It is therefore necessary to determine the factors that impact most on reliability and determine control measure to be adopted in order to reduce their effect.

In this study, the Pareto analysis was used to identify the main factors contributing to power outages on a selected distribution portion of the Nigerian power system and how they can be mitigated in order to increase electric power distribution reliability in this area.

MATERIALS AND METHODS

Power outage data can create large quantities of data most especially in economies where electric power is unreliable. The application of computers in power outage data analysis has increased the capability of collection and data management.

Corresponding Author: E.A. Ogujor, Department of Electrical and Electronic Engineering, University of Benin, Benin City, Edo State, Nigeria

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The Pareto analysis and historical data used in this paper are discussed in this section.

Pareto analysis uses the principle that problem solvers should focus on 20% of factors causing 80% of the problems instead of the 80% of factors causing only 20% of the problems. It is also called the 80/20 rule. The numbers 80 and 20 are not absolute (Leavengood and Reeb, 2002). In other words, it can also be stated that by doing 20% of work you can generate 80% of the advantage of doing the entire research (Mindtools LTD, 2007). This principle was named after Vilfredo Pareto, an Italian sociologist and economist in the 19th century who observed that 80% of Italy's wealth was owned by 20% of the population (Strickland, 2006). This methodology has been employed in the design and optimization of industrial processes (Haaland, 1989).

This analysis can be applied in electric power distribution systems. It is a principle centered on 'significant few and the insignificant many'. Large proportion of Electric power distribution system failures are due to a small number of frequently occurring causes (Connor, 2002). Therefore, if we analyse the failure data, we can solve the largest proportion of the overall reliability problem with the most economical use of resources. A large number of failure causes can be eliminated from further analysis by creating a Pareto plot of the failure data (Connor, 2002).

The Pareto analysis will help the Power Holding Company of Nigeria (PHCN) in decision-making on where in the distribution network effort and money need to be applied in order to improve reliability, by solving the most critical problems first.

RESULTS AND DISCUSSION

The faults that occurred in all the feeders are shown in Table 1. In order to apply the Pareto principle, the data was arranged in descending order. The relative and cumulative frequencies of each fault were calculated for the Eguadaiken, Uselu, Ugbowo, FGGC Road feeders and presented in Table 2-5, respectively. A sample calculation using the Load Shedding factor in Table 2 of the Eguadaiken feeder is given as:

Total Faults (F) = 739

Frequency of Load Shedding Faults (L) = 525

$$\text{Relative Frequency of Load Shedding Faults (\%)} = (F/L)\times 100 = (525/739)\times 100 = 71.04\% \quad (1)$$

Table 1: Faults distribution in the Ugbowo Substation feeders

	Feeders			
Fault	FGGC Road	Ugbowo	Eguadaiken	Uselu
Load shedding	525	467	525	405
Earth fault	38	134	38	62
33kV line failure	118	100	118	112
Animal (Bird,snakes,etc)	1	0	1	0
Broken pole/ Cross arms	3	4	3	7
Jumper and J and P fuse closure	38	75	38	63
Maintenance/repairs	6	22	6	28
Tree faults	1	2	1	4
Unknown	1	6	1	5
Jumper/Wire cut	5	6	5	13
Over current	3	0	3	2
Transformer test	0	0	0	1
Others	0	0	0	0

Table 2: Faults arranged in descending order with relative and cumulative frequencies in Eguadaiken feeder

Fault	Frequency of faults	Relative frequency (%)	Cummulative frequency (%)
Load shedding	525	71.04	71.04
33 kV line failure	118	15.97	87.01
Earth fault	38	05.14	92.15
Jumper and J and P fuse closure	38	05.14	97.29
Maintenance/repairs	6	00.81	98.10
Jumper/Wire cut	5	00.68	98.78
Broken pole/ Cross arms	3	00.41	99.19
Over current	3	00.41	99.59
Animal(Bird,snakes,etc)	1	00.14	99.73
Tree faults	1	00.14	99.86
Unknown	1	00.14	100.00
Transformer test	0	00.00	100.00

Table 3: Faults arranged in descending order with relative and cumulative frequencies in Uselu feeder

Fault	Frequency of faults	Relative frequency (%)	Cummulative frequency (%)
Load shedding	405	57.69	57.69
33kV line failure	112	15.95	73.64
Jumper and J and P fuse closure	63	08.97	82.62
Earth fault	62	08.83	91.45
Maintenance/repairs	28	03.99	95.44
Jumper/Wire cut	13	01.85	97.29
Broken pole/ Cross arms	7	01.00	98.29
Unknown	5	00.71	99.00
Tree faults	4	00.57	99.57
Over current	2	00.28	99.86
Transformer test	1	00.14	100.00
Animal (Bird,snakes,etc)	0	00.00	100.00

Table 4: Faults arranged in descending order with relative and cumulative frequencies in Ugbowo feeder

Fault	Frequency of faults	Relative frequency (%)	Cummulative frequency (%)
Load shedding	467	57.23	57.23
Earth fault	134	16.42	73.65
33kV line failure	100	12.25	85.91
Jumper and J and P fuse closure	75	09.19	95.10
Maintenance/repairs	22	02.70	97.79
Unknown	6	00.74	98.53
Jumper/Wire cut	6	00.74	99.26
Broken pole/ Cross arms	4	00.49	99.75
Tree faults	2	00.25	100.00
Animal (Bird,snakes,etc)	0	00.00	100.00
Over current	0	00.00	100.00
Transformer test	0	00.00	100.00

Table 5: Faults arranged in descending order with relative and cumulative frequencies in FGGC Road feeder

Fault	Frequency of faults	Relative failures(%)	Cummulative frequency(%)
Load shedding	429	68.53	68.53
Earth fault	122	19.49	88.02
33 kV line failure	26	04.15	92.17
Jumper/Wire cut	17	02.72	94.89
Animal (Bird,snakes,etc	13	02.08	96.96
Broken pole/Cross arms	7	01.12	98.08
Tree faults	6	00.96	99.04
Maintenance/repairs	5	00.80	99.84
Overcurrent	1	00.16	100.00
Jumper and J and P fuse closure	0	00.00	100.00
Unknown	0	00.00	100.00
Transformer test	0	00.00	100.00

The cumulative frequency was used to show the combine effect of the significant few faults leading to power outages in the distribution system. This was carried out by adding the relative frequency of each type of fault to the sum of all preceding relative frequencies. A sample calculation is given using Table 2 of the Eguadaiken feeder as:

The 33kV line failure cummulative frequency = Sum of Load shedding and 33kV line failure relative frequency (2)
= 71.04 + 15.97
= 87.01%

Using line-column in two-axis of Microsoft Excel spreadsheet, the Pareto Charts of Fig. 1-4 were plotted based on the data of Table 2-5, respectively. The line plots and bar graphs represent the cumulative faults frequency curve and frequency of faults, respectively.

In Fig. 1, the 80% line was traced to intercept the cumulative frequency curve. Load shedding is the single significant fault event that need to be attended to. Solving this fault event , will lead to the following fault reduction in the feeder as given in Eq. 3:

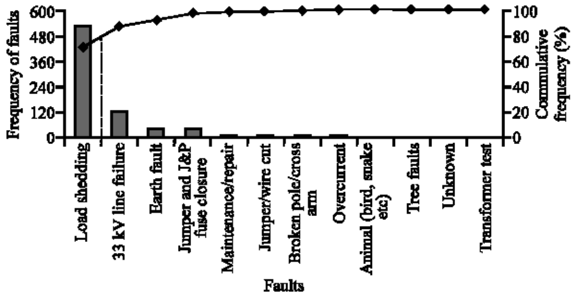

Fig. 1: Pareto chart of Eguadaiken feeder's fault

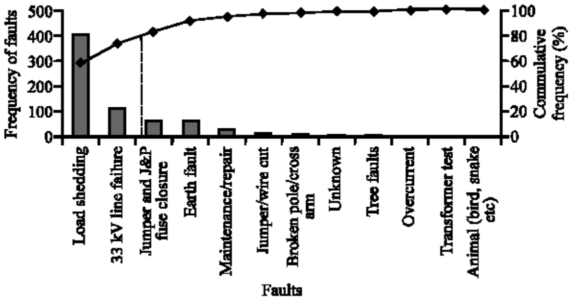

Fig. 2: Pareto chart of Uselu feeder's fault

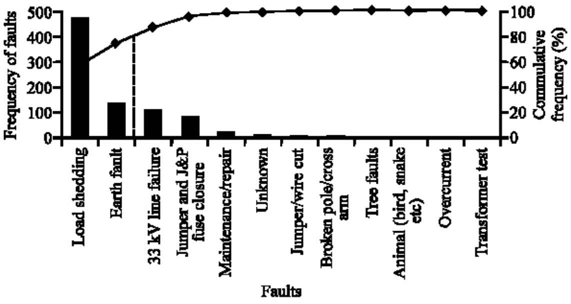

Fig. 3: Pareto chart of Ugbowo feeder's fault

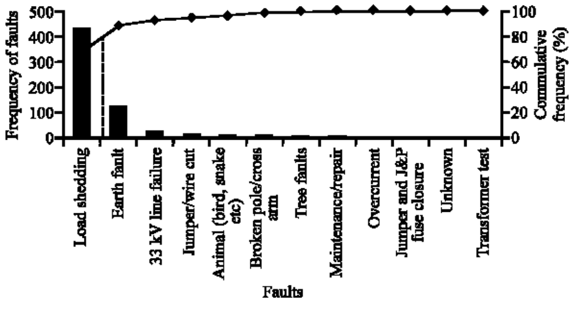

Fig. 4: Pareto chart of FGGC Road feeder's fault

$$\text{Percentage of fault events that require attention} = \left(\frac{\text{Few faults that require attention}}{\text{Total faults}}\right)\times 100 \tag{3}$$

$$= \left(\frac{525}{739}\right)\times 100$$

$$= 71.04\%$$

Thus, attending to load shedding in the Eguadaiken feeder solves 71.04% of the fault events that lead to power outages in the feeder. This will lead to the following increase in reliability. The relationship between reliability and unreliability is given in Eq. 4 as:

$$\text{Unreliability} = 1 - \text{reliability} \tag{4}$$

From Table 6, using Eq. 4, the reliability of the Eguadaiken feeder is 0.75938. Therefore,

$$\text{Unreliability} = 1 - 0.75938 = 0.24062$$

The improvement due to the application of the Pareto analysis is the product of the percentage of faults that require attention and unreliability. This is given as:

$$= 0.7104 \times 0.24062 = 0.17094$$

Thus, attending to load shedding in this feeder will lead to unreliability reduction of 0.17094.This fractional reduction of unreliability will lead to the same fractional increase in reliability using Eq. 4. Therefore, the feeder's reliability after attending to load shedding in this feeder is given as:

$$= 0.75938 + 0.17074 = 0.93032$$

Similarly, in Fig.2, the 80% line was traced to intercept the cumulative frequency curve. Load shedding and 33kV line fault events are the significant few faults that need to be attended to. Solving these two fault events, will lead to the following fault reduction in the feeder using Eq. 3:

$$\begin{aligned}&\text{Percentage of fault events that require attention}\\&= \left(\frac{\text{Few faults that require attention}}{\text{Total faults}}\right) \times 100\\&= \left(\frac{517}{702}\right) \times 100\\&= 73.65\%\end{aligned}$$

Thus, attending to load shedding and 33 kV line fault events in the Uselu feeder solves 73.65% of the faults that lead to power outages in the feeder. This will lead to the following increase in reliability.

From Table 6, using Eq. 4, the reliability of the Uselu feeder is 0.78797. Therefore,

$$\text{Unreliability} = 1 - 0.78797 = 0.21203$$

The improvement due to the application of Pareto analysis is the product of the percentage of faults that require attention and unreliability. This is given as:

$$= 0.7365 \times 0.21203 = 0.15616$$

Thus, attending to load shedding and 33kV line fault events in this feeder will lead to unreliability reduction of 0.15616.This fractional reduction of unreliability will lead to the same fractional increase in reliability using Eq. 4. Therefore, the feeder's reliability after attending to load shedding and 33 kV line fault events in this feeder is given as:

$$= 0.78797 + 0.15616 = 0.94413$$

Also, in Fig.3, the 80% line was traced to intercept the cumulative frequency curve. Load shedding and earth fault events are the significant few faults that need to be attended to. Solving these two fault events, will lead to the following fault reduction in the feeder using Eq. 3:

$$\begin{aligned}&\text{Percentage of fault events that require attention}\\&= \left(\frac{\text{Few faults that require attention}}{\text{Total faults}}\right) \times 100\\&= \left(\frac{601}{816}\right) \times 100\\&= 73.65\%\end{aligned}$$

Thus, attending to load shedding and earth fault events in the Ugbowo feeder solves 73.65% of the faults that lead to power outages in the feeder. This will lead to the following increase in reliability.

From Table 6, using Eq. 4, the reliability of the Ugbowo feeder is 0.69483. Therefore,

$$\text{Unreliability} = 1 - 0.69483 = 0.30517$$

The improvement due to the application of Pareto analysis is the product of the percentage of faults that require attention and unreliability. This is given as:

$$= 0.7365 \times 0.30517 = 0.22476$$

Thus, attending to load shedding and earth fault events in this feeder will lead to unreliability reduction of 0.22476.This fractional reduction of unreliability will lead to the same fractional increase in reliability using Eq. 4. Therefore, the feeder's reliability after attending to load shedding and earth fault events in this feeder is given as:

$$= 0.69483 + 0.22476 = 0.91959$$

Lastly, in Fig. 4, the 80% line was traced to intercept the cumulative frequency curve. Load shedding is the single significant fault that need to be attended to. Solving this fault event, will lead to the following fault reduction in the feeder:

$$\text{Percentage of fault events that require attention}$$
$$= \left(\frac{\text{Few faults that require attention}}{\text{Total faults}}\right)\times 100$$
$$= \left(\frac{429}{626}\right)\times 100$$
$$= 68.53\%$$

Thus, attending to load shedding in the FGGC Road feeder solves 68.53% of the faults that lead to power outages in the feeder. This will lead to the following increase in reliability.

From Table 6, using Eq. 4, the reliability of the FGGC Road feeder is 0.78879. Therefore,

$$\text{Unreliability} = 1 - 0.78879 = 0.21121$$

The improvement due to the application of Pareto analysis is the product of the percentage of faults that require attention and unreliability. This is given as:

$$= 0.6853 \times 0.21121 = 0.14474$$

Thus, attending to load shedding and earth faults in this feeder will lead to unreliability reduction of 0.14474. This fractional reduction of unreliability will lead to the same fractional increase in reliability using Eq. 4. Therefore, the feeder's reliability after attending to load shedding in this feeder is given as:

$$= 0.78879 + 0.14474 = 0.93353$$

From the foregoing analysis, load shedding is the most frequent occurring fault event. This is due to insufficient electric power generation. Thus, loads are dropped in order to avoid system collapse. The reduction of load shedding as suggested by the analysis implies the increase of electric power generation in Nigeria. The other faults that are not captured by this analysis will cost more to solve than the derivable benefits.

Table 6: Electric power diatribution reliability in 2004 of the selected feeders (Ogujor, 2007)

	------------2004--------------
Feeder	Electric power reliability
FGGC Road	0.78879
Ugbowo	0.69483
Eguadaiken	0.75938
Uselu	0.78797

CONCLUSION

A Pareto analysis has been successfully applied to faults that lead to power outages in a selected portion of the Nigeria electric power distribution system. The Pareto chart generated from the frequency and cumulative frequency of faults, focuses attention on the significant few faults that when solved will result in remarkable increase in electric power distribution reliability. Load shedding is the most frequent occurring fault event in the Nigerian Power System. The analysis shows that the elimination of load shedding in the Nigeria Power System will lead to having reliability with a '9' in its first decimal place.

ACKNOWLEDGEMENT

We gratefully acknowledge the members of staff of the 33/11kV Ugbowo injection substation for making data available for this research.

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