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MODELING THE IMPACT OF RAINFALL ON POWER OUTAGES IN NIGERIA

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Abstract

The seasonal variation of the weather condition impacts humans' economic and sociological activities in diverse ways. This study sought to model the relationship between the intensity of rainfall during rainy and dry seasons on the frequency of forced outages in a typical distribution system in Nigeria. Regression and descriptive statistical techniques were used to analyze the rainfall and outage data of a distribution system for the period 2015 – 2021. The developed model demonstrated a strong relationship (with R^2 value of 0.81) between the precipitation level and power outages in Nigeria. Findings showed that a rainfall depth of 10.8mm could cause a forced outage. The highest interruption period was found to occur in July and October, coinciding with the high intensity of rainfall, while the fewest outages occurred in December and January during the dry season. It is expected that the findings of this research will guide institutions, industries, power-dependent individuals, system regulators, and engineers in formulating and effecting efficient season-based contingency and maintenance policies for their operations.

***Keywords*:** Regression, ANOVA, Rainfall, Power Outages, Correlation Coefficient, Maintenance

1.0. Introduction

Adverse weather conditions have been found to be responsible for a lot of damages to lives and properties. In Nigeria, the most common extreme weather conditions mainly occur during rainfall as rainstorm, windstorm, lightning, or even increase in vegetational effects on nearby infrastructure. These conditions have the potential to destroy power system facilities thereby causing forced outages [1]. Consequently, the probability of outages during adverse weather conditions is very high [2], [3], [4], [5], [6]. Therefore, an understanding of the weather in a particular area can give an idea of the frequency of outages to be expected.

In the western world, the major seasons are spring, summer, autumn, and winter. These seasons come with varying load demand and can affect the number of outages and the magnitude of the consequences of outages [7]. In Nigeria, the two major seasons are rainy and dry seasons. The rainy season is from April to October while the dry season is from November to March [8]. The evidence for the seasonal variation of precipitation in different major towns in Nigeria was presented by [9]. Consequently, if we are to go by the assertion of Alsenani *et al*. [2], that there is a relationship between power outages and the seasons, it will mean that in the case of Nigeria, the frequency of outages during the dry season will be different from those of the rainy season because of the effect of seasonal changes.

Power outage is a condition whereby there is service failure of the facilities responsible for the delivery of electric energy to a customer. It is one of the power industry's most avoided yet unavoidable events [10], [11]. Power outage events cause a lot of social, psychological, and economic losses to power industries, individual customers, and the managers of electricity dependent industries [12].

The causes of power outages are many and the effects cannot be undermined. The specific causes of these events have been investigated and highlighted in literature [13]. The major causes of outages are component failures, faults, insufficient capacity to meet up with system requirements, and natural disasters such as fire outbreaks, tsunamis, flooding, rainstorm etc. [14]. These outages usually result in underutilization of assets, insecurity, unemployment, loss of profit, wastages, increase in the cost of production, death etc. [15], [16].

The power outage event data from utility companies have been used in multiple kinds of research to investigate the outcome of different hypotheses, analyze the behavior, and assess the performance of the power systems [2], [17], [18],

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[19]. One of the contributions of these works is that they helped to collect, process, and analyze disjointed data and turn them into a meaningful and reports. These reports have proven to be very vital tools in gauging important decisions that are taken in the management and administration of the power industries. Furthermore, they have been a reference point for maintenance planning, system expansion and strengthening, budgeting, contingency plans, and other vital intelligent business decisions.

In a world where the implications of climatic change has become a global concern, it is very important to understand the effect of seasonal changes on the performance of the power system. Such knowledge could help in developing a robust season-based maintenance policy. However, it has been observed that less or no consideration has been made to examine the strength of relationship between the intensity of downpour and the annual outage trend in Nigeria. Consequently, the objective of this work is to investigate and model the annual pattern of power outages in a typical distribution network in relation to the intensity of rainfall in Nigeria. It is hoped that the findings will assist system engineers, management, investors, and the regulators of the industry in engendering intelligent decisions that will be of great benefit to the power industry.

2.0. Materials and Methods

The data for this study utilizes the forced outage data of Ehor, Ubiaja, and Uzebba 33kV. These distribution feeders emanated from Irrua Transmission Station in Irrua, Edo state of Nigeria. Also, the rainfall data of Edo state were also collected from World Bank data [20]. The monthly values of these data were collected for the period 2015 to 2021.

For the purpose of annual interruption and rainfall trend analysis, the average values for these variables were determine and presented in Table 1.

The monthly average values of the rainfall were obtained as follows:

1. The magnitude of the monthly rainfall for all the years were summed together. That is, the values for January in 2015, 2016, 2017, 2018, 2019, 2020, and 2021 were summed, likewise, for the other months. The mathematical expression for this is as presented in equation (1).
2. Then each of these summed values was divided by the number of years (which is 7) to obtain the average value.

$$R_{m(T)} = \sum_{y_1}^{y_n} R_y \tag{1}$$

$R_{m(T)}$ *is the total rainfall from* 2015 − 2021 *for the different months of the year*

R_y *is the amount of rainfall in a particular month in each year*

y1, y2, y3, …. yn represent 2015, 2016, 2017 …. 2021.

The monthly average values of the power outages were obtained as follows:

1. The outage record of each of all the feeders was summed together for the identical months for the 7 years as presented in equation (2).
2. The monthly average outages in the study area were then obtained by dividing the sum of the outages of the three feeders by the numbers of years (7).

$$O_{m(T)} = \sum_{f_1}^{f_3} \sum_{y_1}^{y_n} O_f \tag{2}$$

$O_{m(T)}$ *is the total outages of the* 3 *feeders from* 2015 *to* 2021 *for a particular month of the year*

O_f *is the number of outage events of a feeder in a particular month in each year*

f_1, f_2, f_3 represent Ehor, Ubiaja and Uzebba 33kV feeders

Table 1: Average rainfall and feeder outage records

Month	Rainfall (mm)	Outages (No.)
Jan	7.81	60.14
Feb	30.85	62.29
Mar	95.86	82.14
Apr	132.02	69.86
May	196.57	85.00
Jun	248.71	83.71
Jul	282.05	92.43
Aug	233.79	84.57
Sep	337.00	84.71
Oct	234.20	87.43
Nov	47.71	65.00
Dec	14.44	61.43

Using linear regression approach, a correlation test was carried out utilizing the Microsoft Data Analysis module in the Microsoft Excel Spreadsheet application to determine the level of influence of rainfall on outage events. Also, Analysis of variance (ANOVA) was done to test for the significance of the relationship between precipitation level and outages. Furthermore, regression coefficients were also used to model the relationship between the dependent and the independent variables [21]. The mathematical expression for linear regression is given by equation (3).

$$Y = a + bX + \varepsilon \quad (3)$$

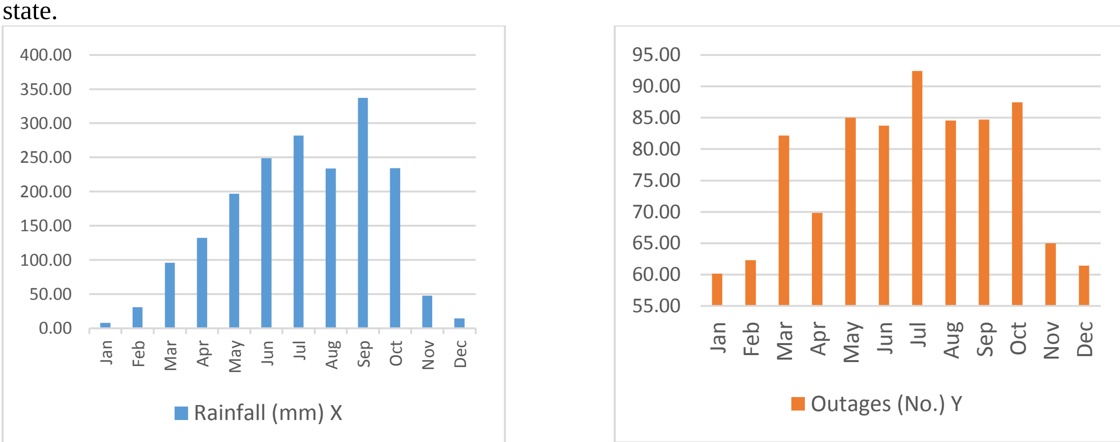
Where Y is the dependent variable while X is the independent variable. For this work, power outage is the dependent variable (Y) while rainfall is the independent variable (X). The numbers of outages that could occur in the absence of rain in this study is represented by a. While the error margin (ε) represents the numbers of outages due to other unaccounted causes of outages.

In regression analysis, the null hypothesis is that there is no relationship between the variables (i.e., between rainfall and outages, in our case). This assumption will only be rejected if the significant value of F (or the P value) is less than 0.05.

3.0. Results and Discussion

3.1. Rainfall and Outage Annual Trend

The annual trend of rainfall in Edo state, Nigeria and the frequency of outages in Ehor, Ubiaja and Uzebba 33kV feeders were analyzed in section 2 and the results are graphically presented in Figure 1. The rainfall trend shows that the rain is very low in January. Then picked up in February and maintained a steady increase till July with a little break in August then pick up to hit a peak in September before declining from October to December. The peak rainfall occurred in September while the least occurred in January. This trend closely agrees with the curve presented in [9] for the Benin City region. This is so because Benin City region is within Edo state. It means that there is no significant disparity in rainfall within Edo state.



(a) (b)

Figure 1: Annual rainfall intensity and forced outages on Ehor, Ubiaja and Uzebba 33kV feeders

The annual outage curve presented in Figure 1b showed that outage is usually lowest in January and increases in February and then increases disproportionately in March. The curve recedes in April while maintaining January and February growth trends and increases in May with a slight reduction in June but still slightly higher than the spike in March. The peak outage value is attained in July. The frequency of outages is reduced in August to mimic May outage scenarios and then increases in September and then hits another peak in October (though lower than July outages). The tripping was drastically reduced in November and still reduced more in December to almost the number of outages in January.

It was observed that the outages were very minimal in the months of January, February, November, and December. However, the outages were very high from the month of May to October. This is likely due to the weather and ecological characteristics of the study area. The area where this study was carried out is in the central parts of Edo state, Nigeria. The geographical location falls within the rainforest ecological zone with some mangrove swamps [9]. These rainforests are known for their tall trees which can cause outages in the rainy season as a result of their proximity and interference with power infrastructure during rainstorms [14], [22]. This understanding coupled with the variation of rainfall within the different months of the year as presented in figure 1a can help to understand the outage curve presented in Figure 1b.

It was noticed that there was an unusual spike in outages in the month of March compared to January and February. This could be due to the heavy storms that usually accompany the early rains in March [23]. Another observation is that the highest amount of rainfall was in September. However, it was not the month with the highest number of outages. The likely explanation for this is that the average intensity of storms that usually accompanies every unit of rainfall (per mm) in the other months is higher than what is obtainable in September. That means, even though the amount of rainfall may be high in September, it is not usually proportionately accompanied by the intensity of storms that follow the rainfall in the other months. Hence the effect of such rainfall is not able to produce the number of outages an equivalent amount of rainfall can cause in the other months.

It is therefore evident from our findings that the outage pattern in Nigeria is weather based with the worst power supply situation occurring during rainy season. These findings align with the exertions made by [3], [4], [5], [6].

3.2. Rainfall and Outage Modeling Result

The results from the regression analysis as done in Section 2 are presented in Tables 2, 3 and 4. The standard error in Table 2 and the coefficients obtained from Table 4 were substituted into equation (3) to formulate the regression equation presented in equation (4).

Equation (4) is a mathematical model that expresses the relationship between the magnitude of rainfall and the frequency of power outages. The model represents the number of outages that could occur given a certain amount of rainfall.

Table 2: Regression Statistics

Multiple R	0.898880896
R Square	0.807986865
Adjusted R Square	0.788785551
Standard Error	5.428994716
Observations	12

Table 3: ANOVA Table for Simple Linear Regression

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	1240.25846	1240.25846	42.0797703	0.000070
Residual	10	294.739836	29.4739836		
Total	11	1534.99829			

Table 4: Coefficients of the Simple Linear Regression

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	62.1981011	2.712486194	22.9302922	0.000000
X Variable 1	0.09260377	0.014275522	6.48689219	0.000070

$$Y = 62.2 + 0.093X \pm 5.4 \quad (4)$$

The coefficient of the dependent variable in equation (4) showed that every millimeter increase of rainfall will likely cause 0.093 forced outages. By this trend, it will require an average of 10.8mm of rainfall to produce a forced outage. It is important to note that rainfall may not be very potent in causing power outages in a power system. However, the major disruptive effect on the overhead lines in the power system is caused by the rainstorm, windstorm, and lightning that often accompany rainfall [3], [14].

The error margin (standard error) of 5 in equation (4) means that the results from the outage model could be less or more by 5 outages depending on the degree of deviation from the average adversity impact of the weather condition in the area. This variation can also be influenced by the length of the line, and vegetation density on the path of the power system [22], [24], [25].

The magnitude of the intercept (62) showed that 62 trippings (within the range of + or – 5 outages) could occur from Ehor, Ubiaja, and Uzebba 33kV feeders without the effect of rain. These could have occurred because of animal activities on the line, fire outbreak, accident due to vehicular incidents and excavations, broken cross arms and other equipment failures in the system [26].

Other important statistical parameters that explain the model are presented in Table 2. The correlation coefficient (multiple R) of 90% means that there is a strong linear relationship between rainfall and trippings. The coefficient of determination (R^2) showed that 81% of the variations in tripping for a particular month is caused by the quantity of rainfall within that month. In other words, 81% of the numbers of monthly outages adequately fits into the mathematical model of equation (4). From Table 3, the ANOVA F distribution of 42.08 returned an F value of 0.00007 for the model. This proves that the model is statistically significant because the F value is less than 0.05. Therefore, the null hypothesis is rejected, and it is established that there is a strong relationship between rainfall and power outages as defined in equation (4).

4.0. Conclusion

Power outage events have become part of our social and economic activities. This study demonstrated the annual trend of these interruptions monthly alongside the level of rainfall during such periods. A mathematical model to establish the relationship between precipitation magnitude and the frequency of outages was developed and validated. The model has shown that there could be other variables that are responsible for the variation in outage during rainy season. However, the validation results shows that this model is robust and can sufficiently represents the situation in the tropical rainforest region of Nigeria. The model has provided strong documented evidence for the direct impact of rainfall on the power system. Hence, it is expected that good preventive maintenance that includes the cutting of trees that are close to the power lines and replacement of weak network infrastructure will help to mitigate the effect of rainstorms and windstorms on the power system during the rainy season. System managers should ensure that sky wires and lightning arrestors are also part of the components for power network during planning and operation phases. It will also be good to construct redundant links for those critical facilities such as healthcare institutions and other essential service providers during the rainy season in case of failure on the primary supply link.

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