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Analysis of the Dependence of Power Outages on Lightning Events within the Ijebu Province, Nigeria

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Abstract: The study aimed at developing a model for lightning-induced outages in Nigeria from results obtained on determining the proportion and rate of lightning-induced outages out of the total power outages experienced in Ijebu province of Nigeria. Power outage records for Ijebu province, comprising Ijebu-Ode and Sagamu areas, Ogun state, Nigeria for the years 2002-2006 were collected from Power Holding Company of Nigeria (PHCN). Unintentional stochastic outages were separated from those due to deliberate load shedding. Lightning events records were collected from Nigeria Meteorological Agency for the same period. The two sets of time series were superimposed. Outages with time, $t<1$ min after lightning events were classified as 'Lightning-Induced' (LI). Those with $1 \leq t \leq 6$ min were classified as 'Possibly Lightning-Induced' (PLI) while those with $t>6$ min were classified as 'Others' (OT). The two sets of data were analyzed in order to determine percentage of lightning-induced outagfes. Also, thunderstorm days and power line parameters were used as input data for modified FLASH 1.7 software (considering tropical region) to estimate the rate of lightning induced outages. The five-year period, 2002 to 2006, experienced no significant difference ($p<0.05$) in the mean of percentage of LI outages for both areas, calculated as 8.6 for Ijebu-Ode and 9.5 for Sagamu. The corresponding values for PLI being 1 and 2%; whereas OT had values 90.4 and 88.5%. Where earth wires were available on the transmission lines, the mafn lightning-induced outage rate was 1/100 km-year. The mean flashover rate for unshielded lines was 22/100 km-year. A linear relationship was established between the annual lightning-induced outages and the annual lightning days for the province. Lightning accounted for approximately 10% of the random outages experienced in Ijebu province. Lightning-induced outages are linearly related to lightning days. Lightning-induced outage rate is much higher over unshielded than shielded transmission lines.

Keywords: Lightning-induced outage distribution, power outages, thunderstorm days

INTRODUCTION

An electrical outage is defined as the unplanned loss of power to a load. This condition is also commonly referred to as a 'forced outage' or a 'failure' of power system component under study; in this case, the overhead transmission and distribution lines. (IEEE Standard, 493-1990).

A number of factors are responsible for power outages, resulting into power interruption; thus affecting the reliability of a power distribution system. Some of the causes of power outages are:

Wind: Wind may cause power lines to touch, resulting into a fault or a short-circuit may occur, which can interrupt electrical service.

Snow: Winter storms can create a buildup of snow and ice on power lines and trees. The weight of the snow and ice can cause tree limbs and trees to fall onto power lines, either knocking the lines and poles down and breaking them, or causing a short-circuit by knocking the lines into each other.

Vehicle accidents: Another common cause of electrical outages is collision of vehicles with power poles. At times a collision will cause a pole to break or make the lines sway enough that they touch and cause a short-circuit.

Birds and small animals: Birds often climb or nest on certain pieces of equipment such as transformers and fuses. Sometimes the birds or small animals, as the case may be will touch two wires at one time and cause a short-circuit.

Trees: Trees often fall on power lines as a result of storm or rain or flood uprooting a tree. At times the

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branches of a tree may come in contact with power lines.

Bush burning: This is common during the dry season and base of wooden poles are often burnt thus resulting into power lines coming in contact with one another.

Erosion: Erosion often washes off the base of electric poles, causing poles to collapse resulting in short circuit.

Vandalization: of power lines: Sometimes cases of vandalization of power lines by disgruntled elements result in outages lasting weeks or months.

Outages caused by lightning: Electrical power interruptions are one of the most readily apparent effects of lightning on human activity. Lightning strokes to nearby ground and overhead power lines have been reported as a major cause of power outages worldwide. Most of the twenty first century electronics equipments are highly sensitive with low damage threshold level. Thus they are easily damaged by either transient voltage or current. Lightning has always been suspected as one of the reasons of power line outages and damage to equipments in distribution network. For instance, in 2003 United States, Canada and Europe suffered a series of blackouts leaving more than 60 million people without electricity. Some of the reason adduced to the outage was believed to be due to lightning strike (Andersson *et al*. 2005). Lightning damage to power lines in the U.S. costs almost $ 1 billion annually and 30% of all power outages are lightning related, according to studies by the Electric Power Research Institute (Kithil, 1998). Assessment of the 32 year reliability of 13.8 kV electrical distribution systems at Oak Ridge National Laboratory (ORNL) in Tennessee revealed that weather-related events accounted for 56% of the feeder outages recorded. Fifty seven out of 76 weather-related outages were attributed to lightning (Tolbert *et al*., 1995). According to Power Holding Company of Nigeria (PHCN), a total of 13,324 faults at 33 KV and 22,255 faults at 11 KV levels were recorded in year 2002 and a bulk of these faults were caused by thunder storms and lightning (NEPA 2002 Annual Report and Accounts).

The reliability of the supply provided by an electric power system is judged by the frequency and duration of supply interruptions to consumers.

Load shedding and outages are regular occurrences with PHCN. However, PHCN had always adduced the reason for frequent outages to lightning strikes. The PHCN report raised question such as: "What percentage of these faults was caused by lightning and what fraction of the faults resulted into full outage? The dearth of information on the contribution of lightning strokes to the perennial power outages in Nigeria has rendered any preventive action unfeasible. This study aimed at analyzing data on lightning events and power outages in Ijebu-Ode and Sagamu areas of Ijebu province, Nigeria for five years (2002-2006) in order to determine the association between the two variables; and to develop a model for lightning-induced outages in Nigeria.

Modified IEEE FLASH 1.7: The soft ware is used to determine the backflash and shielding failure rate of power lines. The calculation is based among other input parameters on:

- Ground flash density of the terrain over which the line passed
- Tower geometry and line configuration

IEEE Flash 1.7 is designed with relationship between ground flash density, N_g and thunderstorm days, T_d, as $N_g = 0,04T_d^{1.25}$. This is suitable for temperate regions only. The errors found in applying equation $N_g = 0,04T_d^{1.25}$ in determination of ground flash density in Colombia have reached values up to 1568% (Torres, 2003). Hence, it was necessary to modify the software by replacing $N_g = 0,04T_d^{1.25}$ with $N_g = 0,0017.T_d^{1.56}$; which is suitable for tropical regions between 2-10° North (Torres, 2003). This is region within which Ijebu-Ode, situated (6º48′N, 3°52′E) and Sagamu (6°0′N, 3°38′E) fall.

METHODOLOGY

Power outage records for Ijebu province, comprising Ijebu-Ode (6°48′N, 3°52′E) and Sagamu (6º50′N, 3º38′E) areas, Ogun state, Nigeria for the years 2002-2006 were collected from Power Holding Company of Nigeria. Unintentional stochastic outages were separated from those due to deliberate load shedding. Lightning events records were collected from Nigeria Meteorological Agency for the same period for Ijebu-Ode station. Sagamu has no meteorological station. Hence same lightning data were used for Sagamu due to proximity to Ijebu-Ode. The two sets of time series were superimposed. Outages with time, $t<1$ minute after lightning events were classified as 'Lightning-Induced'(LI). Those with $1 \leq t \leq 6$ min were classified as 'Possibly Lightning-Induced' (PLI) while those with $t>6$ min were classified as 'Others'(OT). The two sets of data were analyzed in order to determine statistical parameters and estimate lightning induced outages. Also, thunderstorm days and power

Table 1: Dimensions of vertically configured transmission and distribution lines in Ijebu province

Line type	Tower height (m)	Cross-arm height (m)	Phase conductor distance from center (m)	Phase conductor Height (m)	Phase conductor Sag (m)	Phase conductor Radius (mm)	Shield wire Sag (m)	Shield wire Radius (mm)	Span (m)
132 kV	26.296	17.2 17.2 21.8	(+)2.743 (-)2.743 (+)2.743	15.02 15.02 19.55	4.00	6.90	2.00	3.30	365.00
33 kV	10.363		(+)0.762 0 (-)0.762	10.36		5.64			250.00
11 kV	8.534		(+)0.762 0 (-)0.762	8.53	2.00	5.64			250.00

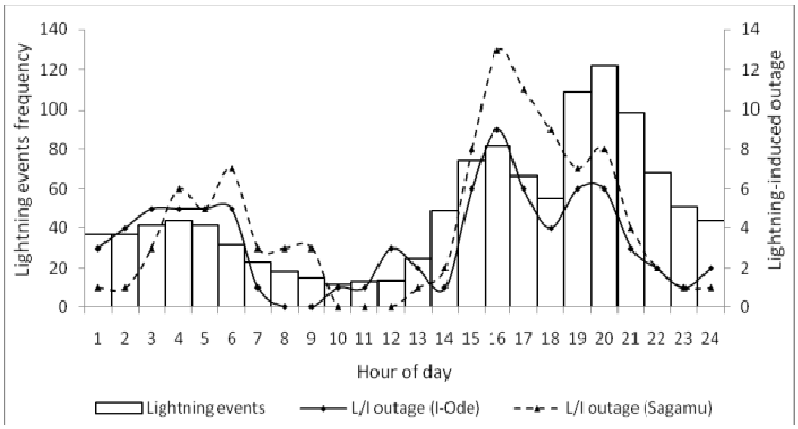

Fig. 1: Correlate of lightning-induced outages with lightning events (hourly basis)

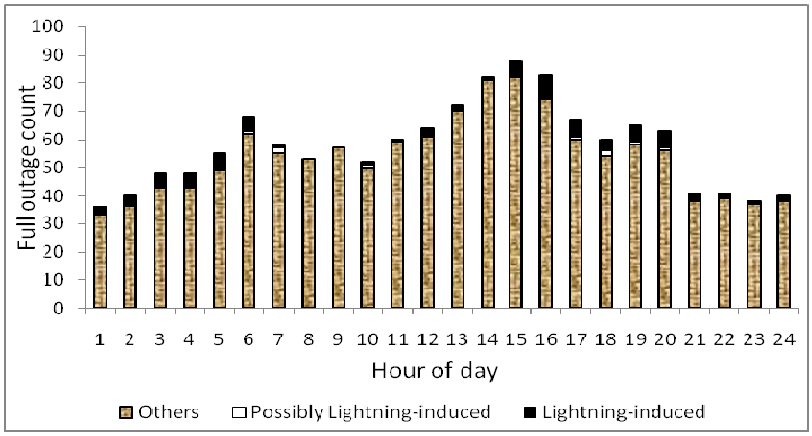

Fig. 2: Time of day trend of causes of full outages at Ijebh-Ode area (2002-2006)

line parameters (Table 1) were used as input data for modified FLASH 1.7 software (considering tropical region) to estimate the rate of lightning induced outages.

RESULTS AND DISCUSSION

Lightning-induced outages peaks were recorded at 15:00 and 20:00 h LT. This was due to the fact that lightning activities equally reached peaks at these periods (Fig. 1). The observation is corroborated by Oladiran *et al*. (1988); while carrying out a research on the lightning flash rate at Ibadan (Lat. 7º21′N, Long. 3º51′E) -a meteorological environment of Ijebu-Ode- discovered that lightning activities are high around 15:00 and 20:00 h LT with peak coming up around 18:00 h LT. No lightning-induced outage was recorded during 10:00 to 12:00 h LT in Sagamu and 08:00 and

09:00 h LT in Ijebu-Ode. This was due to the fact that 08:00 to 12:00 h LT recorded period of low lightning activities (Fig. 1). The observation was corroborated by Oladiran *et al*. (1988), which revealed 0600 to 1300 h LT as period of low lightning activities.

Figure 2 and 3 revealed that for the five years under consideration, there was no hour of the day that one type of outage or the other was not recorded at Ijebu-Ode and Sagamu areas.

The highest number of lightning-induced power outages was recorded during the month of June, for type of outage or the other was not recorded at Ijebu-Ode and Sagamu areas.

The highest number of lightning-induced power outages was recorded during the month of June, for the raining season, when lightning activities is on the increase.

There was no lightning-induced power outage recorded during the months of August and December in both areas; due to the fact that there is usually a break of raining activities in August and most Decembers are free of rain with little or no thunder and lightning activities (Fig. 4 and 5).

The Mean random power outage frequencies for Ijebu-Ode and Sagamu areas for the period under consideration were 94 and 104 outages outages/year, respectively. The five-year period, 2002 to 2006, experienced no significant difference ($p<0.05$) in the mean of percentage of lightning-induced outages for both areas, calculated as 8.6% for Ijebu-Ode and 9.5% for Sagamu. The mean Percentage Of Possibly Lightning-Induced (PLI) outage for Ijebu-Ode and Sagamu areas were 1 and 2%, respectively; while OT had values 90.4 and 88.5% (Table 2). The mean duration of lightning-induced outage was 2 h for Ijebu-Ode area and 2.5 h for Sagamu area (Table 2).

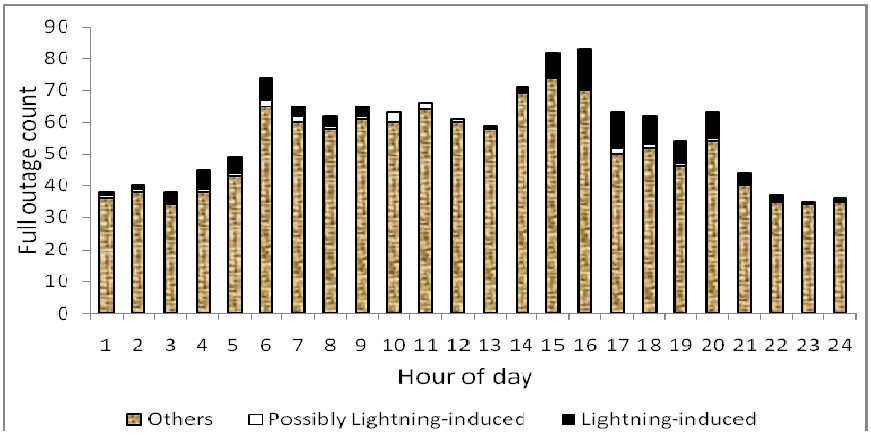

Fig. 3: Time of day trend of causes of full outages at Sagamu area (2002-2006)

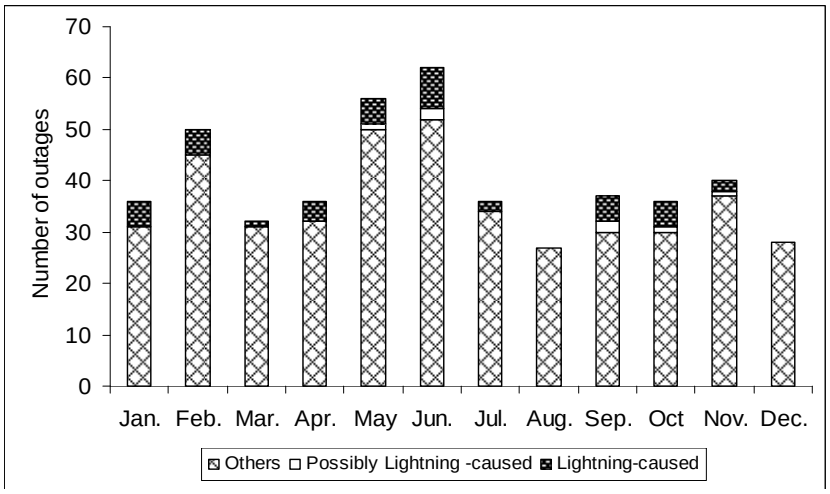

Fig. 4: Time of year trend in full outages at Ijebu-Ode area (2002-2006)

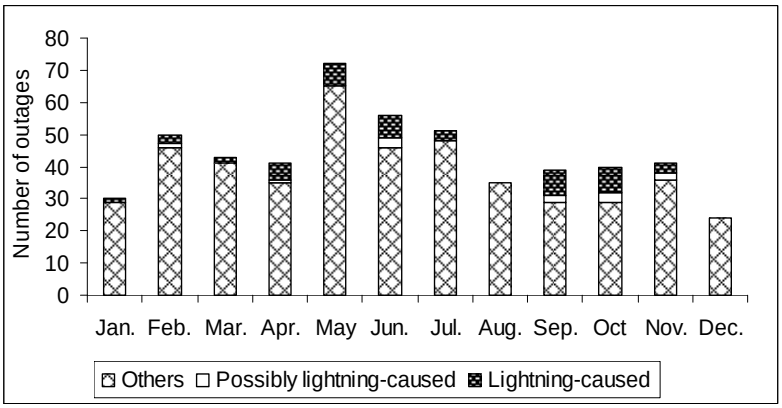

Fig. 5: Time of year trend in full outages at Sagamu area (2002-2006)

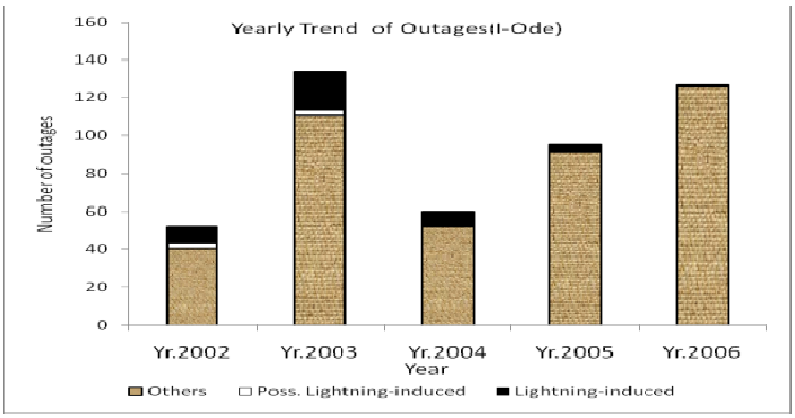

Fig. 6: Yearly trend of lightning-induced outages in Ijebu-Ode area

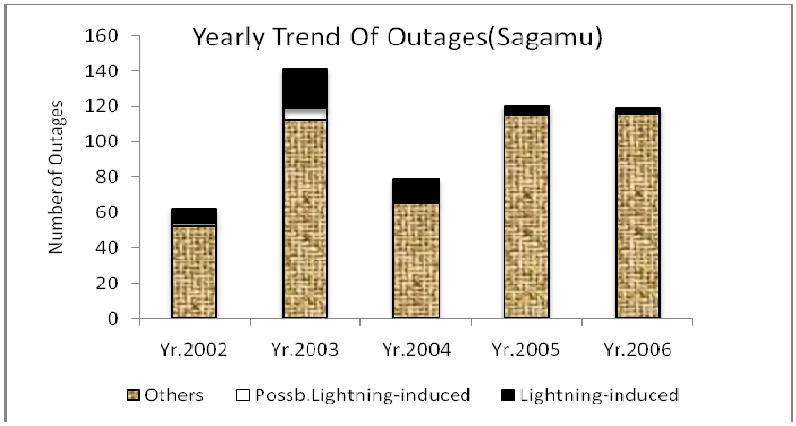

Fig. 7: Yearly trend of lightning-induced outages in Sagamu area

Generally, an annual increase in total power outages were recorded over the years (Fig. 6 and 7) at Ijebu-Ode and Sagamu areas, though lightning-induced outages declined over the years (Fig. 8). A linear relationship was developed between the annual lightning- induced outages, F and the annual lightning days, T. For Ijebu-Ode, F = -19.1 + 0.38T. And for Sagamu; F = -19.5 + 0.40 T (Fig. 9).

Using the modified IEEE Flash 1.7, Table 3 showed the Flashover rates (outages per 100 km-year) of overhead power lines in the province. Where earth wires were available on the transmission lines, the

Table 2: Annual outage frequency (number/year) and duration (h) in Ijebu province

		Ijebu-ode outages						Sagamu outages					
		Total		Lightning-induced			P LI	Total		Lightning-induced			PLI
Year	Thunder storm days	Count	Hour	Count	Hour	Hour/Count	Count	Count	Hour	Count	Hour	Hour/ Count	Count
2002	90	52	119	9	19	2.1	3	64	144	8	16	2.0	2
2003	92	134	403	20	47	1.9	3	147	332	22	53	2.4	7
2004	95	60	298	8	22	2.8	0	71	268	14	34	2.4	0
2005	97	95	210	4	5	1.3	0	120	276	5	11	2.2	0
2006	93	127	343	1	1	2.0	0	119	309	2	7	3.5	1
Mean	93	94	274.6	8	18.8	2.0	1	104	265.8	10	24.2	2.5	2

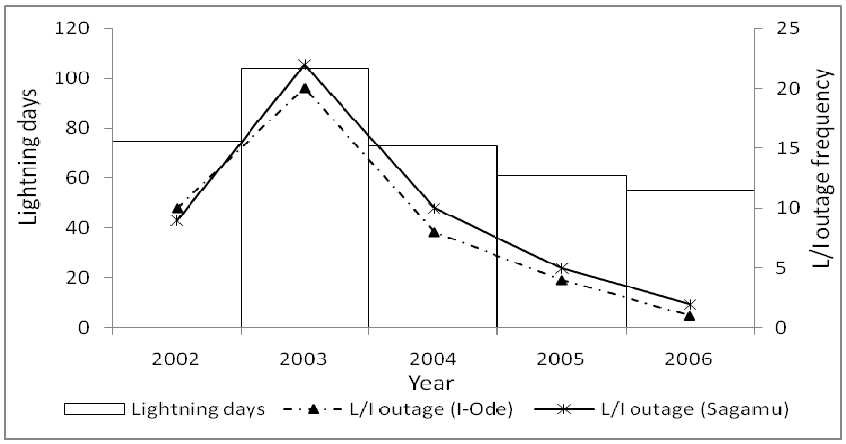

Fig. 8: Correlate of lightning-induced outages with lightning events (annual basis)

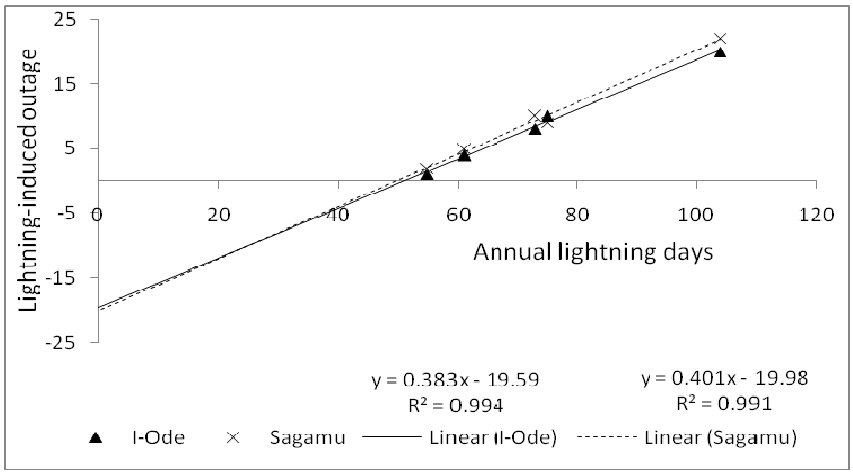

Fig. 9: Graph of lightning-induced outages against lightning days

Table 3: Flashover rates (outages per 100 km/year) of overhead power lines in Ijebu province

Year	Thunder storm days	132 kV shielded transmission line	132 kV unshielded transmission line	33 kV distribution line	11 kV distribution line
2002	90	1	21	21	19
2003	92	1	22	22	19
2004	95	1	23	23	20
2005	97	1	24	24	21
2006	93	1	22	22	20
Mean	93	1	22	22	20

mean lightning-induced outage rate was 1/100 km-year. The mean flashover rate for unshielded lines was 22/100 km-year.

CONCLUSION

Lightning accounted for approximately 10% of the random outages experienced in Ijebu province. Lightning-induced outages are linearly related to lightning days. Lightning-induced outage rate is much higher over unshielded than shielded transmission lines.

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