HUMIDITY EFFECTS AND MITIGATION ON GENERATORS IN THE COASTAL AREAS OF NIGERIA

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ABSTRACT

Owing to unreliable electricity supply from the national grid, petrol generators are now an essential part of the energy supply in Nigeria. But Nigeria's climatic environment affects the operation of these generators. This study investigated the effect of humidity on small petrol generators (rated 500W - 10KVA) in the coastal areas of Nigeria. Climatic data on three coastal states namely Rivers, Bayelsa and Akwa Ibom were collected from the Nigerian Meteorological Agency (NiMET) in Oshodi, Lagos. The data which covered a period of ten years (2008-2017) were analysed using the Statistical Package of the Social Science (SPSS) version 16.0. The stator winding insulation of select brands of generators were tested using the Fluke 1555 Insulation Resistance Tester (IRT). Oral interviews were conducted amongst the generator owners and the generator repairmen to obtain operational information about the generators. The results of the study were represented by appropriate tables and charts. The findings show that small generators in the coastal areas of Nigeria are exposed to high humidity climatic conditions which adversely affect the performance and drastically reduce the designed life spans. The paper suggests regular inspection and scheduled preventive maintenance programs as well as additional ingress protection (IP) to help reduce operational failures as well as boost the life span of the generators.

Keywords: Electricity consumers; Humidity effects; National grid; Power Supply; Small generators

INTRODUCTION

Due to rampant power outages from the national grid, an estimated 60 million electricity consumers in Nigeria rely on electric power from their own generators. Owing to the high cost of the equipment, however, many invest in the small generators otherwise called "I big pass my neighbor" by the locals. See Figure 1.

A generator converts mechanical energy into electrical energy for use in an external circuit. It is therefore expected to remain in good working condition such that it is capable of producing the required electromotive force (EMF) needed to generate the designed quantity of electrical energy. Unfortunately, however, this is not always the case. Dirt, heat and moisture have adverse effects on generators. Dirt can block the heat transfer necessary to keep the windings cool. Heat can damage the insulation on the windings. Moisture can cause windings to short to each other or to ground. Any of these situations will reduce the EMF or the power that a generator winding can produce. Most manufacturers recommend the application of additional

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coat, varnish or impregnation to protect the windings and metallic components from environmental conditions [1].

Generators have a long service life. But it is really total runtime, not the total years of service that counts. If there has been a period during which the generator ran for days on end, expect to replace the generator sooner than normal, perhaps in 18 to 20 years [2]. Generally, a generator lasts 15 to 20 years depending on the availability of the repair components. The repair is an important part of the life of the generator [3]. The average life expectancy of a typical small standby generator could be less. Faults on the stator windings account for about 40% of the outage time of generators and result in time-consuming repair outages and serious loss of production [4][5].

Water or high humidity in the air reduces the insulation resistance of the windings and diminishes the design life of the insulation system. It is generally understood that certain locations on earth are more prone to high humidity conditions than others (e.g. desert vs. tropics). However, even in relatively temperate climates, high humidity can occur depending on altitude, proximity to bodies of water, and seasonal effects. Environment thus plays a key role in the performance and life span of generators. The more severe the environment (dusty, extremely hot or cold, highly humid, etc.), the more frequent the need to service the generator and in extreme cases the shorter its life. The purpose of this paper is to investigate the effect of humidity on generators rated between 500W and 10KVA in Nigeria; this class of generators being the most popular with Nigerian homes and small businesses like beauty salons, hair barbing salons, small business centers, and so on because of its affordability, capacity to conserve fuel and the spare parts being cheap and relatively easy to fix when compared with the bigger generators.

Figure 1. (a) Small generator (b) A repairman working on a faulty generator [6]

STUDY AREA

Nigeria is located in the tropics where the climate is seasonally damp and very humid. Over 4,000mm of rainfall is received in the coastal region of Nigeria [7]. The coastal states in Nigeria are Akwa-Ibom, Bayelsa, Delta, Rivers, Ondo, Ogun, Cross Rivers, Edo and Lagos states. This study focuses only on Rivers, Bayelsa and Akwa Ibom States.

Rivers State is bounded by Bayelsa State in the west, Imo State in the North, Abia State in the East and the Gulf of Guinea in the south and lies along the Bonny River. The climate condition is characterized by high temperature, high humidity and rainfall. Rivers State is also bounded by the Atlantic Ocean and therefore near to large water bodies. It is unlike Akwa Ibom State that is in most part land log and far from the sea shores. Ref [8] among others had demonstrated that large water bodies affect relative humidity.

Bayelsa State has its capital as Yenagoa and it is bordered on the west by Rivers State, on the East and South by the Atlantic Ocean and on the North by Delta State. The climatic condition in Bayelsa is tropical with significant rainfall in most months of the year.

Like Rivers and Bayelsa States, Akwa Ibom lies within the coastal areas of Nigeria and so enjoys a humid tropical type of climate with high rainfall, high temperatures and high relative humidity [9].

Generator Working Principle

Generators have two parts - the moving part otherwise known as the rotor and the stationary part called the stator. The stator core is where the usable electricity is generated. The windings carrying the usable electricity are placed in the stator core slots. When the rotor rotates, the stator conductors which are static cut by magnetic flux, they have induced EMF produced in them (according to Faraday's law of electromagnetic induction which states that if a conductor or coil links with any changing flux, there must be an induced EMF in it. This induced EMF is mathematically expressed as follows:

Let:

Z = No. of conductors or coil sides in series per phase

$\Phi =$ Flux per pole in webers

$P =$ Number of rotor poles

$N =$ Rotor speed in r.p.m

In one revolution (i.e. 60/N second), each stator conductor is cut by $P\Phi$ webers i.e.

$$d\Phi = P\Phi; dt = \frac{60}{N} \quad \text{.......} (1)$$

$\therefore$ Average e.m.f. induced in one stator conductor

$$= \frac{d\Phi}{dt} = \frac{P\Phi}{60/N} = \frac{P\Phi N}{60} volts \quad \text{.......} (2)$$

Since there are Z conductors in series per phase,

$\therefore$ Average e.m.f. per phase $= \frac{P\Phi N}{60} \times Z$

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$$= \frac{P\Phi N}{60} \times \frac{120f}{P}$$

$$= 2f\Phi Z \ \ volts \ \left(N = \frac{120f}{P} \right)$$

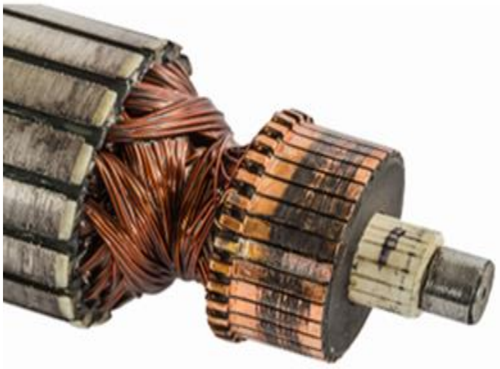
R.M.S value of e.m.f./phase = Average value/phase x form factor

$$= 2f\Phi Z \times 1.11$$

$$= 2.22 f\Phi Z$$

$E_{r.m.s}$./phase $= 2.22 f\Phi Z \ \ volts$

Figure 2 (a) shows the stator winding of a small generator while Figure 2 (b) shows a stator winding that is in good working condition.



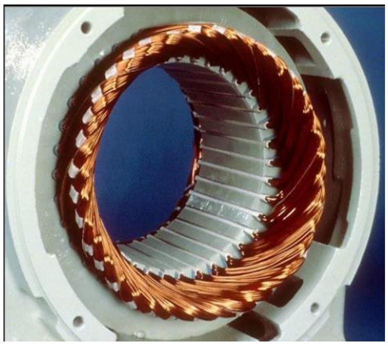


Figure 2. (a) Generator stator winding (b) Good stator winding [10]

METHODOLOGY

This study was carried out from 2008 to 2017 in three designated zones each from Rivers, Akwa-Ibom and Bayelsa States of Nigeria. These were Port Harcourt zone in Rivers State, Yenagoa zone in Bayelsa State and Uyo zone in Akwa-Ibom State. The Port Harcourt zone was made up of Port Harcourt Town, Bonny and Ahoada areas. The Yenagoa zone comprised Yenagoa Town, Oloibiri and Brass areas while the Uyo zone had Uyo Town, Ikot-Ekpene and Ikot-Abasi areas.

Data on mean annual rainfall, mean temperature and relative humidity (See Table 1 to Table 3) for Port Harcourt, Uyo and Yenagoa zones respectively and covering the period, 2008-2017 were acquired from the Nigerian Meteorological Agency (NiMET) in Oshodi, Lagos, Nigeria. These data were analysed using the Statistical Package of the Social Science (SPSS) Version 16.0 and the results appropriately represented on Table and Charts.

The insulation resistance of stator windings of select brands of generators was tested using the Fluke 1555 Insulation Resistance Tester (IRT). The IRT was used in measuring the resistance between the lead and the stator laminations. The stator winding insulation was tested at a voltage higher than the working voltage so that any leakage could show up and so that it would be revealed if there was a potential for arcing.

Table 1. Mean Air Temperature, Mean Rainfall and Relative Humidity for Port Harcourt Zone

	Year of Study									
	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Mean Air Temperature (^oC)	25.6	26.2	26.0	26.3	26.5	26.1	25.2	25.7	26.8	25.4
Mean Precipitation/Rainfall (mm)	34	72	136	189	209	276	350	400	347	328
Relative Humidity (%)	75.5	79.1	80.4	82.8	83.1	84.4	74.6	68.9	64.3	60.5

Table 2. Mean Air Temperature, Mean Rainfall and Relative Humidity for Yenagoa Zone

	Year of Study									
	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Mean Air Temperature (^oC)	26.7	27.3	27.7	27.0	26.4	25.8	25.9	26.0	26.4	26.6
Mean Precipitation/Rainfall (mm)	40	76	148	250	310	430	390	480	385	360
Relative Humidity (%)	77.2	80.4	86.3	88.7	88.9	89.1	80.6	79.3	72.4	62.3

Table 3. Mean Air Temperature, Mean Rainfall and Relative Humidity for Uyo Zone

	Year of Study									
	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Mean Air Temperature (^oC)	26.4	26.9	27.0	27.3	27.9	26.6	25.4	25.1	26.7	26.2
Mean Precipitation/Rainfall (mm)	32	74	146	190	285	296	401	330	300	298
Relative Humidity (%)	70.8	75.0	78.3	80.2	82.1	83.0	79.3	68.0	60.7	57.4

The insulation resistance test was performed in order to determine the insulation quality between the copper winding and the iron core of the stator. The Fluke 1555 insulation resistance tester (IRT) was used for the insulation test because it is the perfect tool for preventative or predictive maintenance programs designed to identify potential generator failures before they occur [11].

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The positive terminal of the IRT was connected to the stator terminal while the negative terminal is connected to the stator core. The appropriate voltage (see Table 4) was then applied across these terminals via the IRT and the insulation resistance simply read on the instrument. Figure 3 shows the setup for the insulation resistance test.

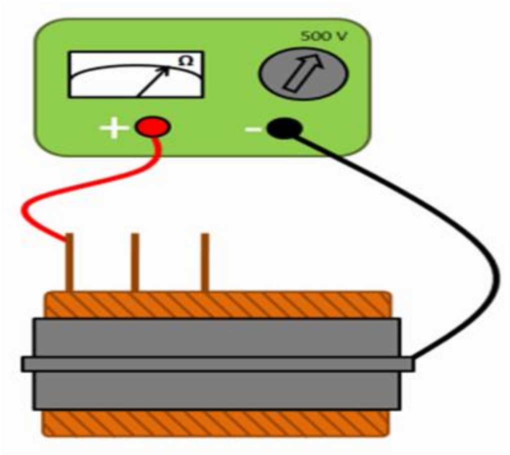

Figure 3. Setup for testing of generator winding insulation resistance

The Table 4 shows the recommended test voltages and minimum insulation values as provided by the International Electrical Testing Association (IETA) for various voltage ratings of equipment for use when manufacturer's data is not available.

Table 4. Recommended Test Voltages and Minimum Insulation Values [11]

Nominal Voltage Rating of Generator	Minimum Insulation Resistance DC Test Voltage	Recommended Minimum Insulation Resistance in Megaohms
250	500	25
600	1,000	100
1,000	1,000	100
5,000	2,500	1,000
15,000	2,500	5,000

Generator Failure Rate

Generator stator windings are often designed to withstand more than the normal load and any transient fault events. A typical characteristic curve for generator failure rate is shown in Figure 4.

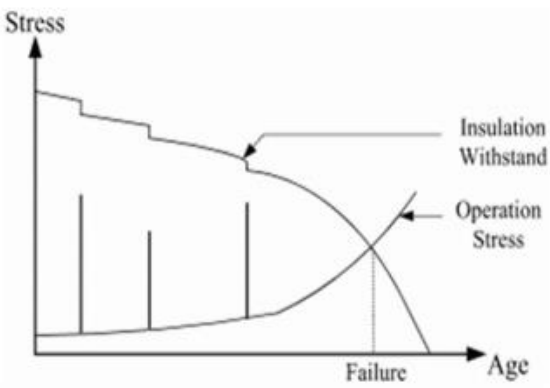

Figure 4. Generator stator winding failure rate

To determine the generator failure rate, the following formula was used:

$$\lambda = \frac{\sum_{1}^{i} n_i}{\sum_{i}^{i} N_i} .100 \ \% \qquad (3)$$

Where:

λ = Failure rate per annum (p.a.) in percentage

n_i = Number of generators that failed in the i^{th}

Ni = Number of generators in service during the i^{th} year

For the calculation of failure rates among generators in this study, a constant generator population of two hundred and fifty (250) was assumed for the investigated time period. For the purposes of this study also, the possible causes of generator failures were classed into: Overloading, Inadequate maintenance, Overheating, Insulation Issues e.g. Moisture, Ageing, Oil, etc. and Other Causes e.g. Dirt, Vibration, etc.

RESULTS AND DISCUSSION

The average values of insulation resistance of stator windings measured for the generators located in each of the three zones under study during the period 2008-2017 are as shown in Table 5.

The results in Table 5 and Figure 4 show that due to poor maintenance, use of wrong engine oils, overloading of generators beyond nameplate limits, use of inexperienced generators repair personnel, poor ventilation (the use of the generators in tight enclosures), etc. worsened the performances and further shortens the life span. It could be observed from Figure 4 that the generator stator winding insulations deteriorates over time due to the decreasing resistance of the winding insulation caused by attack of moisture, aging etc.

Table 5. Average Values of Insulation Resistance of Stator Windings Measured (2008-2017)

Year	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Ave. Insulation Resistance Measured in Port Harcourt Zone (Megohms)	120	102	87	74	65	54	48	39	33	29
Ave. Insulation Resistance Measured in Yenagoa Zone (Megohms)	95	82	79	66	60	50	41	30	26	20
Ave. Insulation Resistance Measured in Uyo Zone (Megohms)	143	125	120	116	100	98	87	82	77	63

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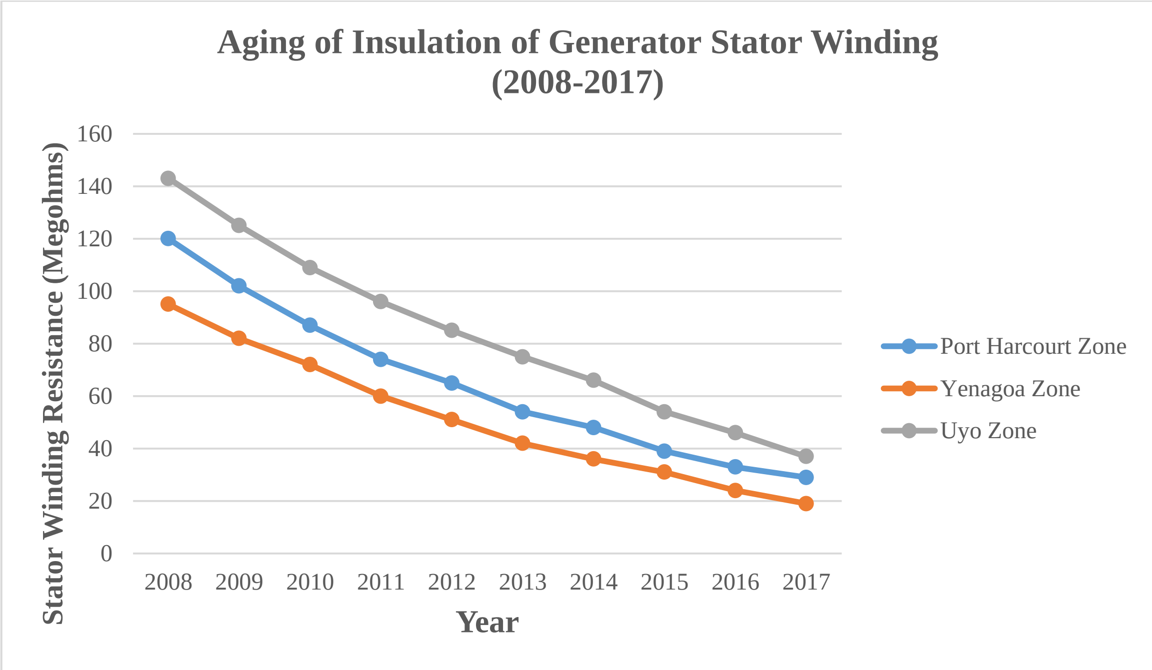

Figure 4. Aging of Stator Winding Insulation over a period of time (2008-2017)

As shown in Table 6 and in Figure 5, the highest number of generator failures of 24.0% occurred at Brass in Bayelsa State. This is followed by Bonny in Rivers State with 16.0%. The high failure rate in these two areas is attributable to the nearness of the areas to larger rivers and the associated high humidity and salt content which attack the generator windings shorting the windings to each other or to the earth.

Table 6. Generator Failures according to Location

S/N	Generator Location	No. of Generators in Use	Failures	
			Frequency	Percentage
Port Harcourt Zone				
1.	Port Harcourt Town	32	7	9.3
2.	Bonny	25	12	16.0
3.	Ahoada	25	6	8.0
Yenagoa Zone				
1.	Yenagoa Town	30	9	12.0
2.	Oloibiri	26	8	10.6
3.	Brass	30	18	24.0
Uyo Zone				
1.	Uyo Town	28	4	5.3
2.	Ikot-Ekpene	26	6	8.0
3.	Ikot-Abasi	28	5	6.7
	Total	**250**	**75**	**100**

It could be observed that out of a total of two hundred and fifty generators investigated in the three zones of Port Harcourt, Yenagoa and Uyo during the 2008-2017 study period, seventy-five generators or thirty percent (30%) failed. A breakdown of this number showed that, out of the eighty-two generators studied in the Port Harcourt zone, thirty-three percent (33%) failed. Similarly, in the Yenagoa zone, out of the eighty-six generators studied, thirty-four percent (34%) failed while in the Uyo zone, out of the eighty-two generators investigated, only eighteen percent (18%) failed. The high percentage of failures among generators located in the Port Harcourt and the Yenagoa zones is attributable to the fact that unlike the Uyo zone that is mostly land log, the Port Harcourt and the Yenagoa zones are located very closely to large water bodies and are therefore exposed to higher humidity and moisture both of which attack the generator winding insulation and adversely affect the performances and life span of the generators. This finding confirms the earlier study by Ref [8] which demonstrated that large water bodies affect relative humidity.

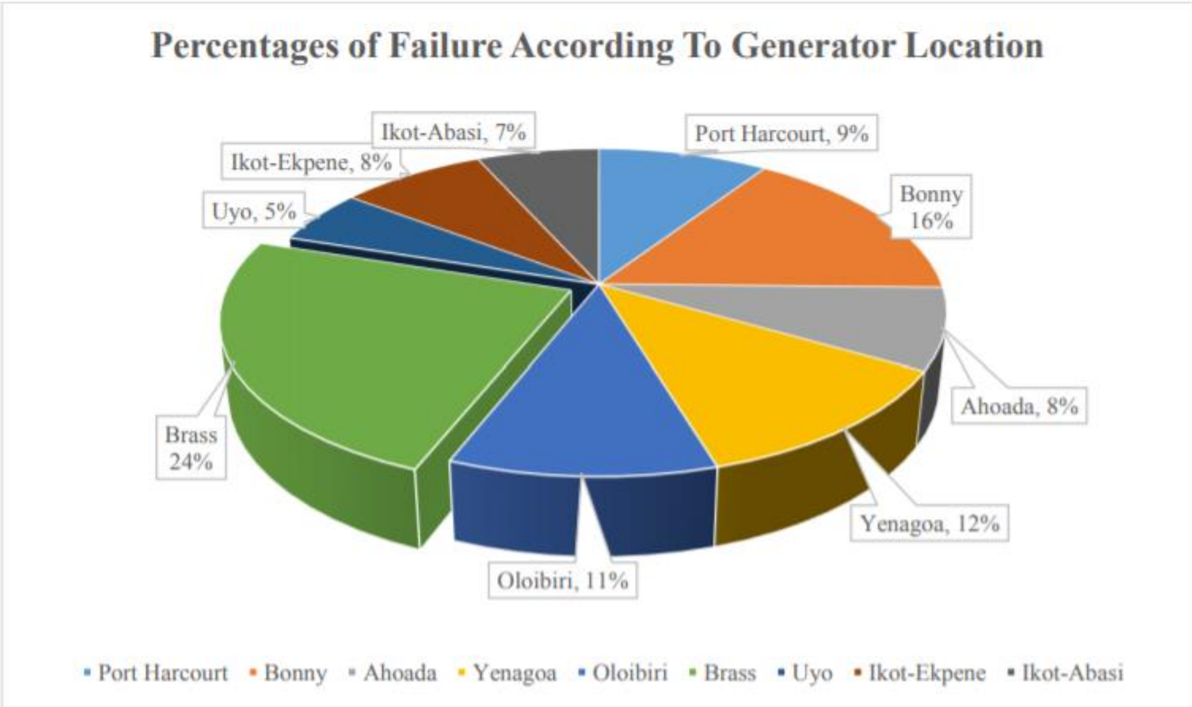

Figure 5. Percentages of Failure Occurrences according to Generator location

A further breakdown of the failures according to areas (as shown in Figure 5) indicated that the highest number of generator failures (24%) occurred in Brass area in the Yenagoa zone. This was followed by 16% recorded in Bonny area in the Port Harcourt zone. The least number of failure of 5% was recorded in Uyo area in the Uyo zone.

In terms of failure causes, as shown in Table 7 and Figure 6, the highest percentage, i.e. 40.8% of the failures resulted from Insulation issues (e.g. Moisture, Ageing, Oil, etc.). This is attributable to the presence of salt in the atmosphere of the coastal areas of Nigeria which causes corrosion of the generator parts e.g. the windings resulting to degradation of the winding insulation resistance and eventual increase of the contact resistance. This was followed by 20.8% due to Other Causes (e.g. Dirt, Vibration, etc,). Inadequate maintenance was responsible for 15.0% of the failure while 12.5% of the failures were due to Overheating and 10.8% resulted from Overloading.

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Table 7. Failure Causes, Frequency and Percentages during 2008-2017

S/N	Failure Cause	Failures	
		Frequency	Percentage (%)
1.	Overloading	13	10.8
2.	Insulation Issues	49	40.8
3.	Overheating	15	12.5
4.	Inadequate Maintenance	18	15
5.	Others	25	20.8
	Total	**120**	**100**

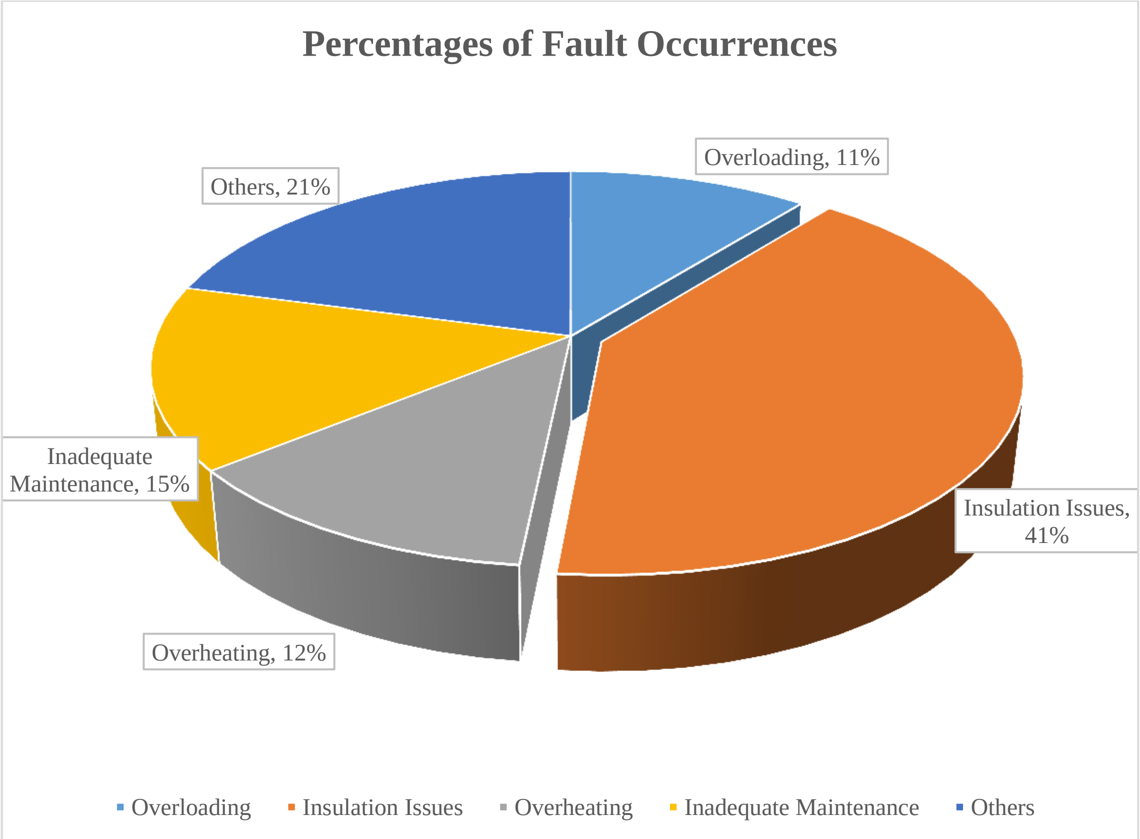

Figure 6. Percentages of Fault Occurrences

It can be seen from Table 8 and Figure 7 that the life span of generators varied according to specific geographical locations. Generators located in the less humid areas often have longer life spans compared to those in the more humid environments.

Generally, generators in the coastal areas of Nigeria have a maximum average life span of thirteen years and minimum life span of seven years. The Uyo zone being less humid than either the Port Harcourt or the Yenagoa zone, recorded the highest value of average life span of thirteen years. The Yenagoa zone had the least average life span of seven years. Moisture was the most commonly reported fault in the three zones studied.

Table 8. Nature of Generator Usage, Average Life Span and Most Common Fault

Generator Location	Nature of Usage		Average Life Span of Generator	Most Commonly Reported Fault
	Residential	Commercial		
Port Harcourt Zone				
Port Harcourt Town	13	19	9	Moisture
Bonny	8	22	8	Moisture
Ahoada	10	15	9	Overheating
Yenagoa Zone				
Yenagoa Town	19	11	9	Moisture
Oloibiri	16	10	8	Moisture
Brass	18	7	7	Moisture
Uyo Zone				
Uyo Town	11	17	13	Overloading
Ikot-Ekpene	12	14	10	Moisture
Ikot-Abasi	12	16	12	Moisture

The average life spans of the generators here investigated is low compared to the widely known generator life span of eighteen to twenty years [3]. The short life span of some of the generators is attributable to the exposure to the harsher environment of higher humidity and moisture. For generators in such areas, additional ingress protection (IP) may be needed to afford protection from severe environmental conditions like humidity, chemicals, water ingress etc. It is recommendable also that additional coat/varnish/impregnation be applied in order to protect the windings and metallic parts from harsh environmental conditions [1].

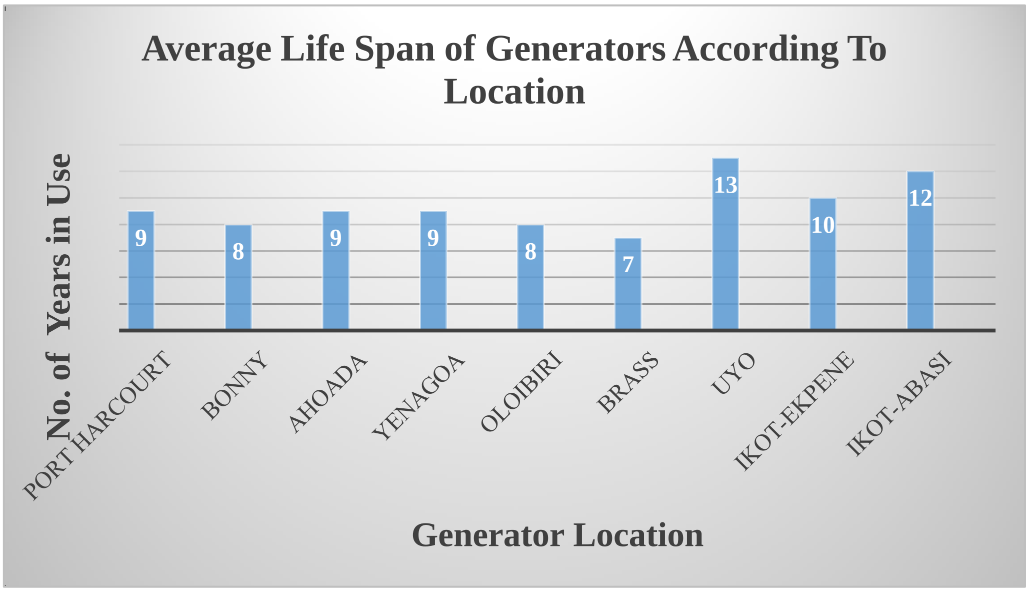

Figure 7. Average life span of Generators according to location

CONCLUSION

One way to ensure a long, reliable operating life for generators is to implement a preventive maintenance (PM) program.

1. Generators should be inspected often and serviced regularly.

2. Frequent and regular maintenance of generators, at least twice a year, is advised. However, depending on the make, model, and purpose, maintenance may need to be performed more frequently than that. A good maintenance plan for a generator not only ensures that it keeps running when the owner needs it most - but it also protects and prolongs its lifespan by minimizing the need for repairs, increasing reliability, and reducing long term costs. Generator maintenance should involve full exterior and interior inspection, checking of cables and connections, checking for worn parts e.g. armature brushes, changing fuel and engine oil, changing spark plugs, checking for leakages, etc.

3. Use of recommended or suitable engine oils while servicing the generators. The brand of electricity generator oil matters little, but its viscosity grade (10W-30W, for example) is important. Use only what the owner's manual specifies. Using the wrong generator engine oil can lead to reduced lubrication, serious damage that may lead to costly repairs and shorter engine life.

4. Avoid overloading of the generator beyond the nameplate specification.

5. Generators should be maintained only by skilled and experienced persons.

6. Beware of old, long time stocked fuel. As most small electricity generators are petrol-operated, it is important to always use FRESH (not old) fuel. If petrol is left in the tank for several months, its chemical composition might change and the resulting deposit lining the carburettor walls or the valves could affect good system efficiency.

CONFLICT OF INTEREST

The author declares that no conflicting interests exist.

APPRECIATION

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