

Evaluation of Power System Outages of the 330kV Transmission Network in Nigeria: A Case study of the Benin Region

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Abstract

This paper examined the causes of power outages in the Benin Region of the Nigeria 330kV Transmission network. Power outages in the network were categorized into forced, planned, urgent and emergency outages respectively. Analysis of events leading to power outages revealed results of cascading effects; such as stressed systems, component failures, vandalism, lightning storms, transient's instability, equipment ageing, environmental factors, mis-operations of protective devices and possible human error.

A total of 449 outages were recorded in 2014 in the 330KV network, out of which 178 were force outages and constitutes 40 %, planned 114(25%), urgent 71 (16 %), and emergency outages 86 (19%) respectively. Similarly, total power outages of 470 recorded in 2015 represents 4.67% increase of that of 2014 outages of 449, and in 2016, a total of 392 outages (12.69%) reduction of that of 2014. Analysis show that forced outages recorded the highest for the three years under review, while planned outages represented second position. These does not urged well with the system as it constitutes major treat to power system security and reliability. Efforts to mitigate these outages are proffered in this paper to ensure power reliability and security in the network.

Keywords: Power outages, component failures, blackout, forced outages, planned outages, equipment ageing.

1. Introduction

Transmission lines are electrically the connecting links between the generating stations and the distribution systems and connect other power systems via interconnections. These lines cover long distance over the entire country and therefore may account for the many types of faults in the National grid. Transmission lines are among the power system components with the highest fault incidence rate, since they are exposed to the Environment. The 330kV transmission lines networks remains a single Utility Company under the Transmission Company of Nigeria (TCN) arrangement with sole responsibility for power transmission and system operation of the national grid. Transmission networks in Nigeria are characterized by several outages; more so, the available energy generated is not enough to meet the demands of the users leading to constant load shedding and blackout. Outages can be either scheduled or unscheduled. Scheduled outages are known in advance (e.g., planned outages for periodic maintenance). Unscheduled outages result from contingencies [1]. According to the National Electric Power Authority [2] Technical Committee Report (2004), the last transmission line in Nigeria was built in 1987 while none of the on-going ones have been completed. The Benin Zone electricity supply systems – (generation and transmission Lines) for instance came into operations in the mid-sixty (1960s).

2.0 DESCRIPTION

Power System outages also known as Power failure, Power Loss or blackouts are total interruptions of electrical supply. It can be a short or long-term loss of the electric power to an area. Any pieces of equipment in the system can fail, either due to internal causes or due to external causes such as lightning strikes, objects hitting transmission towers, faults at power stations, sub-stations, a short circuit, overloading of electricity mains, or human errors in setting relays. Other factors include acute shortage of generation, vandalization of equipment, inadequate gas supply to generating stations and other technical causes etc. [3].

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The abnormal tripping of transmission lines is mostly responsible for a system surge with its attendant power swing. This forces the voltage to be much higher than the normal system voltage in some place. The system frequency also fluctuates and can be higher than the set value at the power stations. The generation protection relays may activate on high frequency causing the generators to trip on reverse power and also opening the out-going transmission lines [4]. The loss of some units, unless compensated by adequate spin reserve from other power stations will plunge the system into further swings until there is loss of synchronism of the components of the system resulting total collapse of the system [5].

A transmission line may be damaged by a storm and taken out by automatic relaying. If, in committing and dispatching generations, proper regard for transmission flows is maintained, the remaining transmission lines can take the increased loading and still remain within limit.

Because the specific times at which initiating events that cause components to fail are unpredictable, the system must be operated at all time in such a way that the system will not be left in a dangerous condition should any credible initiating event occur. Since power system equipment's are designed to be operated within certain limits, most pieces of equipment are protected by automatic devices that can cause equipment to be switched out of the system if these limits are violated. If any event occurs on a system that leaves it operating with limits violated, the event may be followed by a series of further actions that switch other equipment out of service. If this process of cascading failures continues, the entire system or large parts of it may completely collapse. This is usually referred to as a system blackout.

An example of the type of event sequence that can cause a blackout might start with a single line being opened due to an insulation failure, the remaining transmission circuits in the system will take up the flow that was flowing on the now-opened line.

If one of the remaining lines is now too heavily loaded, it may open due to relay action, thereby causing even more load on the remaining lines. This type of process is often termed a cascading outage. Most power system is operated such that any single initial failure event will not leave other components heavily overloaded, specifically to avoid cascading failures.

2.1 POWER OUTAGE

Transmission networks in Nigeria are characterized by several outages. Power outage occurs when a piece of equipment is de-energized. Outages can be either scheduled or unscheduled. Scheduled outages are known in advance (e.g., planned outages for periodic maintenance). Unscheduled outages result from contingencies. These include forced, urgent or emergency outages.

- **Scheduled Outages:**

This is associated with maintenance schedules and load shedding. Outage is planned when maintenance is to be carried out on equipment and transmission lines as well as Load shed to restore system stability. Planned outages are always schedule prior to its execution. According to National control center (NCC) operational procedure (OP 10 2006), a unit of the power holding company of Nigeria [6-7], stipulate that power stations and transmission stations are required to forward their planned outages schedules for the following year to NCC. This enable the NCC to plan a master programmed of plan outages properly coordinated to ensure maintenance of Grid integrity after a thorough study and analysis of the various outages [8]. It is sometimes necessary to interrupt customer service when performing work on radial transmission systems. Since this work is scheduled in advance, customers can be notified as to the time and expected duration of the interruption. Advance knowledge greatly reduces the economic impact and negative perception that interruptions have on customers.

Certain types of transmission maintenance require equipment to be de-energized and grounded. During maintenance, all customers downstream of the maintenance location will experience interruptions unless they can be fed from an alternate path.

- **Unscheduled outages**

Unscheduled (forced) outages can be traced back to the outage of single transmission and / or to generation element. The majority of these events tends to be as a result of equipment failure which include ageing equipment, lightning, wind, vandalization, mis-operation of protective devices, environmental factors such as tree fell, tripping of lines due to sagging, big truck pulling down the electric pole in accident, poor job execution by contractors, human error etc. However, forced outages can be minimized if the system is properly designed and maintained but this will not completely eliminate interruptions. Most of the power system outages are triggered by a very single event or multiples of it that easily lead to cascading outage and finally collapse of the system. A careful examination of this problem of power system can often identify means of mitigating the initial event or minimizing its impact to reduce the risk of the ensuring cascading trips of lines and generating stations [9-11].

3.0 MATERIAL AND METHODS:

The method adopted for this study includes: Data collection on the Benin region of the transmission company of Nigeria (TCN) power outages based on PHCN annual reports for the year 2014, 2015 and 2016; and analysis of power outages in the network.

Administratively, TCN is divided into eight (8) Transmission regions namely Shiroro, Kaduna, Bauchi, Oshogbo, Benin, Enugu, Port-Harcourt and Lagos. In this paper, emphasis is focus on power outages in the Benin region of the Transmission Company of Nigeria Networks (BRTCN). Benin region Transmission network comprises of Edo, Ondo, and Ekiti states of Nigeria. Tables 1, 2, and 3 shows the monthly data of power outages for the year 2014, 2015, and 2016 on the 330 kV network while table 4 presented summary of outages recorded for the years under review.

Table 1: Summary of Power outages in 2014

| Months | Planned outages | Forced outages | Urgent outages | Emergency outages | Total |
|-----------|-----------------|----------------|----------------|-------------------|-------|
| Jan | 12 | 19 | 4 | 9 | 44 |
| Feb | 6 | 10 | 6 | 7 | 29 |
| Mar | 8 | 16 | 4 | 9 | 37 |
| Apr | 14 | 10 | 7 | 6 | 37 |
| May | 7 | 19 | 5 | 8 | 39 |
| June | 13 | 13 | 8 | 10 | 44 |
| July | 9 | 19 | 7 | 6 | 41 |
| Aug | 10 | 11 | 3 | 3 | 27 |
| Sept | 8 | 19 | 10 | 5 | 42 |
| Oct | 9 | 20 | 7 | 7 | 43 |
| Nov | 7 | 10 | 3 | 9 | 29 |
| Dec | 11 | 12 | 7 | 7 | 37 |
| Sub-total | 114 | 178 | 71 | 86 | 449 |

Table 2: Summary of power outages in 2015

| Months | Planned outage | Forced outage | Urgent outage | Emergency outage | Total |
|-----------|----------------|---------------|---------------|------------------|-------|
| Jan | 12 | 24 | 6 | 5 | 47 |
| Feb | 5 | 20 | 3 | 6 | 36 |
| Mar | 6 | 9 | 6 | 3 | 24 |
| Apr | 12 | 15 | 9 | 6 | 42 |
| May | 5 | 12 | 12 | 4 | 33 |
| June | 10 | 26 | 11 | 8 | 55 |
| July | 3 | 14 | 7 | 6 | 30 |
| Aug | 14 | 19 | 12 | 3 | 48 |
| Sept | 16 | 23 | 10 | 2 | 51 |
| Oct | 9 | 26 | 7 | 5 | 47 |
| Nov | 3 | 11 | - | 6 | 20 |
| Dec | 6 | 18 | 5 | 8 | 37 |
| Sub-total | 101 | 217 | 88 | 64 | 470 |

3.1 Causes of power outages

The load on any network must be matched by the supply to it and its ability to transmit that power. Any over load of the power line can cause hard-to-repair and costly damage, so the affected device is disconnected from the network if a serious imbalance is detected [12].

- Major causes of power outages

As transmission line carry more current, they get hotter. This causes them to lengthen and sags between towers. They may safely reach a specific minimum clearance height above the ground. If the transmission lines sag further, a flashover to nearby objects can occur causing a transient increase in current. Automatic protective relays detect the high current and quickly act to disconnect the faulted line from service. Should a fault occur and take a line out of service, the change in current flow is compensated by other transmission lines, which must have enough spare capacity to carry the excess current. If they do not, overload protection in those lines will also trip causing a cascading failure as the excess current is switched onto neighbouring circuits running at or near their capacity.

Ideally in any electrical distribution system, when fault occur it is desirable to interrupt and remove only that portion of the electrical system in trouble, leaving the remaining system intact. When this is accomplished a system is said to be coordinated. In power supply networks, the power generation and the electrical load demand must be very close to equal every second to avoid overloading of network components, which can severely damage them. In order to prevent this, parts of the system will automatically disconnect themselves from the rest of the system, or shut themselves down to avoid damage. Under certain conditions, a network components shutting down can cause current fluctuations in neighbouring segments of the network leading to a cascading failure of a larger section of the network. This may range from a community to an entire city, and to an entire electrical grid. The following items are some of the causes of power failures.

Table 3 Summary of power outages in 2016

| Months | Planned outages | Forced outages | Urgent outages | Emergency outage | Total |
|-----------|-----------------|----------------|----------------|------------------|-------|
| Jan | 8 | 16 | 3 | 5 | 32 |
| Feb | 5 | 11 | 5 | 13 | 34 |
| Mar | 13 | 13 | 7 | 3 | 36 |
| Apr | 9 | 10 | 3 | 10 | 32 |
| May | 7 | 17 | 9 | 5 | 38 |
| June | 4 | 22 | 10 | 8 | 44 |
| July | 6 | 14 | 4 | 5 | 29 |
| Aug | 9 | 15 | 6 | 7 | 37 |
| Sept | 10 | 13 | 4 | 5 | 32 |
| Oct | 6 | 15 | 5 | 6 | 32 |
| Nov | 7 | 9 | 2 | 5 | 23 |
| Dec | 4 | 11 | 4 | 4 | 23 |
| Sub-total | 88 | 166 | 62 | 76 | 392 |

Table 4: Summary of power outages for the year 2014, 2015, and 2016

| Year | Forced outage | Planned outages | Urgent outages | Emergency Outage | Total |
|------|---------------|-----------------|----------------|------------------|-------|
| 2014 | 178 | 114 | 71 | 86 | 449 |
| 2015 | 217 | 101 | 88 | 64 | 470 |
| 2016 | 166 | 88 | 62 | 76 | 392 |

A summary of power outages recorded for three years 2014, 2015, and 2016 is presented in table 4.

- **Transients**

Transient commonly called surges are sub-cycle disturbances of very short duration that vary greatly in magnitude. It is a momentary loss of power typically caused by a temporary fault on a power line. When transient occur, thousands of voltages can be generated into the electrical system, causing problems for equipment down the line. Transient faults could be caused by flashover from the high transient voltage induced by lightning to the tower, swinging wires and temporary contact with foreign objects. Various studies have shown that about 70% of fault on most overhead lines are transient. Power is automatically restored once the fault is cleared. Transient faults do not damage the insulation permanently and as such allow the circuit to be safely re-energized after a short period of time. It occurs mainly on outdoor equipment where air is the main insulating medium. A typical example would be an insulator flashover following a lightning strike which would be successfully cleared on opening of the circuit breaker, which could be automatically reclosed.

- **Vandalism**

Vandalisation of transmission lines by unscrupulous individuals for selfish gains is very rampant in the Nigerian power system. A common form of vandalism occurs when thieves steal conductor wire to sell as scrap metal. Removal of ground wire, counterpoise and substation grounding may not directly result in interruptions, but may cause safety concerns and compromise protection schemes. More sophisticated criminals may choose to steal phase conductors, resulting in open circuits and customer interruptions. Typical terrorist attacks involve the use of explosives targeted at towers, poles, or substations. Most successful attacks result in customer interruptions since the usual intent of the terrorists is precisely to cause these interruptions.

- **Equipment Ageing**

The Transmission Company of Nigeria (TCN Plc) has generating, transmission and distribution systems with a large percentage of very old equipment. The amount of very old equipment is increasing, and age-related deterioration is, in many cases, beginning to have a detrimental impact on power system reliability.

The Nigeria transmission network is characterized by frequent outages due to aging of equipment/lines leading to frequent conductor/jumper cuts, frequent earth faults resulting from reduction in overhead clearance and refuse burning, circuit breaker problems, etc. The maximum Installed capacity and quality of electricity supply to customers then has increased considerably, and it is important that ageing equipment should not prejudice the quality of supply being provided, given that operational standards and safety regulations have become more stringent over the years. While maximum fault levels and rated voltages in the power system have also increased.

Considerations of Equipment Aging Includes

- The likelihood of failure tends to increase
- Maintenance costs tend to increase
- Replacement parts can become difficult to obtain
- Old equipment may become technologically obsolete

Although all of the above considerations are important, the first bullet point is the most difficult to address. This is because issues such as maintenance cost, spare parts availability, and technological obsolescence can be addressed in a business case. It should be emphasized that old equipment is not undesirable simply because it is old. It is undesirable because it may have a high likelihood of failure. In fact, any piece of equipment that has a high likelihood of failure is also undesirable.

- **Increasing Failure Rates**

As the useful life of a piece of equipment comes to an end, the previously constant failure rate will start to increase as the components start to wear out. This time is referred to as the wear out period of the equipment. During the wear out period, the failure rates of many categories of distribution equipment tend to increase, typically at an increasing rate. For electrical equipment with insulation subject to thermal aging (such as transformers and cables), failure rates tend to increase exponentially with age. This means that after an initial infant mortality period, failure rates tend to be low during the design life of the equipment. After a certain point, failure rates will tend to dramatically rise as the electrical and mechanical strength of the insulation becomes insufficient to withstand physical or electrical disruptions. Population aging dynamics become more complicated if failure rates are assumed to increase with equipment age. If failure rates tend to increase rapidly after an expected useful life, large amounts of equipment can fail in a relatively short period of time. Widespread replacement will then have a rejuvenating effect on the system, but will eventually result in a “failure echo” when the replacement equipment reaches the end of its useful life.

- **Lightning Storms**

A lightning strike occurs when the voltage generated between a cloud and the ground exceeds the dielectric strength of the air. This results in a massive current stroke that usually exceeds 30,000 amps. To make matters worse, most strokes consist of multiple discharges within a fraction of a second. Lightning can affect power systems through direct strikes (the stroke contacts the power system) or through indirect strikes (the stroke contacts something in close proximity and induces a traveling voltage wave on the power system). The lightning strike causes a flashover that causes a short circuit on the power system.

- **Human Errors**

Mistakes by utility workers often result in customer interruptions. Switching errors occur when operators or crews reconfigure the system in a manner that unintentionally interrupts customers. This usually occurs when a wrong circuit breaker or SCADA controlled switch is opened. Customers can also be interrupted when the system is being reconfigured to mitigate losses or low voltage conditions. Interruptions can also occur when mistakes are made during relay testing, resulting in undesired breaker tripping.

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When working near energized equipment, crews' mistakes can cause faults resulting in customer interruptions. Substation work is another example of an activity where faults can easily occur due the close proximity of equipment and the large amount exposed bus work. Mistakes made while equipment is de-energized can manifest itself as a fault when the equipment is energized.

Looking at the complex nature of Nigeria power system, it is not easy to entirely eliminate the risk of power outages. However there are certainly means of reducing the risk based on engineering understanding from the general root causes and nature of these events.

4.0 FAULT ANALYSIS

Electric power outages commonly referred to as blackouts, have been more prevalent in recent years. Blackout refers to the total loss of power to an area and is the most severe form of power outage that can occur. Annual faults outages per feeder is determine using the expression

$$S = \dots\dots\dots (1)$$

Where N represent types of fault, and m is the total numbers of fault in a feeder.

Evaluating the collected data in Table 4 summary of power outages for the year 2014, 2015, and 2016. From the table, there were 449 total number of power outages for the year 2014, these include 178 forced outages, 114 planned outages, 71 urgent outages and 86 emergency outages respectively.

Substituting numerical values in to equation (1),

The percentage forced outages for the year is given as

$$S = = 39.64\%$$

For planned outages $S = = 25.39\%$,

Urgent outages $S = = 15.81\%$, and

Emergency outages $S = = 19.15\%$.

Similarly, annual percentage power outages for the year 2015, and 2016 were also evaluated.

RESULTS

Power outages that occur in the transmission network were categorized into (i) forced, (ii) planned, (iii) urgent and (iv) emergency outages respectively. A total of 449 outages were recorded in 2014 in the 330KV network, out of which 178 were force outages and constitutes 40 %, 114(25%) planned, 71 (16%) urgent, and 86 (19%) emergency outages respectively. Summary of power outages bar charts representing different types of power outages in the Benin zone of the Nigeria transmission network for the year 2014, 2015 and 2016 is presented in Figure 1. Also, total power outages of 470 recorded in 2015 represents 4.67 % increase of that of 2014 outages of 449, and in 2016, a total of 392 outages (12.69%) reduction of that of 2014 respectively. Figures 2(a), 3(a), and 4(a) shows monthly power outages bar charts for 2014, 2015, and 2016. Figures 2(b), 3(b), and 4(b) depicts the annual percentage contributions of various types of outages for 2014, 2015 and 2016 on the 330KV network.

Analysis of blackouts has revealed that they are never the result of a single event. Majority of these events tends to be as a result of a stressed systems, component failures, vandalism, lightning storms, transients instability, equipment ageing, environmental factors such as tripping of lines due to sagging, mis-operation of protective devices and possible human error. The fundamental system designed criteria of being able to withstand one or more outages and the relay philosophy of high dependability at the cost of somewhat reduced security may, under abnormal system conditions, be a contributor to further stress and eventual outage.

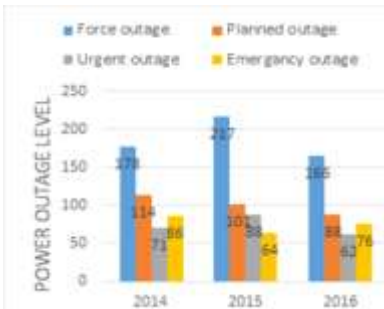


Figure 1: Power outages summary for 2014, 2015 and 2016.

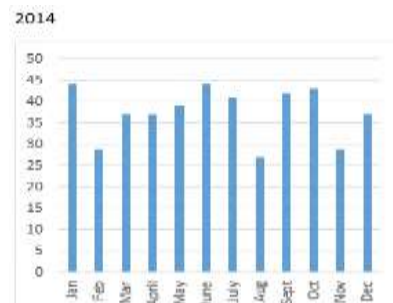


Figure 2: (a) Monthly power outages chart for 2014.

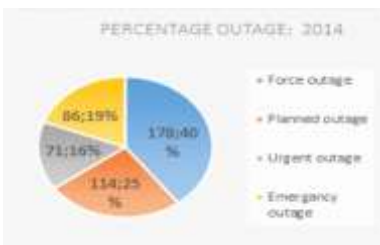


Figure 2: (b) Annual percentage outages for 2014.

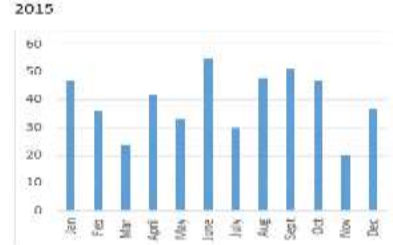


Figure 3: (a) Monthly power outages chart for 2015.

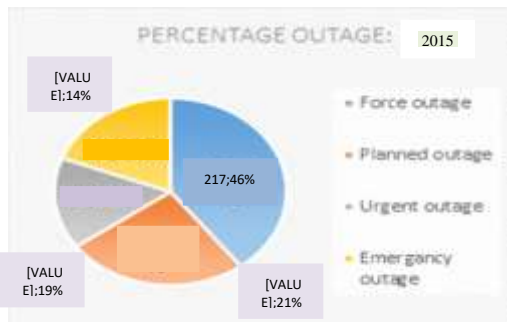


Figure 3: (b) Annual percentage outages for 2015

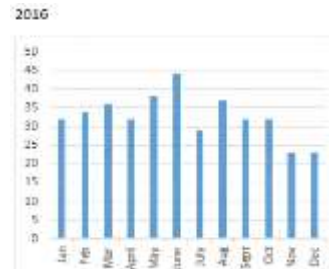


Figure 4: (a) Monthly power outages chart for 2016.

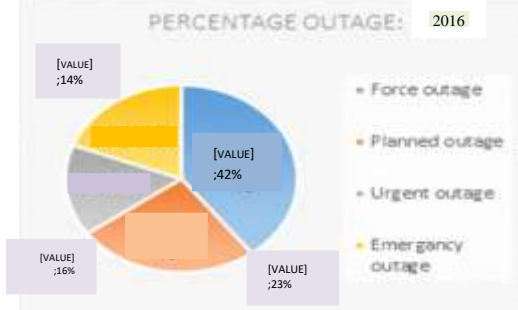


Figure 4: (b) Annual percentage outages for 2016

5.0 CONCLUSION

Outages and total blackouts are major catastrophic failure in large interconnected Nigeria power systems. The various causes and effects of power outages in the Nigeria transmission network have been examined in this study. The economic impact of these outages is not only restricted to loss of revenue by the utility or loss of energy utilization by the customers, but in order to estimate true costs, evaluation should also include indirect costs imposed on society and the environment due to the outages. Regular maintenance, evaluation and testing of power plant and substation equipment to ensure that the equipment is maintained in a good condition and is operating within design parameters. The electricity supply industry operates a very complex and highly integrated system. Failures in any part of it can cause interruptions which range from inconveniencing a small number of local residents to a major and widespread catastrophic disruption of supply. In order to reduce power outages in the Nigeria transmission networks, and to ensure the stability of the system and limit the risks of system outages, some of the controllable factors outlined for the prevention of power outages should be consider. These factors include:

- Very long and fragile lines should be reinforced to improve stability and efficiency in the network.
- Adequate and effective protective relaying control schemes should be put in place to assist in fault isolation and protection of the network, taking into consideration the short circuit current in the network.
- More substations should be introduced into the network to assist in the reduction of long lines and improves the voltage profiles of the network.
- Faults should be promptly rectified and all the lines should be energized to reduce the incident of vandalization.
- Proper clearing should be carried out for transmission lines that have be overgrown by trees and weeds to reduce the effect of constant tripping of the lines.
- Additional circuits and loops should be introduced into the network to reduce the single line contingency constraints associated with most parts of the network.
- Regular patrol and monitoring of the transmission lines to guide against vandalization which constitute a major setback in the network.
- Avoid overloading of transmission lines/equipment and increase transmission lines capacity.
- Replacement of ageing equipment that are prone to failure and avoid human error and
- The supply authority should build more power stations, sub-stations; new transmission lines and rehabilitates existing lines.

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