



ENHANCEMENT OF ARC CONTROL AT BORIKIRI 11/33KV DISTRIBUTION STATION, PORT HARCOURT, RIVERS STATE

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ABSTRACT: This research work has highlighted the benefits of enhancement of arc at Borikiri 33kV Distribution Network in Rivers State, Nigeria. The flash arc analysis was modelled and simulated using ETAP 12.6 software environment to show the sequence of operation of arc flash from the Injection substation to the Transmission Station. The analysis focus on the fault current occurred at some point once the relay protection device issued a clearing time in seconds, the circuit breaker was absolutely tripped and when an arc fault occurs, the latched fault occurred showing that a short circuit that has no electrical resistance at the point of the fault, that is characterised by an absence of arcing. The case study shows the connection between the clearing/tripping time and fault current for the prevailing and simulated case study; for the existing case study shows the minimum values and therefore the most values, once the clearing/tripping time was 0.011 sec, the fault current was 32.20 kA and when the clearing/tripping time was 0.025 sec, the fault current was 34.12 kA, the result show the behavior of the graph as linearity. The graph shows that as clearing/tripping time will increase, fault current increases slowly at first. Similarly, because the clearing/tripping time and the the} fault current will increase slowly at first, then additional rapidly, then slows down once more and reaches a most level. The simulated case study also shows the link between the fault current and clearing time shows the minimum values and the maximum values, once the clearing/tripping time was 0.062 sec, the fault current was 4.62 kA and when the clearing/tripping time was 0.26 sec, the fault current was 5.01 kA, the graph show that as clearing/tripping time increases, fault current increases slowly at first. Relationship between the incident energy, flash protection boundary and clearing time of the prevailing case study; once clearing or tripping time was zero.011 sec, the flash protection boundary was 1.03 feet, and

therefore the incident energy of 0.73 cal/cm², according to standard for Electrical Safety, our result shows that Hazard Risk categories is 0 (HRC 0) that cause a second degree burn to unprotected skin.

KEYWORDS: Fault current, incident energy, flash protection boundary, clearing time enhancement of arc and flash arc

I. INTRODUCTION

The network of distribution lines is understood as a grid, and therefore, the grids are completely interconnected by connecting lines in the form of a regional grid, while these different regional grids are connected to each other to create a national grating. Multi-port DC distribution is now the main type of flexible DC distribution and will eventually become a flexible DC network as the variety and capacity of converters are still increasing. Compared with the multi-port DC distribution, the flexible DC network has many advantages: From an economic point of view, it saves the line and reduces the investment cost [8]; due to network liability considerations, it has higher system redundancy and network reliability [10]; Starting from the network integration of distributed power considerations, it can solve the distribution disadvantage of multiple power supply and multiple power consumption, which is suitable for the distribution of distributed power. In addition, it can reduce the impact of distributed power supply on network stability [2]. Today's flexible DC distribution often uses DC cables as distribution lines, which could reduce the chance of distribution line failure. With the rapid development of DC circuit breakers, considering the advantages of overhead lines to reduce investment costs, grid-supported overhead lines can become the best direction for flexible DC distribution. Due to the poor external design of the overhead lines, however, the probability of a line failure is higher, which apparently leads to a large-scale blackout [9]. Taking into account that the failures of DC distribution lines are mainly temporary



errors, the enforcement operation of the circuit breakers can restore the power supply, which can improve the power supply. The study on the features of the fault arc is in with respect to a different power outage of the fault arcs at a given interval of time [7], it means that the arc voltage of the AC system is a periodic rectangular signal and therefore the harmonic content reduces the entire secondary fault arcs.

1.2 Statement of the Problem

The most common explanation for arc flash and different electrical accidents is carelessness, regardless of however well an individual is also trained, distractions, weariness, pressure to revive power, or certitude will cause an electrical employee to bypass procedures, work unprotected, drop a tool or create contact between energized conductors. that is a rise within the population size over time can have an effect on the prevailing distribution lines to be overloaded on the far side their designed ratings with a resulting reduction in power distribution quality and in extreme cases; there is a complete power outage. The severity and causes of electrical hazards are varied; however the simplest protection is to weaken equipment before acting on it. The severity associated causes of electrical hazards are varied, but the best protection is to de-energize equipment before working on it. Both OSHA and NFPA 70E need an Electrical Hazard Analysis before starting work on or close to electrical conductors that are or might become energized.

Therefore, this has led to the subsequent downside encountered as a result of:

- i. the shortcoming to worn or broken conductor insulation
- ii. Improperly maintained switches and switches and circuit breakers.
- iii. Carelessness and exposure of live components or loose wire connections.
- iv. Stopped-up disconnect panels and exposure of high voltage cables.
- v. Water or liquid close to the equipment and broken tools and equipment

1.3 Aim of the Study

The aim of this research is to evaluate and improve the enhancement of arc control at Borikiri 11/33kV distribution station, Port Harcourt, Rivers State.

1.4 Objectives of the Study

The objectives of the study are as follows:

- (i) Using collected data from field survey i.e. from Port-Harcourt Electricity Distribution Company of Nigeria

(PHEDC) and Transmission Company of Nigeria (TCN) to evaluate the current status of the distribution lines.

- (ii) Model and simulate the network using Newton-Raphson load flow based technique in Electrical Transient Analyzer Program (ETAP) environment.
- (iii) Using the Results of the base case simulation to improve the arc fault currents, calculate the recording/tripping time of the arcs, the working distances, and the incident energy for all devices, and determine the Flash protective boundary for all equipment.

1.5 Scope of the Study

This study will be a detailed investigation of the general characteristics of the power distribution problems of the Borikiri 11/33 kV, Port Harcourt, Rivers State Network and a full recommendation with a complete design of the power distribution system, including a detailed energy assessment. Distribution and achievement of economic results of the designed system will be considered.

II. LITERATURE REVIEW

In recent decades, the use of electric arc furnaces for the production of steel and its alloys has increased worldwide. Steel production from electric arc furnaces accounted for 36% of total steel production in 2007 and this proportion is expected to increase. it will rise to 55% by 2035. The reason for this increased utilization is the lower capital costs and the lower energy requirements for steel production. The electric arc furnace works with alternating or direct current. It converts electrical energy into thermal energy. Energy (arc) to melt the waste material retained by the furnace.

The arc is created between the low voltage and high current electrodes supplied by the furnace transformer [1]. The operation of the electric arc furnace can be divided into intervals, namely melting and refining periods. The refining time is divided into several phases. During the melting phase, the electrode is lowered by a hydraulic actuator system to keep the arc stable. In this state, the furnace consumes active power. Arc furnaces also produce harmonic charge currents and asynchronous spectral components. Harmonics are a major power quality problem as they can cause undesirable operating conditions [3].

Hence, the approach of wavelet entropy may be used to differentiate the transient arc fault [5], declaring that the arc fault is a non-linear process, and there are better harmonics in arc voltage and arc present day. The fault kinds may be prominent via way of means of detecting the voltage and current of the fault traces.



In the arc version for evaluation of brief faults in flexible DC grid [6], recommend the Zeller version on the idea of the precept of thermal equilibrium and the physical properties of air. It is believed that there may be an arc column and the voltage drop is particularly at the arc column.

According to [4] pollutants are the main criterion for the layout of transmission line insulators. Pollution has a bad impact on the insulation device of power lines and substations, which may arise within side the shutdown of the power line. Pollution falling at the insulators produces a conductive film at the floor which causes the surface leakage current to increase, in the end ensuing in flashover / nearby arcing on insulators. The arc from the instant of fault to the operation of the breakers is the number one arc. During this period, the fault current is provided through the electrical device on each side of the lines, which is heavy. However, there may be no considerable elongation of the arc length.

Electric arc furnaces are extraordinarily flexible and may be utilized in construction and manufacturing levels. It may be used as a smelting and refining mode. The electric power may be utilized in a managed manner according to the demand. The electric-powered arc furnace additionally may be mixed with an oxygen fuel burner while making unique steels [13].

A DC arc furnace generally includes a graphite electrode (cathode) vertically hooked up through a gap within side the centre of the furnace roof. The anode connection is within side the coronary heart of the furnace. The anode is in direct touch with the scrap fabric to soften. The arc is generated among

the top of the cathode and the top layer of the scrap held within side the furnace. A very excessive temperature (1500°C) is generated that is applied to melt and refine the scrap [11].

III. MATERIALS AND METHOD

3.1 Materials Used

- I. The distribution data were collected from the Port Harcourt Electricity Distribution Company (PHEDC).
- II. Substation feeder data
- III. Conductor size, cross-sectional area with 160mm² (aluminum conductor)
- IV. Transmission/distribution line data, bus-data including network diagram.
- V. 15kV switchgear, 5kV switchgear, low-voltage switchgear, low voltage MCCs and panel boards, or cable runs
- VI. Application of Electrical Transient Analyzer Program (ETAP version 12.6) software is exploited for the results.

3.2 Description of Electrical Power Utilization for Borikiri 11/33kV Distribution Network

The existing 11/33 kV Borikiri distribution network consists of a single line diagram where the 11/33 kV comes from Afam to Woji substation, which is a substation. The substation is powered by the 132 kV Afam power line from the Afam generation station in Rivers State.

Figure1 shows the single line network diagram of Borikiri 11/33kV Substation, Port Harcourt, Rivers State.

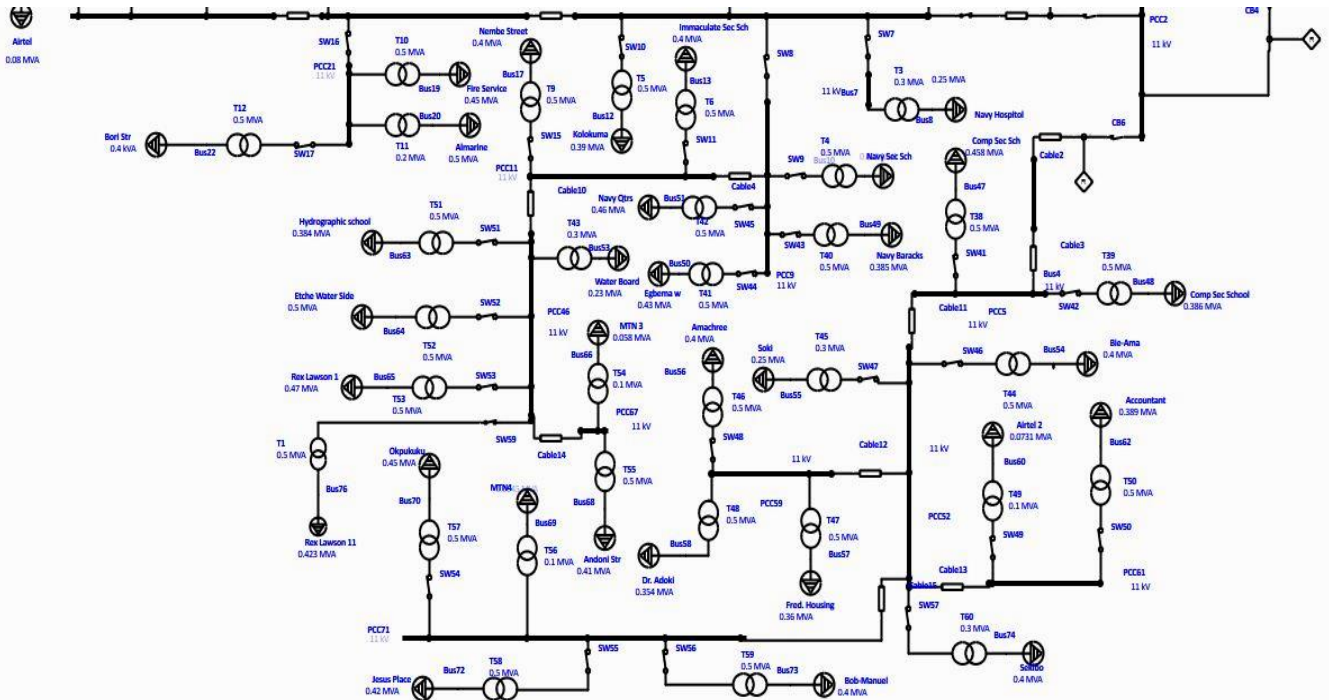


Fig1: Single Line Network Diagram of Borikiri 11/33kV distribution station, Port Harcourt, Rivers State

Table 1: NFPA 70E, Standard for Electrical Safety in the workplace categorizes Arc-

Flash Hazards into five Hazard Risk Categories

Incident Energy (cal/cm ²)	Hazard Risk Category
0 to 1.2	0
1.21 to 4	1
4.1 to 8	2
8.1 to 25	3
25.1 to 40 4	4

Source: NFPA 70E, Standard for Electrical Safety in the workplace for Arc-Flash Hazards

The studies show that many industrial Arcflash events generate 8 cal/cm² (HRC 2) or less, but other accidents can generate 100 cal/cm² or more (exceeding the total HRC). It is important to remember that only 1.2 cal/cm² (HRC 0) is required to cause a second-degree burn on unprotected skin.

3.3 Mathematical Modelling

3.3.1 Arc Length

In an arc furnace, the length of the arc varies over time due to the movement of the electrode and at the same time the movement of the scrap under the electrode. The time-varying arc length of the arc length can be modeled as a stochastic process and hence the proposed arc furnace model is expressed in equation (3.1).

$$V_a(I_a, \Theta[k]) = \Theta[k] * \text{sign}(I_a) \tag{3.1}$$

Where;

V_a and I_a are the voltage and current in the arc and

$\Theta[k]$ is the parameter directly related to the arc length.

The parameter $\Theta[k]$ takes different value every time when the electric arc is started, which is every time I_a crosses zero. The index k is the counter of the discrete time signal $\Theta[k]$ whose sampling period is $T_s = 0.01$ sec which is the time of half cycle of 50 Hz system. Such a stochastic model of electric arc furnace generates harmonic voltage in the distribution system.

3.3.2 Dynamics of Arc Model Based on Principle of Energy Conversion



The differential equation which represents the dynamics of arc model is based on principle of energy conversion. The following differential equation is given as;

$$K_1 r^n + K_2 r \frac{dr}{dt} = \frac{k_3}{r^{m+2}} \quad i^2 \quad (3.2)$$

Where;

r is the arc radius which is chosen as the state variable instead of the arc resistance or the arc conductance.

The arc voltage is given as;

$$v = \frac{l}{g} \quad (3.3)$$

Where;

g is the arc conductance and is given by

$$g = \frac{r^{m+2}}{k_3} \quad (3.4)$$

The parameters are chosen as m = 0 and n = 2 for refining stage in the electric arc furnace. The second part of the electric arc furnace is to generate the chaotic signal of the arc voltage.

3.3.3 Static arc equation

To avoid the current condition we rewrite both equations with a unique equation:

$$V_{arc} = \frac{\alpha}{\arctan(\beta I_{arc})} \quad (3.5)$$

Where parameters α and β play the same role as the Warrington equation parameters P_o and n. Parameters α is also a linear function of the arc length:

$$\alpha = \tau \cdot d + \delta \quad (3.6)$$

3.3.4 Arc polarization

Polarization of the arc in a circuit is pretty similar to the polarization of a transistor. As an example, we consider a series arc occurring in a simple

resistive circuit of resistance R powered by a DC supply voltage V_g . The voltage equation of the circuit is:

$$V_g = RI_T + V_T$$

(3.7)

Expressing this equation in function of V_T gives all the possible discharge voltages allowed by the circuit:

$$V_T = V_g - RI_T$$

(3.8)

The cross points, or polarization points, are the solutions for V_T and I_T . In real static cases, when the arc is stable, the solution is generally the one that have the maximum current I_T .

It means that we consider the circuit as dynamic but not the arc. When the load line is moving, we have to choose one of the possible cross points as solution. Then, we calculate for each solution the variation of power:

$$\Delta P = |V_T \cdot I_T - V_{arc} \cdot I_{arc}|$$

(3.9)

Knowing ΔP for all the possible points, we choose the one that implies the minimum of power variation ΔP .

IV. EXPERIMENT AND RESULT

4.1 Description of Work

The outcome of results is to evaluate and improve the enhancement of arc control at Borikiri 11/33kV distribution station, Port Harcourt, Rivers State were simulated and analysed for the purpose of investigations. The research critically examined the existing case study and the new (simulated) case study as the possible solutions.

4.2 Result Analysis

Electrical Transient Analyzer Program 12.6 was used in modelling the relay coordination of Borikiri, 33/11kV Injection Substation. The analysis was done in ETAP 12.6 software environment.

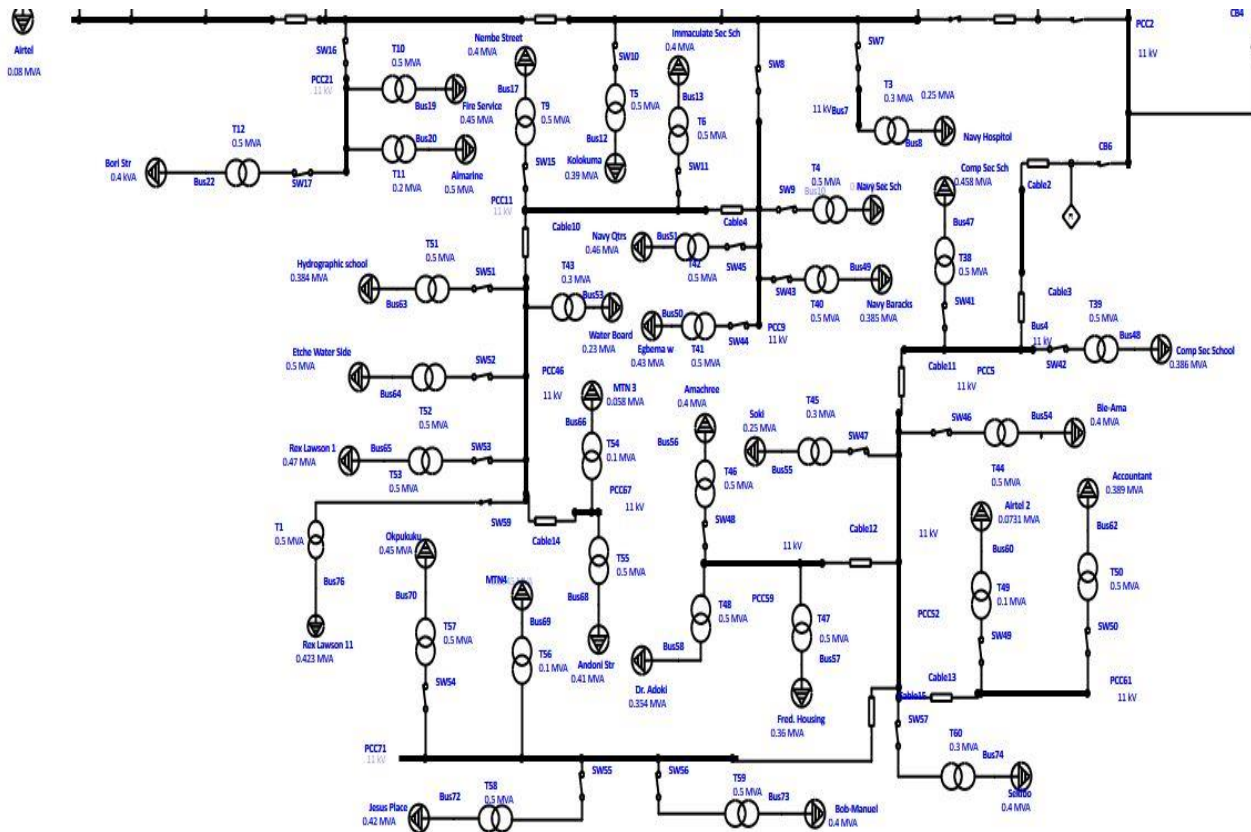


Fig 2: Single line diagram showing Borikiri network diagram (not simulated)

The above figure display the single line diagram showing Borikiri network diagram not simulated.

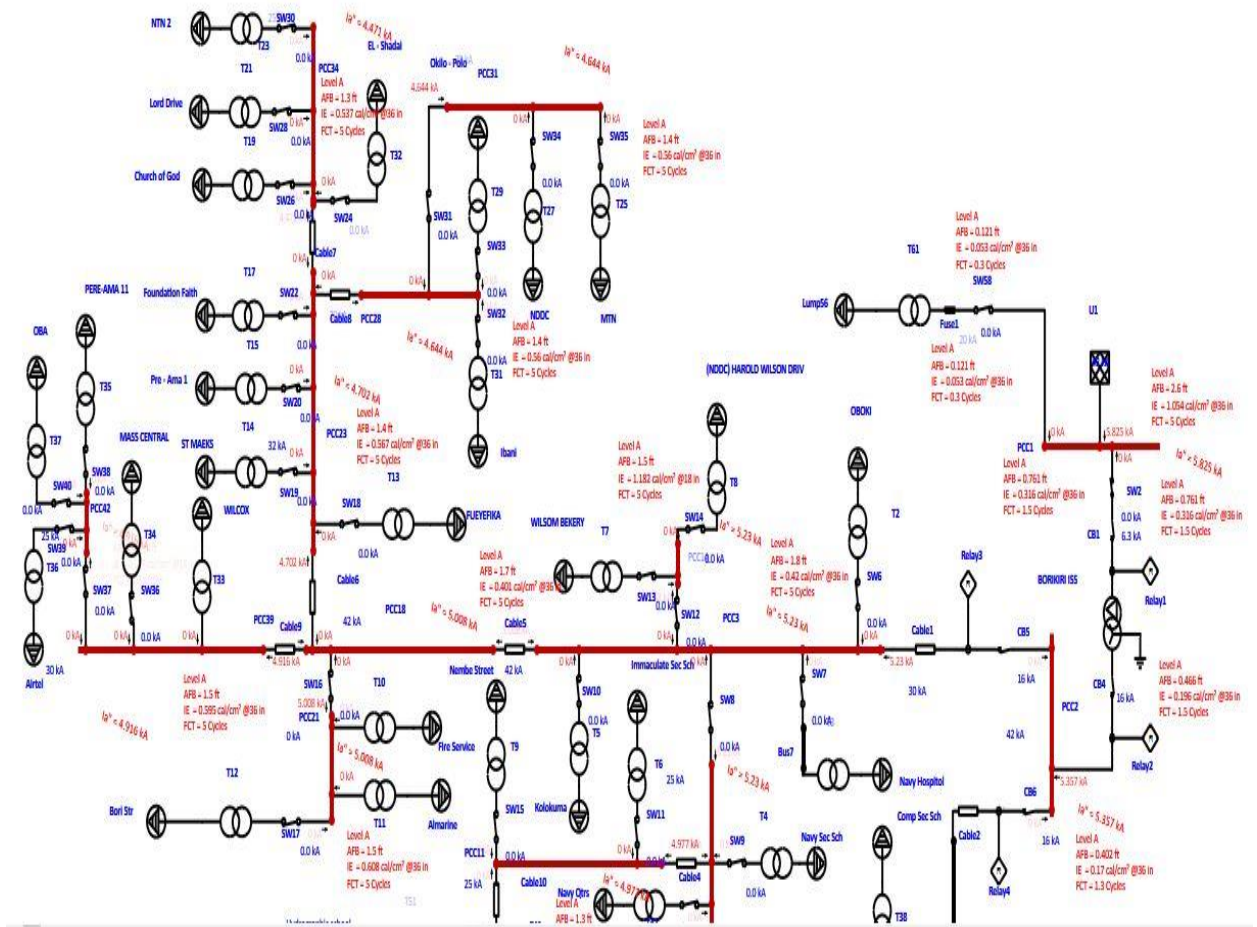


Fig 3: Single line diagram of Borikiri network showing Arch flash Analysis

The above figure display the single line diagram of Borikiri network showing arch flash analysis capturing the affected regions as a result of inability to worn or broken conductor insulation.

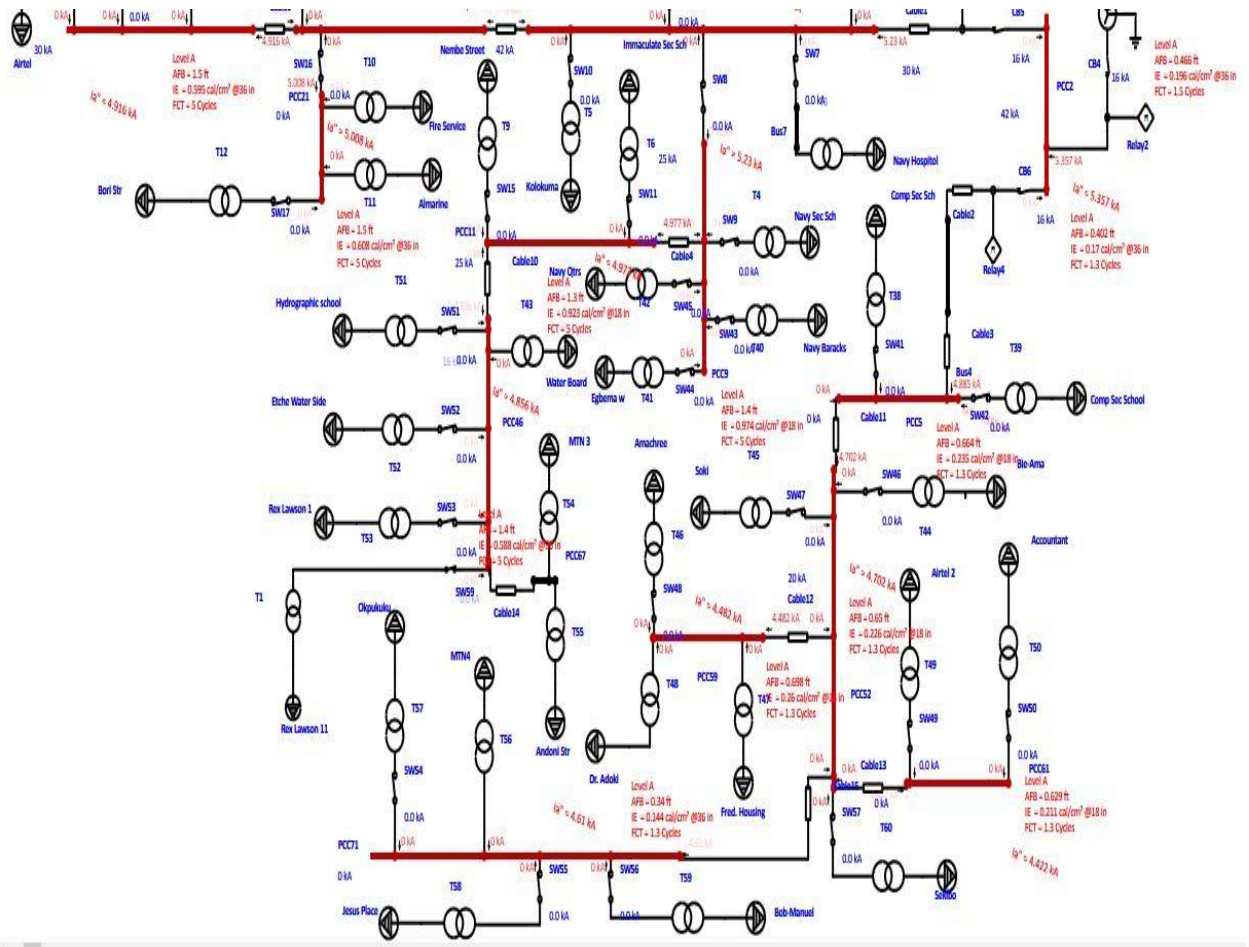


Fig 4: Single line diagram of Borikiri network showing Arch flash Analysis for the capture affected area
 The above figure display the single line diagram of Borikiri network showing arch flash analysis capturing the affected regions as a result of improperly maintained switches and switches and circuit breaker.

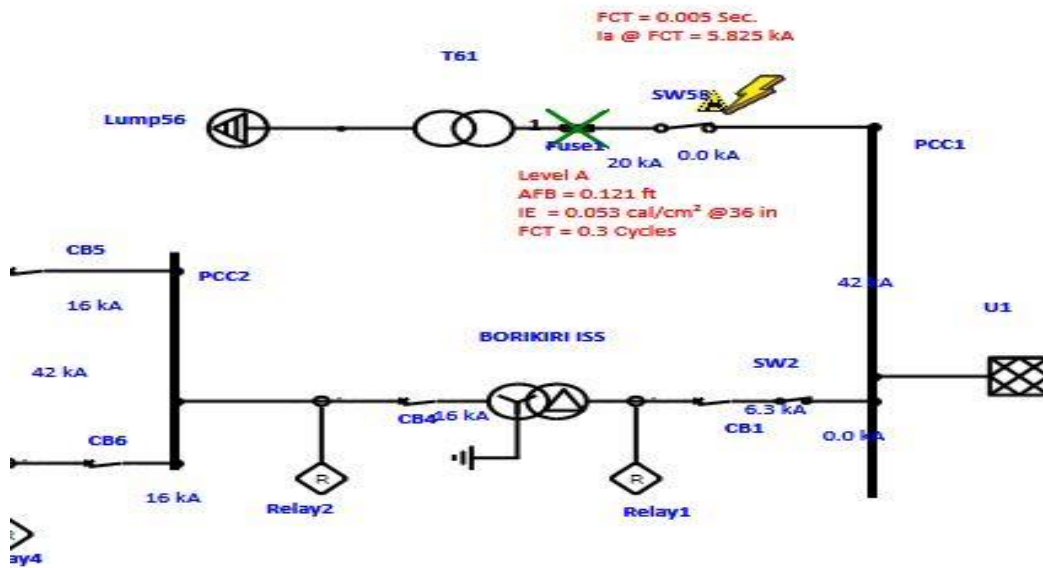


Fig 5: Single line diagram of Borikiri network showing Arch flash Analysis



4.2.1 Analysis from Sequence of Operation Result for (Existing case)

The section contains the discussion of the results for the existing case study. The flash arch parameters such as clearing or tripping time, flash protection boundary, incident energy, bolted fault, working distance and fault current were discuss exclusively.

Table 2: Existing Case Showing the Flash Arc Parameters

Load Point	Clearing time (Sec)	Flash Protection Boundary (Feet)	Incident Energy Cal/cm ²	Bolted Fault (kA)	Work Distance (Inches)	Fault Current (kA)
Bori by Anasi	0.019	1.83	3.08	36.40	22	48.42
Fire service	0.017	1.28	1.41	26.04	15	36.23
Navy School	0.012	1.07	2.60	56.68	12	54.67
Dr. Adoki	0.011	1.03	0.73	23.15	13	32.20
Okilopolo	0.018	1.39	4.32	40.82	17	56.78
Egbema	0.014	0.42	3.35	47.17	18	56.74
Comprehensive Sec. Sch	0.020	1.38	3.60	36.36	17	50.58
Kolokuma/Etche	0.023	1.68	5.26	46.29	20	55.69
Abiye Sekibo	0.025	1.18	1.47	26.59	14	34.12

The above table shows the arch parameters of the existing case study.

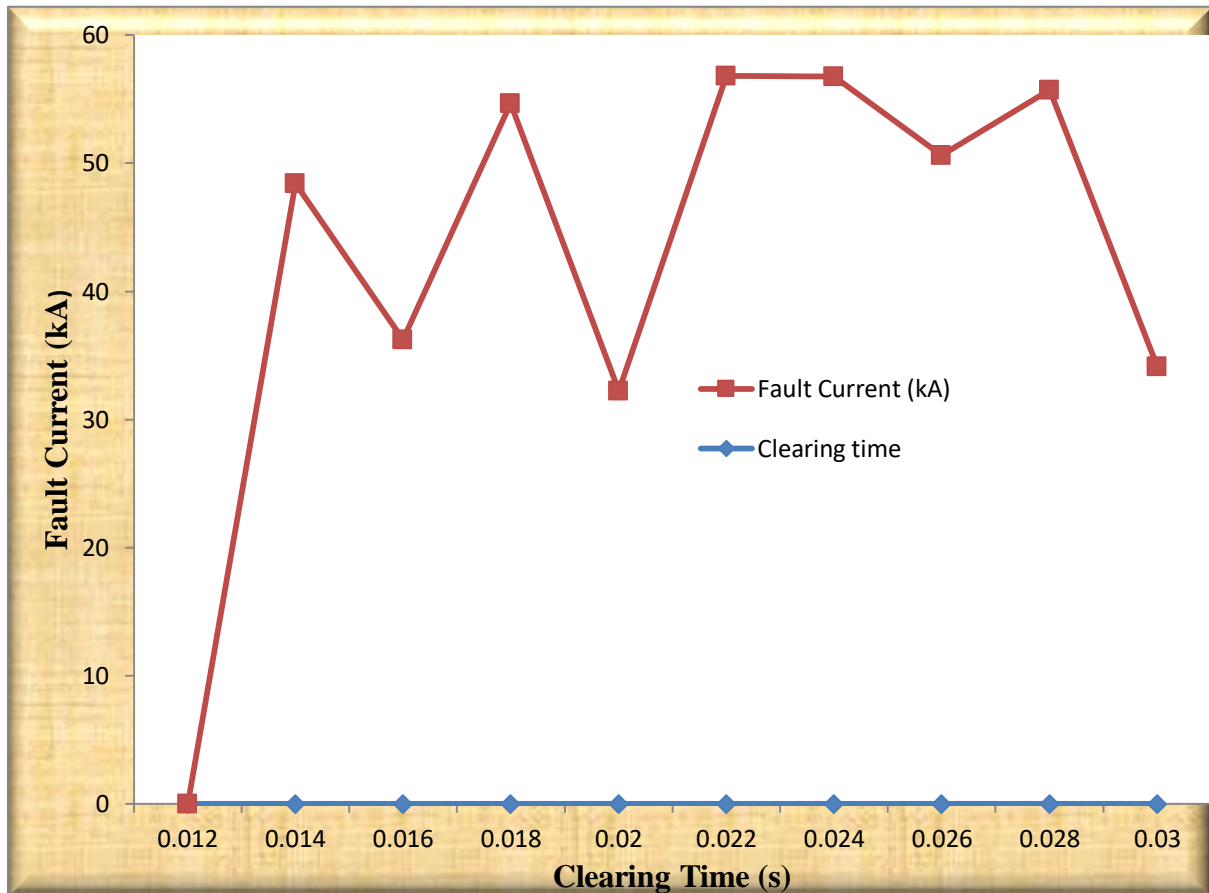


Fig 6: Relationship between the clearing time and fault current of the existing study case



When the clearing/tripping time was 0.011 sec, the fault current was 32.20 kA, when the clearing/tripping time was 0.012 sec, the fault current was 54.67 kA, the result show the behavior of the graph as linearity.

When the clearing/tripping time was 0.014 sec, the fault current was 56.74 kA, and when the clearing/tripping time was 0.025 sec, the fault current was 34.12 kA, the graph show that as clearing/tripping time increases, fault current increases slowly at first.

Therefore, the existing results show the relationship between the clearing/tripping and the fault current, this indicates that there is an overcurrent detected fault from the inception of the overcurrent until the current is completely interrupted by the fault current. The fault current designates that there is a current flowing outside its normal path as a result of a breakdown of insulation or by faulty equipment connections, showing that the current bypasses the normal load.

From table 2 the NFPA 70E, Standard for Electrical Safety in the Workplace categorizes Arc-Flash Hazards into five Hazard Risk Categories (HRC 0 through 4) based on the amount of energy that can be released at a certain working distance during an Arc-Flash event.

Studies show that many industrial Arc-Flash events produce 8 cal/cm² (HRC 2) or less, but other accidents can produce 100 cal/cm² or more (exceeding all HRC). It is important to remember that it only takes 1.2 cal/cm² (HRC 0) to cause a second degree burn to unprotected skin.

4.2.2 Analysis from Sequence of Operation Result for (Simulated case)

The section contains the discussion of the results for the simulated case study. The flash arch parameters such as clearing or tripping time, flash protection boundary, incident energy, working distance and fault current were discuss exclusively.

Table 3: Simulated Case showing the flash arc parameters

Load Point	Clearing time (Sec)	Flash Protection Boundary (Feet)	Incident Energy Cal/cm²	Working Distance (Inches)	Fault Current (kA)
Bori by Anasi	0.250	1.50	0.596	36	4.916
Fire service	0.260	1.56	0.608	36	5.008
Navy School	0.258	1.33	0.923	18	4.977
Dr. Adoki	0.062	0.34	0.144	36	4.615
Okilopolo	0.251	1.40	0.974	18	5.230
Egbema	0.064	0.66	0.235	18	4.885
Comprehensive Sec. Sch	0.065	0.40	0.170	36	5.357
Kolokuma/Etche	0.065	0.69	0.260	24	5.674
Abiye Sekibo	0.066	0.65	0.226	18	4.938

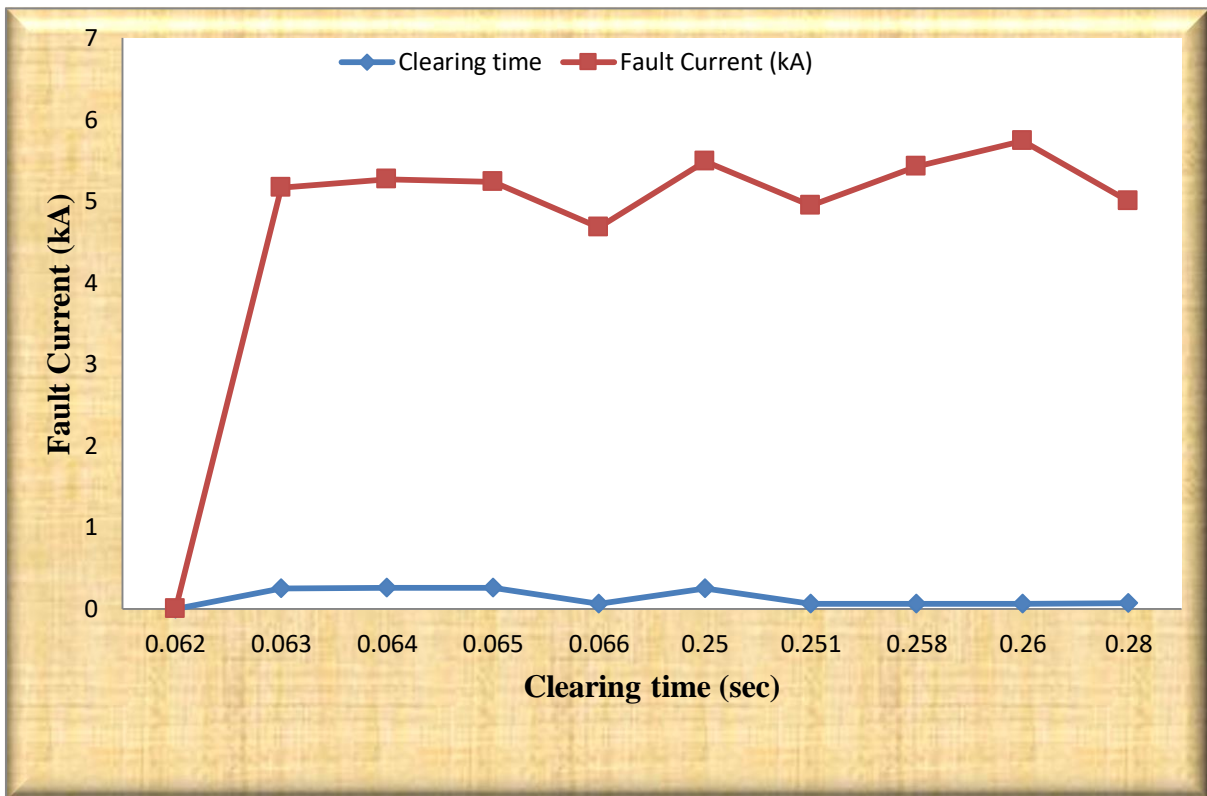


Fig 7: Relationship between the fault current and clearing time of the new (simulated) case study

The figure illustrates the relationship between the fault current and clearing time of the new (simulated) case study. When the clearing/tripping time was 0.062 sec, the fault current was 4.62 kA, when the clearing/tripping time was 0.063 sec; the fault current was 5.67 kA.

When the clearing/tripping time was 0.064 sec, the fault current was 4.89 kA, and when the clearing/tripping time was 0.26 sec, the fault current was 5.01 kA, the graph show that as

clearing/tripping time increases, fault current increases slowly at first.

Therefore, the simulated results show the relationship between the clearing/tripping and the fault current, this indicates that there is an overcurrent detected fault from the inception of the overcurrent until the current is completely interrupted by the fault current. The fault current designates that there is a current flowing outside its normal path as a result of a breakdown of insulation or by faulty equipment connections, showing that the current bypasses the normal load.

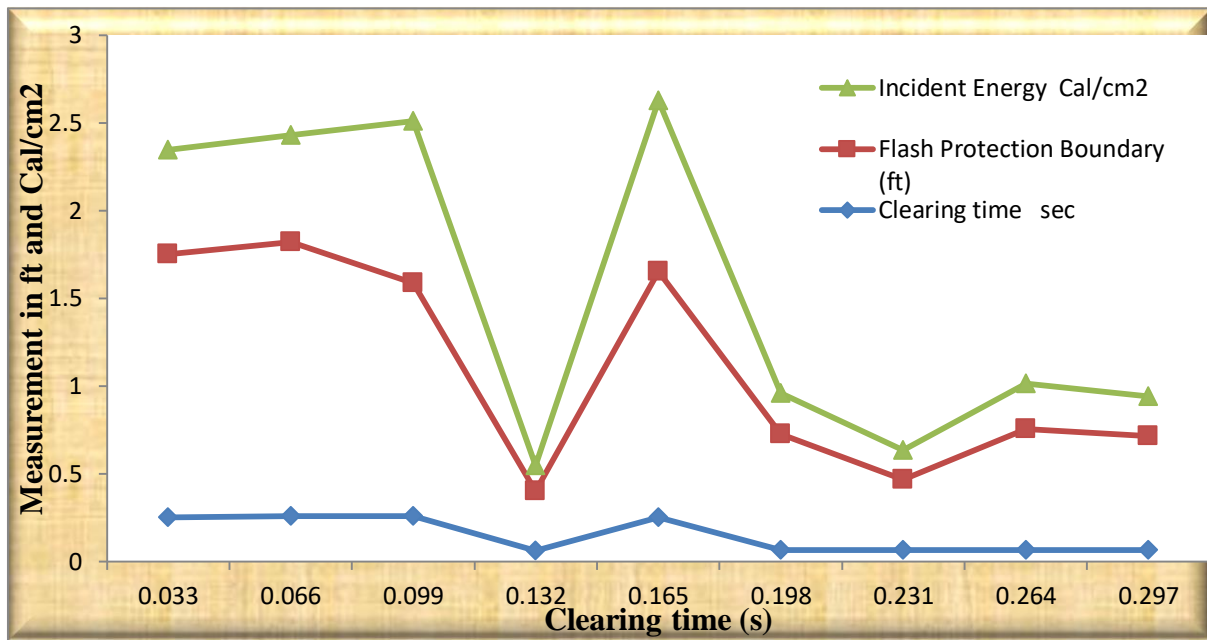


Fig 8: Relationship between the incident energy, flash protection boundary and clearing time of the new (simulated) case study

When clearing or tripping time was 0.062 sec, the flash protection boundary was 0.34 feet, and the incident energy of 0.144 cal/cm², according to Standard for Electrical Safety, our result shows that Hazard Risk Categories is 0 (HRC 0) which cause a second degree burn to unprotected skin. When clearing or tripping time was 0.063 sec, flash protection boundary has 0.69 feet and the incident energy has 0.260 cal/cm², our result shows that Hazard Risk Categories is 0 (HRC 0) which cause a second degree burn to unprotected skin.

When clearing or tripping time was 0.260 sec, flash protection boundary of 1.56 feet, incident energy of 0.608 cal/cm², our result shows that Hazard Risk Categories is 0 (HRC 0) which cause a second degree burn to unprotected skin.

From our results the clearing or tripping time detected the fault from the inception of the overcurrent until the current is completely interrupted by fault current, the flash protection boundary is used to protect personnel from Arc-Flash hazards, which show the distance at which an unprotected worker can receive a second-degree burn to bare skin. While the incident energy indicates the amount of thermal energy impressed on a surface generated during an electrical arc at a certain distance from the arc.

4.3 Discussion of the Result

The fault current occurred at some time when the relay protection device issued a reset time in

seconds, the circuit breaker was fully tripped, and when an arc fault occurs, the bolted fault will be produced, which shows that a short circuit without electrical resistance at the point of the fault characterized by an absence of arc.

However, the fault current is the combined effect of the short circuit current supplied by the converter which increases immediately, the fault current will increase during charging, causing the fault current oscillation to increase. Our results show that after the occurrence of the fault, the protective device relay on the fault line issued the reset or trip signal, therefore, the power switches start to trip, when the fault line is completely disconnected, the power supply no longer feeds the current short circuit at the point of failure. Then the fault current will decrease rapidly.

However, due to the influence of incident energy accumulation, the value of arcing current does not become 0 but fluctuates in a small range. The fault arc extinguishes completely after a few seconds and the fault current decreases. It is following the extinction of the arc at this moment that the re-ignition phenomenon will occur shortly after the extinction of the fault arc.

V. CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

This research work has highlighted the benefits of arc enhancement in the Borikiri 33kV distribution network in Rivers State, Nigeria. The arc flash analysis was modeled on the work. All arc flash



parameters such as compensation/tripping time, flash protection limit, incident energy, working distance and fault current were analyzed and served as input data to model and perform the arc flash analysis on the injection substation using the ETAP 12.6 software environment to show the arc flash operation sequence from the injection substation to the transmission station.

The analysis focuses on the fault current that occurred at a given time when the relay protection device issued a reset time in seconds, the circuit breaker was fully tripped and when an arc fault occurs, the bolted fault has occurred, indicating that a short circuit which has no electrical resistance at the fault point, which is characterized by the absence of arcing. Now, the fault current is the combined effect of the short-circuit current supplied by the converter which increases immediately, the fault current will increase during the load, causing an increase in the fault current oscillation.

5.2 Recommendations

- I. The Electricity supplier management should include a database system in which network details are updated regularly so that researchers who intend to study a network in any part of the country have adequate data to carry out research activities.
- II. Modern, accessible and accurate record keeping facilities should be maintained at all power stations.
- III. PHEDC should have effective policies in place for effective arc flash precaution between voltage levels without restrictions from any power supplier.

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