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Mitigating Faults Effects on Equipment and Personnel on Substations

Oputa, O[a], Ezeonye, C.S[b], Obi, P.I[*a] and Onwuka, I. K[a]

[a]*Department of Electrical/Electronic Engineering, Michael Okpara University of Agriculture, Umudike, Abia State, Nigeria*
[b]*Department of Electrical/Electronic Engineering, University of Agriculture and Environmental Sciences, Umuagwo, Imo State, Nigeria*
[a]connectositao@gmail.com [b]ezeonyechinonso@yahoo.com [*a]patndyobi@gmail.com
[a]onwuka.ifeanyichukwu@mouau.edu.ng

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Abstract

Faults occur in substations and the effects of these faults range from damage of electrical equipment connected to the substation to electrocution of personnel operating the substations. When protective devices fail in their operations after fault occur, mitigating the fault effects can be the only option of saving the lives of the personnel and equipment around the fault location in the substation. A balanced three phase fault, line-to-ground (LG) fault, line-to-line (LL) fault and double line to ground (LLG) fault at the primary and secondary of the respective transformers in the 80 MVA 132/33 kV Ohia Transmission substation were simulated in Electrical Transient Analyzer Program (ETAP). Ranges of fault current flow into the bus of the primary of the respective transformer causing corresponding arc flash energy in calories/cm^2, arc flash boundary in centimeters and arc flash distance in centimeters, appropriate recommendations of respective levels of radiating personnel protective equipment (PPE) amongst levels A, B, and D based on the results were made in accordance with National Fire Protection Association (NPFA) 70E2009/2012. The results recorded show the highest fault current flow of 451.01 kA in the primary of the second transformer as a result a three-phase fault and LG fault causing 8.962 cal/cm^2 energy to radiate within an arc flash boundary of 76.50 cm (2.51 ft.) given an arc flash distance of 9.75 cm (3.840 inches) and a corresponding choice level D PPE. Further mitigation of the faults effects can be done with a well-designed earth grid with touch potential of 797.7 volts, step potential of 938.5 volts and earth resistance of 2.9 ohms all being within the IEEE tolerable range. Mitigating faults effects can also be achieved using a well-designed fault current limiter (FCL) with normal operating condition of negligible impedance and maximum impedance during fault as 70 ohms and 1200 ohms respectively for the secondary sides of superconducting fault current limiter (SFCL).

1.0. Introduction

Substations are normally made up of high voltage electric transformers, protective relays, circuit breakers, switchgears, current transformers and other related power devices [1]. Transformers are very key in substations' operations since they transform voltage from one voltage level to another [2]. These transformers also measure electric power flowing in circuit by supplying power within specified voltage, frequency limits, maximize security of supply, connect power generators to the grid system, optimize the efficiency of generating plants and the network.

However, these substations are highly exposed to faults especially on the transformers (both internal and external) [3]. When these faults occur, abnormal current (and voltage) flows both in the internal transformer and the output circuit [4, 5].

The effect of these faults on the substation operation include; fire outbreak, terrible failure of the grid, breakdown of insulation of transformer oil and conductors. The effects may also lead to death of humans (personnel), among other financial damages [6].

For this reason, protective devices especially circuit breakers [7, 8] are always put in place to isolate any faulty transformer (or substation) to prevent it from sending this abnormal current to the outside circuit which may cause damages to power system equipment and even personnel working around the system [9, 10]. These protective systems can fail to perform their protective functions; in such times, the components and personnel are again exposed to the faulty effects despite that protective devices were initially installed. There is therefore a need to make a backup protection system or reduce the danger these faults pose in the event of failure of these protective systems. This paper provides a backup protection scheme for substations thereby giving protection to the substation external circuitry and personnel working in the external circuit; it also focused on providing means of mitigating the harmful effects these faults current cause on power systems and substations in particular [11]. This was done by:

(i) Providing a suitable and well-planned earthing grid
(ii) Choice of personnel protective equipment (PPE) to wear in different areas.
(iii) Limiting the fault current using FCL.

1.1 Theoretical Analysis

Safe operation of a substation**:** Substation as a very critical constituent (node) in the power grid, plays a very important role in the whole power grid operation with good intention to deliver electricity efficiently and economically to the eventual consumer [12 – 14]. Primarily, a very good design according to appropriate standards ensures safety of a substation [15].

For the fact that a substation consists of many equipment, there are bound to be failure of some of the equipment from time to time therefore, there supposed to be frequent checks and maintenance to identify necessary components that need urgent attention. It is of utmost importance therefore to do an excellent job in the safe operation of a substation. Irrespective of the well-designed substation, there are a number of threats exclusive to substations that must be seriously taken cognizance of on the daily operation of a substation. They include, notification of entry and exit of a new entrant to the operational crew of the substation, barricades should be placed at strategic points to warn personnel of dangers and threats, special substation ethics of “coming and going” as regards security must be adhered to, mobile equipment shall be grounded to the substation ground grid, only trained staff will work inside or near capacitor banks, reactors or other fenced-in areas in a substation and all signs of warning must be taken serious notice of. The last but not the least is the living variety – insects, reptiles and animals. These living varieties must be carefully guarded against entrance into the substation gadgets since their presence may cause big explosions [16].

Managerial Defeats in Substation Operation**:** The management of a Power Supply Company should also reduce the managerial bottlenecks in substation safety and the consequential accidents and their effects. They should improve on the business level of the electric operators in substations’ operation by making the operators improve on their comprehensive qualities which include – work quality, awareness quality and emotional quality. The seriousness of obedience to the routine safety regulations should be drawn into the ears of the operators to avoid the mistake of "I have known it all" syndrome. The security information of the substations should be strengthened and the electrical production system of the establishment be improved. Proper shift transfer checks should be put in place and the shift log books always monitored by the management. Serious attention should be paid to skills training and Staff development as well as facility regular maintenance [17].

2.0. Methodology

The Ohiya 132/33 kV transmission substation in Abia State was used to discuss the three means mentioned in this work. This transmission substation is rated 80 MVA and takes power at 132 kV from Alaoji transmission line. The substation has two 40 MVA, 132/33 kV power transformers and both feed the Abia State power distribution system that has a total load demand of about 57 MW as shown in Figure 1. However, the study focuses on the substation housing the two 132/33 kV, 40 MVA power transformers.

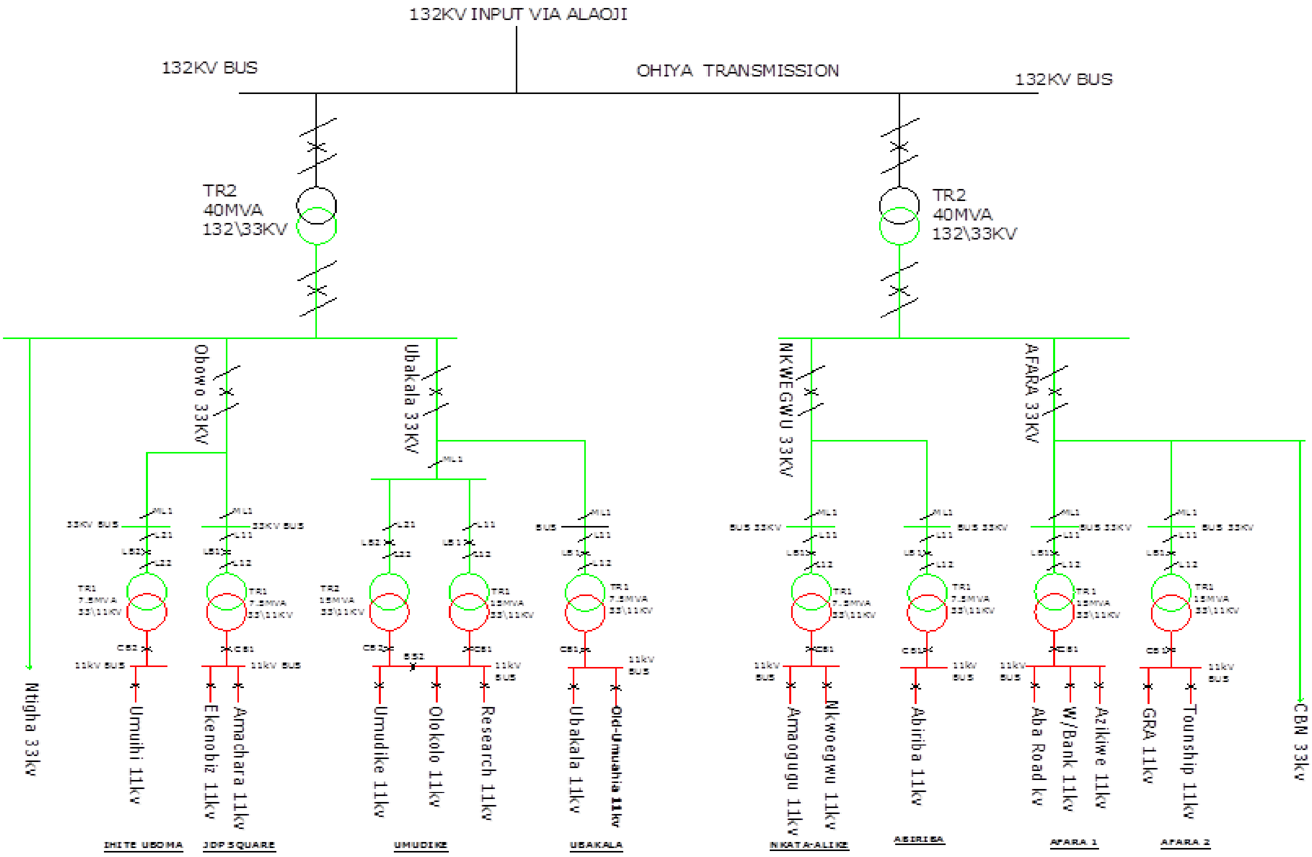

Figure 1: Abia state power system network

2.1 Arc Flash and Protection of Personnel from Arc Flashes:

Arc flash is an electrical phenomenon [18] in electrical equipment that occurs when current passes through air from a loosed, damaged or corroded terminals of one of the conductors to another conductor or ground. The resultant explosion or discharge is normally very hazardous and may cause damage to the equipment, death or injury to personnel depending on the proximity to discharge which means that arc flash injuries may occur without direct contact with energized conductors. Researches have shown that the brutality of damage is averagely more complex at low voltage than high voltage [19 – 21]. Arc flash in substations occur more on faulty buses as shown in Table 1. Hence, it is important for personnel to know how far they should stay away from these faulty buses or what type of personnel protective equipment (PPE) [22] that should be worn when working in such areas.

This can be done by running an arc flash simulation in ETAP. First, we run a load flow on the substation to know how the load current flows around the substation. This gives the result in the Tables 1, 2 and 3.

Table 1: Bus loading

Bus ID	Nominal kV	Voltage	MW Loading
Ohiya 1 Secondary	33	96.23	29.167
Ohiya 2 Secondary	33	95.86	30.26
Ohiya 1 Primary	132	100	29.26
Ohiya 2 Primary	132	100	30.364

Table 2: Load supply

ID	Load 1	Load 2
Rating	35MVA	37MVA
Rated kV	33	33
kW	29,167	30,260
Loading kVA	14,126	15,502
Loading Amp	589.2	620.5
% Loading	96.2	95.7
% Terminal Vol	96.23	95.86

Having known the current flow for each bus, we can then perform the arc flash simulation on any point of the substation and advice personnel on what type of PPEs they should wear when working around such areas [23]. With the fault occurring at different areas in the substation, the arc flash simulation gives the result shown in Table 3.

Table 3: Arc flash simulation results in ETAP for the two 132/33 kV transformers

Fault Location	Fault type	Fault current (kA)	Arc flash boundary (Ft)	Incident energy (Cal/cm^2)	Arc flash distance (inches)	Energy level/PPE required
Primary of Ohiya 1	3-ϕ	437.0	2.45	8.934	3.812	Level D/level D PPE
	LG	437.0	2.45	8.934	3.812	Level D/level D PPE
	LL	0.00	0.02	0.143	0.221	Level A/level A PPE
	LLG	437.0	2.45	8.934	3.812	Level D/level D PPE
Secondary of Ohiya 1	3-ϕ	9.94	1.73	3.614	1.819	Level B/level B PPE
	LG	9.96	1.73	3.672	1.837	Level B/level B PPE
	LL	0.00	0.01	0.112	0.161	Level A/level A PPE
	LLG	9.94	1.73	3.614	1.819	Level B/level B PPE
Primary of Ohiya 2	3-ϕ	451.0	2.51	8.962	3.840	Level D/level D PPE
	LG	451.0	2.51	8.962	3.840	Level D/level D PPE

	LL	0.00	0.02	0.162	0.231	Level A/level A PPE
	LLG	451.0	2.51	8.962	3.840	Level D/level D PPE
Secondary of Ohiya 2	3-ϕ	9.94	1.77	3.631	1.821	Level B/level B PPE
	LG	9.96	1.80	3.672	1.852	Level B/level B PPE
	LL	0.00	0.01	0.112	0.170	Level A/level A PPE
	LLG	9.94	1.80	3.614	1.852	Level B/level B PPE

The PPEs approved by ETAP is in accordance with NPFA 70E 2009/2012.

2.2 Arc Flash Results Interpretation:

For a balanced three phase fault, line to ground fault and double line to ground fault at the primary of the second transformer of the substation, a fault current of 451 kA flows into the bus of the primary of the transformer, this causes an arc flash of 8.962 cal/cm^2 calorie of heat to be radiated around 9.75 cm (3.840 inches) at an arc flash boundary of 76.5 cm (2.51feet). This radiated energy is at the level D energy range (between 8 – 10 calorie); hence, a class D energy radiating PPE should be worn when working around that vicinity. The interpretation of other results is done in this same way.

2.3 Design of a Substation Grounding System:

In cases where the protective device failed to prevent fault current from entering the substation, a well calculated designed earth system can provide a low resistant and (reactant) path for a large fraction of the fault current to flow to the ground thereby leaving the substation close to being safe. This does not only give protection to the substation but also to personnel working around the substation. The step and touch voltage around the substation is reduced thereby increasing personnel safety.

The step and touch voltage for a high voltage system in a well earthed system is given as

$$E_{step} = \left(R_B + 2R_f\right).I_B \tag{1}$$

$$E_{step} = (1000 + 6C_s\rho_s)\frac{0.157}{\sqrt{t_s}} \tag{2}$$

$$E_{touch} = (1000 + 1.5C_s\rho_s)\frac{0.157}{\sqrt{t_s}} \tag{3}$$

$$C_s = 1 - \frac{0.09(1-\frac{\rho}{\rho_S})}{2h_S+0.09} \tag{4}$$

Where E_{step} is step voltage; E_{touch} is touch voltage; R_B is Human resistance (1000Ω); R_f is ground resistance; ρ_s and ρ are resistivity of surface layer material and earth respectively; h_S is thickness of surface material and t_s is shock duration in seconds [24 – 26].

The input data in running the Grounding system simulation in ETAP are Soil, Grid, and Conductor Library. The earth resistivity range is shown in Table 4.

Table 4: Basic Range of Soil Resistivity

Type of Earth	Wet Organic Soil	Moist Soil	Dry Soil	Bedrock
Average Resistivity (Ω·m)	10	10^2	10^3	10^4

The grid characteristic is shown in Table 5.

Table 5: Earth Grid parameters for ETAP Simulation

S/N	Description	Values
1	Substation input voltage	132kV
2	Substation output voltage	33kV
3	Substation Location soil type/resistivity	Moist soil/$10^2\Omega$-m
4	Depth of earth grid	24ft
5	Dimension of earth grid	$68\text{ft} \times 90\text{ft}$
6	Earth mat/rod material	Copper
7	Substation dimension	$300 \times 800M$
8	Grid coordinate at substation	(120, 360)m, (120, 387)m, (141, 360)m, (141, 387)m

3.0. Results and Discussion

The simulation of the design of the earthing system using ETAP is presented in Tables 6 and 7 and the 3D view showing the step and touch voltages around the substation vicinity is given in the Figures 2 to 5.

Table 6: ETAP Simulation Results for Earth Mat

	Results from Design	IEEE Tolerable range
Touch Potential	797.7 volts	825.8 volts
Step Potential	938.5 volts	2832.2 volts
Grid Resistance	2.926 Ohm	

Table 7: ETAP Simulation for Auxiliary Ground Grid

Design	Ground Pit	IEEE Tolerable range
Touch Potential	420.9 volts	811.4 volts
Step Potential	176.7 volts	2774.4 volts
Grid Resistance	0.475 Ohm	

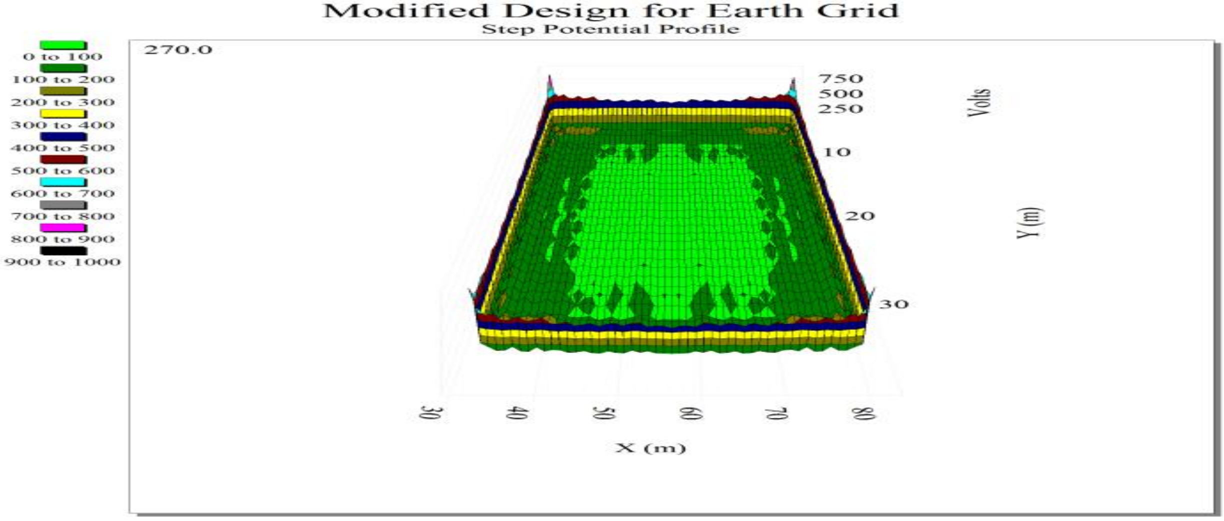

Figure 2: Step Potential Profile for Earth grid around substation

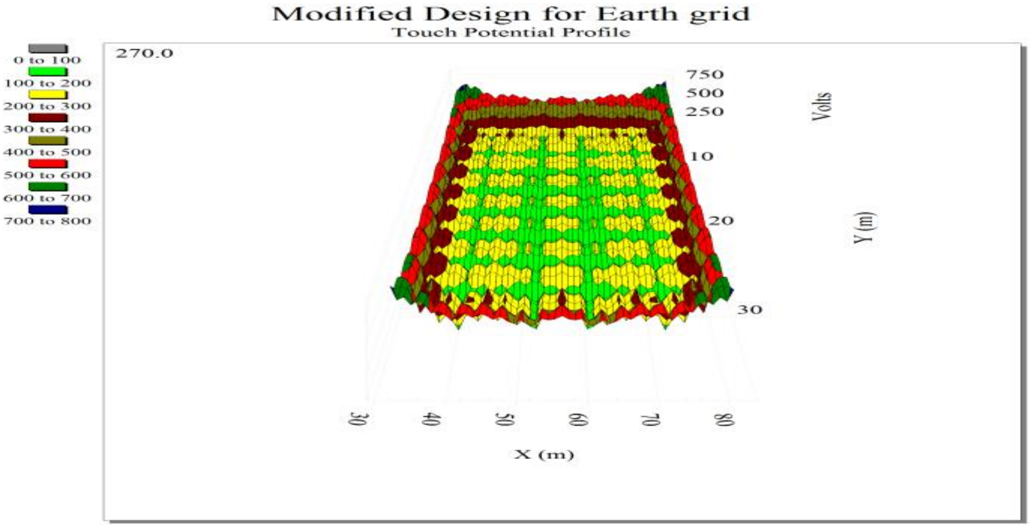

Figure 3: Touch Potential Profile for Earth grid around substation

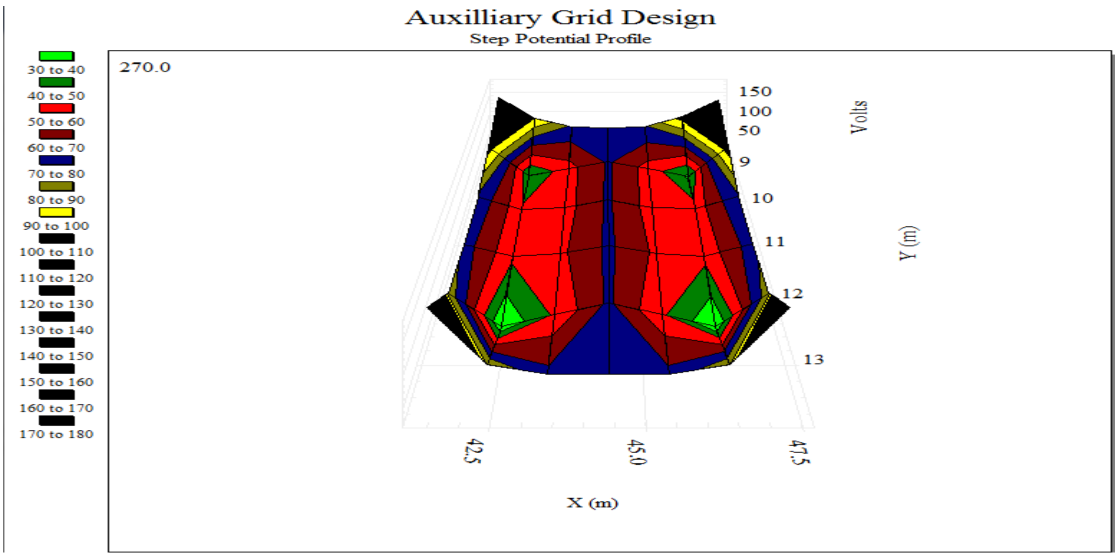

Figure 4: Step Potential Profile for auxiliary grid around substation

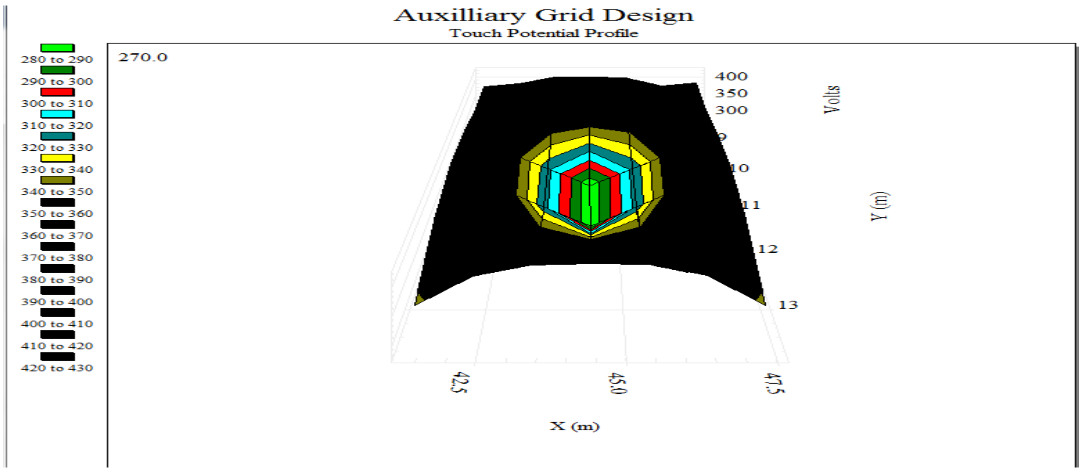

Figure 5: Touch Potential Profile for auxiliary grid around substation

3.1 Grounding System Result Discussion:

The simulation of the design configuration of the substation earth grid gives the optimal touch and step voltage around the substation as given in Tables 5 and 6. This shows that as a result of the earthing, one can effectively touch (holding for a few seconds) and step (holding for a second) on anywhere around the substation with voltage of 797.7 V and 938.5 V without any fear of electrocution. The archived earth resistance is 2.96 Ω. These values are within the IEE tolerance values as indicated. The auxiliary grid system gave a touch and step voltage of 420.9 V and 176.7 V respectively and an earth resistance of 0.475 Ω. This gives the personnel around the substation some protection from voltages between the ranges of the stated values; at the same time, the substation is also protected from high surge current by creating a low resistance path for the high current instead of flowing to the transformer of the substation.

The 3D – view of the Figures 2 to 5 show the step and touch voltages around the vicinity (length Y, and breath X,) of the substation of the design. The Y represents the voltage value while the X and Z axis represent the position vicinity around the substation (with 1 unit representing 10 meters for Figures 2 and 3 while 1 unit represent 17 meters in Figures 4 and 5). Colors are used to show/partition the voltage values at various areas around the vicinity of the substation for easy readability of the 3-D figures. Hence, any personnel at any point in the substation vicinity knows the maximum step and touch voltages at that particular point; this goes a long way in promoting safety around the substation.

3.2 Fault Current Limiters

A fault current limiter (FCL) is an electronic gadget that limits fault current when a fault occurs in an electrical circuit or network without entirely interrupting the network [27, 28]. Insertion of FLC into electrical network helps in mitigating short-circuit damage and unpredictable improvement of the system equipment. There are normally two types of FCL expansively used in power systems: superconducting FCL [29 – 33] and non-superconducting FCL [34 – 37]. Fault current limiter (FCL) circuits have been used for some time now in limiting high faulty current in circuits when they occurred [38, 39].

The fault current limiter shall be employed for this particular case and shall be designed to solve the problem at hand. The simulation on ETAP on Table II shows the load flow on normal condition in the substation while part of the result on Table III shows the value of the fault current flowing into and out of the substation. The FCL circuit that shall be designed for this case shall limit the expected fault current (as recorded on part of Table III) to near the normal load current (as recorded on Table II). For such expected faulty high current, reactors should be used in limiting the current that flows into the transformer (in cases when the fault occurred in the circuit before the transformer primary); and out of the transformer (in cases when the fault occurred in the circuit after the transformer secondary). The design of the circuit shows two FCL circuits for the primary and secondary sides respectively as shown in Figure 6:

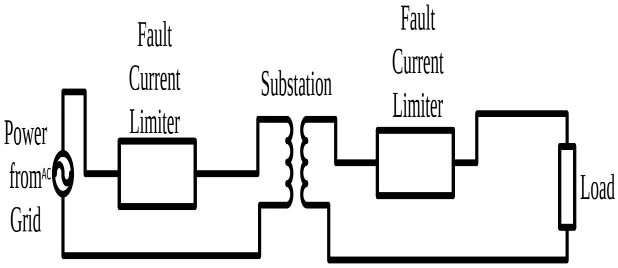

Figure 6: FCL on primary and secondary sides of substation

Superconducting fault current limiters (SFCL) using reactors are most suitable for such cases. These FCLs function in limiting current when their critical working temperature, working current or magnetic field have been exceeded. The SFCL is a transformer with a shorted secondary superconducting winding; a copper primary winding connected in series with a network line. In normal network operation, magnetic flux is excluded from the transformer iron core; hence, low impedance is seen by the system. In a fault limiting scenario, the working current for the superconductor is exceeded and flux enters the core; hence, large impedance is seen by the system. This makes switching from low to high impedance from during normal operation to during faulty operation easy for the SFCL [40, 41].

For this design, the normal operating condition has negligible impedance and maximum impedance during fault as 70 Ω and 1,200 Ω respectively for the secondary and primary sides SFCL respectively.

4.0. Conclusion

Fault occurrence in power system and substations cannot be completely eradicated due to the complication in size of a power system and accompanying high technical requirements. The protective system's reliability therefore is neither equal to hundred percent (100%), nor the system's safety equal to 100%. This likelihood of electrical accidents due to faults in the substations, brings about the need to provide a means of mitigating the effects of these faults when they occur and when the installed protective devices fail to prevent them from getting to unwanted destinations. For a balance three phase fault, line-to-ground fault, line-to-line fault and double line to ground fault at the primary and secondary of the respective transformers in the substation where ranges of fault current flew into the bus of the primary of the respective transformer causing corresponding arc flash energy in calories/cm^2, arc flash boundary in centimeters and arc flash distance in centimeters as stated in Table III, appropriate recommendations of respective level of personnel protective equipment (PPE) amongst levels A, B, and D based on the results were made in accordance with NPFA 70E2009/2012. According to the result in Table III, the highest fault current flow of 451.01 kA in the primary of the second transformer as a result a three-phase fault and single line to ground fault causing 8.962 cal./cm^2 energy to radiated within an arc flash boundary of 75.5 cm (2.51 ft.) given an arc flash distance of 9.75 cm (3.840 inches) and a corresponding choice of level D PPE. Further mitigation of the fault effects can be done with a well-designed earth grid with touch potential of 797.7 volts, Step potential 938.5 volts and earth resistance of 2.9 ohms all being within the IEEE tolerable range guarantee safety of personnel and equipment in a substation. Mitigating faults effects can also be done using a well-designed fault current limiter (FCL) with normal operating condition of negligible impedance and maximum impedance during fault as 70 ohms and 1200 ohms respectively for the secondary sides of superconducting fault current limiter (SFCL).

References

[1] A. Ibrahim, M. A. Kityo, A. Mutabazi, S. Ouma, O. O. Ginabel, E. Ernest and A. N. Mpuuga (2019). Design and Analysis of a Substation Digital Control System. International Journal of Academic Multidisciplinary Research (IJAMAR), Vol. 3(7), pp. 24 – 26.

[2] X. Wu, J. Li and Huang (2021). Big Data-Based Transformer Substation Fault Prediction Method. Journal of Electronic Science and Technology, Vol. 19(2), pp. 173 – 185.

[3] M. Aslam, M. N. Arbab, A. Basit, T. Ahmad and M. Aamir (2019). A Review on Fault Detection and Condition Monitory of Power Transformer. International Journal of Advanced and Applied Sciences, Vol. 6(8), pp. 100 – 110.

[4] J. Iżykowski (2011). Power System Faults. Printpap Łódź, pp. 14-19.

[5] M. Mondal, R. K. J. Jarial, S. Ram and G. Singh (2013). Design and Analysis of Substation Grounding Grid with and without Considering Seasonal Factors using EDSA Software. International Journal of Innovations in Engineering and Technology, pp. 64-77.

[6] S. T. Jan, R. Afzal and A. Z. Khan (2015). Transformer Failures Causes and Impact. Proceedings of International Conference on Data Mining, Civil, Mechanical Engineering (ICDMCME'2015), Indonesia, 1-2 February 2015, pp. 49-52.

[7] P. I. Obi, C. S. Ezeonye and E. A. Amako (2021). Applications of Various Types of Circuit Breakers in Electrical Power Systems: A Review. Arid Zone Journal of Engineering, Technology & Environment (AZOJETE), Vol. 17(4), pp. 481 – 494.

[8] P. I. Obi, E. A. Amako and C. S. Ezeonye (2021). Effect of Circuit Breaker Arc on Faulted Inductive and Capacitive Circuit on a Transmission Line. Nigerian Research Journal of Engineering and Environmental Sciences, Vol. 6(1), pp. 176 – 187.

[9] S. Hossain, R. Ahmed and S. Hossain (2021). Design and Optimization of Substation Grounding Grid for Ensuring the Safety of Personnel and Equipment. Journal of Electrical Power & Energy Systems, Vol. 5(1), pp. 71 – 80.

[10] P. I. Obi, C. K. Okoro and I. I. Okonkwo (2020). Electrocution, Accidents and Electrical Injuries in Nigerian Homes and Work Sites – Causes, Effects and Remedies. IOSR Journal of Electrical and Electronics Engineering, Vol. 15(2), pp. 53 – 61.

[11] R. S. Dahiya (2010). Substation Engineering, Design, Concepts and Computer Applications. 2nd Edition. S. A. Kataria and Sons, New Delhi, India.

[12] P. I. Obi, K. J. Offor and G. C. Chidolue (2013). Reliable and Efficient Power Supply in Nigeria through National Integrated Power Project and Independent Power Projects: A case study of Onitsha Metropolis. International Journal of Advancement in Research and Technology, Vol. 2(5), pp. 421 – 427.

[13] J. Wang, H. Zhang, Y. Fang, Z. Wen, G. Shao and D. Guo (2017). Analysis on Safety Measures of Substation Maintenance. Electronic Science Technology and Application, Vol. 4(1), pp. 17 – 22.

[14] G. U. Nwachi, P. I. Obi, E. A. Amako and C. S. Ezeonye (2022). Modeling and Simulation of a Coordinated Power System Protection using Overcurrent Relay. Nigerian Research Journal of Engineering and Environmental Sciences, Vol. 7(1), pp. 238 – 249.

[15] Y. Oyeleye, D. Adeniran and E. Itodo (2021). Design of Effective 33/11 kV Injection Substation using Appropriate Standards. Journal of Applied Sciences and Process Engineering, Vol. 8(2), pp. 977 – 985.

[16] Y. R. Scott (2013). Safety Awareness for Substations. https://incident-prevention.com/biog/safety-awareness-for-substations. Accessed on 22nd January, 2022.

[17] L. Bo, Z. Wenguang, Z. Hengxin, W. Chuang, C. Huiyan, J. Jing, Z. Shuguang, H. Wenfeng, Z. Jiming and W. Tianhao (2018). Research on Prevention and Management of Substation Operation. Advances in Engineering Research, 6th International Conference on Machinery, Materials and Computing Technology (ICMMCT 2018), Vol. 152, pp. 175 – 177.

[18] P. I. Obi, E. A. Amako and C. S. Ezeonye (2022). High Impedance Fault Arc Analysis on 11 kV Distribution Networks. Nigerian Journal of Technological Development, Vol. 19(2), pp. 143 – 149.

[19] S. Nikolovski, D. Mlakic and E. Alibasic (2017). Arc Flash Analysis and Techniques for Hazard Reduction using Smart Protective Devices. https://www.scitechnol.com/peer-review/protection-coordination-ofbiogas-power-plant-connectedto-distribution-network-4IAB.php?article_id=7000. Accessed on 14th January, 2022.

[20] M. Gopila, S. Purushotham and V. Perumal (2018). Arc Flash Analysis Based on IEEE 1584–2018 and NFPA70E-2018. Turkish Journal of Computer and Mathematics Education, Vol. 12(9), pp. 2869 – 2873.

[21] S. N. Chauhan, S. M. Pujara, P. K. Makhijani and C. D. Kotwal (2019). Arc Flash Analysis of Medium Voltage Level Power System using ETAP. International Journal of Computer Sciences and Engineering, Vol. 7(3), pp. 212 – 219.

[22] Introduction to the Distribution Safety Project (2020) https://distribution.epri.com/safety/public/overview. Accessed on 22nd December, 2021.

[23] NFPA. (2008). National Electric Code. NFPA 70 – 2008.

[24] The Institute of Electrical and Electronics Engineers IEEE. (1983). IEEE Guide for Measuring Earth Resistivity, Ground Impedance and Earth Surface Potentials of a Ground System. IEEE 81 – 1983.
[25] The Institute of Electrical and Electronics Engineers IEEE. (2000). IEEE Guide for Safety in AC Substation Grounding. IEEE 80 – 2000.
[26] C. S. Esobinenwu, B. O. H. Akinwole and C. O. Omeje (2014). Earth Mat Design for 132/33 kV Substation in Rivers State using ETAP. International Journal of Engineering Trends and Technology, Vol. 15(8), pp. 389 – 402.
[27] S. Dhara, A. K. Shrivastav, P. K. Sadhu and A. Ganguly (2016). A Fault Current Limiter Circuit to Improve Transient Stability in Power System. International Journal of Power Electronics and Drive System (IJPEDS), Vol. 7(3), pp. 767 – 778.
[28] S. Alam, M. A. Y. Abido and I. El-Amin (2018). Fault Current Limiters in Power Systems: A Comprehensive Review. Energies, Vol. 11(5), pp. 1 – 24.
[29] H. Hatta, S. Muroya, T. Nitta, Y. Shirai and M. Taguchi (2002). Experimental Study on Limiting Operation of Superconducting Fault Current Limiter in Double Circuit Transmission Line Model System. IEEE Transactions on Applied Superconductivity, Vol. 12(1), pp. 812 – 815.
[30] S. M. Blair, I. M. Elders, C. D. Booth, G. M. Burt, J. McCarthy and N. K. Singh (2011). Superconducting Fault Current Limiter Application in a Power-Dense Marine Electrical System. IET Electrical Systems in Transportation, Vol. 1(3), pp. 93 – 102.
[31] H. C. Jo, S. K. Joo and K. Lee (2013). Optimal Placement of Superconducting Fault Current Limiters (SFCLs) for Protection of an Electric Power System with Distributed Generations (DGs). IEEE Transactions on Applied Superconductivity, Vol. 23(3), pp. 3 – 6.
[32] B. Li, C. Li, F. Guo, Y. Xin, C. Wang and X. Pang (2014). Coordination of Superconductive Fault Current Limiters with Zero-Sequence Current Protection of Transmission Lines. IEEE Transactions on Applied Superconductivity, Vol. 24(5), pp. 1 – 5.
[33] H. C. Jo and S. K. Joo (2015). Superconducting Fault Current Limiter Placement for Power System Protection using the Minimax Regret Criterion. IEEE Transactions on Applied Superconductivity, Vol. 25(3), pp. 1 – 5.
[34] M. T. Tarafdar, M. Jafari and S. B. Naderi (2010). Transient Stability Improvement using Non-Superconducting Fault Current Limiter. Proceedings of the 1st Power Electronic & Drive Systems & Technologies Conference (PEDSTC), Tehran, Iran, 17-18 February 2010, pp. 367–370.
[35] A. Jalilian, M. T. Hagh, M. Abapour and K. M. Muttaqi (2015). DC-Link Fault Current Limiter-Based Fault Ride-Through Scheme for Inverter-Based Distributed Generation. IET Renewable Power Generation, Vol. 9(6), pp. 690 – 699.
[36] B. Li, Q. Li, H. Liu, M. Han, Z. Huang and J. Wang (2016). The Overvoltage of Interrupting Off-Load Transmission Line with Series-Resonant Type Fault Current Limiter. Proceedings of the 7th Asia-Pacific International Symposium on Electromagnetic Compatibility, Shenzhen, China, 17-21 May 2016, pp. 84–87.
[37] M. E. Hossain (2017). Performance Analysis of Diode-Bridge-Type Non-Superconducting Fault Current Limiter in Improving Transient Stability of DFIG Based Variable Speed Wind Generator. Electric Power System Research, Vol. 143, pp. 782 – 793.
[38] T. Verhaege and Y. Laumond (1998). Fault Current Limiters in Handbook of Applied Superconductivity. Seeber B, Inst. Phys. Publishing, Bristol & Philadelphia, Vol. 2, pp. 1691 – 1702.
[39] E. M. Leung, H. Boening and B. Burley (2000). Design and Development of a 15 kV, 20 kA HTS Fault Current Limiter. IEEE Transactions on Applied Superconductivity, Vol. 10(1), pp. 354 – 360.
[40] V. Sokolovsky, V. Meerovich, S. Semperger and I. Vajda (2000). High Temperature Superconductive Fault Current Limiting Devices. Elektrotechnika, Vol. 10, pp. 364 – 374.
[41] M. T. Hagh, M. Jafari and S. B. Naderi (2011). New Series Resonance Type Fault Current Limiter. International Conference on Power Systems Transients (IPST2011), Delft, Netherlands, 14-17 June 2011, pp. 1-5.