Advances in Engineering Design Technology Vol. 4(1) 2022 pp. 1-10 ISSN-2682-5848

NIPES

Advances in Engineering Design Technology

Journal homepage: www.nipesjournals.org.ng

Short Circuit Analysis of a Nigerian 132/33 kV Injection Substation

***Agbontaen F. O.*[a] *and Idiagi N. S.*[b]**

[a,b]Department of Electrical/Electronic Engineering, University of Benin, Nigeria
Corresponding authors: osazee.agbontaen@uniben.edu, neville.idiagi@uniben.edu

ARTICLE INFORMATION

Article history:
Received 23 February 2022
Revised 03 March 2022
Accepted 07 March 2022
Available online 27 March 2022

Keywords:
Injection substation, ETAP 16.0, Load flow analysis, Newton-Raphson iteration technique, short circuit fault, Feeders.

https://doi.org/10.37933/nipes.a/4.1.2022.1

https://nipesjournals.org.ng

ABSTRACT

Every power system, in addition to meeting the present load demand should also be flexible enough to meet, on a continuous basis, the future demands. As a result of this continuous increase in demand, there is the tendency of failures occurring in power systems. Hence there is the need for adequate analyses like short circuit analysis, etc to be carried out so as to have a good protection system. This study is aimed at carrying out short circuit analysis in an injection substation so as to enable adequate protective system to be incorporated. The study was carried out in the 50 MVA 132/33 kV Ado-Ekiti injection substation situated in Ado-Ekiti, Ekiti State, Nigeria. The network was modeled in the ETAP 16.0 environment and then load flow analysis was carried out using Newton-Raphson iteration technique. The load flow analysis was carried out on the original network before short circuit fault was then introduced separately in one bus each in the 132 kV and 33 kV part of the network with the load flow analysis repeated in each case. It was discovered from the study that after the short circuit fault was introduced, the voltages in the faulted buses reduced to 0 A in each case while the currents flowing from the faulted buses increased drastically. The highest current registered was 3138 A, which was flowing from bus 18 when the short circuit current was introduced in that bus as against 722 A which was flowing from bus 1 when the fault was introduced at bus 1. It was also observed that the fault at bus 18, from which 3 feeders (Ado, Iworoko and Ilawe feeders) radiated had a greater impact on the network and as such, efforts should be put in place to avoid such a scenario.

1. Introduction

It is a known fact that under normal operating conditions, the current flowing through all the elements of a power system is the normal pre-designed value, which corresponds to the ratings of these elements. However, as expected, there can be faults in systems when naturally occurring events or accidents take place and this will cause abnormal scenarios like a phase having a direct connection with another, or a connection with the ground, and in some cases, both [1]. Thus, power system analysis is normally carried out by determining the voltages and currents of the system under normal and abnormal cases [2].

A fault is said to occur when there is a massive current flow in an electrical power system through an improper route, and this can lead to injuries and/or deaths to individuals, destruction/damage of electrical equipment, which will in turn interrupt power supply. It can also lead to fluctuation of the system's voltage level, thereby affecting the insulation of the equipment (when there is an increase) or inability of the equipment to start (when there is a decrease below the minimum), thereby leading to an increase in the electrical potential difference of the system's neutral [2]. This brings about the undesired exposure of people and equipment to the risk of electricity. The quest to prevent such ugly scenario has led to the introduction of power system fault analysis. Fault analysis or short circuit analysis in a power system simply involves the determination of the system's voltages and currents when various types of short circuit occur. This analysis helps in establishing the important measures of safety as well as the protection system required [1,2]. The safety of the general public is of utmost importance and this must be guaranteed in a standard power system [3,4]. The correct size/type of fuse, circuit breaker and relay can only be determined and selected after fault analysis has been carried out on the system from which the computation of the correct protection settings can be done [5]. Various factors determine how severe the fault in a system can be, and these include the fault current path, the location of the short circuit, the impedance of the system as well as the system's voltage level. Maintaining uninterrupted power supply is the major purpose of a good power system and this can only be achieved if all faulted parts (in the event of a fault) are temporarily isolated from the system with the help of the system's protection mechanism [2]. There is always the tendency of failures occurring in power systems due to a continuous increase in demand. Thus, there is the need for adequate protective devices whose primary aim is to detect faults on time and take necessary actions to keep the system healthy [6]. This can be achieved by carrying out fault or short circuit analysis in the system. In the event of a fault within the protection zone of a transmission line's relay, the faulty line will be isolated by a circuit breaker which will be opened as a result of a signal sent to it. For this to be successfully done, there is the need to carry out adequate short circuit analysis in every part of the system by assuming various fault conditions. The essence of this is to establish the fault currents and voltages of the system so as to determine the optimum scheme of protection. The minimum protective devices' ratings are determined using the values from the maximum steady-state short circuit current while the minimum steady-state short circuit value becomes handy in relay coordination purposes so as to prevent unnecessary trips and deviations from loadings [3]. Balanced and unbalanced faults are the two types of faults that can occur in a typical power system. The unbalanced faults can be further categorized into single line-to-ground faults, double line faults and double line-to-ground faults. A balanced fault on the other hand involves three-phase fault that affects the three phases of a three-phase system symmetrically [2,3]. In this study, the single line-to-ground fault and the three-phase fault will be considered in the Ado-Ekiti 132/33 kV injection substation located in Ekiti State, Nigeria.

1.1 Short Circuit Analysis in Power Systems

A short circuit fault can simply be referred to as any disturbance which takes place in a power system due to an error between different parts as a result of the appearance of a voltage that is more than the normal value [7]. Short circuit analysis is normally carried out so as to overcome this disturbance and then to determine the appropriate protective devices for the system. Some of the data needed to carry out short circuit analysis in a power system are the line-to-line voltage V_{LL}), short circuit kVA ($kVA_{SC,}$ which refers to the power available at a bolted three phase fault) and reactance-to-resistance ratio (X/R) of the system [7,8].

To calculate for the value of the short circuit kVA, with the short circuit current known, the following expression is used [7]:

$$kVA_{SC} = \frac{\sqrt{3 I_{SC} V_{LL}}}{1000} \tag{1}$$

Where kVA_{SC} , I_{SC} and V_{LL} are the short circuit kVA, short circuit current and line-to-line voltages respectively.

Equation 1 can also be written as:

$$kVA_{SC} = \frac{3I_{SC}V_{LN}}{1000} \qquad (2)$$

Where $V_{LN} = \frac{V_{LL}}{\sqrt{3}}$ is the line-to-neutral voltage.

In most cases, in place of the reactance -to-resistance ratio *X/R*, the power factor (PF) is usually specified and this is actually the system's short circuit power factor. The power factor, which is the cosine of the angle between the system's voltage and current, can also be used to determine the system's *X/R* using equation 3 [9].

$$X/R = \tan\left(cos^{-1}PF\right) \qquad (3)$$

Where PF is the system's power factor (or short circuit power factor as the case may be).

In a situation where neither values for *X/R* nor power factor of the system is stated, it can be assumed that the system's resistance is negligible when compared to its reactance, thus *X/R* is infinite. The system's impedance is normally the generator's reactance (as resistance is negligible) except the transmission line is very long [7].

With all these data available, the system's impedance (Z), resistance (R) and reactance (X) can be calculated using the short circuit calculation program. This can also be computed manually though [10], depending on the complexity of the system.

Using equation 4, the value of the system's impedance (Z) can be obtained [8]:

$$Z = \frac{V_{LL}^2}{1000kVA_{SC}} \qquad (4)$$

But

$$Z = \sqrt{R^2 + X^2} \qquad (5)$$

Therefore, to get the values of *R* and *X*, with *X/R* known, we use equations 6 and 7

$$R = \frac{Z}{\sqrt{1+(X/R)^2}} \qquad (6)$$

and

$$X = R \times \ (X/R) \qquad (7)$$

It should be noted that when computing the values of resistance and reactance, it should be done at the voltages for the points in the circuit where the computation of short circuit currents is done. To make this clearer, even if the power system is a 69 kV system, if the values of the short circuit currents are calculated at points in the circuit where the voltage is about 2.4 kV, then the resistance and reactance must be calculated at this same voltage point (2.4 kV). At the initial stage, the computer program will compute the resistance and reactance values for the system at the system's voltage but gradually, as transformers are being encountered in the circuit by the program, these values are converted to the new voltage by the necessary transformation ratios [7,11,12].

2. Methodology

This study was carried out in the Ado-Ekiti injection substation which supplies electric power to Ado-Ekiti metropolis. The 50 MVA, 132/33 kV Ado-Ekiti injection substation gets its electric power supply from Osogbo 330/132 kV transmission station via the Akure 132 kV line. The single-line diagram of the injection substation is shown in figure 1. Two (2) step-down transformers of 40 MVA each, radiate from the substation with relays R_1 and R_2. A 300 kVA 33/0.415 kV step down distribution transformer is connected to each of the feeders. A total of four (4) feeders are fed from the two (2) 40 MVA, 132/33 kV transformer.

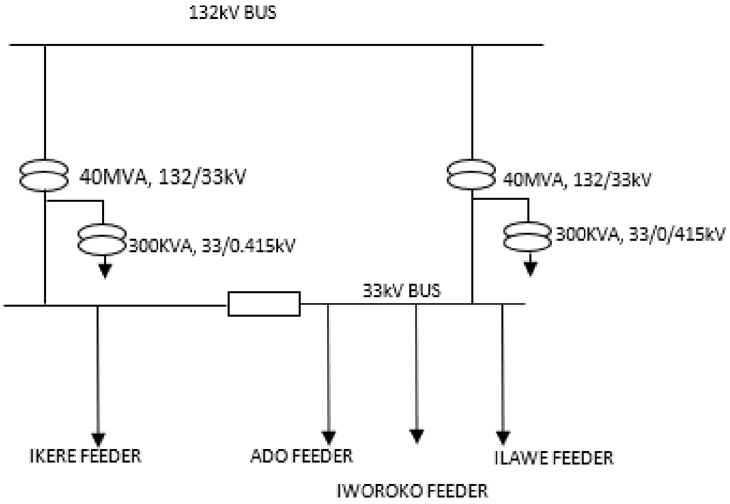

Figure 1. One line diagram of the Ado-Ekiti injection substation.

The power injected by the sub-station into the network is 47.5MW, while the load on the four (4) feeders which are Ikere, Ado, Iworoko and Ilawe are 12MW, 14.9MW, 9MW and 10.6MW respectively as shown in Table 1. The various route lengths are also shown in Table 1

Table 1. Route Lengths and Feeder Loading of Ado-Ekiti Injection Substation

S/N	Feeder name	Length (km)	Loading (MVA)
1	Iworoko	5.2	9.474
2	Ikere	70.7	12.632
3	Ado	33.5	15.684
4	Ilawe	47.6	11.158

The network was modeled in ETAP 16.0 software environment as shown in Figure 2. Load flow analysis was then carried out on the network using Newton-Raphson iteration technique, using the relevant data like the route length, feeder loading, transformer parameters, etc. The Short circuit fault was then introduced in the network at both the 132 kV bus (Bus 1) and the 33 kV bus section which contains the Addo, Iworoko and Ilawe feeders (Bus 18) so as to see how the entire system is affected as a result of these faults. As mentioned earlier, only the three-phase fault and the single line-to-ground fault were considered in this study.

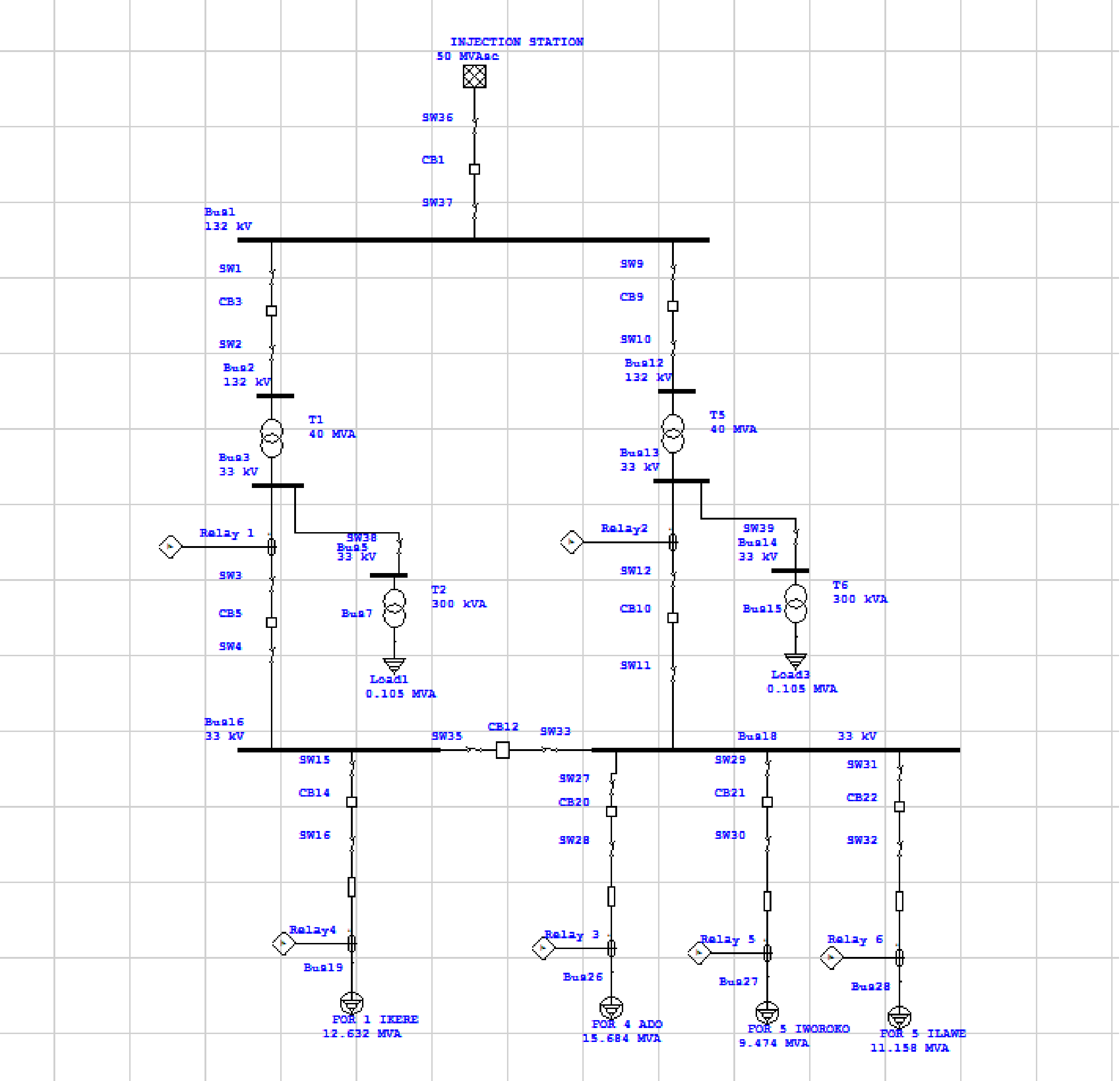

Figure 2. Ado-Ekiti Injection Substation Network diagram on ETAP edit mode.

3. Results and Discussion

As stated earlier, load flow analysis was carried out on the original network (without the introduction of short circuit fault) as shown in Figure 3 after which a short circuit fault was introduced separately at buses 1 and 18 respectively and the load flow analysis repeated in each case as shown in Figures 4 and 5.

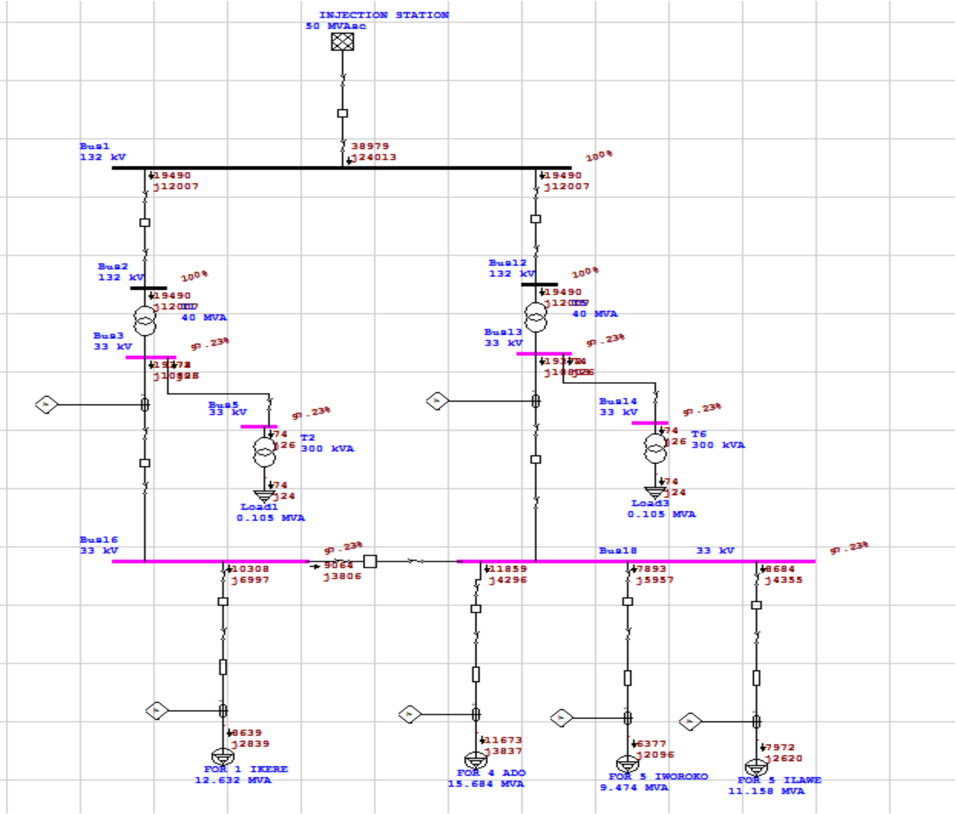

Figure 3. Load Flow of the Injection Substation on ETAP Run Mode.

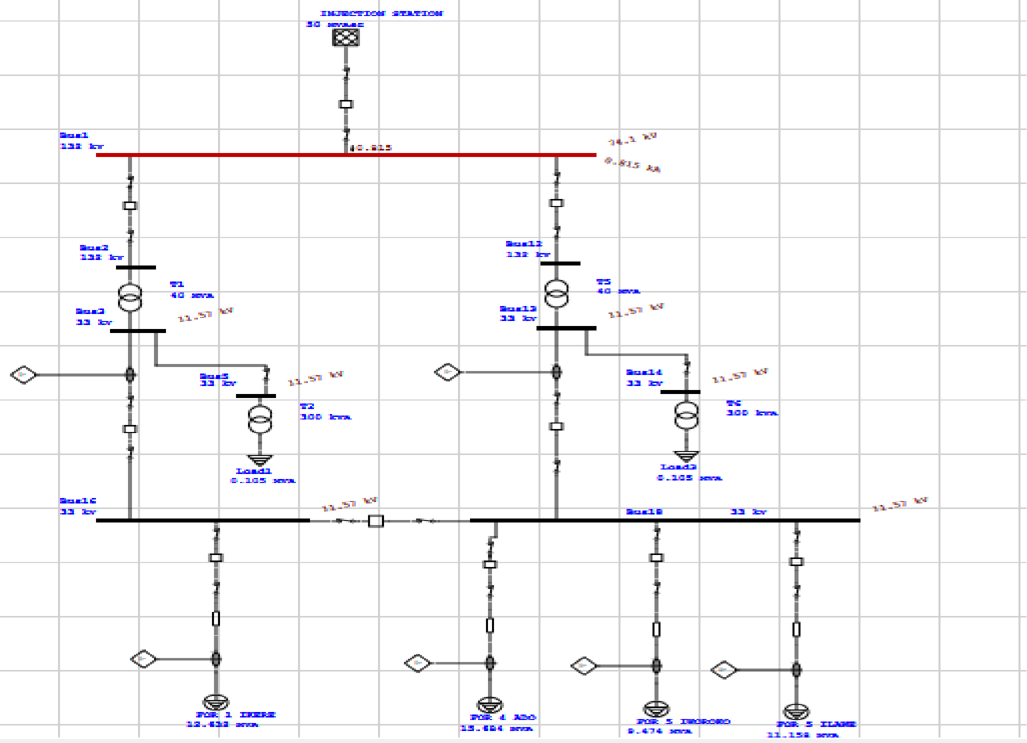

Figure 4. Fault at Bus 1

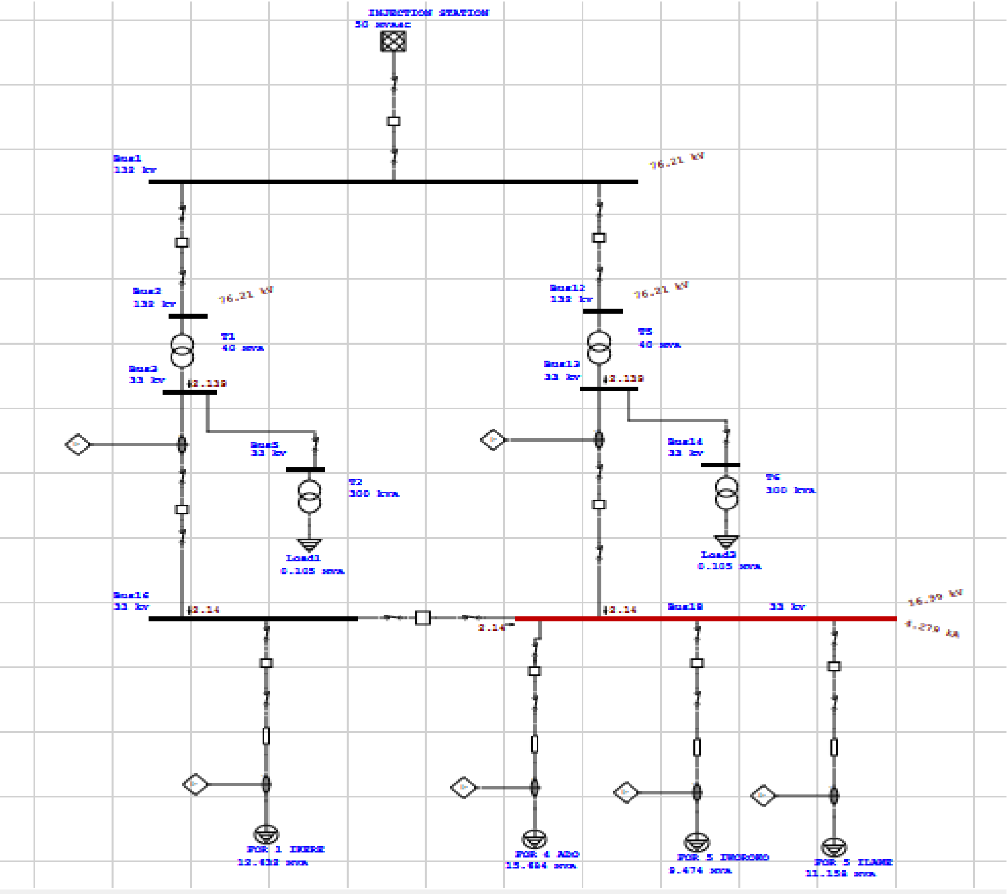

Figure 5: Fault at Bus 18.

When the load flow analysis was carried out on the original network, the results obtained are shown in Tables 2, 3 and 4. From Table 2, it is observed that all the bus voltages fall within the acceptable limit (0.95 to 1.05 p.u). The loadings (in amperes) are also given with bus 15 having the highest value of 575 A. The branch losses in the network are shown in table 3 and they add up to 4170.286 kW and 12570.994 kVAR. The loads on the network are shown in Table 4 and they add up to 34808.306 kW and 11440.418 kVAR.

Table 2: Bus loading Report on the Original Network

Bus ID	Nominal Voltage (kV)	Voltage (%)	Loading (kW)	Loading (kvar)	Loading (Amp)
Bus2	132	100	19490	12006	100.1
Bus3	33	97.23	19446	10828	400.5
Bus5	33	97.23	74.138	25.706	1.412
Bus12	132	100	19490	12006	100.1
Bus13	33	97.23	19446	10828	400.5
Bus14	33	97.23	74.138	25.706	1.412
Bus16	33	97.23	19372	10802	399.1
Bus18	33	97.23	28436	14608	575.2
Total			125828.276	71129.412	

Table 3: Branch Losses in the Original Network

ID	Power Flow (kW)	Power Flow (kvar)	Power Flow (Amp)	kW Losses	kvar Losses
Line1	10308	6997	224.2	1669	4157
Line2	11859	4296	227	186	459
Line3	7893	5957	177.9	1516	3861
Line4	8684	4355	174.8	712	1735
T1	19490	12006	100.1	43.158	1178
T2	74.138	25.706	1.412	0.485	1.497
T5	19490	12006	100.1	43.158	1178
T6	74.138	25.706	1.412	0.485	1.497
Total				4170.286	12570.994

Table 4: Load on the Original Network

ID	Rating (KVA)	kW	kvar
IKERE	12632	8639	2839
ADO	15684	11673	3837
ILAWE	11158	7972	2620
IWOROKO	9474	6377	2096
Load1	105	73.653	24.209
Load3	105	73.653	24.209
Total		34808.306	11440.418

When a short circuit fault was introduced in bus 1, the configuration of the network changed and the results obtained are shown in table 5. As mentioned earlier, emphasis will be laid on three-phase faults and line-to-ground faults. It should be noted that only the buses in the network that were affected by the fault are captured in the result tables. From Table 5, for the three-phase fault, voltages of buses 1, 3 and 13 fell outside the permissible limits with buses 13 and 3 reducing drastically to 13% while bus 1, as expected, is 0%. For the three-phase fault, it is observed that the currents flowing from bus 3 to bus 1 and also from bus 13 to bus 12 are both 250 A while the current flowing from bus 1, which is the bus with the short circuit fault, increased drastically to about 720 A. For the line-to-ground fault, as can also be seen from table 5, it can be observed that the line fault current contribution (I_a) and the zero-sequence fault current contribution ($3I_0$) from bus 1 are both as high as 815 A and this can be attributed to the presence of the short circuit fault in the bus. The corresponding values of the line fault current contribution (I_a) and the zero-sequence fault current contribution ($3I_0$) from bus 13 to bus 12 and from bus 3 to bus 1 are both 190 A and 0 A respectively. With the short circuit fault introduced at bus 18, which is a 33 kV bus, a larger portion of the network was affected as seen in table 6. This can be attributed to the fact that the bus contains three (3) feeders as compared to bus 1 that has just one (1) feeder. For the three-phase fault, buses 2, 7, 12, 15, 18, 19, 26, 27 and 28 all fell outside the acceptable range with buses 18, 7 and 15 all having 0% voltages. the current flowing from bus 18 was discovered to be the highest with a value of 3,138 A while 0A flowed from bus 7 to bus 5 and also from bus 15 to bus 14. For the line-to-ground fault, the highest value of line fault current and zero-sequence fault current flowed from bus 18 and they both have a value of 4.279 A while majority of the zero-sequence fault current flowing in the circuit were 0 A.

Table 5: Results of Short Circuit Fault at Bus 1

Contribution		3-Phase Fault		Line-to-Ground Fault					Positive & Zero Sequence Impedances Looking into "From Bus"			
From Bus ID	To Bus ID	%V	kA	% Voltage at From Bus			kA Symm. rms		% Impedance on 100 MVA base			
		From Bus	Symm rms	V_a	V_b	V_c	I_a	$3I_0$	R_1	X_1	R_0	X_0
Bus1	Total	0.00	0.722	0.00	97.23	91.25	0.815	0.815	8.23E+000	6.00E+001	8.00E-001	4.00E+001
INJECTION STATION	Bus1	100.00	0.219	100.00	100.00	100.00	0.436	0.815	4.00E+000	2.00E+002	8.00E-001	4.00E+001
Bus13	Bus12	13.01	0.253	55.77	60.75	100.00	0.190	0.000	3.21E+001	1.70E+002		
Bus3	Bus1	13.01	0.253	55.77	60.75	100.00	0.190	0.000	3.21E+001	1.70E+002		

Table 6: Results of Short Circuit Fault at Bus 18

Contribution		3-Phase Fault		Line-to-Ground Fault					Positive & Zero Sequence Impedances Looking into "From Bus"			
From Bus ID	To Bus ID	%V	kA	% Voltage at FromBus			kA Symm. rms		% Impedance on 100 MVA base			
		From Bus	Symm rms	V_a	V_b	V_c	I_a	31_0	R_1	X_1	R_0	X_0
Bus 18	Total	0.00	3.138	0.00	89.19	86.16	4.279	4.279	8.85E+000	5.50E+001	4.12E-001	1.12E+001
Bus 26	Bus 18	19.82	1.147	18.02	88.95	89.98	1.042	0.000	2.33E+001	1.51E+002		
Bus 27	Bus 18	67.25	0.287	61.12	95.88	98.48	0.261	0.000	1.65E+002	5.86E+002		
Bus 28	Bus 18	53.43	0.480	48.57	92.76	96.16	0.436	0.000	8.83E+001	3.54E+002		
Bus 19	Bus 16	64.98	0.410	59.06	95.22	98.19	0.373	0.000	1.16E+002	4.10E+002		
Bus 2	Bus 3	5.33	0.414	52.19	100.00	50.69	1.087	2.139*	8.82E+000	4.22E+002	8.24E-001	2.25E+001
Bus 7	Bus 5	0.00	0.000	49.75	51.49	100.00	0.000	0.000				
Bus 12	Bus 13	5.33	0.414	52.19	100.00	50.69	1.087	2.139*	8.82E+000	4.22E+002	8.24E-001	2.25E+001
Bus 15	Bus 14	0.00	0.000	49.75	51.49	100.00	0.000	0.000				

*** Indicates a zero-sequence fault current contribution ($3I_0$) from a grounded Delta-Y transformer**

4. Conclusion and Recommendation

It can be deduced from the study that the presence of short circuit faults in different parts of the network greatly affected the overall performance of the network with the bus voltages captured in the results all falling outside the acceptable limit. It was discovered that in each case, the voltage in the bus with the short circuit fault was always zero while the current flowing from it increased drastically.

The intention in the study was to introduce short circuit faults in one feeder each in the high voltage (132 kV) and the low voltage (33 kV) part of the network. Bus 1 was chosen for the high voltage part since it's the only one there while bus 18 was chosen for the low voltage part since it has 3 feeders (Ado, Iworoko and Ilawe feeders) radiating from it as against 1 feeder (Ikere feeder) radiating from bus 16 and it is expected that it will have a greater impact on the network.

As expected, the fault at bus 18, from which 3 feeders radiate, had a greater effect on the network and as such, this scenario should be avoided by all means. It is recommended that relevant protective devices should be incorporated into the network to avoid short circuit faults occurring in the network. Also, more attention should be paid to bus 18, since the impact of a fault on this section is quite severe and this will greatly affect electricity supply to Ado-Ekiti community being fed by the network. With these taken into consideration, the power supply to Ado-Ekiti community will be largely healthy, all things being equal.

References

[1] J. Zhu (2004); "Analysis of Transmission System Faults the Phase Domain", Texas A&M University. Master Thesis.

[2] A.M. Ghadban and M.W. Abdulwahhab (2015); "Short Circuit Analysis for Power System Networks". Second Engineering Scientific Conference-College of Engineering –University of Diyala 16-17 December. 2015. Diyala Journal of Engineering Sciences, Vol. 8, No. 4, Special Issue 344. Pp 343-354

[3] A.Z. Latt (2019); "Short Circuit Analysis of 33/11/0.4 kV Distribution System Using ETAP". International Journal of Latest Technology in Engineering, Management & Applied Science (IJLTEMAS) Volume 8, No. 5. ISSN 2278-2540, pp 79-85.

[4] T.K. Nagsarkar and M.S Sukhija (2005); "Power System Analysis". New York Oxford University Press, pp.14-25.

[5] P.M. Anderson (1995); "Analysis of Faulted Power Systems", The Institute of Electrical and Electronics Engineers

[6] F.O. Agbontaen and N.S. Idiagi (2021); "Coordination of Overcurrent Relay of 132/33 kV Injection Substation". Umudike Journal of Engineering and Technology (UJET), Michael Okpara University of Agriculture, Umudike, Abia State, Nigeria; Vol. 7, No. 1, pp. 22 – 31; Print ISSN: 2536-7404, Electronic ISSN:2545-5257; http://ujetmouau.net; doi: https://doi.org/10.33922/j.ujet_v7i1_4

[7] H. Khairul, I. Tukiman, M. Putra and L. Subekti (2019); "Short Circuit Analysis on Electrical Power Supply Building # 71 BATAN for Case Reliability Study of Nuclear Power Plant Electrical Protection System". AIP Conference Proceedings **2180**, 020036 (2019); https://doi.org/10.1063/1.5135545 Published Online: 10 December 2019.

[8] R. Kapahi (2013); "Load Flow Analysis of 132 kV Substation using ETAP software", International Journal of Scientific & Engineering Research'' Volume 4, Issue 2, ISSN 2229-5518 India.

[9] R.A.J. Khan (2009); "AnalysIs and Monitoring of 132 kV Grid using ETAP Software". Journal of Electrical and Electronics Engineering, Turkey.

[10] K. Natkar (2015); "Design Analysis of 220/132 kV Substation using ETAP". International Research Journal of Engineering and Technology (IRJET), vol 2.

[11] J. Dharamjid (2012); "Load Flow Analysis on IEEE 30 Bus System". International Journal of Scientific and Research Publications, Volume 2, Issue 11, ISSN 2250-3153.

[12] A.M. Eltamaly (2016); "Load Flow Analysis by Gauss-Seidel Method: A Survey". International Journal of Mechatronics, Electrical and Computer Technology, PISSN: 2411-6173, EISSN: 2305-0543, Egypt.