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Short Circuit Analysis in Power System Using Per Unit Resolution - Based Model

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ABSTRACT: *The behaviour of electrical power system differs significantly under steady and transient states. It is imperative to keep the system fit in power delivery even after fault conditions as efficient protective arrangement is necessary. Rumuola 10-bus power system in Rivers State, Nigeria was found useful in the required short circuit analysis using per unit resolution – based model. Short circuit analysis in Electrical Transient Analyzer Program (ETAP) software showed the fault currents at the respective buses in the network which is pertinent for adequate selection of protective devices thereby improving the reliability of power supply. Under three-phase short circuit faults, buses 1, 2, 3, 4, 5, 6, 7, 8, 9, and 10 had fault currents of 5.59KA, 2.624KA, 13.666KA, 13.666KA, 12.75KA, 12.75KA, 13.666KA, 13.666KA, 12.75KA, and 12.75KA respectively while for single line to ground fault, buses 1, 2, 3, 4, 5, 6, 7, 8, 9, and 10 had fault currents of 0.311KA, 0.311KA, 4.92KA, 4.92KA, 4.678KA, 4.678KA, 4.92KA, 4.92KA, 4.678KA and 4.678KA respectively. Under minimum short circuit analysis where only three-phase fault analysis was performed, buses 1, 2, 3, 4, 5, 6, 7, 8, 9, and 10 had fault currents of 2.624KA, 2.624KA, 5.249KA, 5.249KA, 5.249KA, 5.249KA, 5.249KA, 5.249KA, 5.249KA, and 5.249KA respectively. Maximum short circuit analysis was performed for both three-phase faults and single line to ground faults while minimum short circuit analysis was performed for three-phase faults only for the purpose of providing efficient protection to the system.*

KEY WORDS: *Short circuit, Fault current, Three-phase fault, Single line to ground fault, Bus, Load.*

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I. INTRODUCTION

The injection substation is usually the first component of the electrical distribution where the sub-transmission line voltage being 33kV is stepped down to 11kV primary distribution line voltage by power transformer. The primary distribution line also called feeder takes energy to the load centre which further steps down the voltage to secondary distribution line voltages- 415V for three phase ssystem and 240V for single phase and neutral. Jibril &Ekundayo [1] analysed the reliability performance of 11kV by using the daily outage data of the feeders. Rumuola is an urban town in Port Harcourt, Rivers State, Nigeria. Power distribution network in Rumuola has become so important because of its cardinal position in Port Harcourt. There are more power outages compared to the durations of uninterrupted power supply in most parts of Rivers State all the year round. It is a known fact that electricity plays a critical role in the socio-economic development of every nation. In view of the foregoing, it is imperative to identify the problems militating against uninterrupted and good quality electric power supply at Rumuola town, Port Harcourt, Rivers State with a view to identifying the causes of power outages and at the same time provide means of curtailing the abnormalities. It is in the light of this the need to conduct short circuit analysis became very imperative. So much complaints have arisen due to frequent power supply interruption mostly because of fault. This has become so obvious due to long outage durations attached to most of the outages. Time taken to clear faults is so large that customers are very uncomfortable. Jibril &Ekundayo [1] analyzed the reliability performance of 11kV by using the daily outage data of the feeders.

Electric power system is basically set up to supply electricity with little or no interruptions to its customers. The number of interruptions that occur while the system performs its intended function is part of what determines the overall analysis of the system. The other factor that determines its network analysis is the quality of electricity delivered. Furthermore, the capability of a power system to continuously deliver quality electricity means that the customers are satisfied and the electricity providers are having favourable returns on their investment as they continue their business of supplying electricity. As electricity consumption has become an important factor that affects the drive needed for technology to grow and to facilitate the development of modern society, it is very important therefore to take seriously the issue of fault analysis of an electric power system. During normal operating condition, current will flow through all elements of the electrical power network within pre-designed values which are appropriate to these elements' ratings. Unfortunately, short-circuit faults could happen as a result of natural events or accidents where the phase will establish a connection with another phase or ground, a falling tree on a distribution line could cause short circuit fault where all the phases share a point of contact.

Short-circuit Analysis in the electrical distribution industry is of great significance in order to maintain continuity in power supply to all consumers. All faulted parts must be isolated from the system temporary by the protection schemes. This is achieved when a fault exists within the relay protection zone on the network, then the relay will trip or open the circuit breaker associated with the faulty part. Short-circuit analysis on every bus is necessary to accomplish the task of providing a healthy power system.

II. RELATED WORKS

A short-circuit current analysis is probably one of the most crucial calculations of the electrical design process. This analysis allows designers to find the maximum available short-circuit current at various points or locations in the electrical networks. The short circuit current found is then used to design and specify fault ratings for electrical components that can withstand the tremendous forces of short-circuit without harming or endangering the life of the occupants and without damaging equipment. This analysis can also help identify potential problems and weakness in the system and assist in system planning. To analyze the results correctly, it is important to be abreast of all the parameters of a circuit especially in short circuit situations, the behaviour of the circuits is strange and there is no linearity between the voltage of the system and the current flowing [2].

Three-phase electric power is a kind of polyphase system and it is a method of AC electric power generation, transmission and distribution. It is the most popular and the most common used method by electric power grids worldwide to transfer power. It is also used to power heavy loads and large motors. A three-phase system is normally more economical than an equivalent single-phase system or two-phase system at the same voltage level, since it uses less conductor material to transmit electrical power. The three-phase system is as independently invented by Galileo Ferraris, MiktailDolivo-Dobrovolsky and Nikola Tesla in the late 1880s [3]. In a three-phase system, various types of short-circuit can occur which may be categorized as shunt and series faults. The most occurring types of shunt faults are phase to earth and phase to phase faults. Series faults can occur along the power lines as the result of an unbalanced series impedance condition of the lines in the case of one or two broken lines for example, in practice, a series fault is encountered for example, when lines (or circuit are controlled by circuit breakers or fuses) or any device that does not open all three phases; one or two phases of the line (or the circuit may be open while the other phases or phase is closed [4].

Undesired short-circuits can occur for many different reasons. Some causes of faults are natural lightning strikes, storms, tree branches touching power lines, animals gnawing at electricity insulation and animals coming in contact with two conductors simultaneously, and sometimes short-circuits can even be caused by humans. Short-Circuit Current may flow through high voltage distribution lines especially when short-circuits abruptly occurs. The magnitude of this short-circuit current is so high that it could rampage through a network destroying everything in its wake. Short-circuit current subjects all components to thermal, magnetic and mechanical stress. This stress varies as a function of the current squared and the duration of its propagation. It also increases the potential to damage equipment, cause personnel injury or fatality and start an unsuspecting fire.In an attempt to have any control over short-circuits, power systems and equipment are designed carefully as well as proper installation and maintenance are done to deliver power to the end users in a safe manner. Unfortunately, even after all of these precautions short-circuit do occur. Short-circuits must be detected and removed from the system as quickly as possible. This is achieved through protective circuit devices, circuit breakers and feeder protection relays. These devices must be able to interrupt high currents instantly and repeatedly because several faults can occur in quick success until the current falls down to a safe level, the devices should turn the system backup. They should also be able to stop and withstand the maximum short-circuit current that can flow through the circuit, otherwise, the protective devices would be changed regularly making it costly and impractical. So, it is very important to be able to calculate the maximum short-circuit current at any point in the system in order to select and install the correct devices.

Short-circuit currents are mixture of symmetrical and asymmetrical currents, they are asymmetrical during the first few cycles after short-circuit occurs and gradually becomes symmetrical after a few cycles oscillation of a typical short-circuit current where the maximum peak occurs during the first cycle of the short-circuits current when the current is asymmetrical, the maximum value of the peak gradually reduces to a constant value as the current becomes symmetrical. Adegboye&Dawal [5] maintained that short-circuit fault contributes more to outages than open circuit faults, and its occurrence is higher during the rainy season than the dry season. According to Short [6], animals come second to trees as causes of fault which led to outages in overhead distributions. For instance, short-circuit as a result of animals such as lizards and rats entering the control panels, leads to short circuit faults. Min Gui*et al.* [7] suggested a model for computing the weekly animal related outages which will help utilities to monitor its performance trends from year to year. The paper is useful in helping track the impact of animal related outages. It however does not provide ways to minimize outages by animals.Also, frequent interruption can be as a result of tree branches coming in contact with the lines. The paper presents an adaptive fuzzy modelling technique to calculate the effects of wind, lightning, tree trimming and tree density on distribution network.This model used the field observation of the selected inputs for few feeders and the resulting numbers of failure as a result of these inputs were recorded, and hence the protective device required were used in clearing this fault. Okorie [8] maintained that route length is also a factor that reduces the reliability of the power system as longer circuits are susceptible to interruptions. Samuel *et al.* [9] assessed the reliability of a typical 11kV network line protection scheme using fault tree analysis to enhance the reliability of a power distribution network. In addition, Johnson [10] maintained that different customers experience different levels of reliability and availability of supply even if they are under the same feeder and/or substation.

III. MATERIALS AND METHOD

3.1 Per Unit Short Circuit - Based Calculation Strategy

In large power system, it is useful to express

$$per\ unit\ quantity\ (voltage, current, etc.) = \frac{actual\ quantity}{base\ quantity} \quad (3.1)$$

Usually, a convenient value is chosen for base apparent power which is in volt-amperes, and a base voltage at one level is selected to match the transformer rated voltage at that level. However, base voltages at other levels are then established by transformer turns ratios. The value for apparent power can be chosen in the following ways: selecting the highest rated MVA of the system, selecting a value higher than the highest rated MVA in the system, and summing up all the rated MVA in the system.

$$Base\ current\ (amperes) = \frac{base\ KVA}{\sqrt{3}\,(base\ kV)}\ or\ \frac{base\ MVA}{\sqrt{3}\,(base\ kV)} \quad (3.2)$$

$$Base\ impedance\ (ohms) = \frac{(base\ kV)^2}{base\ MVA} \text{or} \frac{(base\ V)^2}{base\ KVA} \quad (3.3)$$

$$Z_{pu} = \frac{actual\ impedance\ \ in\ ohms\ (base\ MVA)}{(base\ kV)^2} (3.4)$$

$$Or\ Z_{pu} = \frac{percent\ impedance\ \ (base\ kVA)}{kVA\ rating\ \ (100)} (3.5)$$

Considering a one feeder section of the Rumuola 11kV distribution network of the Port Harcourt Electricity Distribution Company and performing a per unit shortcircuit resolution - based calculation for Bus 3 as shown in Figure 3.1.

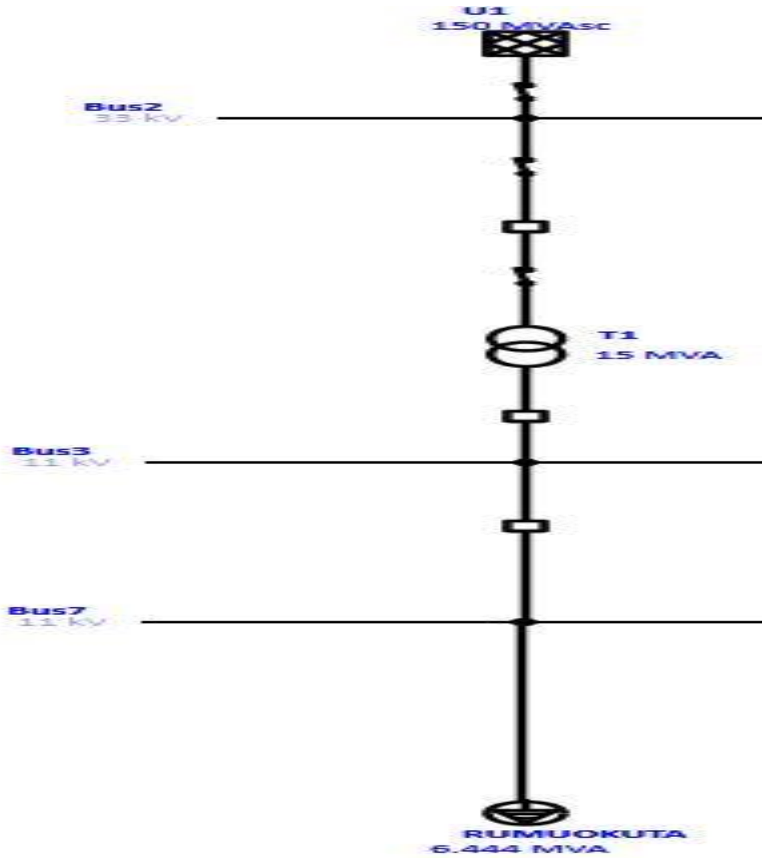

Figure 3.1: Rumuokwuta 11kV feeder at Rumuola Injection Substation

Table 3.1: Relevant Data for Per Unit Short Circuit Calculation

Data Section	Data	Unit/Dimension
Grid Data	Grid Voltage	33KV
	X/R Ratio	14
	Fault MVA	1800.47
Bus Data	Bus 2 Voltage	33KV
	Bus 3 Voltage	11KV
Transformer Data	Voltage Rating	33/11KV
	MVA Rating	15MVA
	% Impedance	10
	X/R Ratio	20
Load Data	Voltage Rating	11KV
	MVA Rating	6.444MVA
	Motor Load	80%
	Static Load	20%
	Power Factor	0.85
	Base MVA	100

In resolving Z_{pu} for power grid/source

$$Z_{pu} = \frac{Z_{ohms}}{Z_{base}} \quad (3.6)$$

$$But\ Z_{base} = \frac{V_{base}^2}{S_{base}} \quad (3.7)$$

$$Z_{base} = \frac{33^2}{100} = 10.89\Omega$$

$$Fault\ MVA = \frac{Base\ MVA}{X_{eq\,(pu)}} \quad (3.8)$$

$$X_{eq\,(pu)} = \frac{Base\ \ MVA}{Fault\ \ MVA} \quad (3.9)$$

$$X_{eq\,(pu)} = \frac{100}{1800.47} = 0.05554$$

$$R_{pu} = \frac{X_{eq\,(pu)}}{\left(\frac{X}{R}\right)} (3.10)$$

$$R_{pu} = \frac{0.05554}{14} = 0.003967$$

$$Z_{pu} = \sqrt{R^2 + X^2} \quad (3.11)$$

$$Z_{pu} = \sqrt{(0.003967)^2 + (0.05554)^2} = 0.0557$$

From the equation

$$Z_{ohms} = Z_{pu}\ X\ Z_{base} \quad (3.12)$$

$$Z_{ohms} = 0.0557 \times 10.89 = 0.6066\Omega$$

In resolving $Z_{pu}$for Transformer

$$Z_{pu}^{n} = Z_{pu}^{o} \left(\frac{V_B^o}{V_B^n}\right)^2 \left(\frac{S_B^n}{S_B^o}\right) \quad (3.13)$$

$$Z_{pu}^{n} = 0.1 \left(\frac{33}{33}\right)^2 \left(\frac{100}{15}\right) = 0.66667$$

$$X_{pu} = \frac{Z_{pu} \times \left(\frac{X}{R}\right)}{\sqrt{1+\left(\frac{X}{R}\right)^2}} \quad (3.14)$$

$$X_{pu} = \frac{0.66667 \times 20}{\sqrt{1+(20)^2}} = 0.66584$$

$$I''_k = \frac{cU_n}{\sqrt{3}Z_k} (3.15)$$

Considering equation (3.10)

$$R_{pu} = 0.033292$$

$$Z_{pu}\ Total = Z_{pu}\,(Source) + Z_{pu}\,(Transformer) \quad (3.16)$$

$$Z_{pu}\ Total = 0.0557 + 0.66667 = 0.72237$$

Using equations (3.10) and (3.14)

$$X_{pu} = 0.7214687$$

$$R_{pu} = 0.036073435$$

$$X/R = 20$$

Considering equation

$$I''_k = \frac{cU_n}{\sqrt{3}Z_k})$$

the threshold symmetrical short-circuit current for bus 3 becomes:

$$I''_k = 7.47kA$$

Having performed the threshold symmetrical short circuit and maximum short circuit calculations using per unit resolution – based strategy, the data realized coupled with the data collected from the Port Harcourt Electricity Distribution Company were used as input data in the Electrical Transient Analyzer Program as shown in Figures 3.2 – 3.4.

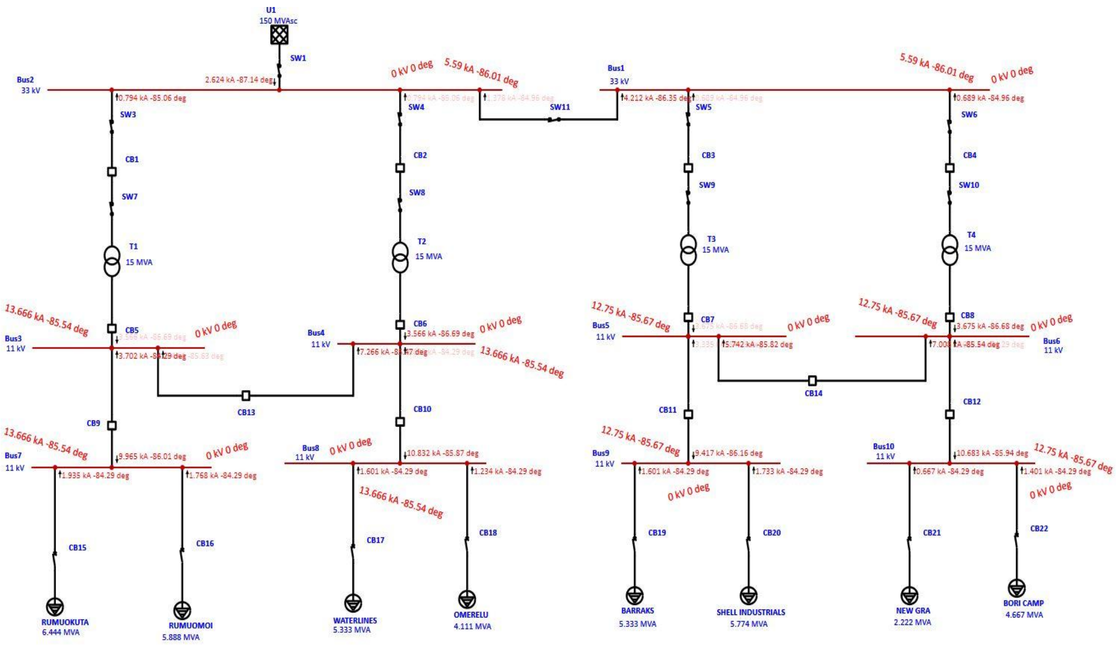

Figure 3.2: Maximum Short-Circuit Analysis

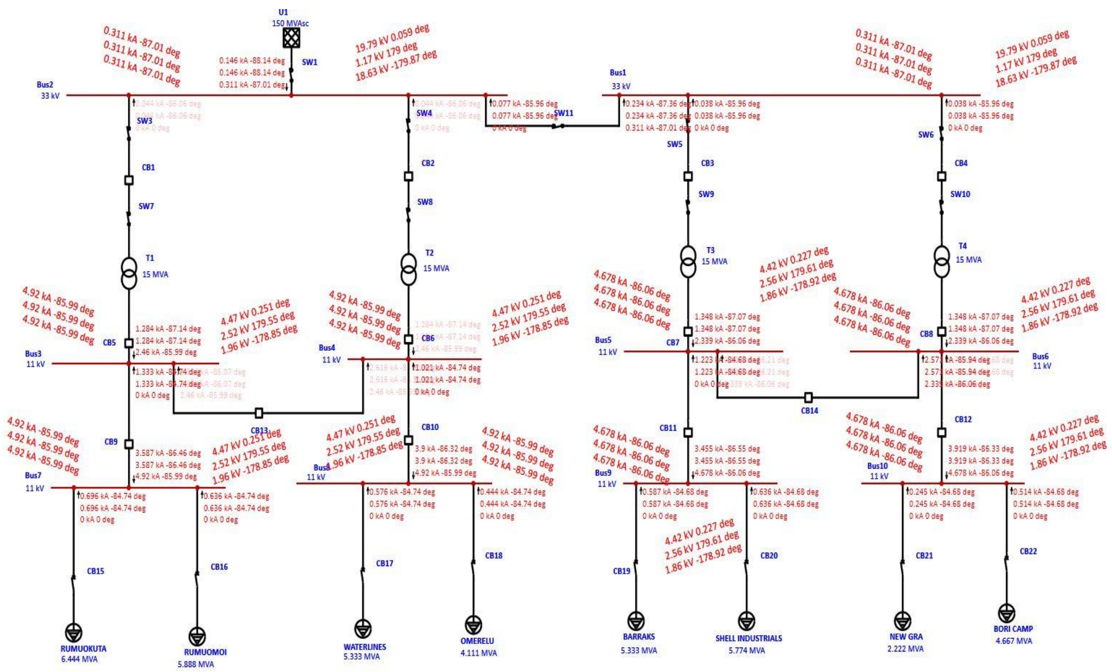

Figure 3.3: Maximum Line to Ground Fault

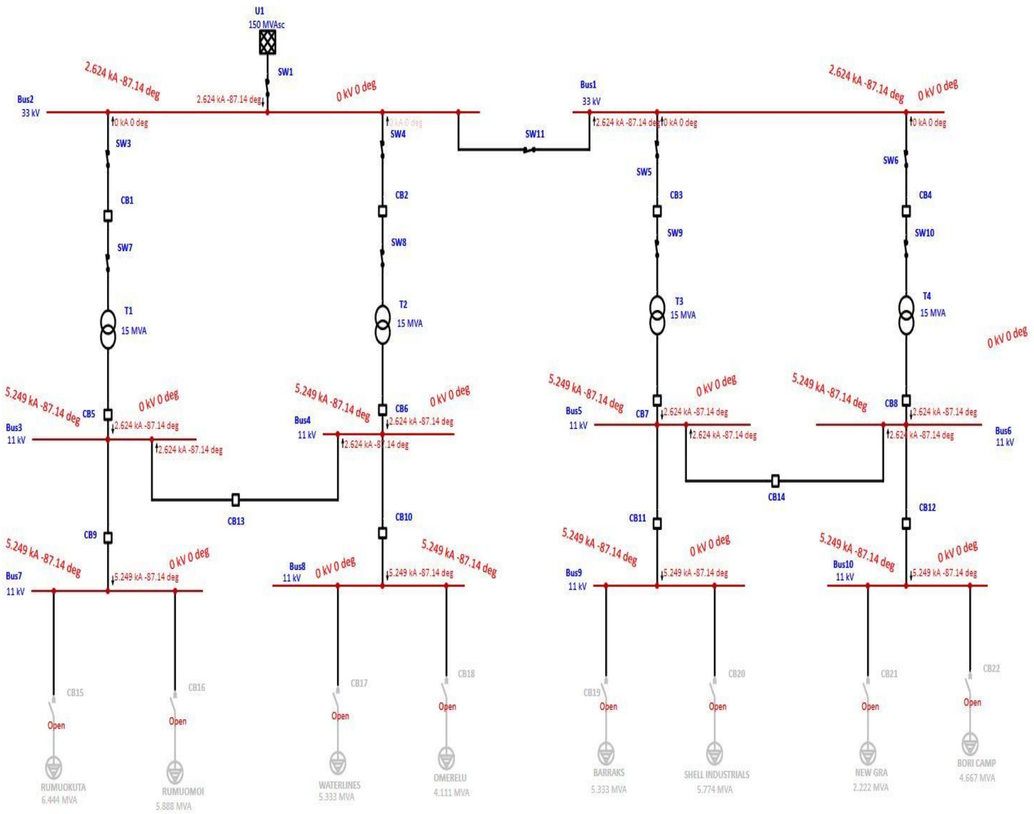

Figure 3.4: Minimum Short-Circuit Analysis

IV. RESULTS AND DISCUSSION

4.1 Short Circuit Result Summary

Short circuit results are displayed in this section for quick assimilation of the concept. The results obtained from the maximum short circuit analysis are shown in Tables 4.1 – 4.3 and Figures 4.1- 4.3 respectively.

Table 4.1: Maximum Short Circuit Analysis – Three Phase

Bus	Voltage (KV)	Three-Phase Short Circuit Current (KA)
1	33	5.59
2	33	2.624
3	11	13.666
4	11	13.666
5	11	12.75
6	11	12.75
7	11	13.666
8	11	13.666
9	11	12.75
10	11	12.75

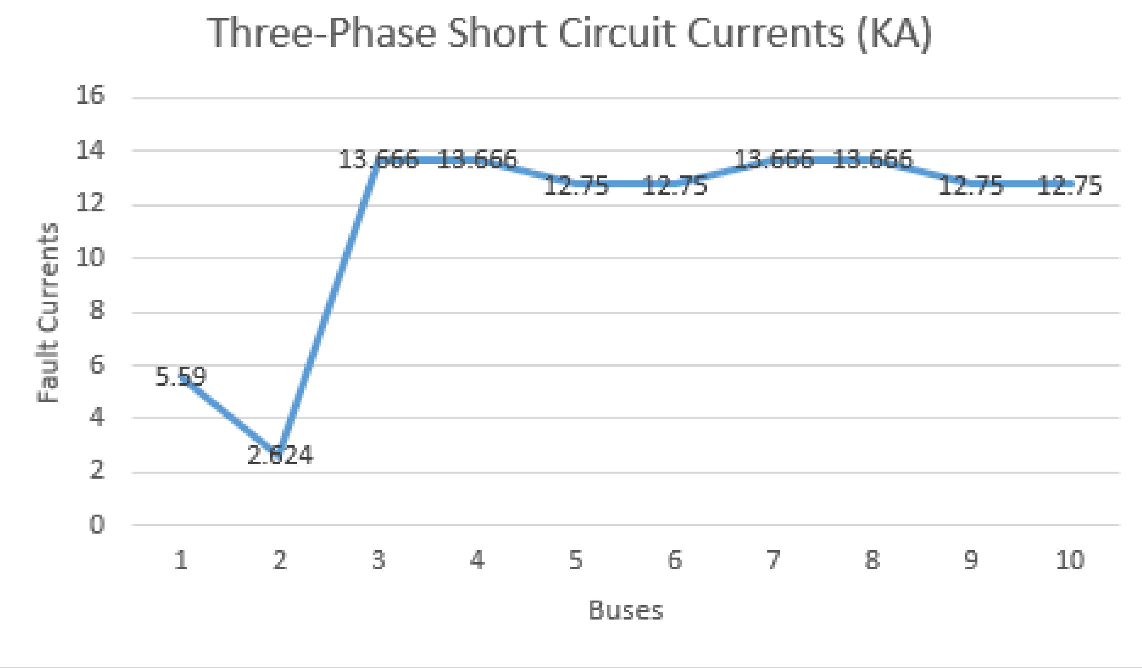

Figure 4.1: Graph of Three-Phase Short Circuit Currents

Table 4.2: Maximum Short Circuit Analysis – Single Line to Ground

Bus	Voltage (KV)	Single Line to Ground Fault (KA)
1	33	0.311
2	33	0.311
3	11	4.92
4	11	4.92
5	11	4.678
6	11	4.678
7	11	4.92
8	11	4.92
9	11	4.678
10	11	4.678

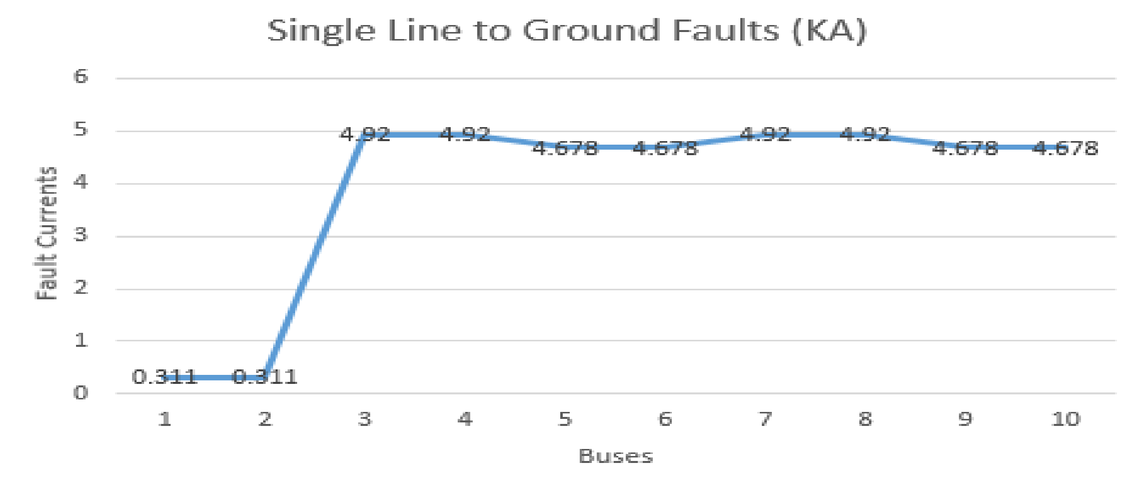

Figure 4.2: Graph Showing Single Line to Ground Faults

Table 4.3: Minimum Short Circuit Analysis – Three Phase

Bus	Voltage (KV)	Three-Phase Short Circuit Current (KA)
1	33	2.624
2	33	2.624
3	11	5.249
4	11	5.249
5	11	5.249
6	11	5.249
7	11	5.249
8	11	5.249
9	11	5.249
10	11	5.249

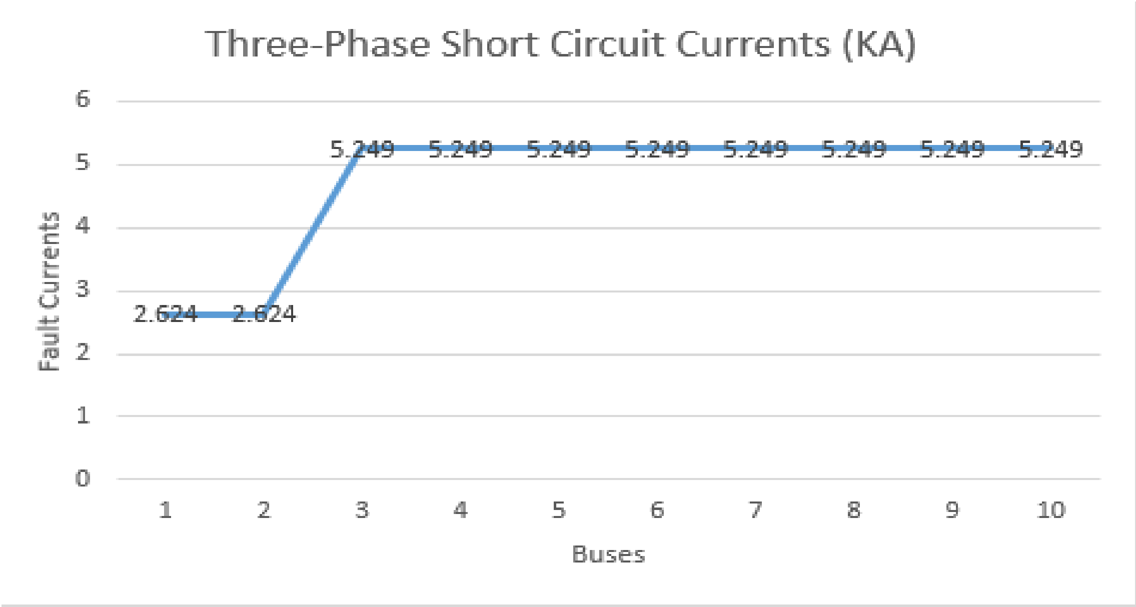

Figure 4.3: Graph Showing Three-Phase Short Circuit Currents

V. CONCLUSION

5.1 Conclusion

The status of the 10-bus system investigated was found to be healthy as diagnostic report after simulation showed a low level of voltage profile defect within the permissible limit of +/- 5%. The short-circuit analysis by simulation displayed the fault currents at each bus in the network which is pertinent for adequate selection of protective devices thereby improving the reliability of power supply.

Maximum short circuit analysis and minimum short-circuit analysis were performed for both three-phase faults (which is the most dangerous type of short-circuit) and single line to ground fault was also performed using maximum short circuit analysis technique (which has the highest tendency of occurrence). The whole idea was to guarantee adequate selection of protective devices as it is geared toward providing efficient protection in the system.

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