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ESTIMATION OF APPROPRIATE CIRCUIT BREAKER APACITY TOINTERRUPT SEVERE FAULT CURRENT AT ANY POINT ON 330kVTRANSMISSION GRID SYSTEM IN NIGERIA

M.O. Okelola[1] and C.O.A. Awosope[2]

[1]Department of Electronic and Electrical Engineering,Faculty of Engineering and Technology, Ladoke Akintola University of Technology P.M.B. 4000 LAUTECH, Ogbomoso.
[2]Department of Electrical and Electronics Engineering, University of Lagos, Nigeria.

ABSTRACT.

Two different stages of analysis were strictly gone through before arriving at the circuit breaker capacity to protect 330kV transmission grid system in Nigeria gauss-Seidel iterative method for solving load flow equations is presented in this paper on one hand to study the pre-fault condition. While on the other hand Thevenin's method of approach for analysis circuit parameters is presented to estimate the highest fault current during fault condition. It was the understanding of the two studies that led to the capacity of the protective device required. A MATLAB program was developed for each of the studies.

INTRODUCTION

The purpose of an electrical power system is to generate and supply electrical energy to consumers with reliability and economy. Reliability is very significant in system design, but should not be pursued as an end in itself without taking cost factors into consideration (the cost, especially to repair or re-construct a damaged system as a result of fault).

Security of supply, therefore, can be better by improving plant design, increasing the spare capacity margin and arranging alternative circuits to supply loads. Sub-division of the system into zones, each controlled by switchgear in association with protective gear, provides flexibility during normal operation and ensures a minimum of dislocation following a breakdown.

The greatest threat to the security of a supply system is the short circuit, which imposes a sudden and sometimes violent change on system operation. The large current which flows, accompanied by the localized release of a considerable quantity of energy can cause fire at the fault location and mechanical damage throughout the system, particularly to machine and transformer windings. Rapid isolation of the fault by the nearest switchgear will minimize the damage and disruption that can be caused to the system.

The risk of fault occurring in a Grid System, however slight for each, is multiplied by the number of such items which are closely associated in an extensive system as any fault produces repercussions throughout the network. When the system is so large like this, the chance of a fault occurring and the disturbance it will bring are both so enormous that without equipment to remove faults, the system will become inoperable. The objective of the system will be defeated if adequate provision for fault clearance is not made. The installation of switchgear alone is insufficient, discriminative protective gear, designed according to the characteristics and requirements of the power system must be provided to control the switchgear.

A system is not properly designed and managed if it is not adequately protected. This is the measure of the importance of protective system in modern practice and of the responsibility vested in the protective engineer.

Fault analysis can be broadly grouped into two:

1. Symmetrical fault (fault involving all the three phases).
2. Unsymmetrical fault (faults involving only one or two phases).This can be further divided into:
   - Single line to ground ,
   - Line to line and
   - Two lines to ground faults.

The causes of faults are numerous, e.g. lightning, heavy winds, trees falling across lines, vehicles colliding with towers or poles, e.t.c. Majority of the faults are unsymmetrical. However, the circuit breaker rated MVA breaking capacity is based on 3-phase fault MVA. Since 3-phase fault inflicts greatest damage to the power system, except in a situation where a single line to ground fault is very close to a solidly grounded generator's terminal. In this instance the severity of single line to ground fault is greater than that of 3-phase balance fault.

Short circuit studies involve finding the voltages and currents distribution throughout the system during fault conditions so that the protective devices may be set to detect the fault and isolate the faulty portion of the system so as to minimize the harmful effects of such contingencies.

The current trend of erratic power supply and system collapse in Nigeria has made this project study of paramount importance to the nation's power industry. Because power industry itself is the backbone of industrial development of any developing nation.

EQUATION OF MACHINES SYNCHRONOUS GENERATORS

Though the analysis of short circuit on a loaded synchronous machine is complicated, we cannot run away from the complication because a short circuit can occur at any time not minding loaded or unloaded condition.

Since this study involves the Grid of very large interconnected system, the synchronous machines (generators) will be replaced by their corresponding circuit models having voltage behind sub-transient reactance in series with sub-transient reactance while the remaining passive network components remain unchanged.

The circuit model of this representation is illustrated in Fig. 2(a), while its phasor representation is given in Fig. 2(b).

The equation for the induced e.m.f. [Nagrath and Kothari, 1998], is given as:

$$E_g^{''} = V_0 + jI_0X_d^{''} \quad (1)$$

$$E_g^{''} = I_0r_a + jI_0X_d^{''} \quad (1)$$

where;

$E_g^{''}$ = Voltage behind the sub-transient reactance.

V_0 = terminal voltage.

I_0 = machine loaded current.

r_a = armatüre resistance.

$X_d^{''}$ = Sub-transient reactance.

POWER SYSTEM EQUATION
LOAD REPRESENTATION

During sub-transient period, power system loads, other than motors are represented by the equivalent circuit as static impedance or admittance to ground.

For the purpose of short circuit analysis in order to select appropriate circuit breaker to clear a fault instantly before transient condition on a power system, pre-fault condition of the system (i.e. pre-fault voltages and currents) should be known. This can be obtained from the load flow solution for the power system; the initial value of the current for a constant current representation is obtained from:

$$I_{po} = \frac{P_{lp} - jQ_{lp}}{V_p^*} \quad (2)$$

where;

P_{lp} and Q_{lp} = the scheduled bus load.

V_p^* = the calculated voltage.

The current I_{po} flows from bus P to ground, that is, to bus 0.

The magnitude and power factor angle of I_{po} remain constant.

The static admittance;

$$y_{po} = I_{po} \quad (2)$$

where;

V_p^* = the calculated bus voltage and V_o (the ground voltage) = 0.

Therefore,

$$y_{po} = \frac{I_{po}}{V_p^*} \quad (4)$$

NETWORK PERFORMANCE EQUATION

The Gauss- Seidel method of solution used for the load flow equation can be applied to describe the performance of a network during a sub-transient period, using the bus admittance matrix with ground as reference. The voltage equation for bus P [as reported by Elgerd; 1973], is given by:

$$V_p = \frac{(P_p - jQ_p)L_p}{V_p^*} - \sum_{q=1}^{p-1} YL_{pq}V_q^{k+1} - \sum_{q=p+1}^{n} YL_{pq}V_q^k \quad (5)$$

where;

$$YL_{pq} = Y_{pq}L_p ; L_p = \frac{1}{Y_{pp}}$$

The term $\frac{(P_p - jQ_p)}{V_p^*}$ in equation (5) represents the load current at bus P. For the constant load current representation,

$$\frac{P_p - jQ_p}{(V_p^k)^*} = |I_{po}|\angle(\Theta_p^k + \Phi_p) \quad (6)$$

where;

Φ_p = the power factor angle,

and Θ_p^k = the angle of voltage with respect to the reference.

When the constant power is used to represent the load, $(P_p - jQ_p)L_p$ will be constant but the bus voltage V_p will change in any iteration. When the load at bus P is represented by a static admittance to ground, the impressed current at the bus is zero and therefore,

$$\frac{(P_p - jQ_p)L_p}{V_p^*} = 0 \quad (7)$$

For a sub-transient analysis in short circuit studies, the parameters of equation (2.5) must be modified to include the effect of the equivalent element required to represent synchronous, induction and loads. The line parameters YL_{pq} must be modified for the new elements and additional line parameter must be calculated for each new network element.

METHOD OF SOLUTION
PRELIMINARY CALCULATIONS

It had been mentioned earlier that for short circuit studies, it is necessary to have the knowledge of pre-fault voltages and currents. These pre-fault conditions can be obtained from the result of load flow solution by Gauss-Seidel iteration method using Y_{BUS}, the flowchart of which is illustrated in Fig.5.

The pre-fault machine currents are calculated from load flow by Gauss-Seidel iterative method from:

$$I_{ki} = \frac{P_{ki} - jQ_{ki}}{V_{ki}^*} \quad ; \; i = 1,2,\cdots,m. \quad (8)$$

where;

P_{ki} and Q_{ki} = the scheduled or calculated machine real and reactive terminal powers.

V_{ki}^{*} = the last iteration voltage.

m = the number of machines in the system.

The network is then modified to correspond to the desired representation for short circuit studies. Being a linear network of several voltage sources, further calculation can be computed by application of Thevenin's theorem.

THEVENIN'S THEOREM

This is a powerful method of solution for a large network. The model representation of the Thevenin's equivalent of the system is shown in Fig. 3(a).

The circuit in Fig.3(a) can be replaced by the one in Fig.3(b) if a ground fault is assumed through Z_f. Therefore, fault current can be immediately written as:

$$I_f = \frac{V_0}{jX_{TH}'' + Z_f} \quad (9)$$

This is a very fast method for computing short circuit fault current.

CONSIDERATION OF PRE-FAULT LOAD CURRENT

If the magnitude of fault current is small, the pre-fault current can be superimposed on the fault current in order to know its effect. But in this instance, it is not necessary because the resulted fault current is satisfactorily large enough (i.e. larger than the specified 10 –20 p.u. changes caused in current by short circuit) [Nagrath and Kothari].

Moreover, the load currents and fault current are nearly in quadrant and their phasor sum is nearly equal to the larger component, which is the fault current. Again, a fault can occur at any time and there is no way of predicting the loading condition of the system at the instant of fault.

EQUATION FOR SHORT CIRCUIT STUDIES

It has to be reiterated once again before proceeding on short circuit computation that the admittance bus matrix formed and used in load flow has to be inverted to obtain the impedance bus matrix for easy computation. Building the Z_{BUS} algorithm is of paramount importance in the calculation process. The best method employed for digital calculation is a step-by-step programmable technique, which proceeds branch by branch. It has the advantage that any modification of the network does not require complete rebuilding of Z_{BUS}. It is described in terms of modifying an existing bus impedance matrix designated as $|Z_{bus}|_{old}$. The new modified matrix is designated as $|Z_{bus}|_{new}$. This is described as follows:

$$Z_{Bus(Old)} \xrightarrow{Z_b = branch\ \ impedance} Z_{Bus(new)}.$$

In the process of adding a new bus to an old one, the likely modifications are:

Addition of Tree Branch Z_b from a New Bus k to Reference.

(i) Addition of Tree Branch Z_b from a New Bus k to Old Bus j.

(ii) Addition of a Link Z_b between an Old Bus j and Reference.

(iii) Addition of Link Z_b between two Old Busses i and j.

(iv) Modification of $[Z_{bus}]$ for changes in Network.

The effect of (i) above is that Z_{BUS} dimension goes up by one, (ii) above will form a new loop without affecting the Z_{BUS} dimension. For (iii), (iv) and (v), the Z_{BUS} remains unaffected at all. To know more about this technique, read more about the effect. [Gupta, 1993] and [Nagrath and Kothari, 1998].

CALCULATION OF LINE CURRENT

As mentioned earlier, the aim of a short circuit study is to determine fault current, bus voltages and line currents under fault conditions. The line currents can be calculated from the values of bus voltages determined in the earlier part of this report. From Fig. 4 below, the current in the line joining ith and kth buses is given by:

$$I_{ik}^{n} = \frac{V_i^n - V_k^n}{Z_b^n} \quad (10)$$

where;

n = the sequence, $n = 0,1,2.$

I_{ik}^{n} = nth sequence current from ith bus to kth bus.

V_i^n = nth sequence voltage at ith bus.

V_k^n = nth sequence voltage at kth bus.

Z_b^n = nth sequence impedance of branch connecting ith and kth buses.

SEQUENCE COMPONENT FOR SHORT CIRCUIT STUDIES

Due to the effect of large changes (between 10 –20 p.u) brought about by short circuit fault, a pre-fault load current is very negligible compared to the fault current. It can be assumed that all pre-fault bus voltages are 1p.u., [Gupta, 1993]. Therefore, the sequence quantities can be represented as follows:

$$V_{0-bus} = -|Z_{0-bus}|I_{0-bus} \quad (11a)$$

$$V_{1-bus} = E_{bus} - |Z_{1-bus}|I_{1-bus} \quad (11b)$$

$$V_{2-bus} = -|Z_{2-bus}|I_{2-bus} \quad (11c)$$

where;

V_{o-bus} = zero sequence bus voltage vector (n×1), general entry V_k^0.

V_{1-bus} = positive sequence bus voltage vector (n×1), general entry V_k^1.

V_{2-bus} = negative sequence voltage vector (n×1), general entry V_k^2.

I_{0-bus} = zero sequence bus current vector (n×1), general entry I_k^0.

I_{1-bus} = positive sequence bus current vector (n×1), general entry I_k^1.

I_{2-bus} = negative sequence bus current vector (n×1), general entry I_k^2.

$|Z_{0-bus}|$ = zero sequence bus impedance matrix (n×n), general entry Z_{ik}^0.

$|Z_{1-bus}|$ = positive sequence bus impedance matrix (n×n), general entry Z_{ik}^1.

$|Z_{2-bus}|$ = negative sequence bus impedance matrix (n×n), general entry Z_{ik}^2.

Where superscripts on each of the symbols V_k^0, I_k^1 and Z_{ik}^2 indicates the sequence while the subscripts indicates bus number.

SYMMETRICAL AND UNSYMMETRICAL FAULT EQUATIONS

The equation for fault analysis can be developed using Equations (2.11) with the assumption that network is terminated at the faulted bus (bus k).

THREE-PHASE FAULT

The negative sequence and zero sequence quantities are absent in a three-phase fault (because both of them are equal to zero). Also all currents except the current at the faulted bus (I_k^1) are zero. Hence we have:

$$V_k^1 = E - Z_{kk}^1 I_k^1. \tag{12}$$

If Z_f is the fault impedance, then;

$$I_k^1 = \frac{E}{Z_{kk}^1 + Z_f}. \tag{13}$$

The effect of the fault on other busses linked to the faulted bus can be obtained as:

$$V_i^1 = E - Z_{ik}^1 I_k^1 = E\left[1 - \frac{Z_{ik}^1}{Z_{kk}^1 = Z_f}\right] \tag{14}$$

(For i = 1,2,......, n).

The summary of the flowchart for 3-phase fault is shown on Fig.6.

SINGLE LINE-TO-GROUND FAULT

For a single line to earth fault, all sequence currents of other buses other than faulted bus are zero. Also the sequence currents on the faulted bus are equal and the sum of the sequence voltages is given as:

$$V_k^0 + V_k^1 + V_k^2 = 3Z_f I_k^1 \tag{15}$$

Combining the above explanation with equations (2.11) and (2.15) we have:

$$I_k^1 = \frac{E}{Z_{kk}^0 + Z_{kk}^1 + Z_{kk}^2 + 3Z_f}. \tag{16}$$

The sequence voltages at all other busses linked to the faulted bus can be given as:

$$V_i^0 = -Z_{ik}^0 I_k^0 = Z_{ik}^0 I_k^1 = \frac{-Z_{ik}^0 E}{Z_{kk}^0 + Z_{kk}^1 + Z_{kk}^2 + 3Z_f}. \tag{17a}$$

$$V_i^1 = E - Z_{ik}^1 I_k^1 = E\left[\frac{Z_{kk}^0 + Z_{kk}^1 + Z_{kk}^2 + 3Z_f - Z_{ik}^1}{Z_{kk}^0 + Z_{kk}^1 + Z_{kk}^2 + 3Z_f}\right] \tag{17b}$$

$$V_i^2 = -Z_{ik}^2 I_k^2 = -Z_{ik}^2 I_k^1 = \frac{-Z_{ik}^2 E}{Z_{kk}^0 + Z_{kk}^1 + Z_{kk}^2 + 3Z_f}. \tag{17c}$$

(For i= 1,2, ..., n).

The summary of the flowchart for single line-to-ground fault is shown on Fig.7.

LINE-TO-LINE FAULT

For a line – to – line fault, all sequence currents at busses other than the faulted bus are zero. Also, on the faulted bus, the zero sequence quantities are zero. Therefore,

$$V_k^1 = V_k^2 + I_k^1 Z_f. \tag{18}$$

After few manipulations we have:

$$I_k^1 = \frac{E}{Z_{kk}^1 + Z_{kk}^2 + Z_f}. \tag{19}$$

The positive and negative sequence voltages at busses linked to the faulted bus are given as:

$$V_i^1 = E - Z_{ik}^1 I_k^1 = E\left[\frac{Z_{kk}^1 + Z_{kk}^2 + Z_f - Z_{ik}^1}{Z_{kk}^1 + Z_{kk}^2 + Z_f}\right]. \tag{20a}$$

$$V_i^2 = -Z_{ik}^2 I_k^2 = Z_{ik}^2 I_k^1 = \frac{Z_{ik}^2 E}{Z_{kk}^1 + Z_{kk}^2 + Z_f}. \tag{20b}$$

The summary of the flowchart for Line – To – Line Fault is shown on Fig.8.

DOUBLE LINE-TO-GROUND FAULT

For a double line – to – ground fault, all sequence currents at busses other than the faulted bus are zero. Also the sum of the sequence currents on the faulted bus is equal to zero.

Moreover, positive sequence voltage and negative sequence voltage at the faulted bus are equal and lastly,

$$V_k^0 - V_k^1 = 3I_k^0 Z_f. \tag{21}$$

Combining all the above explanations with equations (2.11) and (2.21), we have:

$$I_k^1 = \frac{E - V_k^1}{Z_{kk}^1}. \tag{22a}$$

$$I_k^2 = -\frac{V_k^2}{Z_{kk}^2} = -\frac{V_k^1}{Z_{kk}^2} \quad (22b)$$

$$I_k^0 = \frac{V_k^0}{Z_{kk}^0} = -\frac{V_k^1}{Z_{kk}^0 + 3Z_f} \quad (22c)$$

As a result of the validity of the above explanations and equations, we have:

$$V_k^1 = V_k^2 = \frac{E(Z_{kk}^0 + 3Z_f)Z_{kk}^2}{Z_{kk}^1(Z_{kk}^2 + Z_{kk}^0 + 3Z_f) + Z_{kk}^2(Z_{kk}^0 + 3Z_f)} \quad (23)$$

Let $Z_{kk}^1(Z_{kk}^2 + Z_{kk}^0 + 3Z_f) + Z_{kk}^2(Z_{kk}^0 + 3Z_f) = \Delta$.

Hence,

$$I_k^1 = (Z_{kk}^2 + Z_{kk}^0 + 3Z_f)E/\Delta \quad (24a)$$

$$I_k^2 = -E(Z_{kk}^0 + 3Z_f)/\Delta \quad (24b)$$

$$I_k^0 = -EZ_{kk}^2/\Delta \quad (24c)$$

The sequence voltages at the buses linked to the faulted bus are given as: (ii)

$$V_i^0 = -Z_{ik}^0 I_k^0 = EZ_{ik}^0 Z_{kk}^2/\Delta \quad (25a)$$

$$V_i^1 = E - Z_{ik}^1 I_k^1 = E[\Delta - Z_{ik}^1(Z_{kk}^2 Z_{kk}^0 + 3Z_f)]/\Delta \quad (25b)$$

$$V_i^2 = -Z_{ik}^2 I_k^2 = Z_{ik}^2[Z_{kk}^0 + 3Z_f]E/\Delta \quad (25c)$$

(for i = 1,2,.........., n).

The summary of the flowchart for Double Line – To – Ground fault is shown on Fig.9.

COMPARISON OF SINGLE LINE-TO-GROUND FAULT AND 3-PHASE FAULT CURRENTS

This comparison[7] is necessary because of the earlier statement in this project study that single line – to – ground fault is more severe than that of 3 – phase fault if the fault is located very close to the terminal of a solidly grounded generator.

The fault impedance can be assumed to be zero because of the enormous effect of the fault current. In addition, if the impedances Z_1,Z_2 and Z_0 are assumed to be pure reactances (X_1,X_2 and X_0), then, for a 3 – phase fault,

$$I_a = \frac{E}{jX_1} \quad (26)$$

and that of single line – to – ground fault is given as:

$$I_a = \frac{3E}{jX_1 + jX_2 + jX_0} \quad (27)$$

The three practical possibilities are as follow:

Fault at the terminals of neutral solidly grounded generator, (for generator $X_0 << X_1$), and it is assumed that $X_1 = X_2$ for sub-transient condition which is the case for the short circuit studies. At this instance single line – to – ground fault is more severe than a 3 – phase fault.

If a generator is grounded through a reactance X_n, this does not have any effect on a 3 – phase fault current, but a single line – to – ground fault will have a fault current:

$$I_a = \frac{3E}{j(X_1 + X_2 + X_0 + 3X_n)}$$

To this end the relative severity of 3 – phase fault and single line – to – ground fault will depend on the value of X_n.

(iii) For a fault on a transmission line (which is the case study) $X_0 >> X_1$ so that for a fault on a line sufficiently far away from the generator terminals, 3 – phase fault current is more than single line – to – ground fault current.

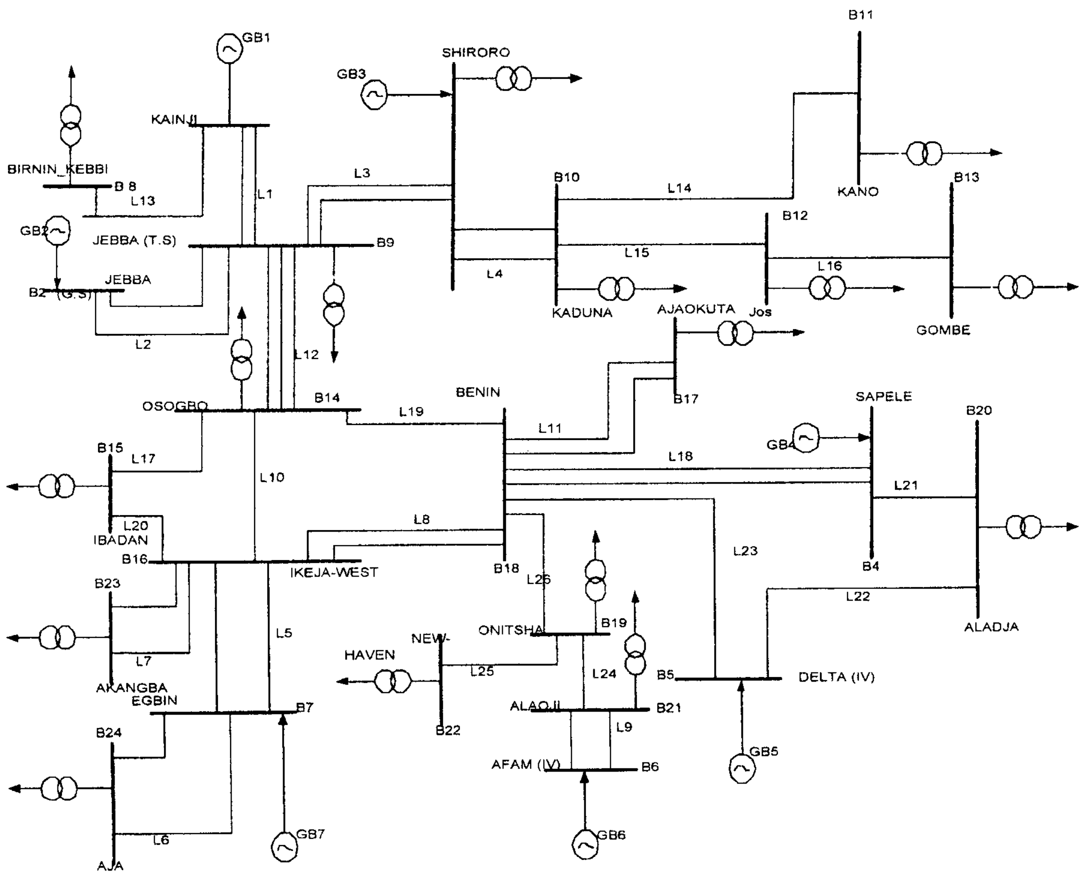

Fig. 1: Line Diagram of Existing National 330kv Network. [NCC Osogbo]

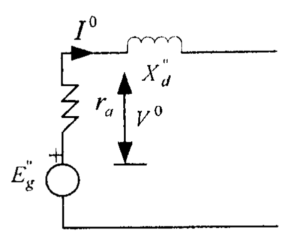

FIG.2a CIRCUIT MODEL FOR LOADEDMACHIN.

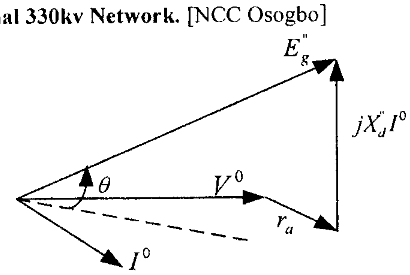

FIG.2b PHASOR DIAGRAM FOR LOADED MACHINE.

Fig. 2: Circuit Model for Loaded Machine

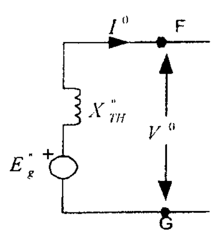

FIG.3a CIRCUIT FOR COMPUTING SUB-TRANSIENT FAULT CURRENT

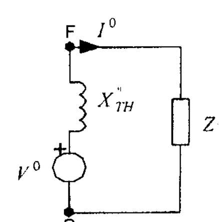

FIG.3b CIRCUIT FOR COMPUTING FAULT CURRENT THROUGH Z^f

Fig. 3: Phasor Diagram For Loaded Machine

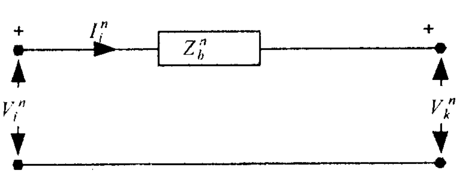

Fig. 4: nTH Sequence Component Current in The Line Joining ith and kth Buses.

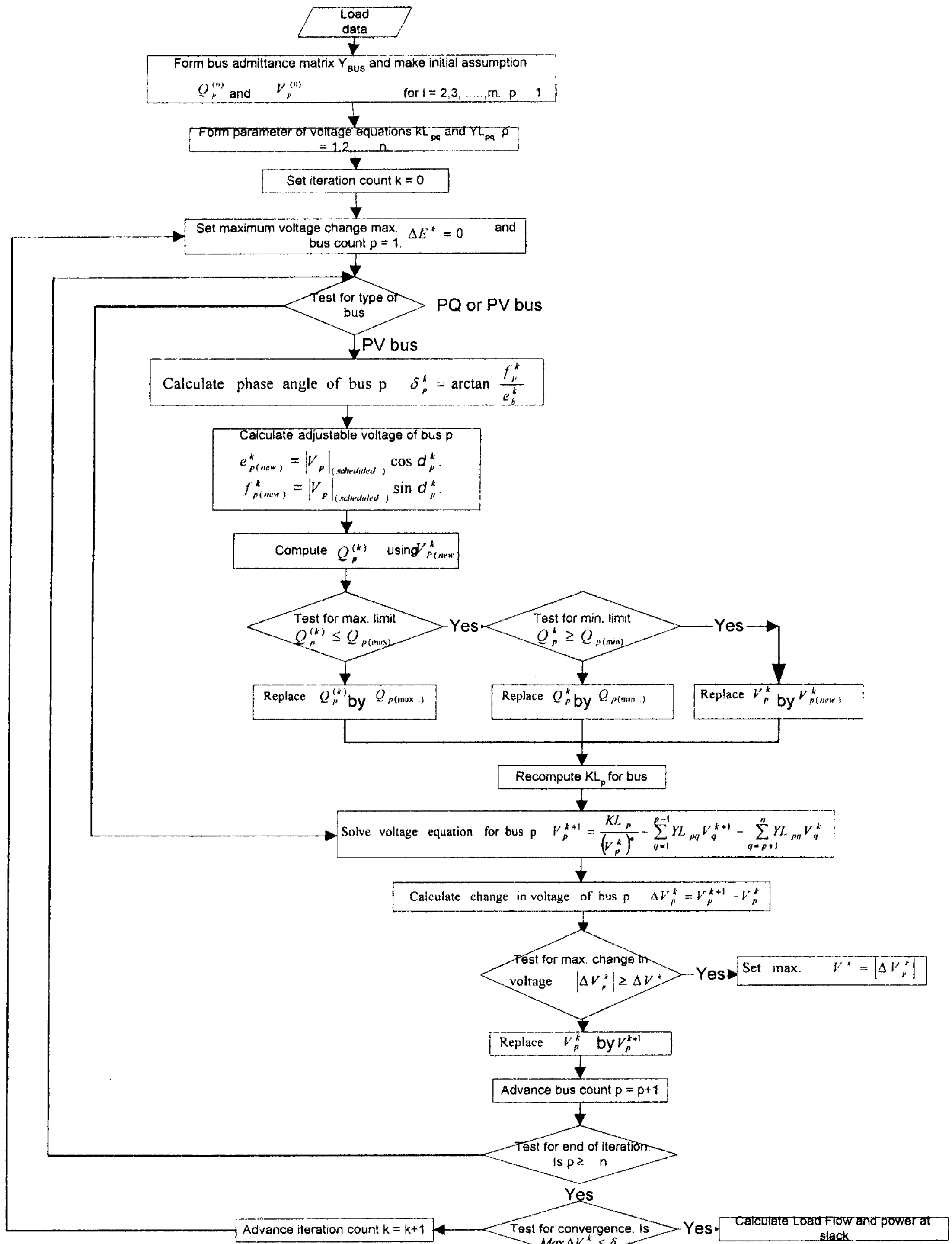

Fig. 5: Flow Chart for Load Flow Solution: Gauss-Seidel Iterative Methods.

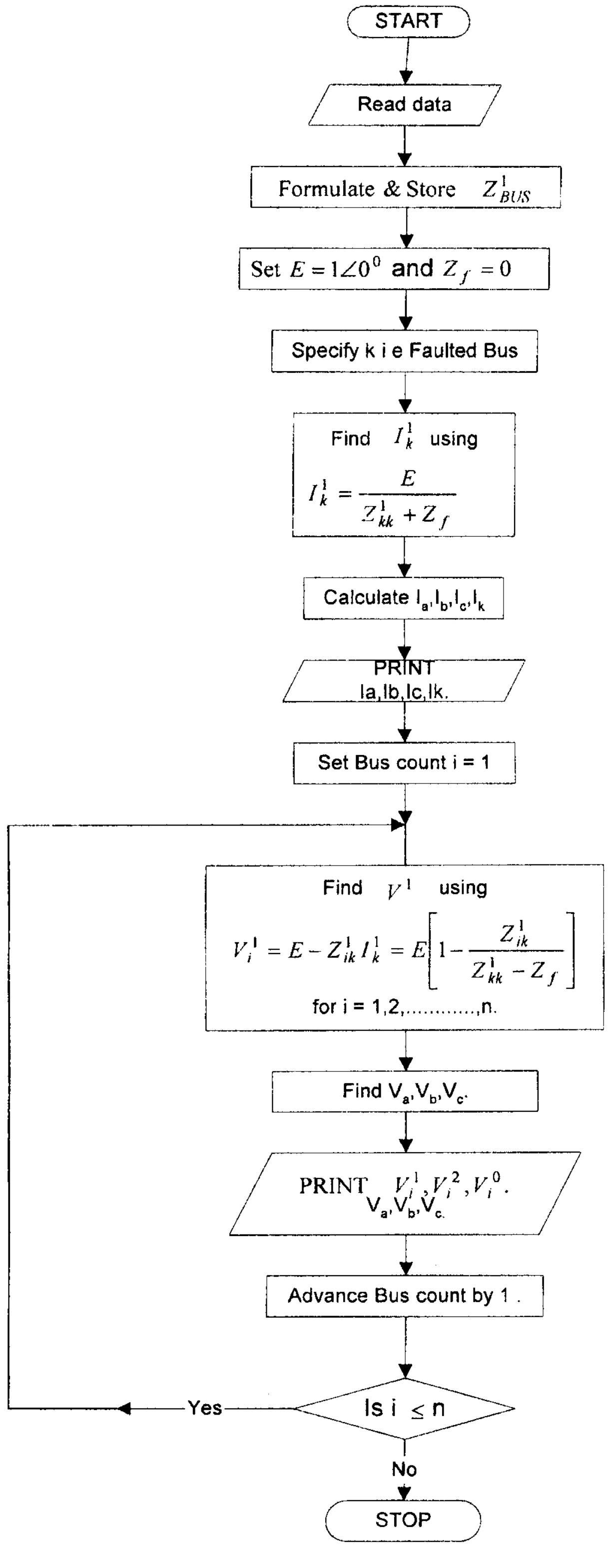

Fig. 6: Flow Chart for 3-Phase (Symmetrical) Fault.

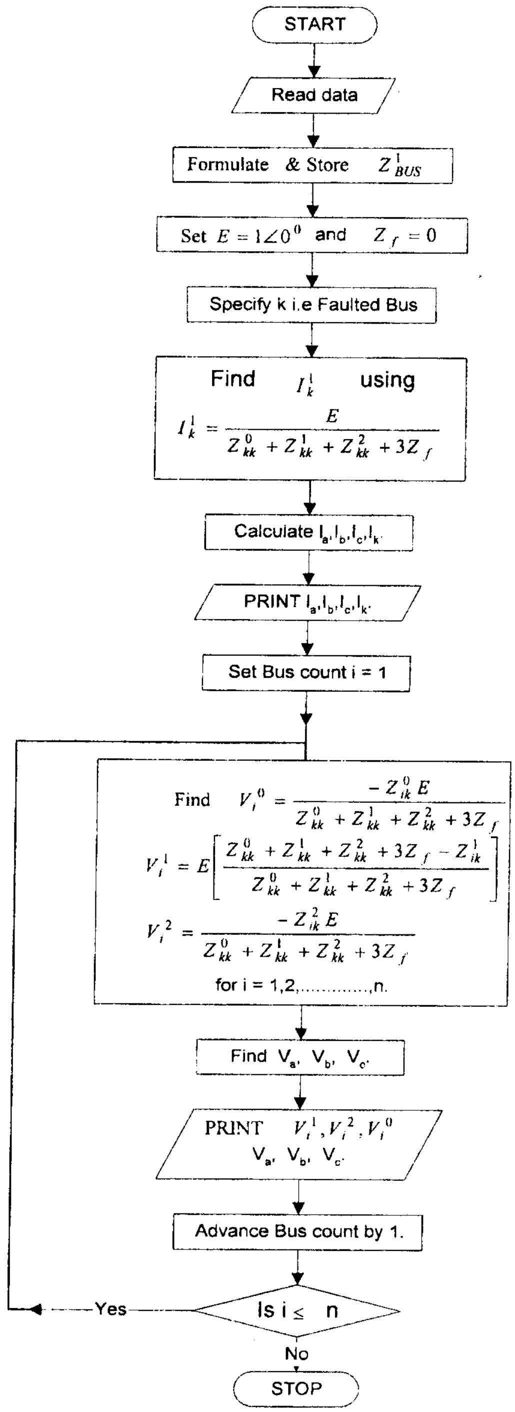

Fig. 7: Flow Chart for Single-Line-To-Ground Unsymmetrical Fault.

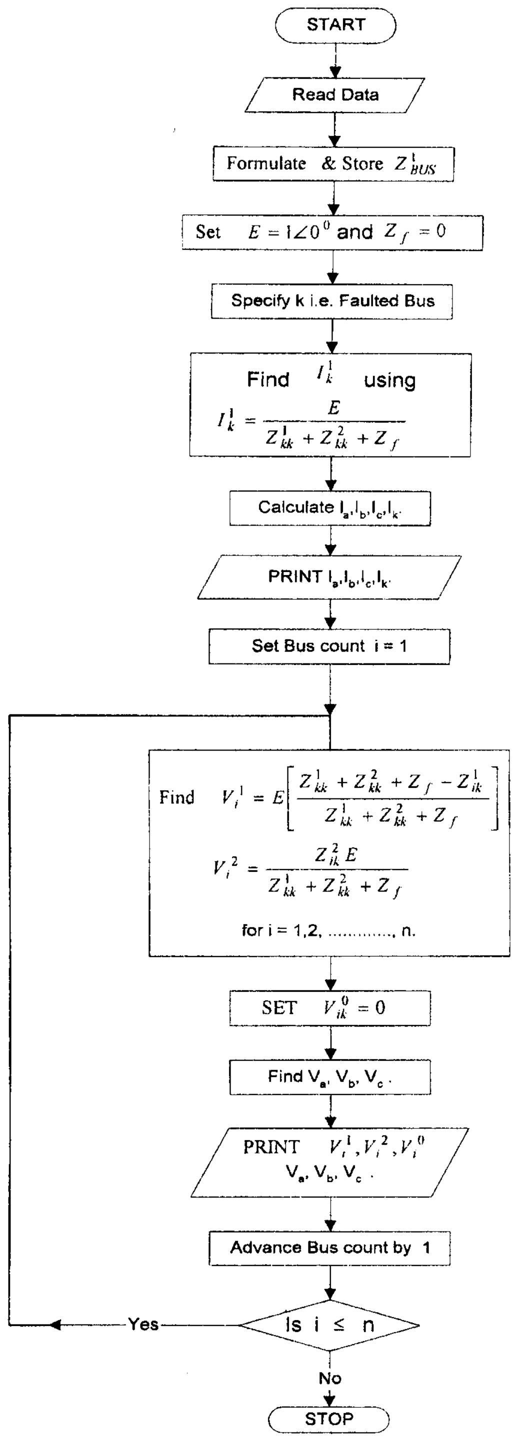

Fig. 8: Flow Chart for Line-To-Line Unsymmetrical Fault.

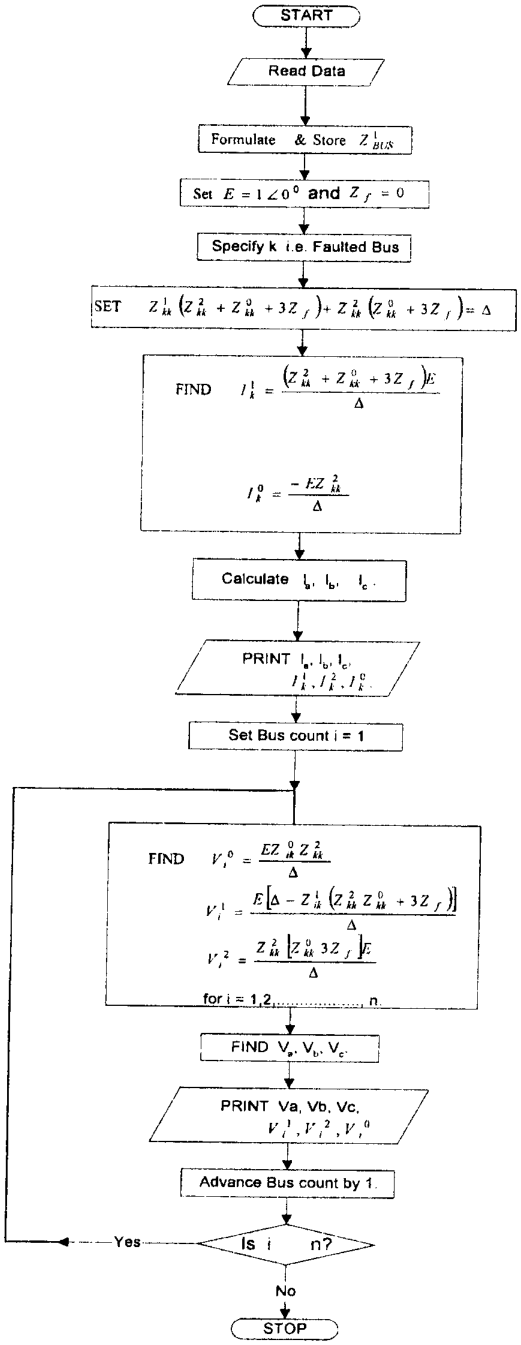

Fig. 9: Flow Chart for Double Line-To-Ground Unsymmetrical Fault.

Table 1 TRANSMISSION LINE DATA ON 330kV, 100MVA BASE (All values are in per unit).

LINE NO.	SENDING END BUS	RECEIVING END BUS	SERIES IMPEDANCE		SHUNT ADMITTANCE		SERIES ADMITTANCE	
			R	X	G	B/2	G	B/2
1	KAINJI	JEBBA (T.S)	0.0015	0.0113	0.0000	0.3363	11.5438	-86.9632
2	JEBBA (G.S)	JEBBA (T.S)	0.0001	0.0011	0.0000	0.0332	81.9672	-901.6393
3	SHIRORO	JEBBA (T.S)	0.0041	0.0339	0.0000	1.0129	3.5162	-29.0733
4	SHIRORO	KADUNA	0.0017	0.0132	0.0000	0.3944	9.5975	-74.5215
5	EGBIN	IKEJA-WEST	0.0011	0.0086	0.0000	0.2574	14.6335	-114.4073
6	EGBIN	AJA	0.0003	0.0019	0.0000	0.0581	81.0811	-513.5135
7	IKEJA-WEST	AKANGBA	0.0004	0.0027	0.0000	0.0707	53.6913	-362.4161
8	IKEJA-WEST	BENIN	0.0051	0.0390	0.0000	1.1624	3.2967	-25.2099
9	AFAM (IV)	ALAOJI	0.0005	0.0035	0.0000	0.1038	40.0000	-280.0000
10	SAPELE	BENIN	0.0009	0.0070	0.0000	0.2076	18.0687	-140.5340
11	AJAOKUTA	BENIN	0.0035	0.0271	0.0000	0.8095	4.6875	-36.2950
12	JEBBA (T.S)	OSOGBO	0.0021	0.0154	0.0000	0.9252	8.6931	-63.7496
13	KAINJI	BIRNIN-KEBBI	0.0122	0.0916	0.0000	0.6089	1.4287	-10.7267
14	KADUNA	KANO	0.0090	0.0680	0.0000	0.4518	1.9129	-14.4527
15	KADUNA	JOS	0.0077	0.0582	0.0000	0.3870	2.2341	-16.8865
16	JOS	GOMBE	0.0104	0.0783	0.0000	0.5205	1.6669	-12.5500
17	OSOGBO	IBADAN	0.0047	0.0352	0.0000	0.2337	3.7268	-27.9115
18	OSOGBO	IKEJA-WEST	0.0092	0.0695	0.0000	0.4616	1.8719	-14.1407
19	OSOGBO	BENIN	0.0099	0.0742	0.0000	0.4930	1.7667	-13.2414
20	IBADAN	IKEJA-WEST	0.0054	0.0405	0.0000	0.2691	3.2347	-24.2601
21	SAPELE	ALADJA	0.0025	0.0186	0.0000	0.1237	7.0980	-52.8094
22	DELTA (IV)	ALADJA	0.0001	0.0089	0.0000	0.0589	1.2623	-112.3454
23	DELTA (IV)	BENIN	0.0042	0.0316	0.0000	0.2102	4.1330	-31.0962
24	ONITSHA	ALAOJI	0.0054	0.0408	0.0000	0.2711	3.1881	-24.0878
25	ONITSHA	NEW-HAVEN	0.0038	0.0284	0.0000	0.1886	4.6285	-34.5920
26	BENIN	ONITSHA	0.0054	0.0405	0.0000	0.2691	3.2347	-24.2601

Table 2 VOLTAGE-CONTROLLED BUS DATA

BUS NO.	BUS NAME	QG SLACK BUS	QD	QMIN	QMAX	VSP
1	KAINJI	0.0000	0.0000	-2.7900	2.7900	1.0500
2	JEBBA	0.0000	0.2400	-3.2300	3.2300	1.0000
3	SHIRORO	0.0000	0.1800	-2.0000	2.0000	1.0000
4	SAPELE	0.0000	0.0000	-4.6700	4.6700	1.0000
5	DELTA (IV)	0.0000	0.3700	-3.4300	3.4300	1.0000
6	AFAM (IV)	0.0000	0.0000	-3.6700	3.6700	1.0000
7	EGBIN	0.0000	0.0000	-5.8200	5.8200	1.0000

Table 3 LOAD BUS DATA.

BUS NO.	BUS NAME	ACTIVE POWER (PG)	REACTIVE POWER (QG)
8	BIRNIN-KEBBI	-0.7200	-0.4300
9	JEBBA (T.S)	-0.3900	-0.1800
10	KADUNA	-1.6100	-0.8200
11	KANO	-2.0400	-0.8000
12	JOS	-0.9800	-0.3460
13	GOMBE	-1.5300	-1.0800
14	OSOGBO	-1.5600	-0.8800
15	IBADAN	-1.8000	-0.9300
16	IKEJA-WEST	-5.1500	-2.2900
17	AJAOKUTA	0.0000	0.0000
18	BENIN	-2.4000	-1.1200
19	ONITSHA	-1.0200	-0.4400
20	ALADJA	-1.5600	-0.8500
21	ALAOJI	-2.1600	-1.0400
22	NEW-HAVEN	-1.1000	-0.1800
23	AKANGBA	-3.0750	-1.5400
24	AJA	0.0000	0.0000

RESULT AND DISCUSSION

From the result of this research work, there is a necessity to have the knowledge of pre-fault voltages and currents in order to proceed to the calculation of fault currents for different types of fault conditions (i.e. 3-phase fault, single line-to-ground fault, line-to-line fault and double lines-to-ground fault). It could be seen that the result of load flow for pre-fault condition falls approximately within the acceptable standard except for the Birnin-Kebbi bus (B8) on which the receiving end voltage is higher than the sending end voltage, and this has been known to be an open-ended line. A solution to this abnormality is to connect reactor to the line in order to absorb the excessive power.

Also, in the aspect of fault analysis, it could be seen that 3-phase fault generates the greatest fault current except in some cases as mentioned in the earlier part of this research work.

The summarized result of the pre-fault condition or load flow study is presented in Table 4, the system data employed in both the load flow calculation and short circuit calculation are presented in Tables 1, 2, 3, 6, 7 and 8; while the summarized result of the fault analysis or short circuit calculation is as presented in Table 5. It could be realized that 3-phase fault generates the greatest fault current, therefore, to select the most appropriate size of Circuit Breaker for the Grid System, it has to be borne in mind that rated momentary current and rated symmetrical interrupting currents are required for the computation of circuit breaker ratings. Symmetrical current to be interrupted is computed by using sub-transient reactance for synchronous generators. Momentary current (rms) is then calculated by multiplying the symmetrical momentary current by a factor of 1.6 to account for the presence of D.C. offset current.

The 3-phase short circuit MVA to be interrupted can be computed as in the follow equation:

where;

$MVA_{sc}(3-phase)$ = 3-phase short circuit MVA.

V_{pfl} = Pre-fault line voltage in kV.

I_{sc} = Short circuit current in kA.

If voltages and currents are in per unit values on a 3-phase basis, then,

$$MVA_{sc}(3-phase) = |V|_{pre-fault} \times |I|_{sc} \times MVA_{Base}$$

.

For example: The Short Circuit Current from the output result of the program for the short circuit studies is 29036A with a pre-fault voltage of 331.4520kV. Therefore, from the above formula;

CONCLUSIONS

From the data collected from National Control Centre [NCC] Osogbo, the capacity of the Circuit Breaker is calculated to be 25,080.09569MVA. This is higher compared with the result of this research (i.e. 20,000MVA capacity) and it will be expensive in term of cost.

In conclusion, it is believed that research work is thorough to the limit of available equipment and accuracy of MATLAB program, hence the Circuit Breaker capacity for National Electric Power Authority [NEPA] 330kV Transmission Grid System should be 20,000MVA.

Table 4. OUTPUT RESULT OF LOAD FLOW (in p.u.).

BUS NO	VOLTAGE	POWER ANGLE	POWER FLOW	CURRENT.
1	1.0500	0.0000	2.4783	2.3603
2	1.0000	-0.4063	7.2494	7.2494
3	1.0000	-8.1156	3.7054	3.7054
4	1.0000	13.1979	7.0151	7.0151
5	1.0000	14.1877	3.7006	3.7006
6	1.0000	18.3091	4.4074	4.4074
7	1.0000	2.0216	4.3769	4.3769
8	1.1312	-3.8483	0.8386	0.7413
9	1.0071	-0.6080	0.4248	0.4218
10	1.0167	-13.0214	1.8067	1.7770
11	0.9950	-20.9513	2.1912	2.2022
12	1.0801	-21.4270	1.0393	0.9622
13	1.0670	-27.4478	1.8727	1.7552
14	1.0225	-0.5695	1.7922	1.7528
15	1.0044	-2.2980	2.0265	2.0175
16	0.9911	-0.1259	5.6465	5.6970
17	1.0417	10.4500	0.0017	0.0016
18	1.0189	10.6285	1.1055	1.0850
19	1.0343	12.0094	0.4316	0.4173
20	0.9970	13.3389	1.7721	1.7775
21	1.0002	17.2945	2.3882	2.3878
22	1.0359	10.2950	1.1134	1.0748
23	0.9865	-0.5490	3.4302	3.4773
24	1.0001	2.0226	0.0157	0.0157

Table 5: SUMMARY OF SHORT CIRCUIT STUDIES RESULT

	TYPE OF FAULT.			
BUS NO.	**3 - PHASE**	**SLG.**	**LL.**	**DLG.**
1	22278	11315	19215	19495
2	11598	4201	9784	10127
3	11843	6245	9759	9814
4	15466	8341	12577	12572
5	8738	4619	7613	7653
6	2312	1384	2260	2239
7	25107	12909	21440	21690
8	2152	1080	1911	1934
9	9987	4916	8646	8811
10	5835	2801	5130	5213
11	1935	934	1780	1793
12	1781	841	1585	1607
13	1063	601	1021	1016
14	8954	4154	7742	7907
15	29036	14060	25007	25530
16	21857	9618	18647	19143
17	5729	2864	4961	5052
18	20628	10071	17822	18175
19	3688	1820	3214	3270
20	8808	4258	7697	7830
21	2178	1080	2009	2020
22	2455	1134	2162	2199
23	25452	11945	21795	22307
24	21324	10663	18466	18804

Fault Current Result (in actual value).
Base Current = 174.9546A
Base MVA = 100,000,000VA.
Base Voltage = 330,000V.

TABLE 6: OVERHEAD LINES PARAMETERS

NO.	OVERHEAD LINE	Z(/ KM)	B(/ KM)
1	330kV 2 x 350mm^2 (BISON) SINGLE CIRCUIT	0.0428 + j0.3219	3.6074
2	330kV 2 x 350mm^2 (BISON) DOUBLE CIRCUIT	0.0394 + j0.303	3.812

TABLE 7: NATIONAL GRID MACHINES PARAMETERS

DATABANK OF NATIONAL ELECTRIC POWER AUTHORITY, NATIONAL CONTROL CENTER OSOGBO.

NO. OF M/C	STATIONS	UNIT	NOM MAX. APPARENT POWER MVA	NOM ACTIVE POWER MW	NOM POWER FACTOR	GEN. RATING MVA	NOM VOLT. RATING KV	REACTANCES Rs ohms	Xd	Xq	PER X'd	UNIT X"d
2	KAINJI HYDRO	5-6	145	120	0.95	126	16	0.0064	0.85	0.55	0.30	0.22
4	KAINJI HYDRO	7-10	85	80	0.94	85	16		0.76	0.43	0.27	0.18
2	KAINJI HYDRO	11-12	115	100	0.95	105.26	16	0.0095	0.78	0.44	0.25	0.15
6	JEBBA HYDRO	1-6	119	96.5	0.85	103.5	16	0.008	0.69	0.48	0.3	0.26
4	SHIRORO HYDRO	1-4	176.5	150.0055	0.85	176.5	16	0.024PU	0.8	0.49	0.3	0.2
6	SAPELE STEAM	1-4	136.7	120.573	0.9	133.97	15.75		2.4	1.54	0.215	0.16
4	SAPELE G.Ts.	1-4	110	75	0.8	110	10.5		2.17	1.92	0.21	0.1333
6	DELTA (IV) G.Ts.	15-20	133.75	113.6875	0.85	133.8	11.5		1.91	1.835	0.319	0.226
6	AFAM (IV) G.Ts.	13-18	110	88	0.8	89	10.5		2.17	1.92	0.21	0.154
6	EGBIN STEAM	1-4	276.9	221.2	0.9	245.8	16	0.004PU	2	2	0.308	0.276

TABLE 8

GENERATORS TRANSFORMERS DATA REF. SYSTEM IMPEDANCE DIAGRAMS 1979/80 NO. 39761.

STATION	RATED MVA	XH-L%	XoH-L%	RATIO	TAPPING RANGE
KAINJI 5-6	2 x 145	12	10.8	16/330	1-5 +7.5% - 2.5%
KAINJI 7-10	2 x 184	12	12	16/330	1-4 +7.5% - 3.5%
KAINJI 11-12	2 x 115	12	10.8	16/330	1-5 +7.5% - 2.5%
JEBBA	6 x 119	10.62	10	16/330	1-6 +4.5 - 2.5
SHIRORO 1	200	12.85	*	15.2/330	1-5 +7% - 2.5%
SHIRORO 2	200	13.11	*	15.2/330	1-5 +7% - 2.5%
SHIRORO 3	200	12.9	*	15.2/330	1-5 +7% - 2.5%
SHIRORO 4	200	13.09	*	15.2/330	1-5 +7% - 2.5%
SAPELE G.T	2 x168.5	13	13	10.5/330	1-4 +5% - 2.5%
SAPELE S.T	6 x 140	14.6	11.6	15.75/330	1-4 +5% - 2.5%
DELTA (IV)	4 x 200	7.84	*	11.5/330	1-5 +5% - 5%
AFAM (IV)	3 x 168.5	13	13	10.5/330	1-4 +5% - 2.5%
EGBIN	6 x 270	10.22	10.22	16/330	1-5 +5% - 5%

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