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PRE-FAULT ANALYSIS: AN APPLICATION OF GAUSS-SEIDEL ITERATIVE METHOD TO 330kV TRANSMISSION GRID SYSTEM IN NIGERIA

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ABSTRACT.

Pre-fault condition of fault analysis is a load flow studies. A MATLAB program was developed to use Gauss-Seidel iterative method of approach for solving load flow equations in determining the performance of the Nigerian National Electric Power Authority [NEPA] 330kV transmission grid system. The code was to be effective as the voltage profile of the bus is bars is within the standard acceptable range.

INTRODUCTION

Load flow studies are necessary for power utility companies engineer in order to know the stability condition of the system. Load flow stability condition is a pre-fault condition. And it can be used to compute the amount of fault current during the fault condition, and hence determine the capacity of a protective device that may be necessary.

The development of numerical methods to solve the load flow equation has been continuing for about five decades now. Previous significant developments in load flow solution techniques includes the Gauss-Seidel method as reported by Ward and Hale, [1956], the Newton-Raphson (NR) method as reported by Tinney and Hart, [1967], and the fast –decoupled methods by Scott and Alsac, [1974].

Stagg and El-Abiad [1968] conducted a detailed comparison of different methods and found that the time per iteration for a 30-bus system for both gauss-Seidel and Newton-Raphson methods are approximately the same. This is one of the reasons why Gauss-Seidel iterative method was employed in this paper for the National Electric Power Authority's [NEPA] 24-bus grid system. An accurate and up-to-date Data were sourced from NEPA, National Control Center, Osogbo Data Bank.

Transmission lines are represented by π – equivalent circuits, while synchronous machines are represented by a voltage source behind sub-transient reactance.

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:

$$E_g'' = V_0 + jI_0X_d'' \qquad (2.1a)$$

$$E_g'' = I_0r_a + jI_0X_d'' \qquad (2.1b)$$

where;

E_g'' = Voltage behind the sub-transient reactance.

V_0 = terminal voltage.

I_0 = machine loaded current.

r_a = armature 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:

$$I_{po} = \frac{P_{lp} - jQ_{lp}}{V_p^*} \qquad (2.2)$$

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,

$$y_{po} = I_{po} \qquad (2.3)$$

where;

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

Therefore,

$$y_{po} = \frac{I_{po}}{V_p^*} \qquad (2.4)$$

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[6] for bus P [as reported by Elgerd, 1973] is given by:

$$V_p = \frac{(P_p - jQ_p)L_p}{V_p^*} - \sum_{q=1}^{p-1} YL_{pq}V_q^{k+1} - \sum_{q=p+1}^{n} YL_{pq}V_q^k \qquad (2.5)$$

where;

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

The term $\frac{(P_p - jQ_p)}{V_p^*}$ in equation (2.5) represents the load current at bus P. For the constant load current representation,

$$\frac{P_p - jQ_p}{\left(V_p^k\right)^*} = \left|I_{po}\right| \angle\left(\Theta_p^k + \Phi_p\right) \qquad (2.6)$$

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,

$$\frac{(P_p - jQ_p)L_p}{V_p^*} = 0 \qquad (2.7)$$

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.3.

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

$$I_{ki} = \frac{P_{ki} - jQ_{ki}}{V_{ki}^*} \quad ; \; i = 1,2, \ldots, m. \qquad (2.8)$$

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.

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).

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.

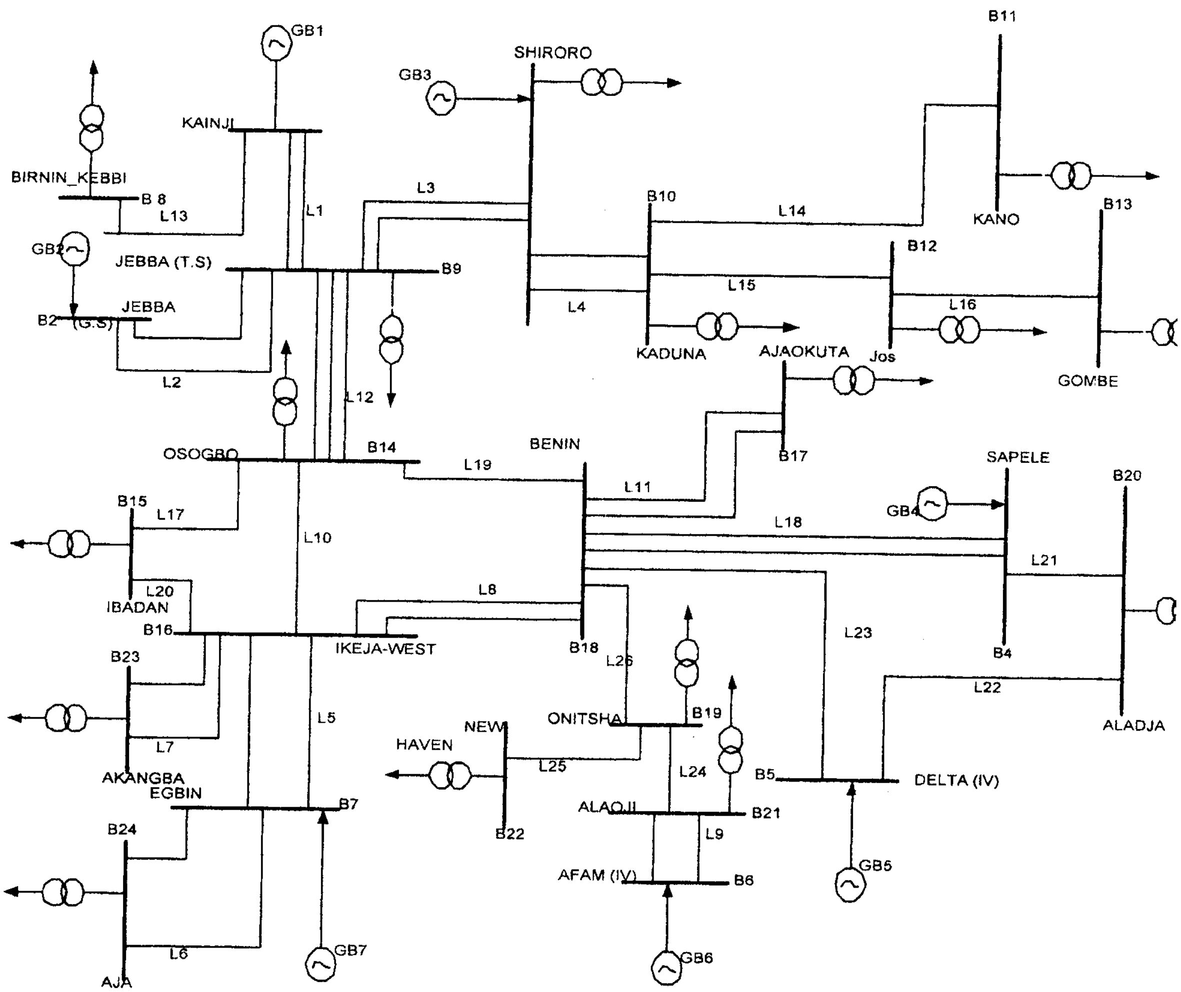

Figure 1: LINE DIAGRAM OF EXISTING NATIONAL 330kV NETWORK [N.C.C. Osogbo].

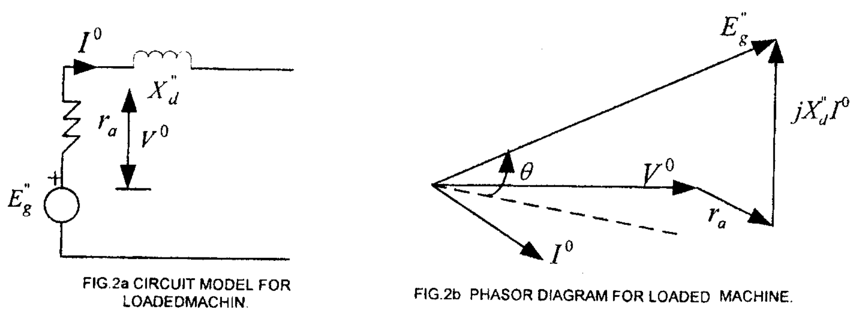

Figure 2: Circuit Model For Loaded Machines.

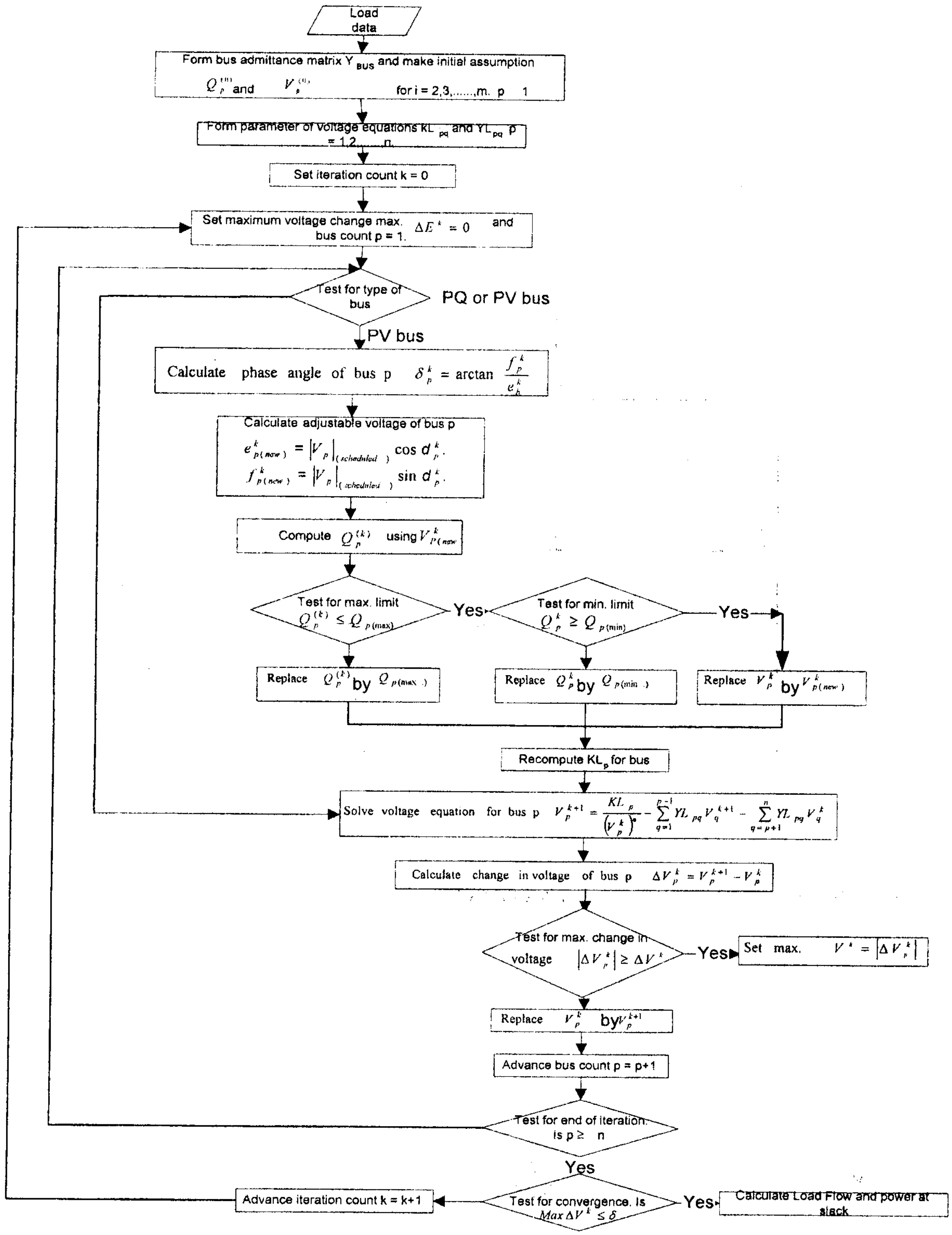

Figure 3: FLOW CHART FOR LOAD FLOW SOLUTION: GAUSS-SEIDEL ITERATIVE METHOD

RESULT AND DISCUSSIONS

There is a necessity to have the knowledge of pre- fault voltages and currents in order to proceed with the calculation of fault currents. The bus-bar pre-fault voltage, pre-fault current and pre-fault power, which flow out of the bus bars, are tabulated in Table 4, while the system data employed in the load flow calculation are shown in Tables 1,2, 3, 5, 6 and 7. It could be seen that the result 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 a reactor to the line in order to absorb the excessive reactive power.

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	Q_G SLACK BUS	Q_D	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 (P_G)	REACTIVE POWER (Q_G)
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

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: 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 6: 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 PER UNIT Rs ohms	Xd	Xq	X'd	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 7

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%
K AINJI 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%

CONCLUSIONS

The pre-fault calculation so far shows that the currents profile along the lines are within an acceptable range, there is no one that deviate up to ±10%. The solution to Birnin-Kebbi (B8) has been as suggested in result and discussion section of this paper. To this end it can be concluded that the Gauss-Seidel iterative method produces good results for small electrical system, and that MATLAB program is a very effective computer program for solving this type of complex equations.

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