Transient Stability Assessment of the Nigerian 330kV Network

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Abstract

Transient stability limit of the Nigerian 330kV power system was assessed in terms of its ability to maintain synchronism among the generating units. The Power (angle) stability limit and voltage stability limit, before, during and after system changes or disturbances were also assessed. The 330kV transmission network was analyzed using the Runge Kutta Method to determine the critical clearing angle and the corresponding critical clearing time. It was observed that a critical clearing angle of 12.85° with critical clearing time of 0.1s gave a more stable result than a critical clearing angle of 166.376° with a corresponding critical clearing time of 0.363s. It was therefore recommended that faults on the network be cleared as quickly as possible so as to maintain the system stability.

Keywords: Power (angle) stability limit, voltage stability limit, synchronism, 330kV Power System, Runge Kutta Method.

1. INTRODUCTION

The 330kV transmission system connects the generating stations and major load centers [4]. Interruptions in this network may hinder the flow of power to the load. Also, the cost of losing synchronism through transient instability is extremely high. This makes transient stability studies significant because it deals with the effects of large, sudden disturbances such as the occurrence of a fault, sudden outage of a line or the sudden application or removal of load.

Consequences of power system instability can be seen in the scenario that occurred in Lagos Nigeria at Murtala Mohammed international airport on the 10th of May 2010. Hundreds of passengers were stranded at the international wing due to power outages that paralyzed operations. This problem was as a result of short circuit fault, which led to the tripping of power supply to some of the areas in the terminal building. The fault lasted for more than three hours. Finally, power was restored after the fault had been cleared [2].

The quality of electricity supply is measured in terms of the voltage, frequency, lack of interruptions to supply of power and ability to withstand faults and recover quickly. It is a well known fact that the Nigerian power supply is inadequate and epileptic in nature and suffers a lot of outages. It is therefore important to assess the Transient and Voltage stability limits of the Nigerian 330kV power system before, during and after system changes or disturbances.

2. MATERIALS AND METHOD

The equation of central importance in power system stability analysis is the rotational inertia equation that describes the effect of unbalance between the electromagnetic torque and the mechanical torque of the individual machines. This equation is known as the *swing equation* and it is given by:

$$M\frac{d^2\delta}{dt^2} = P_m - P_e = P_a$$

Where

M = angular momentum (Joule-sec/rad)
P_{mec} = Input mechanical power (W)
P_{elec} = Output electrical power (W)
P_a = Net accelerating power (W)

This equation is a non linear differential equation that can be solved using Runge Kutta method [5]. Analysis of transient stability of the Nigerian 330kV network involves the computation of nonlinear dynamic responses to large disturbances. The occurrence of fault is followed by the isolation of the faulted element by a protective device.

Determination of Time Response Using the Runge-Kutta Method:
The general formula for Runge Kutta method is

$$\delta_{n+1} = \delta_n + \Delta\delta$$

$$= \delta_n + \frac{k_1 + k_2}{2} \ldots\ldots\ldots(3.1)$$

Where

$$k_1 = f(\delta_n, t_n)\Delta t$$

$$k_2 = f(\delta_n + k_1, t_n + \Delta t)\Delta t$$

This method is equivalent to considering first and second derivative terms in the Taylor series. Hence it is a second order Runge Kutta Method.
The system operating condition with quantities expressed in per unit is specified as follows:

$\Delta t = 1.0s$, and $\Delta\omega = 0$ at pre fault. Let the turbine power $P_m = 1.0$, and $H = 3.5$ *MW.s/MVA*

The critical clearing angle was found to be $\delta_{cr} = 166.376°$
The corresponding critical clearing time is derived from the swing equations and is given by:

$$t_{cr} = \sqrt{(\delta_{cr} - \delta_0).\frac{4H}{\omega_0 P_m}}$$

Thus, the corresponding critical clearing time gotten from this equation is 0.363secs.

One Machine System connected to the National grid.
A one machine system connected to an infinite bus bar is first considered, using Jebba power station as a case study. The power transfer can be formulated as follows:

$$P_e = \frac{|E||V|}{X_e} sin\delta \quad (MW) \ldots\ldots 3.2$$

and

$$P_m = P_{mo} = constant \ldots\ldots\ldots (3.3)$$

At

$$\delta = 90^{\circ}$$

$$P_e = P_{e,max}$$

Therefore,

$$P_{e,max} = \frac{|E||V|}{X_{eq}} \quad \dots\dots\dots (3.4)$$

3. RESULTS AND DISCUSSIONS

Two fault clearing times are specified in this study:

1. A fault clearing time of 0.363secs with a corresponding critical clearing angle of 166.376° is specified.
2. A fault clearing time of 0.1sec with a corresponding critical clearing angle of 12.85° is specified.

Voltage Stability Limit

According to the Grid Code [3], the power system operator endeavours to control the different bus bar voltages to be within the voltage control range of $330kV \pm 5\%$. Therefore, generators must be adjusted during the day to maintain voltages within this secure range. In fact, most generators are designed to have automatic voltage regulators [1]. Also, transmission lines should not be operated too close to their stability limit. There must be a margin to allow for disturbances.

The following plots in figures 1 and 2 demonstrate this.

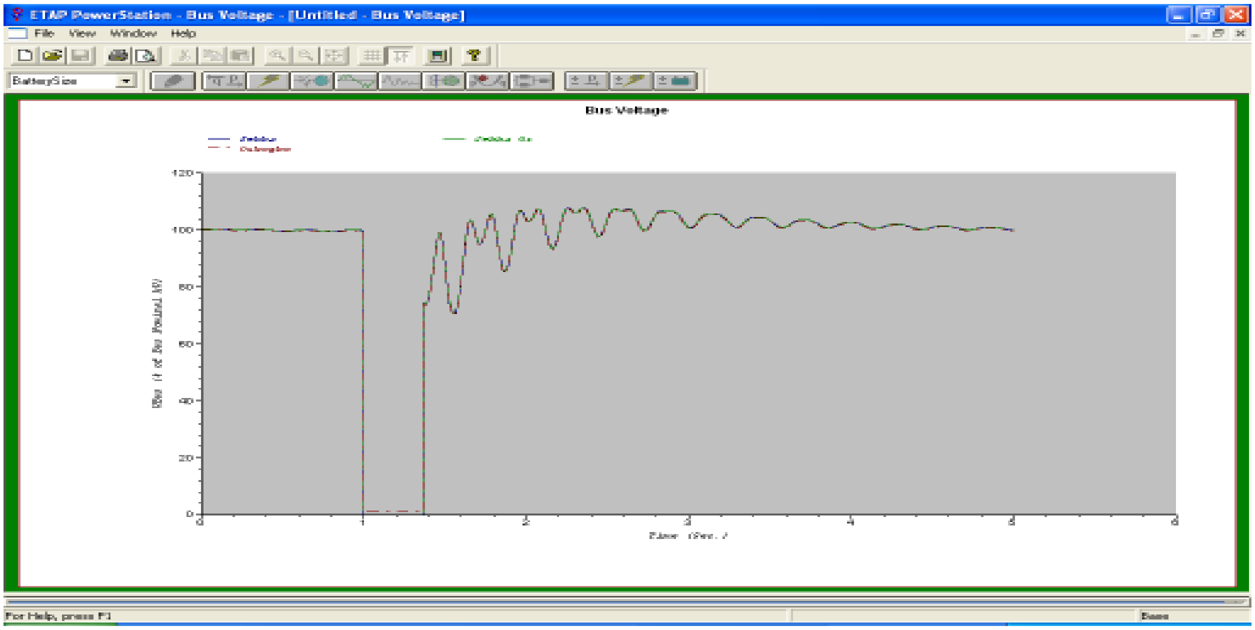


FIGURE 1: Bus Voltage at 0.363 secs

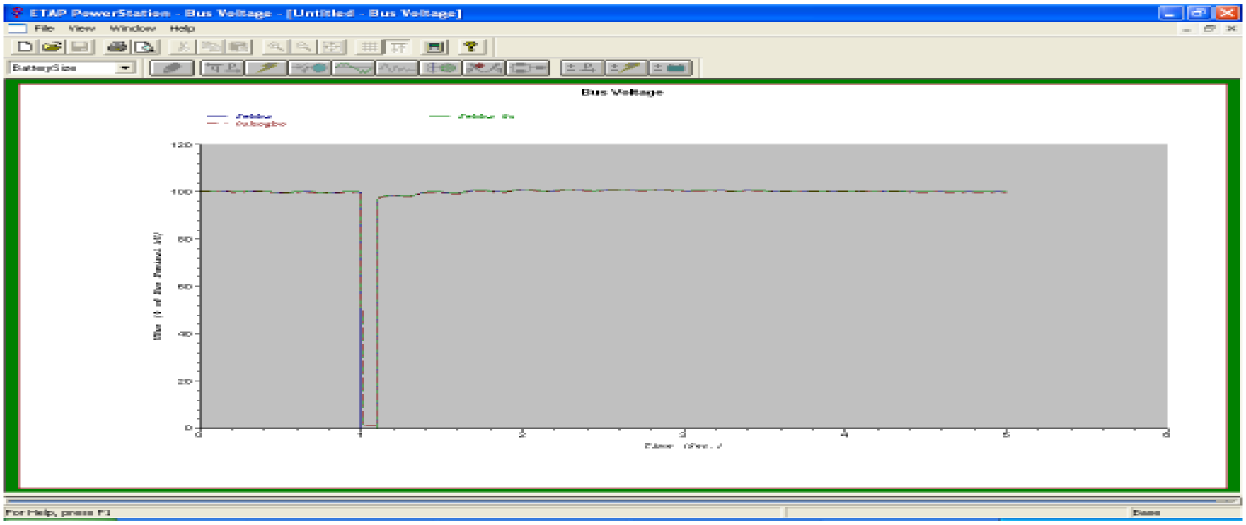


FIGURE 2: Bus Voltage at 0.1 secs

The Voltage stability limit, before, during and after system changes or disturbances is demonstrated in tables 1-3.

Time (s)	Bus Voltage (%) at t_{cr} 0f 0.363s	Bus Voltage (%) at t_{cr} of 0.1s
0.000	100.22	100.22
0.050	100.27	100.27
0.100	100.42	100.42
0.150	100.38	100.38
0.200	100.12	100.12
0.250	100.09	100.09
0.300	100.21	100.21
0.350	100.24	100.24
0.400	100.13	100.13
0.450	99.87	99.87
0.500	99.68	99.68
0.550	99.79	99.79
0.600	99.98	99.98
0.650	100.03	100.03
0.700	99.91	99.91
0.750	99.70	99.70

0.800	99.62	99.62
0.850	99.77	99.77
0.900	99.94	99.94

TABLE1: Transient Stability Analysis for Bus Voltages at Pre Fault

Time (s)	**Bus Voltage (%) at t_{cr} 0f 0.363s**	**Bus Voltage (%) at t_{cr} of 0.1s**
1.000	99.85	99.85
1.050	0.00	0.00
1.100	0.00	0.00
1.150	0.00	98.29
1.200	0.00	98.67
1.250	0.00	98.34
1.300	0.00	98.26
1.350	0.00	99.08
1.363	0.00	99.32

TABLE 2: Transient Stability Analysis for Bus Voltages during Fault

Time (s)	**Bus Voltage (%) at t_{cr} 0f 0.363s**	**Bus Voltage (%) at t_{cr} of 0.1s**
1.400	76.64	99.81
1.450	96.29	100.06
1.500	87.64	99.90
1.550	70.76	99.42
1.600	83.16	99.45
1.650	103.21	100.09
1.700	96.15	100.58
1.750	100.18	100.67
1.800	103.40	100.38
1.850	87.35	100.01
1.900	90.99	100.14
1.950	106.14	100.64

2.000	103.83	100.94
2.100	104.69	100.56
2.200	99.18	100.52
2.300	100.20	101.03
2.400	100.65	100.58
2.500	104.00	100.67
2.600	106.93	100.97
2.700	99.00	100.55
2.800	105.63	100.70
2.900	106.48	100.82
3.000	100.87	100.47
3.100	105.40	100.64
3.500	103.43	100.50
3.600	101.30	100.31
3.700	103.62	100.44
3.800	102.04	100.35
3.900	101.36	100.23
4.000	100.00	100.34
4.100	101.08	100.23

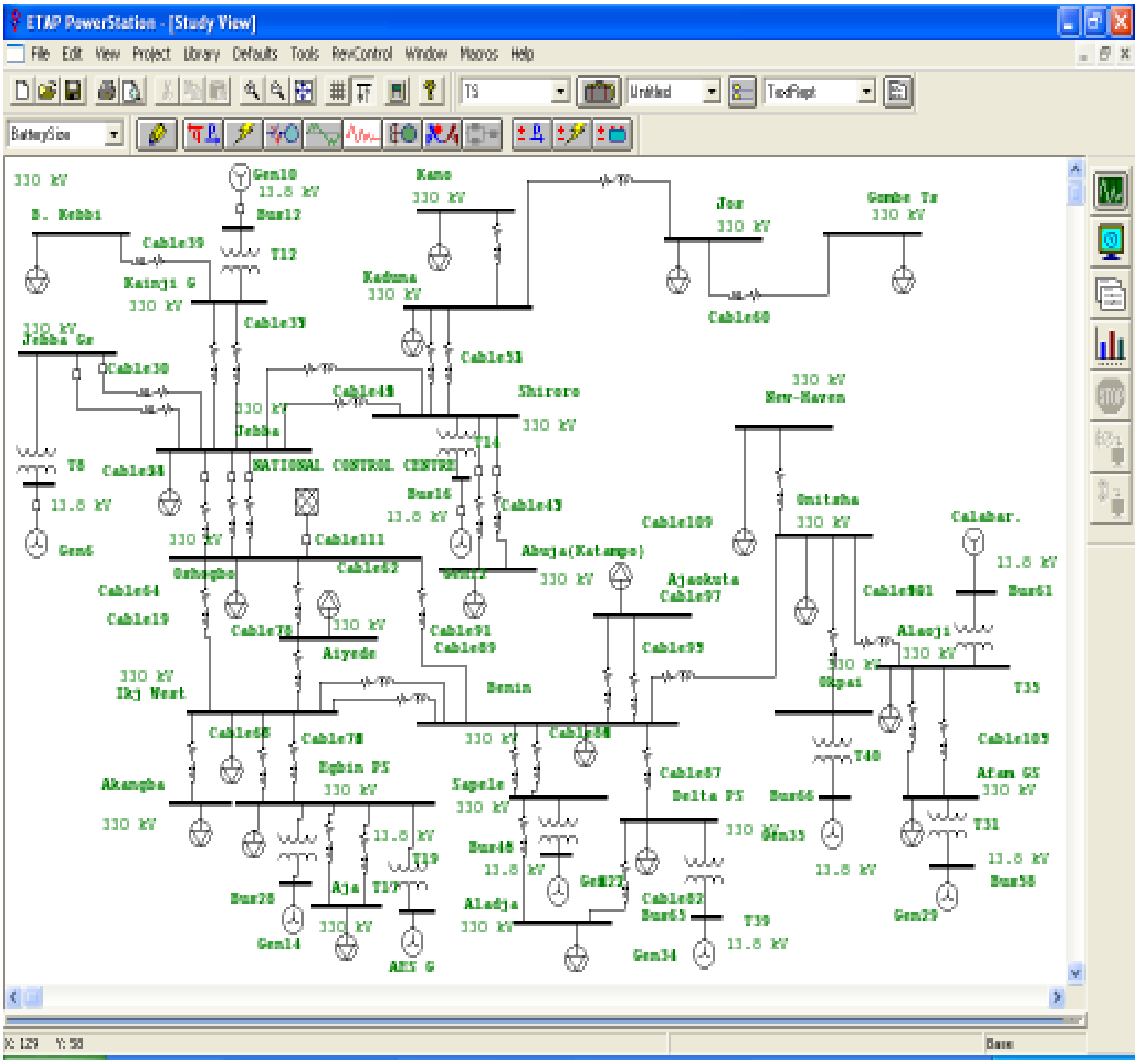
TABLE 3: Transient Stability Analysis for Bus Voltages at Post Fault

The maximum power that the machine can deliver occurs when $\delta = 90^{\circ}$. Any further increase in δ will result in a decrease in the electrical power output. Hence, based on the result gotten, it can be deduced that the system is unstable at a critical clearing time of 0.363s but is stable at a critical clearing time of 0.1s.

Electrical appliances are designed to operate best at its rated voltage. Efficiency and operating characteristics are adversely affected when they are operated at voltages other than their rated values. For example, with a lighting load, a small decrease in voltage causes a great decrease in light output. Motors subject to reduced voltage have poor starting torque and poor speed regulation. They draw more current than they would at their rated voltage. This causes overheating, thus, making them inefficient [6].

Transient Stability Assessment of the Nigerian 330kV Network.

Figure 3 shows the complete Nigeria 330kV Transmission Network with synchronous generators, transformers, transmission lines and loads.



Synchronism

The Nigerian 330kV network consists of synchronous machines connected by transmission links. In order to maintain stability, these machines must rotate at the same speed and frequency of 50Hz. The phase angles between them must not vary appreciably.

Also, if the oscillatory response of the power system during the transient period is damped and the system settles in a finite time to a new steady operating condition, then the system is stable. If the system is not settled in a finite time, then it is considered unstable.

The following plots in figures 1-6 are generated for the 330kV Network with fault clearing times of 0.363s and 0.1s

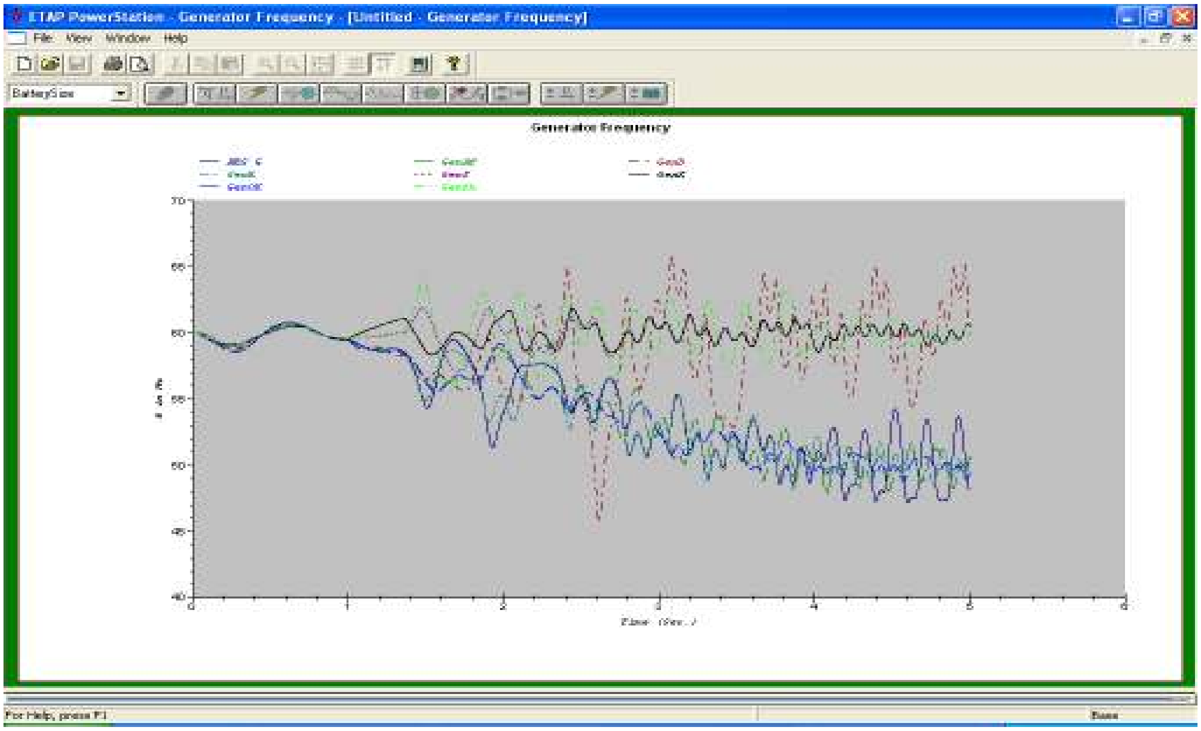


FIGURE 4: Frequency of the various generators at 0.363s fault clearing time

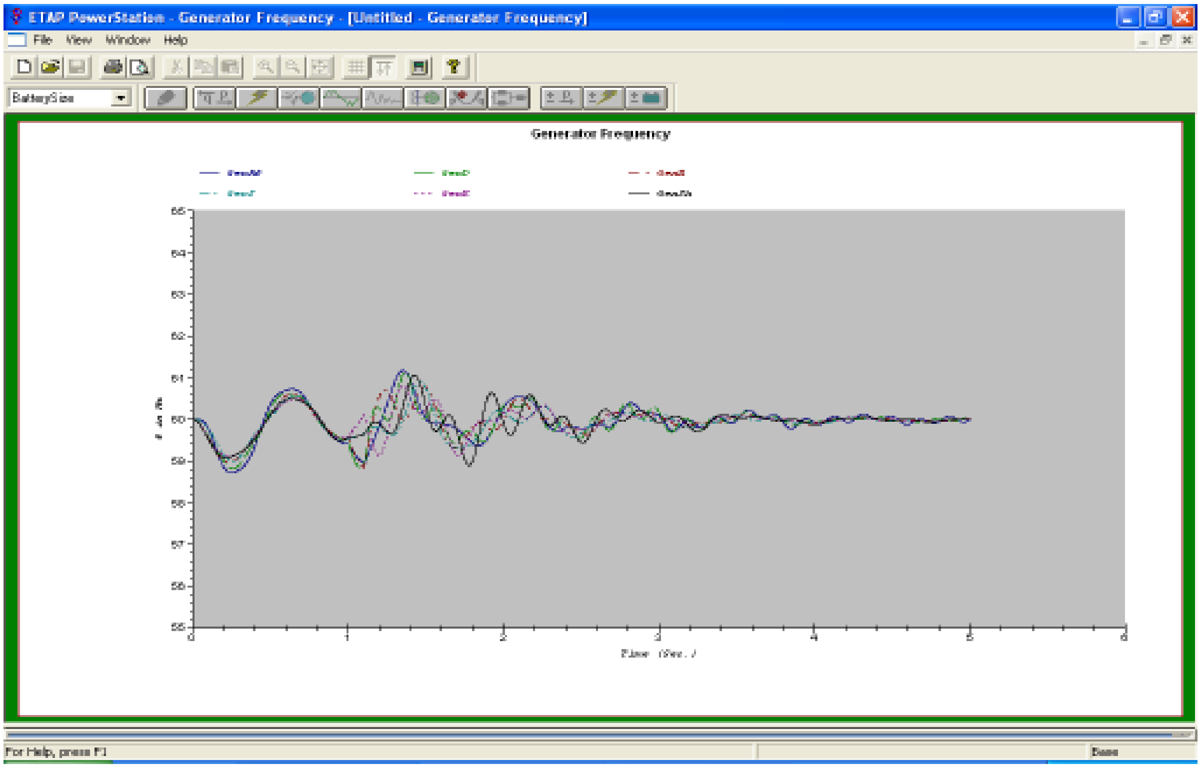


FIGURE 5: Frequency of the various generators at 0.1s fault clearing time

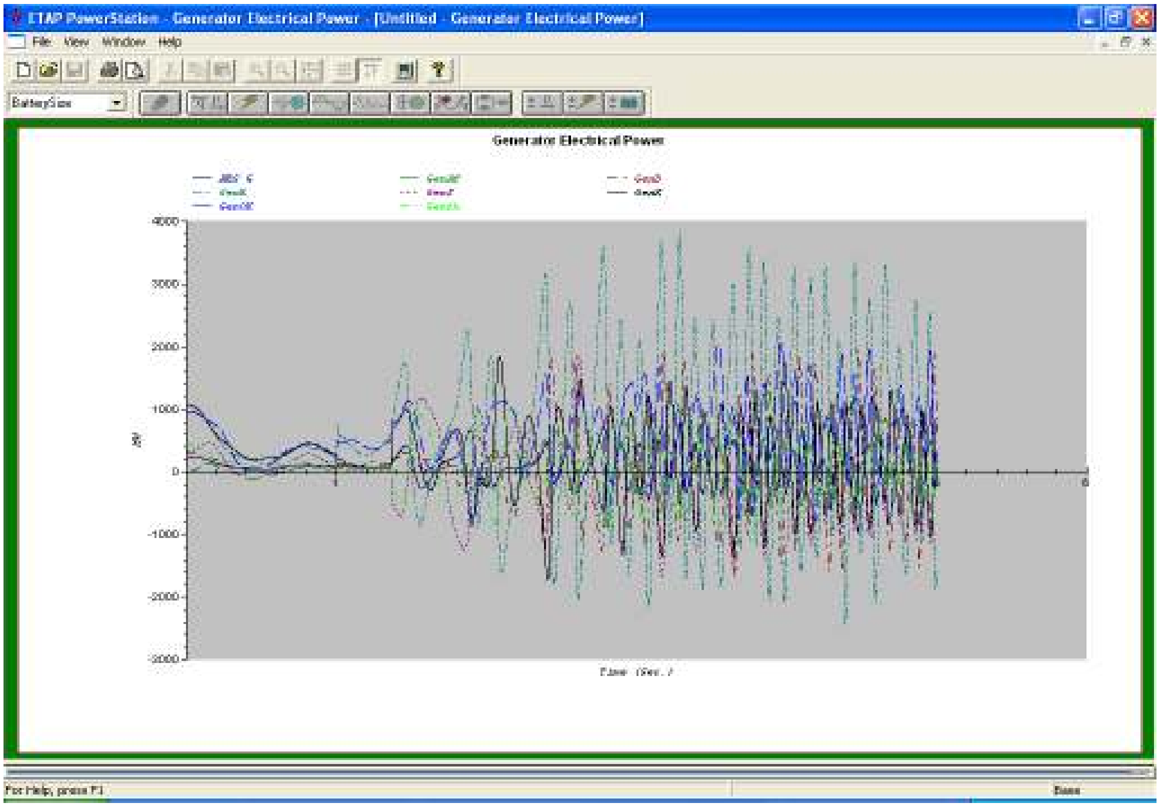


FIGURE 6: Electrical Power for the various generators at 0.363s fault clearing time

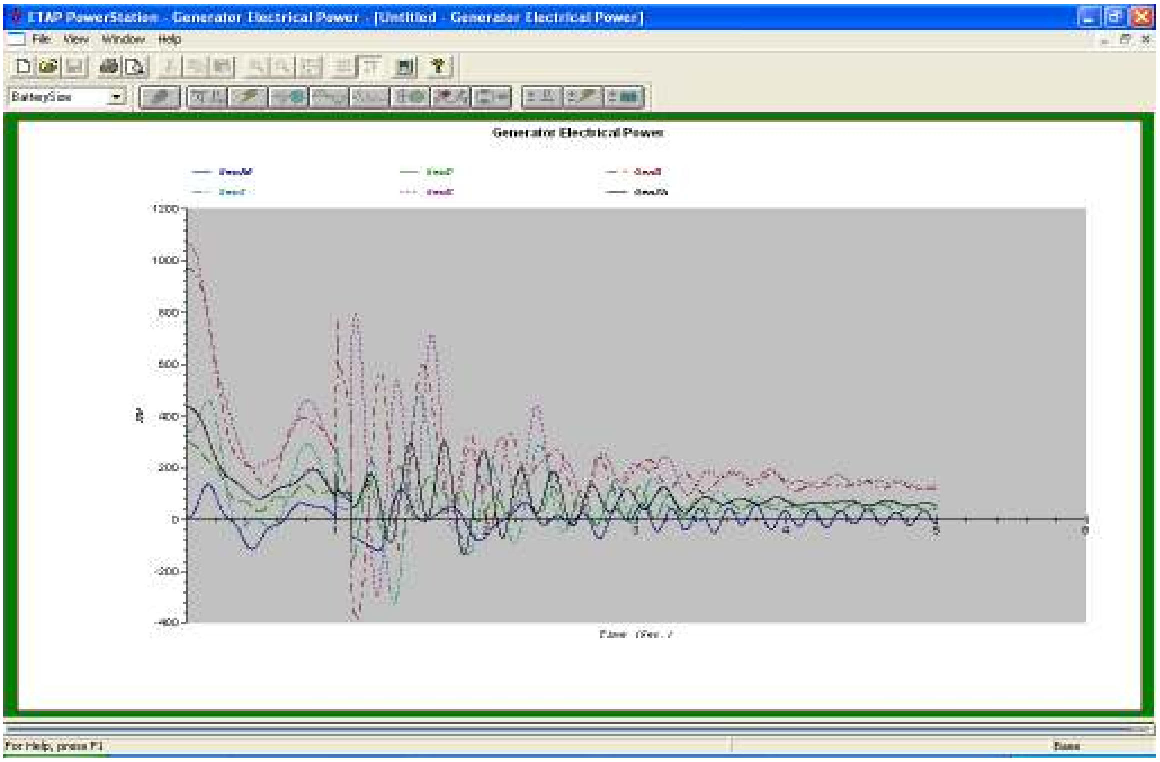


FIGURE 7: Electrical Power for the various generators at 0.1s fault clearing time

ACHIEVEMENTS:

This study has been able to show the urgent need for upgrading and expanding the Nigerian 330kV network. It has been established that faults should be cleared as quickly as possible. This will save the system from total collapse. Analysis of this study showed that a fault clearing time of 0.1s gave a more stable result than a fault clearing time of 0.363s.

CONSLUSION & FUTURE WORK

In summary, this study has assessed the stability limits of the Nigerian 330kV transmission network in terms of its ability to maintain synchronism among the generating units. Also, the Voltage stability limit for a one machine system, before, during and after system disturbances was assessed. A short circuit fault was simulated to occur at one of the lines linking Jebba generating station to Jebba transmission station. The fault was cleared by disconnecting the line by means of a circuit breaker. Runge Kutta Method was then used to analyze the 330kV transmission network.

The critical clearing angle was found to be 166.376˚. The corresponding critical clearing time was 0.363s. After simulation, it was discovered that the system remained unstable.

Another critical clearing time of 0.1s was specified to see the system's reaction. The corresponding critical clearing time was found to be 12.85˚. Plots for the generator frequency, power output and voltage were generated. Results from these plots showed that the system remained stable.

Hence, it was deduced that faults on the network should be cleared as quickly as possible to avoid endangering the system. This can be achieved by means of protective devices and fault location algorithms. Other sophisticated control measures can be employed to achieve this objective.

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