Fault Analysis of 132KV Transmission Grid Power System for Improved Stability Using 4th Order Runge Kutta Numerical Technique

MURANA, A. A[1], IDONIBUOYE-OBU, D. C[2], BRAIDE, S. L[3]
[1, 2, 3] *Department of Electrical Engineering, Rivers State University, Port Harcourt, Nigeria.*

Abstract- System collapse or cascaded outage within a power system is very hazardous to the power system equipment and operation. This work investigates the transient response of the generators in 132KV grid network of Afam power generating station to Port Harcourt Main (Zone 2) injection substation using 4th order Runge Kutta numerical techniques to determine the critical clearing angle (CCA), then critical clearing time. When Electrical Transient Analysis Program (ETAP 19.1) is deployed with circuit breaker and relay time setting of (0.00,0.02, 0.04, 0.06, 0.08, 0.10, 0.12, 0.14), the results obtained indicate that the protective device must be coordinated properly to quickly clear a 3-phase balanced fault at any bus, in order to enhance stability margin to avoid system collapse. The results obtained shows that 4th order Runge Kutta Numerical Technique is stable, accurate, has a response time of 0.02s, lower percentage error of -51% and it gives a significant power transfer capability of network from 0pu to 3.7870pu after fault has been cleared.

Indexed Terms- System collapse, transient stability, 4th order Runge Kutta technique, critical clearing angle, critical clearing time, power transfer capability.

I. INTRODUCTION

Successful operation of a power system depends largely on the engineer's ability to provide an uninterrupted service to the load centers. The consumers must be fed, with specified voltage and frequency at all times for the power supply to be termed reliable.

The stable operation of a power system ensures a continuous match between energy input going to the prime mover and output electrical energy taken out of the synchronous machine [1]. The inability of the power systems in developing countries to generate enough electric power has leads to extra-ordinary power loss [12]. Due to privatization of all sections of the power system network, operating under different power utility companies and the rapidly increasing demand of electricity, the companies operate the power transmission grid very close to voltage stability limit [2] [3]. This has resulted in violations of the system stability limit which in turn causes voltage collapse scenarios around the world with high cost of both utilities and consumers. A power system is said to transiently stable if the load angle return to a steady value following the clearance of sudden and large disturbances of the synchronous machine. Allowing such disturbances in the power system, rotor angle, angular speed and power transfer undergo fast changes whose magnitude are dependent upon the severity of disturbances [12]. The relative motion equation that describes the swinging response of the synchronous machine is a second order differential equation, so it requires the determination of accurate approximate solutions of the problem in order to assist the power system operators to take an informed decision in carrying out physical or programmable actions to minimize system collapse.

II. STATEMENT OF PROBLEM

If an Electric power system must maintain a reliable service, the grid must remain intact and capable of withstanding a variety of small and large disturbances so as to meet the task of delivering all complex loads at normal operating condition. The National transmission grid of developing countries like Nigeria is fragile and highly stressed, with long and radial transmission line,so it takes a longtime to restore power when a voltage collapse occurs which constituted a serious clog in the wheel of the economic and industrial development of the country [5] [6] [3]. The operators have to come up with several measures and methodologies to overcome or ameliorate transient instability in order to maintain system security and performance.

III. AIM OF THE STUDY

The aim of this research work is to assess and predict transient instability on a 132KV transmission power system network of economically developing countries.

The objectives of this research work are presented as:

i. To determine the power history (load profile) of the Afam power generation to transmission and use the information for transient simulations.
ii. To model the transmission network for transient stability studies using Electrical Transient Analysis Program (ETAP)
iii. To use 4th order Runge-Kutta numerical technique for determining transient behaviour of the power system like changes in rotor angle, angular speed of synchronous machine and power transfer capability of the transmission line before, during and after fault occurence.
iv. To compare the proposed numerical technique and its application with conventional swing equation technique, Modified Euler's Method for validation.

IV. LITERATURE REVIEW

According to [7] they applied a static synchronous compensator (STATCOM) based on an intelligent system composed of recurrent neural network (RNN), an adaptive critic network and Proportional Integral Derivate (PID) damping controller for power system transient stability improvement. The technique is applied to wind and wave (sea shore) farms in an integrated hybrid 12-bus multi power system.

According to [8] they performed transient stability simulation studies taken into account balanced and unbalanced fault cases and comparing with different damping techniques with proposed technique [7] they examined the use of an optimal unified power flow controller (OUPFC) based on the Lyapunov energy function (LEF) for enchancement of the transient stability of a test power system. Their proposer OUPFC was compared to the standard Unified Power Flow Controller (UPFC) and they were able to report significant improvements, faster damping for the OUPFC consequently.

According to [9] they investigated the transient stability performance of the Ikeja-West sub-transmission network of the Nigeria 330KV through a number of numerical fault simulation; for these set of simulations, the Electrical Transient Analysis Program (ETAP) software was used with the primary objective to determine the security limits of the case sub-transmission network. By redirecting the focus of transient stability studies towards a pre-fault response system such as the system is able to respond in milliseconds just before instability is induced.

According to [10] they studied the performance of a particle swarm optimization support vector machine (PSO-SVM) approach to transient stability analysis in the context of pre-fault control; this technique is implicated in such a way that the operating points of the power system are predicted and adjusted to secure the power system from consequent instability.

According to [1] they carried out transient stability analysis of a 132KV power transmission line using modified Euler numerical techniques. They opined that Modified Euler technique is accurate in determining the synchronous machine dynamics like rotor angle progressive increase at incremental time setting of the relay when the system is subjected to fault when compared with swing equation technique.

According to [11] they investigate the application of trapezoidal numerical rule on a 33KV transmission network in carrying out transient stability. They found out that the trapezoidal numerical rule is accurate and has a faster respond time when compared with modified Euler method in transient stability studies.

V. MATERIALS AND METHOD

3.1 Description of the Study Case

The network under consideration is 132KV power transmission network from Afam power generating to Port Harcourt Mains (Zone 2) injection substation. The substation has 3x60MVA, transmission transformers, with incoming voltage level of 132KV and outgoing voltage level of 33KV wirh cumulative load of 167.5MW.

3.2 The bus loading conditions for the network under study are the maximum and minimum load ranges from Afam generating plant data base. The generator system and network data used for this research are as presented in Tables 3.1.-3.4

Table 3.1: Bus Loading for the Transmission Network

Bus	MW (Max)	MW (Min)	MVAR (Max)	MVAR (Min)
T_1A	18	10.5	14.4	8.4
T_2A	25	12	20	9.6
T_3A	24.5	16	19.6	12.8

Source: Transmission Company of Nigeria, TCN

Table 3.2: Transmission Network Parameters

S/N	Parameters	Assigned Numerical Values
1.	H (G17&G18)	2.4816pu
	H(G19 & G20)	5.5969pu
	Total	8.08Pu
2.	MW (G17 & G18)	284.4MW
	MW (G19 & G20)	133MW
	Total	381MW
3.	Mechanical power	383MW
4.	Frequency (f)	50Hz
5.	Infinite Bus Voltage	1Pu

Source: Transmission Company of Nigeria

Table 3.3: Generation system parameters (Afam IV & V)

	m	To
T_1A	Afam	Lumped Load on T_1A
T_2A	Afam	Lumped Load on T_2A
T_3A	Afam	Lumped Load on T_3A

Source: Transmission Company of Nigeria

Table 3.4: Designation of Case Study (Afam IV & V)

S/N	Bus	Designation	Description
1.	T_1A	Feeder T_1A	All load on outgoing-going feeder from T_1A sub network
2.	T_2A	Feeder T_2A	All loads on outgoing feeder from T_2A sub network.
3.	T_3A	Feeder T_3A	All loads on outgoing feeder from T_3A sub-network

Source: Transmission Company of Nigeria and Port Harcourt Electricity Distribution Company.

3.5 Transient Stability Analysis Technique

Under normal operating conditions, the synchronous machine is assumed to be operating at its stable prefault equilibrium points. The behaviour of the machine is given by:

$$\frac{Md^2\theta}{dt^2} = Pm - Pe \qquad 3.1$$

Equation (3.1) can be written as

$$\frac{H}{\prod f}\frac{d^2\delta}{dt^2} = Pm - Pe(Pu) \qquad 3.2$$

Equation (3.2) is called the swing equation of a synchronous machine

Where:

H: Inertia constant

Pm: Input mechanical energy

Pe: Output electrical power

δ: Power angle

Thus, for a small disturbance of the rotor ($\Delta\delta$), equation (3.2) becomes:

$$\frac{H}{\prod f}\frac{d^2\delta}{dt^2} = \Delta Pm - \Delta Pe \qquad (3.3)$$

Whereby the mechanical power of the generator is assumed to be constant equation (3.3) becomes

$$\frac{H}{\prod f}\frac{d^2\delta}{dt^2} = \Delta Pm(Pu) - Pe(Pu) \qquad (3.4)$$

By considering maximum electrical transfer, equation (3.4) can written of:

$$\frac{H}{\prod f}\frac{d^2\delta}{dt^2} = Pm - P\max Sin\delta \qquad (3.5)$$

$$PS = \frac{dp}{d\delta}\Big|_{\delta o} 0 \quad = P_{max} \cos \delta o \qquad (3.6)$$

PS = P_{max} Cos δo: The slope of the power angle curve at δo, Ps is positive when $0^o < \delta < 90^o$
Where:

P_S: Shaft power
δo: Initial operating angle of the machine

3.6 Calculation of Line Network Parameters using base of 250MVA

$$Pe = \frac{381}{250} = 1.524Pu$$

$$Pm = \frac{383}{250} = 1.532Pu$$

Reactance, X_{eq} = generator reactance + line reactance + line reactance + transformer reactance
X_{eq} = j0.275 + j0.097 + j0.0405
X_{eq} = j0.4125pu

$$\text{Real power (s)} = \frac{Pe}{Pf}\angle Cos^{-1}(\theta)$$

Where Pf = $\theta = 0.8$

$$S = \frac{1.524}{0.8}\left[Cos^{-1}(0.8)\right] =$$

$1.905 \angle -36.87^o$

$$\text{Current, I} = \frac{S^*}{V^*} = \frac{1.905\angle -36.87^0}{1.0\angle 0}$$

I= $1.905 \angle -36.87^o$)
Excitation voltage, $E^1_g = V + JX_d^1$
E^1_g = $1\angle^o$ + (j0.4125) ($1.905 \angle -36.87^0$)
E^1_g = 1 + j0 + 0.4715 + j0.6286
E^1_g = 1.4715 + j0.6286
E^1_g = 1.600 < 23.2^{o}pu.
Initial operating power angle becomes
δo = 23.20^o = 0.4049rad
Synchronous speed, $W_o = 2\prod f = 2\prod \times 50$ = 314.1593rad/sec.

3.6 Application of swing equation Technique to Transient Stability Applying Values into the Swing equation (3.2)

$$\frac{H}{\prod f}\frac{d^2\delta}{dt^2} = Pm - Pe$$

$$\frac{8.08d^2\delta}{\prod x 50 dt^2} = (1.532 - 0) \quad \text{during fault, Pe = 0}$$

$$\frac{d^2\delta}{dt^2} = \frac{\prod x 76.6}{8.08}$$

Integrating both sides

$$\frac{d\delta}{dt} = \int \frac{\prod x 76.6}{8.08} dt + 0$$

Integrating again

$$d\delta(t) = \frac{\prod x 76.6}{16.16} t^2 + \delta 0$$

$$\delta(t) = \frac{\prod x 76.6}{16.16} t^2 + 0.4049$$

The calculation is repeated for tenth cycles.

3.7 Application of Modified Euler Method Transient Stability

Using the two conventional first order differential equations, the Modified Euler can be investigated for ten cycle as:

$$\frac{d\delta}{dt} = \omega_L - \omega_s \qquad (3.7)$$

Where,
ω_L: Is the latest angular velocity
ω_s: is the synchronous speed
δ_L: is the latest torque angle

$$\frac{d\omega}{dt} = \frac{50\pi}{H}(P_m - P_e) \qquad (3.8)$$

Where,
H: is the inertial constant
P_m: is the mechanical power
P_e: is the electrical power
During fault condition $P_e = 0$
Case 1: First Calculation at t=0.02, 1 cycle

First evaluation of $\left(\delta, \omega, \frac{d\delta}{dt}\right)$

$$\frac{d\delta_1}{dt} = \omega_L - 314.1593$$

$$\frac{d\delta_1}{dt} = 314.1593 - 314.1593$$
$$\frac{d\delta_1}{dt} = 0$$
$$\frac{d\omega_1}{dt} = 19.4405(1.532 - 0)$$
$$\frac{d\omega_1}{dt} = 29.7828$$

The predictor equation were use for both results

$$\delta_1(0.02) = \delta_L + \left(\frac{d\delta_1}{dt} \times \Delta t\right)$$
$$\delta_{1(0.02)} = 0.4049 + (0 \times 0.02)$$
$$\delta_1(0.02) = 0.4049 rad = 23.2^0$$
$$\omega_1(0.02) = \omega_L + \left(\frac{d\omega_1}{dt} \times 0.02\right)$$
$$\omega_1(0.02) = 314.1593 + (29.7828 \times 0.02)$$
$$\omega_1(0.02) = 314.1593 + 0.5957$$
$$\omega_1(0.02) = 314.755 rad/sec$$
$$\omega_1 = \omega_r = 314.755 rad/sec$$

The calculation is repeated for tenth cycles

3.8 Application of 4th Order Runge-Kutta Numerical Technique to Transient Stability

Recalling the two first order differential swing equations are:

$$\frac{d\delta_L}{dt} = \omega_L - \omega_s \quad (3.9)$$

$$\frac{d\omega_L}{dt} = \frac{\pi f}{H}(P_s - P_e) \quad (3.10)$$

Where

δ_L : is the latest rotor angle
ω_L :is the latest angular velocity
ω_s : is the synchronous speed
f : is frequency
P_s : is shaft power
P_e: is Electrical power
During fault condition, $P_e = 0$
Initial point of solution is $\left(0, \delta_{(0)}, \omega_{(0)}\right)$

The synchronous speed, $\omega_s = 2\pi f = 2\pi \times 50 = 314.1593 rad/sec$
If the shaft power is 1.532pu and $H_{eq} = 8.08 MJ/MVA$ as calculated before, $\frac{\pi f}{H} = \frac{50\times\pi}{8.08} = 19.4405$ (3.11)

Substituting values into equations (3.7) and (3.8)

$$\frac{d\delta_L}{dt} = \omega_L - 314.1593 \quad (3.12)$$

$$\frac{d\omega_L}{dt} = 19.4405(1.532 - P_e) \quad (3.13)$$

The differential change in the rotor angle and angular speed with time, using 4th order Runge-Kutta method for analysis of the swing equation is as shown,

$$\frac{d\delta_L}{dt} = (\omega_L - 314.1593)\Delta t \quad (3.14)$$
$$\frac{d\omega_L}{dt} = 19.4405(1.532 - P_e)\Delta t \quad (3.15)$$

Recall the general formula of the RK4 method

$$\delta_L(\Delta t) = \delta_{(0)} + \frac{1}{6} + [K_1 + 2K_2 + 2K_3 + K_4] \quad (3.16)$$
$$\omega_L(\Delta t) = \omega_{(0)} + \frac{1}{6} + [L_1 + 2L_2 + 2L_3 + L_4]$$

Case 1: Determination of Rotor angle and angular speed at t = 0.02, 1 cycle

$$K_1 = \frac{d\delta}{dt} = (\omega_L - 314.1593) \times \Delta t$$
$$\omega_{(0)} = 314.1593 rad/sec$$
$$\omega_L = 314.1593 rad/sec$$
$$\Delta t = 0.02$$
$$Pe = 0$$
$$K_1 = (\omega_L - 314.1593) \times \Delta t$$
$$K_1 = (314.1593 - 314.1593) \times 0.02$$
$$K_1 = 0$$
$$L_1 = \frac{d\omega}{dt} = 19.4405(Ps - Pe)\Delta t$$
$$Pe = 0, \Delta t = 0.02, Ps = 1.532$$
$$L_1 = 19.4405(1.532 - 0) \times 0.02$$
$$L_1 = 19.4405(1.532)(0.02)$$
$$L_1 = 0.5957$$
$$K_1 = 0, L_1 = 0.5957$$
$$\delta_1 = \delta_0 + \frac{K_1}{2}$$
$$\delta_1 = 0.4049 + \frac{0}{2}$$
$$\delta_1 = 0.4049$$
$$\omega_1 = \omega_0 + \frac{L_1}{2}$$
$$\omega_1 = 314.1593 + \frac{0.5957}{2}$$
$$\omega_1 = 314.1593 + 0.2979$$
$$\omega_1 = 314.4572$$
$$K_2 = \frac{d\delta}{dt} = (\omega_1 - 314.1593) \times \Delta t$$
$$K_2 = (314.4572 - 314.1593) \times 0.02$$
$$K_2 = 0.005958$$
$$L_2 = \frac{d\omega}{dt} = 19.4405(1.532 - Pe) \times \Delta t$$
$$Pe = 0, \Delta t = 0.02$$
$$L_2 = 19.4405 \times (1.532)0.02$$
$$L_2 = 0.5957$$
$$K_2 = 0.005958, L_2 = 0.5957$$

Similarly,

$$\delta_2 = \delta_1 + \frac{K_2}{2}$$

$\delta_2 = 0.4049 + \frac{0.005958}{2}$
$\delta_2 = 0.4049 + 0.002979$
$\delta_2 = 0.4079$
$\omega_2 = \omega_1 + \frac{L_2}{2}$
$\omega_2 = 314.7551$
$K_3 = \frac{d\delta}{dt} = (\omega_2 - 314.1593) \times \Delta t$
$K_3 = (314.7551 - 314.1593) \times 0.02$
$K_3 = 0.0119$
$L_3 = \frac{d\omega}{dt} = 19.4405(1.532 - Pe) \times \Delta t$
$Pe = 0, \Delta t = 0.02$
$L_3 = 19.4405 \times 1.532X0.02$
$L_3 = 0.5957$
$K_3 = 0.0119, L_3 = 0.5957$
$\delta_3 = \delta_2 + \frac{K_3}{2}$
$\delta_3 = 0.4079 + \frac{0.0119}{2}$
$\delta_3 = 0.4139$
$\omega_3 = \omega_2 + \frac{L_3}{2}$
$\omega_3 = 314.7551 + \frac{0.5957}{2}$
$\omega_3 = 315.0530$

Similarly,
$K_4 = \frac{d\delta}{dt} = (\omega_3 - 314.1593) \times \Delta t$
$K_4 = (315.0530 - 314.1593) \times 0.02$
$K_4 = 0.0179$
$L_4 = 19.4405\ (1.532 - Pe) \times \Delta t$
$Pe = 0, \Delta t = 0.02$
$L_4 = 19.4405 \times 1.532X\ 0.02$
$L_4 = 0.5957$
$\delta_4 = \delta_3 + \frac{K_4}{2}$
$\delta_4 = 0.4139 + \frac{0.0179}{2}$
$\delta_4 = 0.4229$
$\omega_4 = \omega_3 + \frac{L_4}{2}$
$\omega_4 = 315.0530 + \frac{0.5979}{2}$
$\omega_4 = 315.3509$

Recall the general formula of the RK4 method,
$\delta_{L(\Delta t)} = \delta_{(0)} + \frac{1}{6}[K_1 + 2K_2 + 2K_3 + K_4]$
$\omega_{L(\Delta t)} = \omega_{(0)} + \frac{1}{6}[L_1 + 2L_2 + 2L_3 + L_4]$
Where $\delta_{(0)} = 0.4049rad, \omega_{(0)} = 314.1593rad/sec$

$\delta_{(0.02)} = 0.4049 + \frac{1}{6}[0 + 2(0.005958) + 2(0.0119) + 0.0179]$
$\delta_{(0.02)} = 0.4049 + \frac{1}{6}[0.053616]$
$\delta_{(0.02)} = 0.4138rad$

Similarly,
$\omega_{(0.02)} = \omega_0 + \frac{1}{6}[L_1 + 2L_2 + 2L_3 + L_4]$
$\omega_{(0.02)} = 314.1593 + \frac{1}{6}[0.5957 + 2(0.5957) + 2(0.5957) + 0.5957]$
$\omega_{(0.02)} = 314.1593 + \frac{1}{6}[3.5742]$
$\omega_{(0.02)} = 314.755rad/sec$

The calculation is repeated for tenth cycles

3.9 Error analysis in the Numerical Technique Solution

Error can be defined as the mathematical difference between the true value of mathematical quantity and the calculated value.
The absolute error gives how large the error is,
Mean absolute error (MAE) =

$$\frac{\sum(X_o - X)}{n} \quad (3.17)$$

Where:

n	=	is the number of error
X_o	=	is the actual value
X	=	is the measure or calculated value

The conventional swing equation technique solution is taken as the actual value, that is X_o. More δo it is considered to give the true representation of the rotor angles.

Table 3.6: Mean absolute error in the solution of rotor angle at incremental time

Incremental time(s)	Conventional swing method δ (rad) = X_o	Modified Euler δ (rad) = X_1	RK4 δ (rad) = X_2	Error in X_1	Error in X_2
0.02	0.4109	0.4109	0.4138	0	0.0029

0.04	0.4287	0.4586	0.4645	-0.0299	0.0358
0.06	0.4585	0.6194	0.5568	-0.1609	0.0983
0.08	0.5202	1.0006	0.6909	-0.4804	0.1705
0.1	0.5538	1.7052	0.839	-1.1514	0.3128
0.12	0.6193	2.9600	1.0839	-2.3407	0.4646
0.14	0.6968	4.9471	1.3429	-4.2503	0.6461
0.16	0.7361	7.9329	1.6439	-7.1968	0.9078
0.18	0.8874	12.2033	1.9864	-11.3159	1.099
0.20	1.0006	18.0799	2.37-6	-17.0793	-1.37
				-44.0056	-5.1081

For Modified Euler method, the percentage mean absolute error;

% MAE = $\frac{44.0056}{10} x100$ = -440

For 4th order Rung Kutta technique, the percentage mean absolute error;

% MAE = $\frac{-5.1081}{10} x100$ = -51

3.10 Determination of the Critical Clearing Angle and Critical Clearing Time

The critical clearing time is calculated as show below [13]:

Critical clearing time, t_{cr} =

$$\sqrt{(\delta_{cr} - \delta o)\frac{4H}{W_s P_m}} \qquad (3.18)$$

Where:

T_{cr}: Critical Clearing Time
δ_{cr}: Critical Clearing angle
W_o: Synchronous Speed
P_m: Mechanical Power
H: Inertia constant

When 4th order Runge Kutta numerical technique is applied, the relay will be programmed to clear fault at 7 cycles, so that the rotor angle will not reach 1.6439 radian (94.2^0) which is region of instability, so the critical clearing angle is 1.3429 radian (76.9^0)

Substituting values into equation (3.15)

t_{cr} =

$$\sqrt{(1.3429 - 0.4049)\left(\frac{4x8.08}{314.1593x383}\right)}$$

t_{cr} = $0.015s \cong 0.02$s

3.11 Determination of Power Transfer using 4th order Runge – Kutta Numerical Technique

Electrical output power before the fault, during the fault and after the fault is cleared is calculated to know the power transfer capability of the network.
The output electric power, Pe is given as:

$$Pe = \frac{EqV}{Xeq} Sin\delta \qquad (3.19)$$

At time t = 0_s before the fault was initiated

Eq = 1.600Pu
V = $1\angle o^o$
Xeq = 0.412Pu
δ = 23.20^o

Substituting values into equation (3.16)

$$Pe = \frac{1.600x1.0}{0.4125} Sin23.2^o$$

Pe = 1.5380pu

At time, t = 0.14s, 7 cycles when the fault is cleared;
δ = 1.3429 = 76.94^0

$$Pe = \frac{1.600x1.0}{0.4125} Sin(76.94^o)$$

Pe = 3.7870pu

VI. RESULTS AND DISCUSSION

Simulated Graphs Result Presentation

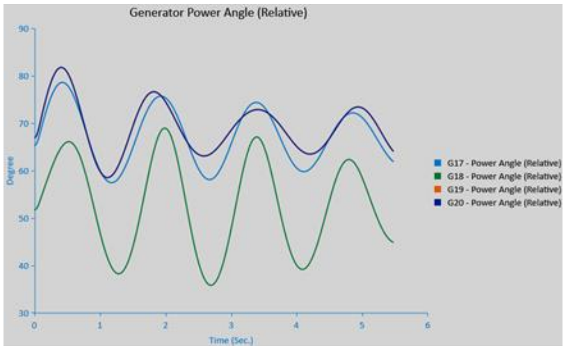

Figure 4.1: Presentation of Generator Rotor Angle

Figure 4.1 shows the result of the generators rotor angels swinging at incremented when a 3-phase fault its indicated at buss at time t=0. The generators 19 and 20 now accelerates to a power angle up to 82 degrees respectively, while generators 17 and 18 accelerated to a power angles of 97 and 65 degrees respectively. When the fault is cleared at 4 cycles, they attain stability after a period as the oscillation decays away with time. Synchronism was maintained by the generators and the network return to stability

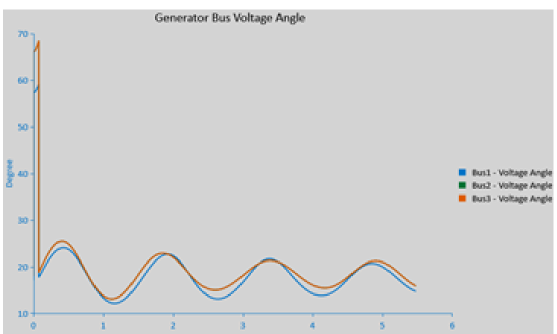

Figure 4.2: Presentation of Generator bus voltage angle

Figure 4.2 shows the result of the generators bus voltage angle with time, it was observed that during fault time at t 0_s, the generator terminal voltage angle suddenly rises up to 68 degree for bus 1, bus 2 and bus 3 respectively. Fault was cleared at 4 cycles, the fluctuation reduced gradually, and stable operating was reached and the generator maintained synchronism.

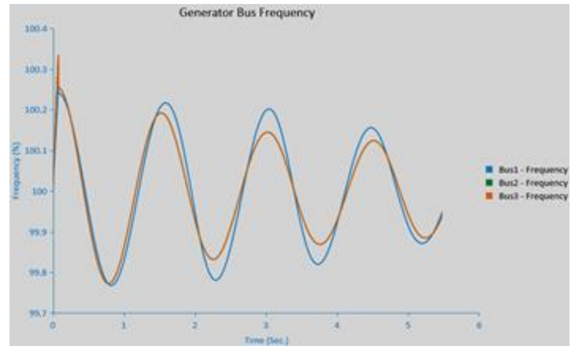

Figure 4.3:Presentation of Generator bus frequency

Figure 4.3 shows the divergence result of the generator bus frequency with time. It was observed that during fault time at $t = 0_s$, the generator frequency rises up to 100.4% for bus 1, bus 2 and bus 3 respectively. When fault was cleared at 4 cycles, the oscillation reduced and a stable operating condition reached. The generators maintained synchronism.

Numerical Methods Result Presentation

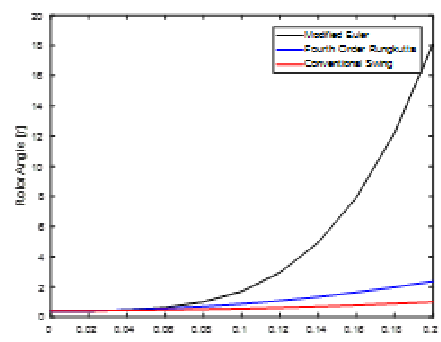

Figure 4.4: Plot of rotor angle (rad) against incremental time(s).

Figure 4.4 shows the predicted behaviour of the rotor angle (δ) with response to various time increase at the instant of fault condition when the convention a swing equation technique, modified Euler method and 4^{th} order Runge Kutta numerical technique were applied in estimating the rotor angle changes at incremental time.

It is observed that the plot of 4^{th} order Runge Kutta method converges faster close to that of the conventional swing equation technique. It indicates that there is less error between the conventional swing equation technique and the 4^{th} order Runge Kutta method as against that of Modified Euler method that is diverging.

4.3 Error in Solution of Selected Numerical Method

Table 4.1: Percentage Absolute Errors Presentation

Percentage Absolute Error (%)	
4th order Rungs Kutta Technique	Modified Euler Method
-51	-440

From table 4.1 which shows the percentage mean error of the solution of this study case, it clearly indicated that 4th order Runge Kutta is more accurate than the modified Euler method.

4.2 Presentation of Critical clearing Angle and Power Transfers

Modified Euler Method			4th Order Runge Kutta Technique		
Critical clearing angle (degree)	Power transfer (pu)		Critical clearing angle (degree)	Power transfer (pu)	
57.3	During fault	After fault	76.94	Purring fault	After fault
	0	3.2714		0	3.7870

From table 4.2 shows that using 4th order Runge Kutta numerical technique has higher critical clearing angle, thus, higher power transfer capability after fault has been cleared.

CONCLUSION

Transient stability problem has been a major issues to the power system operators and consumers over the years. The stable operating condition of the power system is desired. Power system stability issues is on the front burner, which proves the need to the study area. Emphasis was centered on the behaviour of the synchronous machine, when transmission network is subjected to a large and severe disturbances. Analysis was conducted using an electrical transient analysis software program (ETAP). The swing equation technique, Modified Euler method and 4th order Runge Kutta technique were used to strongly investigate the time to power angle when the power system is at fault condition.

For the transient stability analysis of the study case, the numerical solution obtained by modified Euler and 4th order Runge Kutta methods were strongly compared with necessary visualization and analysis error. It is concluded that 4th order Runge Kutta method has a good balance of efficiency and accuracy.

RECOMMENDATION

To guide the power system operator to take quick action to avert system collapse or to prevent future occurrence, it is paramount to adhere to the recommendations reached from the investigation and transient stability study of the study case.

The following points are presented for consideration:

i. Adoption of 4th order Runge Kutta numerical technique to determine the response of the synchronous machines when subjected to disturbance.
ii. Investment in building and expansion of existing transmission grid, in order to increase the wheeling capability of generated power.
iii. Installation of fast and high speed operated relays and circuit breaker with fault clearing time set at t = 0.02 seconds.
iv. For ease of gathering data for future work of this nature, the operator should install phasor Measurement units (PMUS) on the national grid in order to enhance real time analysis.

REFERENCES

[1] Braide, S.L. Ahiakwo, C.O. & Aghaukwu, N.C. Analysis of 132kv Power transmission Stability in Developing Nation, *America Journal of Engieering Research, 8, 124-132*, 2019.

[2] Arya, L.D.J. & Shrivastava, M. Voltage stability evaluation using line voltage index.IE(I) Journal-EL,87, 2006.

[3] Samuel, I.A., Katende, J.S.A. & Awelewa, A.A. Review of System Collapse Incidences on the 330kV Nigeria National Grid. *International Journal of Engineering Science Invention*, 3, 55-59, 2014.

[4] Braide, S. L., Diema, E. J. Analysis of Steady and Transient-State Stability of Transmission Network. *International Journal of Academic Research and Reflection,* 6(5), 01-32, 2018.

[5] Ali, N.A. An overview of system collapse on the Nigeria grid network in proceedings of the international conference on power systems operations and planning. VI (ICPSP), 67-70, 2005.

[6] Sunday, O.O. Power Outages in the Nigeria Grid. *Research Journal of Applied Sciences*, 4(1), 1-9, 2009.

[7] Pour, A.P., Lashjca, A.A. & Niaka, N.S.A. Enhancing Power System Transient stability using Optimal Unified Power Flow Controller based on Lyapunor Control Strategy, *Journal of Scientigranica*, 24(3), 1458-1466, 2017.

[8] Obaid, Z.A. Cipeigan, Z.M. & Muhssin, M.T. Power system oscillations an control: Classification and PSSs Design Methods: A review, *JRSER, 79,* 839-849, 2017.

[9] Oluseyi, P.O., Adelaja, I.S. & Akinbuline, T.O. Analysis of the transient stability limit of Nigeria's 330kV transmission sub network. *Nigerian Journal of Technology, 36*(1), 213-226, 2017.

[10] Zhou, Y., Wu, J., Ji, L., Yu, Z.W., Lin, K. & Hao, L. Transient Stability Preventive Control of Power System using Chaotic particle Swarm Optimization Combined with Two-Stage Support Vector Machine, Electric Power System Research, (155), 111-120, 2018.

[11] Elechi, P., Ahiakwo, C.O. & Okwu, U.N. Transient Stability Analysis of 33kV Transmission Network of Egi Community, Nigeria. *Journal of Power and Energy Engineering,* 8, 18-35, 2020.

[12] Braide, S. L., Idoniboyeobu, D. C. Lecturer notes in Engineering and Computer Science, 216-221, 2019.

[13] Kumar, A. & Dubey, S. B. Enhancement of Transient Stability in Transmission line using SVC Fast Controller. *International Journal of Recent Technology and Engineering,* 2,7-13, 2013.