ISSN 2522-9400 **European Modern Studies Journal** Vol 5 No 2
available at journal-ems.com

Modified Euler Based Transient Stability Assessment of Multi Machine System

Chizindu Stanley Esobinenwu
Department of Electrical/Electronic Engineering,
University of Port Harcourt, Rivers State, Nigeria

Abstract. Transient stability in recent time has become a major challenge in power system operation. The paper examined the impact of the three phase fault created along Delta–Benin transmission line. Benin sub-regional 330kV power grid system was used as the study case. Modified Euler's method was used to solve the swing equation for a multi machine system to obtain the critical clearing angle and time of the circuit breaker. Based on the findings, the result obtained shows that the critical clearing angle and time of the circuit breaker are [77.2247deg, and 0.2seconds] after which the fault was cleared while the oscillation damped gradually to attain stability. Based on this behavior, we can say that the generators maintained synchronism after the fault was cleared and transient stability was improved through the use of high speed circuit breakers.

Key words: Euler, Benin grid, Etap, Clearing time, Multi machine, Transient stability

Introduction

For any society to develop in all ramification, the pre-requisite requirement is electricity. (Gupta, 2016). The 330kV power infrastructures in Nigeria interconnects all major power stations littered within the country in their respective locations (Odia, 2007).

The complex nature of the power grid infrastructures makes it possible for the occurrence of different forms of system problems (Enemuoh, 2018). According to the report made available by the Transmission Company of Nigeria (TCN), the 330kV grid network in 2018 recorded a total number of 529 outages out of which 42.53% were forced outages compared to 35.1% in 2017. The inconvenience and economic cost of the occasioned forced outage on the public residence on the affected areas are enormous and unpleasant.

Statement of Problem

The Nigeria 330kV infrastructure operates closer to its capacity limits. This makes it possible for the occurrence of different forms of system disturbances such as forced outage due to faults.

In order to mitigate this challenge, it is pertinent an evaluation of the power grid system be conducted.

Objectives of the Study

1. To determine the most affected generating stations and buses in the network after the occurrence of a three phase (3-θ) fault.
2. To determine the critical clearing and time of the circuit breaker.
3. To plot the rotor angle swing curve

Study Area

The study area for this work is Benin sub-regional regional 330kV grid network.

Literature Review

It refers to the property of a typical power system to maintain synchronism when it is faced with a subjection of minute and gradual disturbances effected on it (Ashfaq, 2017).

Instability of the power system have undesirable consequences. Limitation in the quantity of transmitted power, loss of synchronisation after its normal condition is distorted, power outage and voltage collapse experienced by consumers due to power system instability (Tejaswini et al., 2015).

Hussain (2010) in his dissertation, defined the concept of electrical power system stability as the quality of the system that enhances it to stay in a state of equilibrium under normal conditions and to obtain an acceptable state of equilibrium after undergoing a disturbance.

According to Barshar (2016) Instability can occur in a system network under different situations based on the configuration of the system and its operating mode. In the field of power system operation, stability problem has been loss of synchronism in common synchronous electrical machines. Transient state stability is the insistence of the electrical power system to retain synchronism after the occurrence of a large disturbance. The large disturbance may take place because of the appearance of unexpected changes in the area of application or removing of massive loads possibly occasioned by Line switching operations, faults on system and unforeseen outages on the line or excitation loss (Ashfaq, 2017).

Methodology

Data Collection

Table 1. Line data of network model

Bus to Bus	**Impedance (Z)**		**Shunt (Y)**
	R	**X**	**(B)**
Txf 1-5	-	0.123	-
Txf 2-4	-	0.124	-
Line 3-4	0.021	0.030	0.030
Line 3-5	0.012	0.025	0.022
Line 4-6	0.014	0.057	0.050
Line 5-6	0.011	0.040	0.057

Table 2. Bus data of network model

Bus ID	**Generation**				**Load**	
	H	Xd^{I}	MW	Mvar	MW	Mvar
1	10.2	0.30	-	-	-	-
2	6.0	0.28	3.00	-	-	-
3	-	-	-	-	-	-
4	-	-	-	-	-	-
5	-	-	-	-	-	-
6	-	-	-	-	-5.0	-3.0

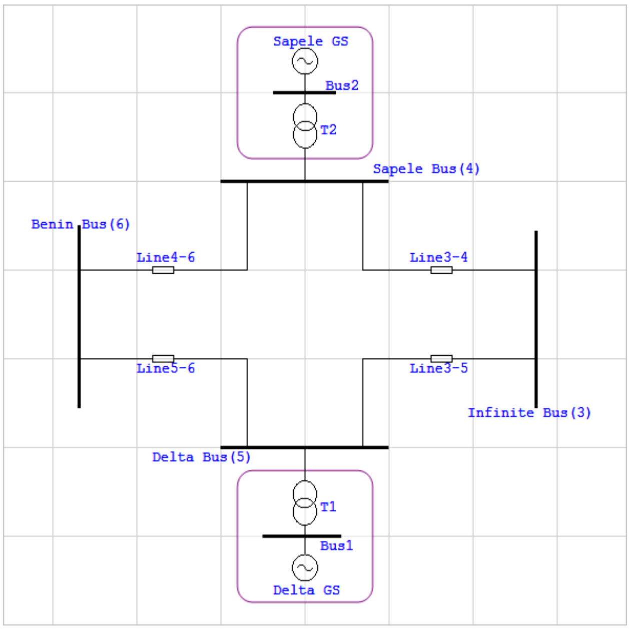

Figure 1. Model of test network

Pre-Fault Analysis

I. Determination of Generator Internal Current and Voltage

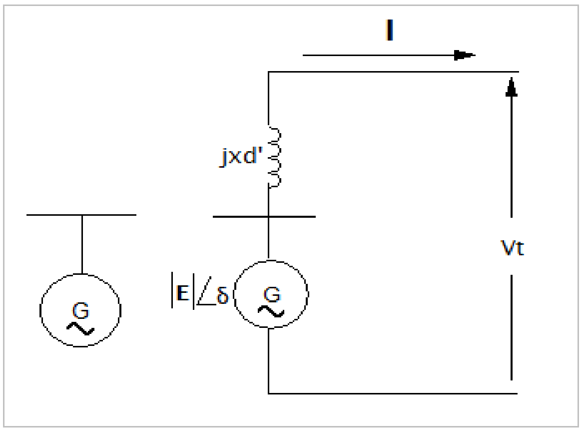

Figure 2. Equivalent circuit of a synchronous machine

Figure 2 shows the equivalent circuit of a synchronous machine. From the power equation the internal current and voltage of the generator can be written by

$$V_t I^* = P_g + jQ_g \quad (1)$$

$$I = \frac{P_g + jQ_g}{V_t^*} \quad (2)$$

$$E = V_t + (jX_d')I = |E'|\angle\delta \quad (3)$$

Where
Pg= generator real power
Qg= generator reactive power
Vt=conjugate of terminal voltage from load flow analysis
Xd'=transient reactance of the generator
$|E'|$ = absolute value of the internal voltage
$\angle\delta$=initial rotor angle

II. Determination of Bus Admittance Matrix

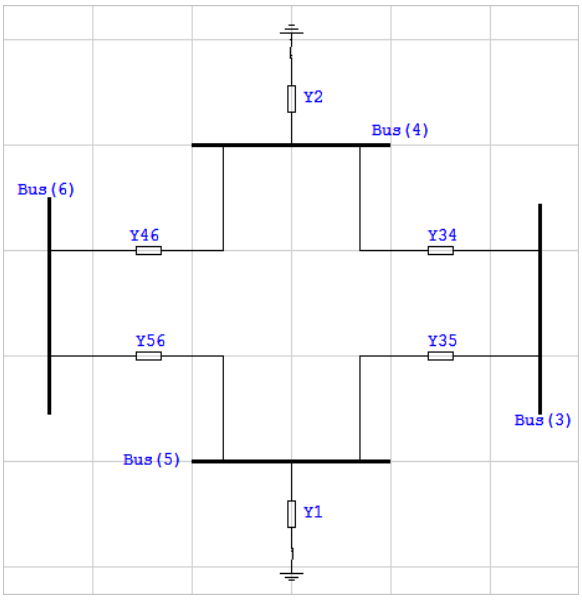

Figure 3. Bus admittance matrix

Considering a network system with n generator buses and r load buses as shown in Figure 1. Then the Y-admittance matrix shown in Figure 3 can be written as

$$\begin{vmatrix} I_n \\ I_r \end{vmatrix} = \begin{vmatrix} Y_{nn} & Y_{nr} \\ Y_{rn} & Y_{rr} \end{vmatrix} \begin{vmatrix} E_n \\ E_r \end{vmatrix} \tag{4}$$

Where

Y_{nn}, Y_{rr} =the diagonal elements of the admittance matrix

Y_{nr}, Y_{rn} = the off-diagonal elements of the admittance matrix

I_n= the injected current at the generator bus

E_n= Internal generator Voltage

E_r= Internal Load Voltage

Y4 and Y5=0

III. Obtaining Pre-Fault Load Flow Data

Table 3 shows the pre-fault load flow values.

Table 3. Pre-fault load flow values

Bus ID	Voltage(p.u)		Generation		Load	
	Mag	Ang	MW	Mvar	MW	Mvar
1	1.02	0.00	-5.85	-1.43	-	-
2	1.01	0.98	2.45	-13.86	-	-
3	1.00	0.00	-	-	-	-
4	1.02	0.50	-	-	-	-
5	1.02	0.43	-	-	-	-
6	1.02	0.46			-5.0	-3.0

IV. Determination of Load Admittance Matrix

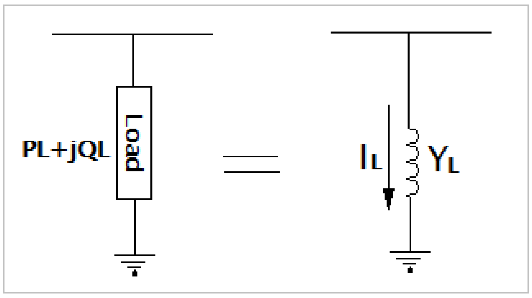

Figure 4. Equivalent circuit of a static load

Figure 4 shows the equivalent circuit of a static load. The admittance of the static load can be written as

$$P_L + jQ_L = V_L I_L^* \quad (5)$$
$$= V_L(V_L^* Y_L^*) \quad (6)$$
$$= |V_L|^2 Y_L \quad (7)$$
$$Y_L = \frac{P_L - jQ_L}{|V_L|^2} \quad (8)$$

Where

P_L= Load real power

Q_L= Load reactive power

$|V_L|$= absolute value of the load terminal voltage from power flow

V. Updating Bus Admittance Matrix before Fault

The algorithm for updating bus admittancematrix before fault is given below with reference to Figure 1.

Step 1: At the generator bus, remove the admittance of transformer 1 and 2.

Step 2: Add the series admittance of generator 1 and transformer 1 to their corresponding diagonal elements in the bus admittance matrix.

Step 3: Add the series admittance of generator 2 and transformer 2 to their corresponding diagonal elements in the bus admittance matrix.

Step 4: At the load bus, add the load admittance matrix to their corresponding diagonal elements in the bus admittance matrix.

During and After Fault Analysis

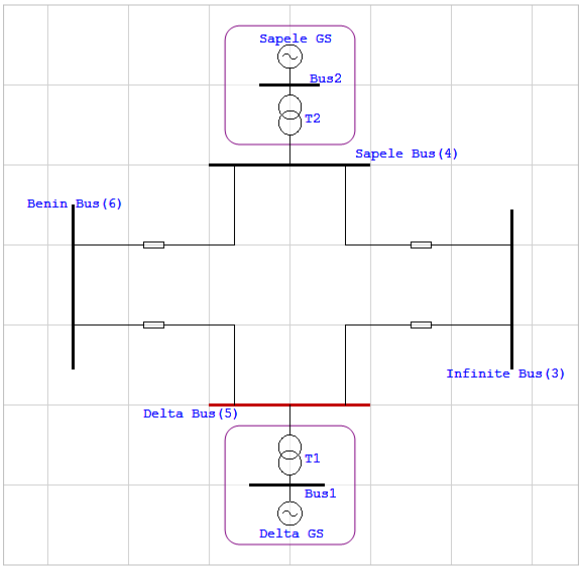

Figure 5. Test network during fault

Figure 5 shows the test network during 3-phase fault occurrence on Line 5-6 (Benin-Delta transmission line). During the fault, bus 5 (Delta) is short circuited to the ground.

I. Reduction of Bus Admittance Matrix

Kron's reduction techniques were used to reduce the bus admittance matrix (8). This was achieved by eliminating the internal load voltages E_r since the injection current at the load buses are zero.

$$|I_n| = |Y_{nn} - Y_{nr}Y_{rr}^{-1}Y_{rn}^{T}||E_n| \tag{9}$$

Where

I_n= the injected current at the generator bus

E_n= Internal generator Voltage

Y_{nn}=the diagonal elements of the admittance matrix

Y_{rr}^{-1}= inverse of the diagonal matrix

Y_{rn}^{T}= transposition of the off-diagonal matrix

II. Updating Bus Admittance Matrix during Fault

The algorithm for updating bus admittancematrix during fault is given below with reference to Figure 5.

Step 1: Remove row 5 and column 5 from the pre-fault bus admittance matrix.

Step 2: Using Kron's reduction technique eliminate the current row 5 and column 5 which was previously pre-fault row 6 and column 6.

III. Updating Bus Admittance Matrix after Fault

After clearing the fault by opening line 5-6 with circuit breaker. The bus admittancematrixis updated. The Algorithm for updating bus admittancematrix after fault is given below.

Step 1: Subtract the admittance of line 5-6 and half line charging admittance from the diagonal and off-diagonal matrix of line 5-6 in the pre-fault bus admittance matrix.

Step 2: Apply Kron's reduction technique to eliminate node 4, 5 and 6.

IV. Determination of Power Output

$$P_{ei} = E_i^2 G_{ii} + \sum_{\substack{n=1 \\ n\neq i}}^{m} |E_i||E_n||Y_{in}|\cos(\delta_{in} - \theta_{in}) \tag{10}$$

$$P_{ei} = E_i^2 G_{ii} + \sum_{\substack{n=1 \\ n\neq i}}^{m} |E_i||E_n||Y_{in}|\sin(\delta_i - \theta_{in} + 90^{\circ}) \tag{11}$$

Where

E_i = the internal generator voltage at bus i

G_{ii}= the real element of the diagonal matrix at bus i

$|Y_{in}|$= absolute value of the off-diagonal element at bus i

θ_{in}= angle of the off-diagonal element at bus i

δ_i= initial rotor angle at bus i

Determination of Critical Clearing Time

The swing equation used to obtain the swing curve.The curve is useful in determining the adequacy of relay protection in power system with regards to fault clearing. The rotor angle swing equation is given by

$$\frac{d^2\delta}{dt^2} = \frac{180f}{H}(P_m - P_e) \tag{12}$$

However, the second order differential equation can be written as two first order differential equation and solution obtained using Modified Euler's method.

I. Predictor Step

Let δ_0 and $\omega_0$be the initial point and Δt the increment in time

$$\frac{d\delta}{dt}|_0 = D_1 = \omega_0 \tag{13}$$

$$\frac{d\omega}{dt}|_0 = D_2 = \frac{180f}{H}(P_m - P_{max}\sin\delta_0) \quad (14)$$

The approximate value of δ and ω denoted as δ^p and$\omega^p$are calculated asfollows:

$$\delta^p = \delta_0 + D_1\Delta t \quad (15)$$

$$\omega^p = \omega_0 + D_2\Delta t \quad (16)$$

II. Corrector Step

With the new value of δ^p and ω^pobtained in the predictor step, the value of P_e is updated.

$$\frac{d\delta}{dt}|_p = D_{1p} = \omega^p \quad (17)$$

$$\frac{d\omega}{dt}|_p = D_{2p} = \frac{180f}{H}(P_m - P_{max}\sin\delta^p) \quad (18)$$

With the above new derivative values obtained, the final value of δ and ω at p denoted as δ_1 and ω_1 are calculated as

$$\delta_1 = \delta_0 + \left(\frac{D_1 + D_{1p}}{2}\right) * \Delta t \quad (19)$$

$$\omega_1 = \omega_0 + \left(\frac{D_2 + D_{2p}}{2}\right) * \Delta t \quad (20)$$

Proceeding further, for calculating δ and ω at 2p, the initial pointsδ_0 and $\omega_0$are replaced by δ_1 and ω_1 respectively.

Solution of Swing Equation by Modified Euler's Method

$$\frac{d^2\delta}{dt^2} = \frac{\pi f}{H}(P_s - P_e) = \frac{50\pi}{3.5}(P_s - P_e)$$

$$\frac{d^2\delta}{dt^2} = 44.8799(P_s - P_e)$$

$$\omega_s = 2\pi f = 314.1593\ rad/s$$

Just before the fault P_s =1.0p.u

During fault $P_e = P_{e2} = 0.6549\sin\sigma$

After fault is cleared $P_e = P_{e3} = 1.5672\sin\sigma$

Increment in time (Δt)= 0.02s

From (13) and (14), the two first order differential equations are:

$$\frac{d\delta}{dt}|_{t=t_0} = \omega_0 - 314.1593$$

$$\frac{d\omega}{dt}|_{t=t_0} = 44.8799(1 - P_e)$$

<u>**To calculate δ(0.02) and ω(0.02)**</u>

Predictor Step:

Initial points $(0.469\ rad,\ 314.1593\ rad/s)$

$$\frac{d\delta}{dt} = 314.1593 - 314.1593 = 0$$

$$\frac{d\omega}{dt} = 44.8799x(1 - 0.6549\sin 0.469) = 31.5949$$

$$\delta^{(1)} = 0.469 + 0.02x(0) = 0.469\ rad$$

$$\omega^{(1)} = 314.1593 + 0.02x(31.5949) = 314.7912\ rad/s$$

Corrector Step:

$$\frac{d\delta}{dt} = (314.7912 - 314.1593) = 0.6319$$

$$\frac{d\omega}{dt} = 44.8799x(1 - 0.6549\sin 0.469) = 31.5949$$

$$\delta_1 = 0.469 + \frac{0.02}{2}[0 + 0.6319] = 0.4753\ rad$$

$$\omega_1 = 314.7912 + \frac{0.02}{2}[31.5949 + 31.5949] = 315.4231\, rad/s$$

To calculate δ(0.04) and ω(0.04)

Predictor Step:

Initial points $(0.4753\, rad,\ 315.4231\, rad/s)$

$$\frac{d\delta}{dt} = (315.4231 - 314.1593) = 1.2638$$

$$\frac{d\omega}{dt} = 44.8799x(1 - 0.6549 \sin 0.4753) = 31.4300$$

$$\delta^{(2)} = 0.4753 + 0.02x(1.2638) = 0.5006\, rad$$

$$\omega^{(2)} = 315.4231 + 0.02x(31.4300) = 316.0517\, rad/s$$

Corrector Step:

$$\frac{d\delta}{dt} = (316.0517 - 314.1593) = 1.8924$$

$$\frac{d\omega}{dt} = 44.8799x(1 - 0.6549 \sin 0.5006) = 30.7732$$

$$\delta_2 = 0.5006 + \frac{0.02}{2}[1.2638 + 1.8924\,] = 0.5322\, rad$$

$$\omega_2 = 316.0517 + \frac{0.02}{2}[31.4300 + 30.7732] = 316.6737\, rad/s$$

To calculate δ(0.06) and ω(0.06)

Predictor Step:

Initial points $(0.5322\, rad,\ 316.6737\, rad/s)$

$$\frac{d\delta}{dt} = (316.6737 - 314.1593) = 2.5144$$

$$\frac{d\omega}{dt} = 44.8799x(1 - 0.6549 \sin 0.5322) = 29.9656$$

$$\delta^{(3)} = 0.5322 + 0.02x(2.5144) = 0.5825\, rad$$

$$\omega^{(3)} = 316.6737 + 0.02x(29.9656) = 317.2730\, rad/s$$

Corrector Step:

$$\frac{d\delta}{dt} = (317.2730 - 314.1593) = 3.1137$$

$$\frac{d\omega}{dt} = 44.8799x(1 - 0.6549 \sin 0.5825) = 28.7111$$

$$\delta_3 = 0.5322 + \frac{0.02}{2}[2.5144 + 3.1137\,] = 0.5885\, rad$$

$$\omega_3 = 316.6737 + \frac{0.02}{2}[29.9656 + 28.7111] = 317.2605\, rad/s$$

To calculate δ(0.08) and ω(0.08)

Predictor Step:

Initial points $(0.5885\, rad,\ 317.2605\, rad/s)$

$$\frac{d\delta}{dt} = (317.2605 - 314.1593) = 3.1012$$

$$\frac{d\omega}{dt} = 44.8799x(1 - 0.6549 \sin 0.5885) = 28.5641$$

$$\delta^{(4)} = 0.5885 + 0.02x(3.1012) = 0.6505\, rad$$

$$\omega^{(4)} = 317.2605 + 0.02x(28.5641\,) = 317.8318\, rad/s$$

Corrector Step:

$$\frac{d\delta}{dt} = (317.8318 - 314.1593) = 3.6725$$

$$\frac{d\omega}{dt} = 44.8799x(1 - 0.6549 \sin 0.6505) = 27.0807$$

$$\delta_4 = 0.5885 + \frac{0.02}{2}[3.1012 + 3.6725\ ] = 0.6562\ rad$$

$$\omega_4 = 317.2605 + \frac{0.02}{2}[28.5641 + 27.0807] = 317.8169\ rad/s$$

<u>To calculate δ(0.1) and ω(0.1)</u>

Predictor Step:

Initial points $(0.6562\ rad, 317.8169\ rad/s)$

$$\frac{d\delta}{dt} = (317.8169 - 314.1593) = 3.6576$$

$$\frac{d\omega}{dt} = 44.8799x(1 - 0.6549 \sin 0.6562) = 26.9476$$

$$\delta^{(5)} = 0.6562 + 0.02x(3.6576) = 0.7294$$

$$\omega^{(5)} = \ 317.8169 + 0.02x(26.9476) = 318.3559\ rad/s$$

Corrector Step:

$$\frac{d\delta}{dt} = (318.3559 - 314.1593) = 4.1966$$

$$\frac{d\omega}{dt} = 44.8799x(1 - 0.6549 \sin 0.7294) = 25.2925$$

$$\delta_5 = 0.6562 + \frac{0.02}{2}[3.6576 + 4.1966\ ] = 0.7347\ rad$$

$$\omega_5 = 317.8169 + \frac{0.02}{2}[26.9476 + 25.2925] = 318.3393\ rad/s$$

<u>To calculate δ(0.12) and ω(0.12)</u>

Predictor Step:

Initial points $(0.7347\ rad,\ 318.3393\ rad/s)$

$$\frac{d\delta}{dt} = (318.3393 - 314.1593) = 4.1800$$

$$\frac{d\omega}{dt} = 44.8799x(1 - 0.6549 \sin 0.7347) = 25.1766$$

$$\delta^{(6)} = 0.7347 + 0.02x(4.1800) = 0.8183\ rad$$

$$\omega^{(6)} = 318.3393 + 0.02x(25.1766) = 318.8424\ rad/s$$

Corrector Step:

$$\frac{d\delta}{dt} = (318.8424 - 314.1593) = 4.6835$$

$$\frac{d\omega}{dt} = 44.8799x(1 - 0.6549 \sin 0.8183) = 23.4243$$

$$\delta_6 = 0.7347 + \frac{0.02}{2}[4.1800 + 4.6835] = 0.8233\ rad$$

$$\omega_6 = 318.3393 + \frac{0.02}{2}[25.1766 + 23.4243] = 318.8253\ rad/s$$

<u>To calculate δ(0.14) and ω(0.14)</u>

Predictor Step:

Initial points $(0.8233\ rad, 318.8253\ rad/s)$

$$\frac{d\delta}{dt} = (318.8253 - 314.1593) = 4.6660$$

$$\frac{d\omega}{dt} = 44.8799x(1 - 0.6549 \sin 0.8233) = 23.3241$$

$$\delta^{(7)} = 0.8233 + 0.02x(4.6660) = 0.9166\ rad$$

$$\omega^{(7)} = 318.8253 + 0.02x(23.3241) = 319.2918\ rad/s$$

Corrector Step:

$\frac{d\delta}{dt} = (319.2918 - 314.1593) = 5.1325$

$\frac{d\omega}{dt} = 44.8799x(1 - 0.6549\sin 0.9166)$ =21.5564

$\delta_7 = 0.8233 + \frac{0.02}{2}[4.6660 + 5.1325] = 0.9213\ rad$

$\omega_7 = 318.8253 + \frac{0.02}{2}[23.3241 + 21.5564\ ] = 319.2741\ rad/s$

To calculate δ(0.16) and ω(0.16)

Predictor Step:

Initial points $(0.9213\ rad, 319.2741\ rad/s)$

$\frac{d\delta}{dt} = (319.2741 - 314.1593) = 5.1148$

$\frac{d\omega}{dt} = 44.8799x(1 - 0.6549\sin 0.9213) = 21.4726$

$\delta^{(8)} = 0.9213 + 0.02x(5.1148) = 1.0236\ rad$

$\omega^{(8)} = 319.2741 + 0.02x(21.4726) = 319.7036\ rad/s$

Corrector Step:

$\frac{d\delta}{dt} = (320.5739 - 314.1593)$ =6.4146

$\frac{d\omega}{dt} = 44.8799x(1 - 0.6549\sin 1.0236)$ =19.7797

$\delta_8 = 0.9213 + \frac{0.02}{2}[\ 5.1148 + 6.4146] = \ 1.0366\ rad$

$\omega_8 = 319.2741 + \frac{0.02}{2}[21.2726 + 19.7797] = 319.6846\ rad/s$

To calculate δ(0.18) and ω(0.18)

Predictor Step:

Initial points $(1.0366\ rad, 319.6846\ rad/s)$

$\frac{d\delta}{dt} = (319.6846 - 314.1593)$ =5.5253

$\frac{d\omega}{dt} = 44.8799x(1 - 0.6549\sin 1.0366) = 19.4246$

$\delta^{(9)} = 1.0366 + 0.02x(5.5253) = 1.1471\ rad$

$\omega^{(9)} = 319.6846 + 0.02x(19.4246) = 320.0731\ rad/s$

Corrector Step:

$\frac{d\delta}{dt} = (320.0731 - 314.1593) = 5.9138$

$\frac{d\omega}{dt} = 44.8799x(1 - 0.6549\sin 1.1471)$ =18.0870

$\delta_9 = 1.0366 + \frac{0.02}{2}[\ 5.5253 + 5.9138] = 1.1985\ rad$

$\omega_7 = 319.6846 + \frac{0.02}{2}[19.4246 + 18.0870\ ] = 320.0597\ rad/s$

To calculate δ(0.2) and ω(0.2)

Predictor Step:

Initial points $(1.1985\ rad, 320.0597\ rad/s)$

$\frac{d\delta}{dt} = (320.0597 - 314.1593) = 5.9004$

$\frac{d\omega}{dt} = 44.8799x(1 - 0.6549\sin 1.1985)$ =17.5016

$\delta^{(10)} = 1.1985 + 0.02x(5.9004) = 1.3165\ rad$

$\omega^{(10)} = 320.0597 + 0.02x(17.5016) = \ 320.4097\ rad/s$

Corrector Step:

$$\frac{d\delta}{dt} = (320.4097 - 314.1593) = 6.2504$$

$$\frac{d\omega}{dt} = 44.8799x(1 - 0.6549\sin 1.3165) = 16.4333$$

$$\delta_{10} = 1.1985 + \frac{0.02}{2}[5.9004 + 6.2504] = 1.3480\, rad$$

$$\omega_{10} = 320.0597 + \frac{0.02}{2}[17.5016 + 16.4333] = 320.3990\, rad/s$$

<u>To calculate δ(0.22) and ω(0.22)</u>

Predictor Step:

Initial points $(1.3480\, rad, 320.3990\, rad/s)$

$$\frac{d\delta}{dt} = (320.3990 - 314.1593) = 6.2397$$

$$\frac{d\omega}{dt} = 44.8799x(1 - 1.5672\sin 1.348) = -23.7174$$

$$\delta^{(11)} = 1.3480 + 0.02x(6.2397) = 1.4728\, rad$$

$$\omega^{(11)} = 320.3990 + 0.02x(-23.7174) = 319.9247\, rad/s$$

Corrector Step:

$$\frac{d\delta}{dt} = (319.9247 - 314.1593) = 5.7654$$

$$\frac{d\omega}{dt} = 44.8799x(1 - 0.6549\sin 1.4728) = 15.6291$$

$$\delta_{11} = 1.3480 + \frac{0.02}{2}[6.2397 + 5.7654] = 1.4681\, rad$$

$$\omega_{11} = 320.3990 + \frac{0.02}{2}[-23.7174 + 15.6291] = 320.3181\, rad/s$$

Results

Table 4. Swing Curve Computation

t/sec	δ/rad	δ/deg	ω rad/s
0	0.4694	26.8912	314.1593
0.02	0.4753	27.2292	314.4231
0.04	0.5322	30.4889	316.6737
0.06	0.5885	33.7142	317.2605
0.08	0.6562	37.5926	317.8169
0.1	0.7374	42.2444	318.3393
0.12	0.8233	47.1655	318.8253
0.14	0.9213	52.7798	319.2741
0.16	1.0366	59.3851	319.6846
0.18	1.1985	68.6601	320.0597
0.2	1.348	77.2247	320.399
0.22	1.4728	84.3743	320.3181

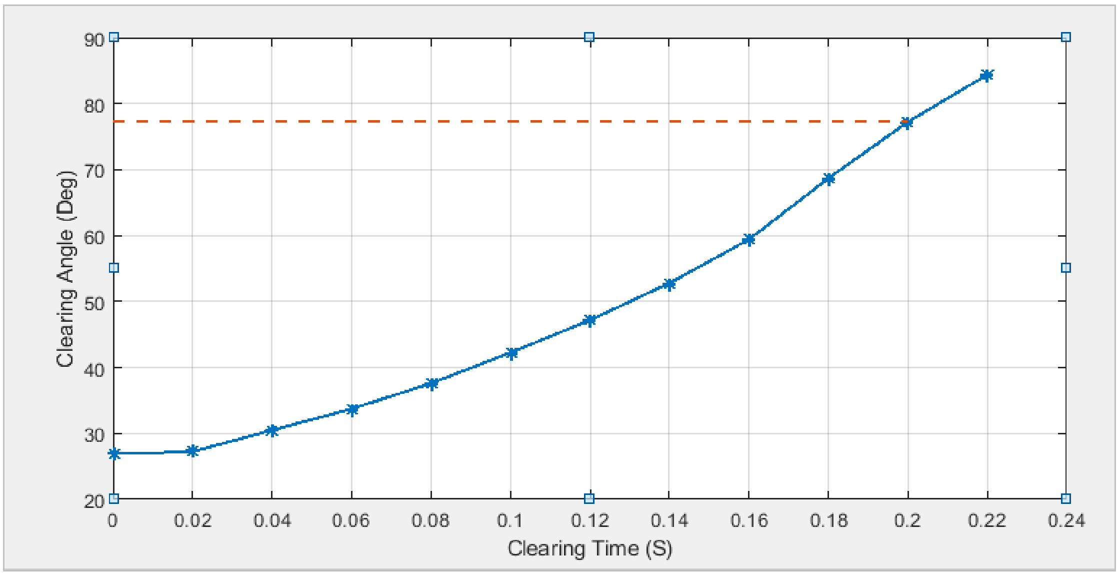

Figure 6. Graph of swing curve

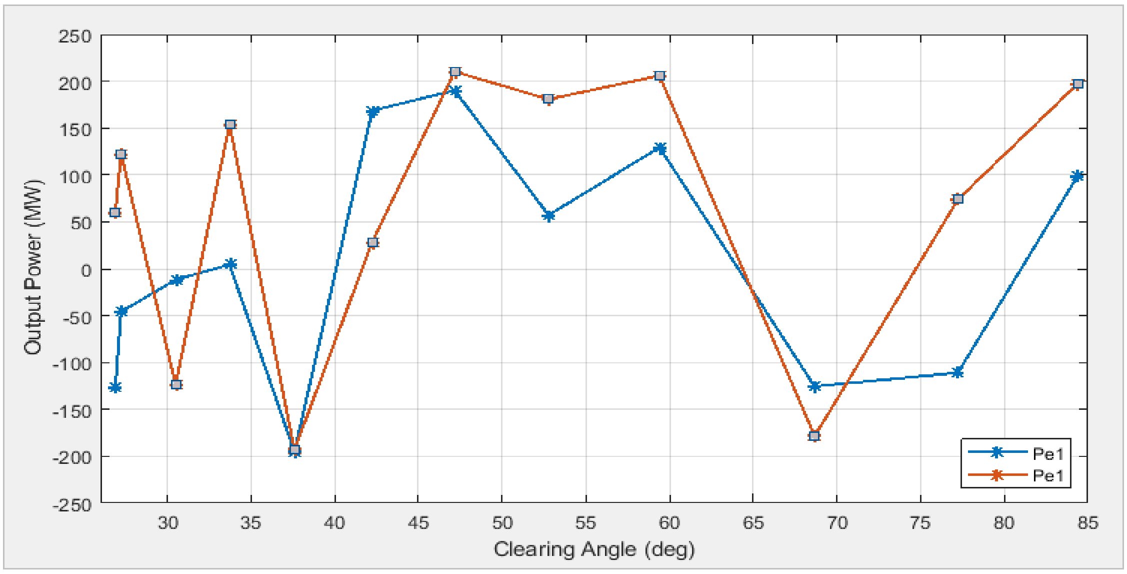

Figure 7. Graph of rotor power output

Discussion

Table 4 shows the result of swing curve obtained from solving the swing equation using modified Euler method. From Table 4 the critical clearing angle and time was obtained [77.2247deg, and 0.2seconds] respectively. Figure 6 shows the plot of the swing curve described in Table 4.

Figure 7 shows the rotor angle power of generator 1 and 2. The graph is an indicator of the generator's stability. A cursory look at Figure 7 shows that generator 1 has less oscillation than generator 2. Due to the fault in the line 5, the generators experienced a power swing and now operates in a new power angle. At 0.2 seconds when the fault was cleared, it oscillated and damped gradually to attain stability. Based on this behavior, we can say that the generators maintained synchronism with the grid.

Conclusion

The study was carried out to examine the capacity of the existing Nigeria 330kV power system network to withstand disturbance while quality of service is maintained. The swing equation was solved using Modified Euler's method used to solve the swing equation to obtain the circuit breaker critical clearing angle and time.

Based on the findings, it is hereby concluded that transient stability was improved through the use of high speed circuit breakers to open faulty areas without collapse of the system.

Reference

Ashfraq, H. (2017). *Electrical Power Systems* (5th ed.). New Delhi: CBS Publishers & Distributors Pvt. Ltd.

Bashar, S.A., & Chin, K.G. (2016). Power system frequency stability and control: Survey. *International Journal of Applied Engineering Research*, *11*(8), 5688-5695.

Enemuoh, F.O. (2018). *Simulation modelling of voltage stability of an interconnected electric power system network* (Ph.D Thesis). University of Nigeria, Nsuka.

Gupta, B.R. (2016). *Power system analysis and design*. Allahabard: Wheeler Publishing.

Hussan, H.A. (2010). *A practical method for power system stability and security* (Master dissertation). University of New orleans, USA

Odia, A. (2007) *Transient stability assessment of the Nigerian 330kV network* (Master dissertation). University of Port Harcourt, Nigeria.