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Analysis of 132kv Power Transmission Stability in Adeveloping Nation

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ABSTRACT:*This research work considered the analysis of 132KV power transmission line stability with a view of mitigating the frequency of fault occurrence in the power network. The supply is taken from AfSam Power generating station to Port Harcourt Zone 2 injection substation of (132/33kv) voltage level. This work basically considered the transient aspect of stability which is the most severe in the power network. Power swings might be observed by protective relays as three – phase faults and cause unwanted system wide separation as a result of relay mis-operation. However, the existing data collected were used for the study case in Nigeria, in order to investigate the power angles (□), angular velocity (ω) and the differential change at various incremental time, via electrical transient analyzer tool (E Tap – version 12.6) for relay time setting of (0.00,0.02,0.04,0.06,0.08,.0.10,0.12,0.14) . This dissertation used the modified Euler numerical technique. From the various stimulated results, it can be seen that when a symmetrical three phase short circuit fault occurs at the generator bus and other network buses there was need to clear the fault based on the relay coordination as quickly as possible, for this work 7 cycles were allowed and at each cycle the incremental changes of the synchronous machine were calculated on the power network simultaneously. The findings showed that Euler method has faster responds time as compared to the conventional swing equation technique in the event of fault occurrence.*

KEYWORDS- *swingequation, transientstability, powerangle, angularvelocity, differentialchange, modifiedEuler, fault clearing time, synchronous speed,*

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I. INTRODUCTION

The stable operation of a power system requires a continuous match between energy input going to the prime mover and the electrical energy taken out of the synchronous machine. Continuous change is essential for an operating power system .Basically the changes are usually very small increment as customer load increases or decreases in the course of operation. Each load increase or decrease may be accompanied by a corresponding change in input to the prime mover of the generators on the system. Changes in loads and generation results in relative change in the position of the generator rotor that must all operates in synchronism, if the power system is to remain "stable". Therefore, power system stability is basically concerned with changes in rotor speeds, rotor-positions and generator loads[1]. This means that "power system stability' has to do with the ability of the system to respond to disturbance from it's normal operating state and return to another state where the condition of operation isstable. Basically there are three types of power system stability , they are steady state stability, transient state stability and dynamic stability [2].

II. BACKGROUND OF STUDY

The modern deregulated electricity sector has improved utilities around the world, which has resulted in operating the power systems near the stability threshold and has brought about efficient utilization of transmission network [3].This new trend in deregulation has resulted in new opportunity for power system operators with new innovations in the power system. Critical analysis of recent widespread occurrence of power outages showed that blackouts is recorded whenever the sequence of normal contingencies exceeds the acceptable security limits and reliability margins [4].However to ensure the stability of power system ,there are two essential parameters that play key role in maintaining stability. They are the fault clearing time (FCT) and the critical clearing time (CCT) [5]

III. METHODOLOGY

A relay plays a key role in the power system ,in the sense that it acts as the watch man on site, It is programmed base on time setting in (seconds) in the case of stability issues to sense the fault and quickly relays the information to the circuit breaker to disconnect or connect a section of the power network, thereby preventing the fault from spreading to other parts of the network. Thereare 3 stages the fault in the network can exist in: pre fault, fault stage and post fault. They are nonlinear and can only be resolved by nonlinear technique. A synchronous machine can be modeled as given in figure 3, with a constant voltage source behind transient reactance [6].This work will strongly consider the application of using modified Euler numerical techniques in resolving transient stability issues in a developing economy, and compare it to the conventional swing equation technique. Figure 2 shows the power transfer capability of the power network at various position of the power angle [1].

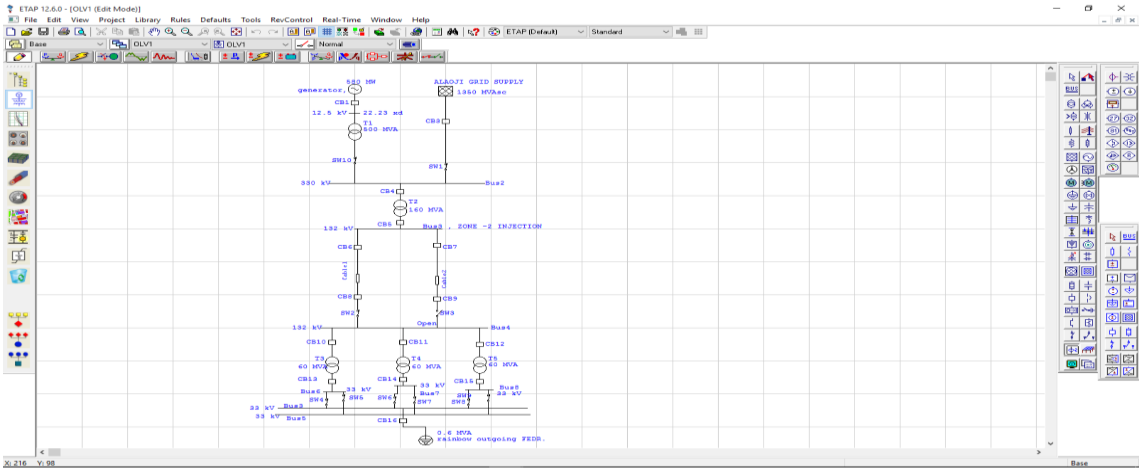

Figure 1: Single Line Diagram of Power Supply from Afam Power Generating Station to Port Harcourt Mains (Z2);Study Case.

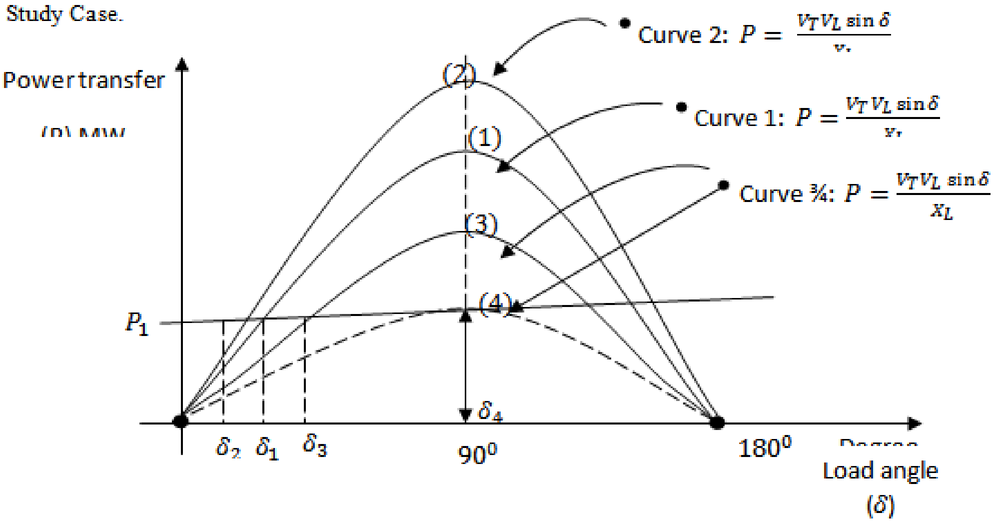

Figure 2:Power transfer capability curve

Figure 3: Simplified Machine Model

The equation for a simplified cylindrical pole machine is given as

$$E = V + jX_d I \qquad (1)$$

The equation for a salient pole machine is given as

$$E = V + rI + jX_d I_d + jX_q I_q \qquad (2)$$

V = terminal voltage

X_d^1 direct axis reactance for cylindrical rotor machine

E^1 = internal voltage for small period analysis which is transient. We use the transient reactance of the machine.

X_d^1 = transient reactance for salient pole

$$E = V + jX_d^1 I_d + jX_q^1 I_q \qquad (3)$$

For Machine connected to infinite Bus, $H = \infty$

The reactance of the machine model is given as

$$X = X_d^1 + X_e \qquad (4)$$

$$X_e = X_L + X_t \qquad (5)$$

Where

X_L = line reactance

X_t = Transformer reactance

$$X_{eq} = X_d^1 + X_L + X_t \quad [7] \quad (6)$$

From eq (6) the electrical power output is given as for both salient and cylindrical pole machines

$$P_e = \frac{|E'||V_\infty|}{Xeq} \sin\delta + \frac{V_\infty}{2}\left(\frac{1}{X_q^1} - \frac{1}{X_d^1}\right)\sin\delta \qquad (7)$$

For cylindrical rotor machine

$$X_q^1 = X_d^1$$

However equ (7) becomes

$$P_e = \frac{|E'||V\infty|}{X_{eq}} \sin\delta = P_{\max} \sin\delta \qquad (8)$$

Equ 8 is the power transfer through thepower network

Bus Data

The bus loading conditions for the network under study are the maximum and minimum load ranges from PHEDC and PHCN data etc. The line data and the generator system parameters are used in this research work which are presented as;

Table 1: Bus Loading for the Transmission Network

S/N	BUS	MW	MW	MVAR	MVAR
1.	BUS 1	158	104	78	57
2.	BUS 2	248	176	132	81

Table 2: Transmission Line Parameter for Transmission Network

S/N	BUS	Length L (KM)	Resistance (RPU)	Inductance (XPU)
1.	BUS 1(Afam)	98	0.023	0.074
2.	BUS 2(Z2)	20	1.1785	0.28

Table 3: Generator System Parameter (Afam Generating System)

S/N	Parameter	Numerical Value
1.	H(Inertia Constant)	8.08
2.	MW(Active Power)	580
3.	MVAR(Reactive Power)	350.00
4.	Frequency, F(Hz)	50.00

Calculation of Line Network Parameter

Using base of 250MVA

$$P_e = \frac{381}{250} = 1.524\text{pu}$$

$$P_m = \frac{383}{250} = 1.532\text{pu}$$

$$X = j0.275 + j0.097 + j\frac{0.081}{2}$$

$$X = j0.275 + j0.097 + j0.0405$$

$$X = j0.275 + j0.1375$$

$$X_{eq} = j0.4125pu$$

$$S = \frac{P_e}{P_f}\angle\cos^{-1}(\emptyset) \qquad (9)$$

Where

S = apparent power

P_f = power factor

P_e = electromechanical outpower

Substituting into equ (9)

$$S = \frac{1.524}{0.8}\angle\cos^{-1}(0.8)$$

$$S = 1.915\angle 36.87$$

The current is computed as

$$I = \frac{S^*}{V^*} = \frac{1.915\angle - 36.87}{1.0\angle - 0}$$

$$I = 1.915\angle - 36.87$$

Excitation voltage is given as;

$$E_g^I = V + JX_d^I I$$

$$E_g^1 = 1\angle 0 + (J0.4125)(1.915\angle - 36.87)$$

$$E_g^1 = 1 + J0 + (0.4125\angle 90)(1.915\angle - 36.87)$$

$$E_g^1 = 1.6036\angle 23.2 \text{ pu}$$

$$E_g^1 = 1.6036 \text{ pu}$$

From the calculation, Initial operating power angle becomes;

$$\delta_o = 23.2^o = 0.4049 \text{ rad}$$

$$\delta_o = \delta_L = 23.2^o = 0.4049 \text{ rad}$$

$$\omega_O = \omega_L = 2\pi f = 314.1593$$

$$H = 8.08MJ/MVA$$

Application of Swing Equation Technique to Transient Stability

Applying the values into the swing equation technique which is given as:

$$\frac{Hd^2\delta}{\pi f dt^2} = P_m - P_e \quad pu \qquad (10)$$

Where
H = the machine inertia constant
Ƒ= the machine frequency
P_m = mechanical input power
P_e = electrical output power
Subsisting into equation (10) we have

$$\frac{8.08}{\pi \times 50} \frac{d^2\delta}{dt^2} = (1.532 - 0) \quad \text{(during fault, } P_e = 0\text{)}$$

$$\frac{8.08}{\pi \times 50} \frac{d^2\delta}{dt^2} = 1.532$$

Double differentiating gives:

$$\delta(t) = \frac{\pi \times 50}{16.6} t^2 + \delta_o$$

Using the result of double differentiation, the power angle can be investigated for seven cycles of time interval which shall be compared to the Modified Euler technique

Application of Modified Euler to Transient Stability analysis
Using the twoconventional first order differential equations, the Modified Euler can be investigated for seven cycles as:

$$\frac{d\delta}{dt} = \omega_L - \omega_S \qquad (11)$$

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

$$\frac{d\omega}{dt} = \frac{50\pi}{H}(P_m - P_e) \qquad (12)$$

First iteration at t = 0.02 =1 cycle
First evaluation of (□ ,ω,$\frac{d\delta}{dt}$)
From equ. (11)

$$\frac{d\delta_1}{dt} = \omega_L - 314.1593, \frac{d\delta_1}{dt} = 314.1593 - 314.1593, \frac{d\delta_1}{dt} = 0$$

From equ (12)

$$\frac{d\omega_1}{dt} = 19.4405(1.532 - 0), (P_e = 0 \text{ at fault point})$$

$$\frac{d\omega_1}{dt} = 29.7828$$

Using the predictor equation for both results of equ (11) and (12)

$$\delta_1(0.02) = \delta_L + \left(\frac{d\delta_1}{dt} \times \Delta t\right)$$

$$\delta_1 = 0.4049 + (0 \times 0.02)$$

$$\delta_1(0.02) = 0.4049 rad = 23.2^0$$

$\omega_1(0.02) = \omega_L + (\frac{d\omega_1}{dt}$ x 0.02) =314.755 rad/sec

$\omega_1 = \omega_r$

Second evaluation **of (□ , ω,$\frac{d\delta}{dt}$) ,** from equ (11) and (12)

$$\frac{d\delta_2}{dt} = \omega_r - 314.1593$$

$$\frac{d\delta_2}{dt} = 314.755 - 314.1593$$

$$\frac{d\delta_2}{dt} = 0.5957$$

$$\frac{d\omega_2}{dt} = 19.4405(1.532 - 0)$$

$$\frac{d\omega_2}{dt} = 29.7828$$

Applying the corrector equation to both first and second evaluation above .

The corrector equation is given as:

$\delta_2 = \delta_L + \frac{1}{2}(\frac{d\delta_1}{dt} + \frac{d\delta_2}{dt}) \times \Delta t.$

We obtain :

$\delta_2\ (0.02) = 0.4109\ \text{rad} = 23.5^0$

$\omega_2\ (0.02) = 314.755\ \text{rad/sec}$

$$\delta_2 = \delta_L = 0.4109\text{rad}$$

$\omega_2 = \omega_L = 314.755\ \text{rad/sec}$

The iteration is repeatecd for seven cycles

IV. RESULTS AND DISCUSSION

Captured results of the power angle and its corresponding speed have been presented for better analysis of the power network behavior. It gives an insight of the simultaneous behavior of the variables in the power network whenever the transmission network is disturbed. The result of such analysis are presented as;

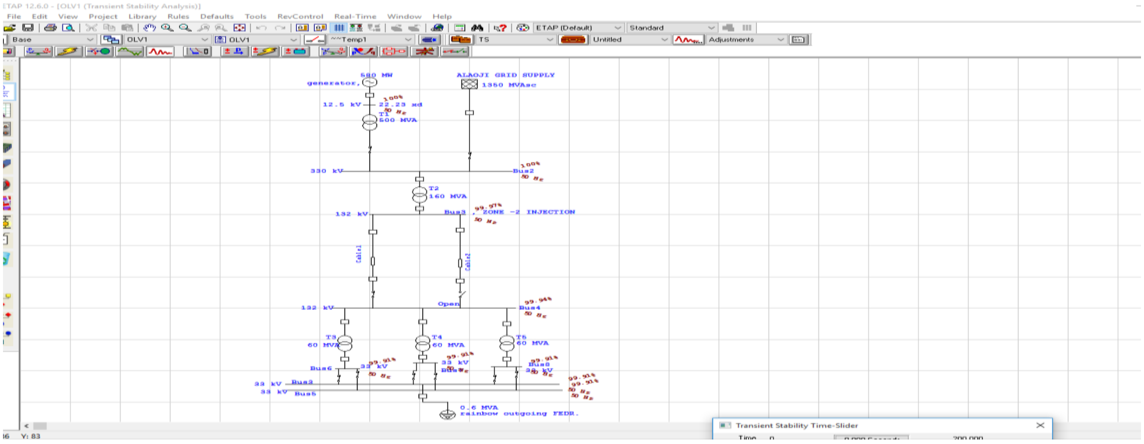

Figure 4: Simulated Network From Afam Power Generating Station To Port Harcourt Mains (Z2)

Table 4: Shows the incremental time (t) with changes in machine rotor angle(δ_2).

t	δ_2(rad)	δ_2(deg)
0	0.4049	23.2
0.02	0.4109	23.5
0.04	0.4586	26.3
0.06	0.6194	35.5
0.08	1.0006	57.3
0.10	1.4271	81.8
0.12	1.3401	77.0
0.14	0.4276	24.5

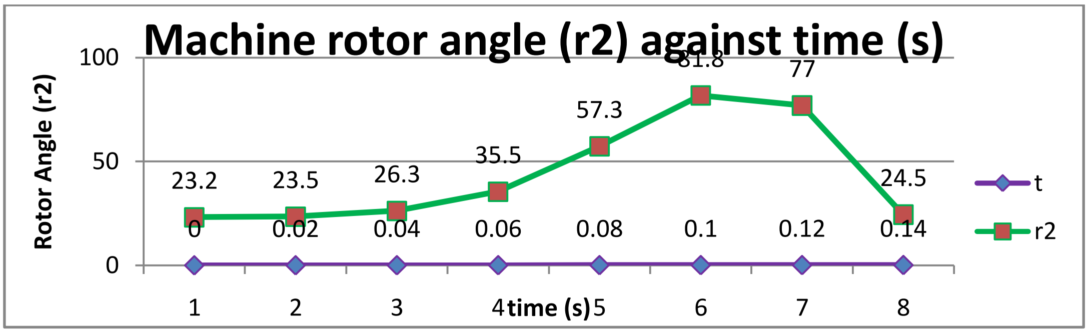

Figure 5: Presentation of machine rotor angle (r2) against time

Fig 5 presents the rotor angle swing curve against time for the corrector case. for a stable system, stability is given by observation of the swing curve from 23.2 to 57.3 degree of the power angle which corresponds to time setting of 0 to 0.08 seconds of the relay setting . After fault clearance at 0.08s the power angle still accelerate further to 81.8 degrees at (time t=0.1) due to stored kinetic energy, and started decreasing haven exhausted it's stored energy. if the system is unstable, the power angle continues to increase indefinitely with time and the machine losses synchronism

Table 5: Shows the incremental time (t) with changes in machine rotor angle (δ_2) for swing equation technique and modify euler.

t	δ_2(swing,deg)	δ_2(modify,deg)
0	23.2	23.2
0.02	23.4	23.5
0.04	24.1	26.3
0.06	25.2	35.5
0.08	26.8	57.3
0.10	28.8	81.8
0.12	31.2	77.0
0.14	34.1	24.5

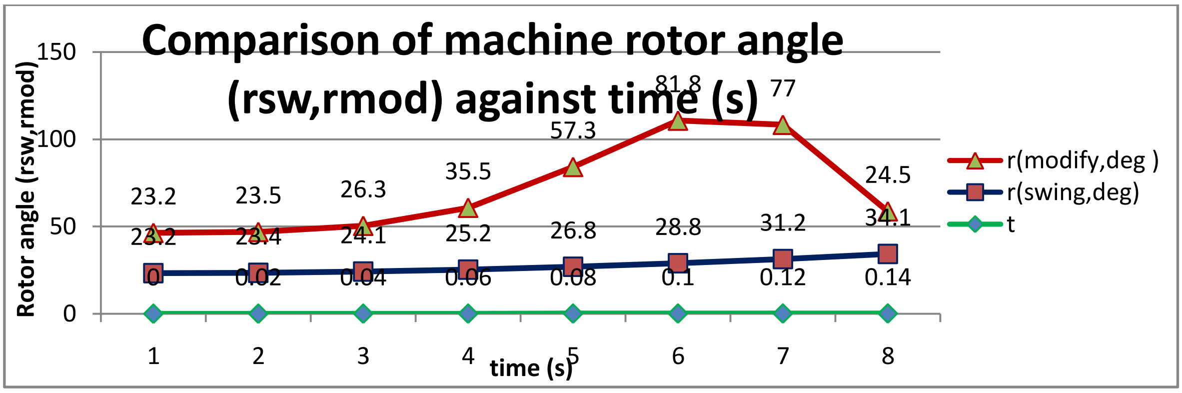

Figure 6: Presentation of comparison of swing equation and modified euler

From the result of analytical solution, the two graphs of fig 6 shows the corrector case of the rotor angle swinging for a gradual time increase from the point of fault initiation at time t = 0 of the relay setting up to the point of fault clearance at time t = 0.08 by the circuit breaker. There was a corresponding increase in both technique but after the fault was cleared at time t = 0.08, the power angle of the modified Euler curve accelerated up to 81.8^0due to the stored kinetic energy, at time t = 0.1 before decelerating which is an indication of fast response toinstability problem, while the swing equation technique curve continued to accelerate which is a sign of poor response to instability at the point of fault occurrence. The modified Euler strongly showed that it has faster response time in the event of fault occurrence than the conventional swing equation technique.for this work 7 cycles were allowed at each point, the power angle (voltage angle), the corresponding angular speed (velocity) and the differential change were obtained.

Discussion of simulated graph

Appendix B2 showed when a three phase fault was initiated at the generator bus, the result of the simulation showed the swinging of the generators which is an indication of stable equilibrium. The closed spreading of the swing curve showed that for fault close to the generator, the system returns to stability faster than fault located far away from the generator. Appendix B3 shows the transient result of the generator bus frequency. A disturbance in the form of a three phase fault was simulated at the generator bus, at different time t=0.02 to 0.14 and the result showed the divergence of the bus frequency from 50Hz to 100Hz indicating that an action must be taken immediately to bring the network back to normalcy through the programming of the relay. Appendix B5 showed when a three phase fault was initiated between the generator bus and bus 2, the swinging action is a sign of stable equilibrium after the fault was cleared. The wider spreading of the swing curve showed that fault located far away from the generator bus, when cleared do not return to stability rapidly.

V. CONCLUSION

This thesis attempted to provide an insight into the power system transient stability issue in a developing nation with emphasis on the behavior of the synchronous machine following a large sudden disturbance on the transmission network. The generation and transmission line data were collected and analyzed. An E-tap software platform was used to draw the network and after which it was used to analyze the network and results were generated in the analysis . The time to power angle and time to angular velocity was strongly investigated using analytical tool. The swing equation and modified Euler model were compared to determine the accelerating power of the synchronous generator when the load is suddenly removed to ascertain there level of response. Stability was achieved for 4 cycles at a power angle of 57.3^0 above 4 cycles without clearing the fault any swinging due to disturbance can cause instability. The load flow results and swing curves were presented at appendices of this work.

RECOMMENDATION

It is important that recommendations resulting from transient stability be taken seriously by power system engineers. Several revelations available before fault can serve as a handy information to prevent future fault occurrence when strictly adhered to. Regardingthis research and result available on the existing network of the case study, the following points are presented for considerations;

1. There should be periodic training for the operators on information gathering and implementation.
2. The protective devices (relay and circuit breaker) should be sensitive enough to respond to fault and slow the spread of fault to other parts of the network.
3. The reactive power and voltage control practices should be evaluated.

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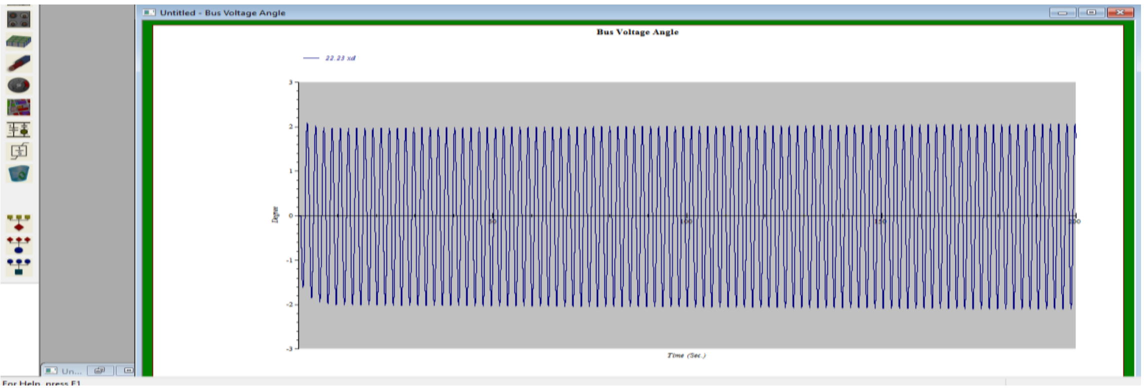
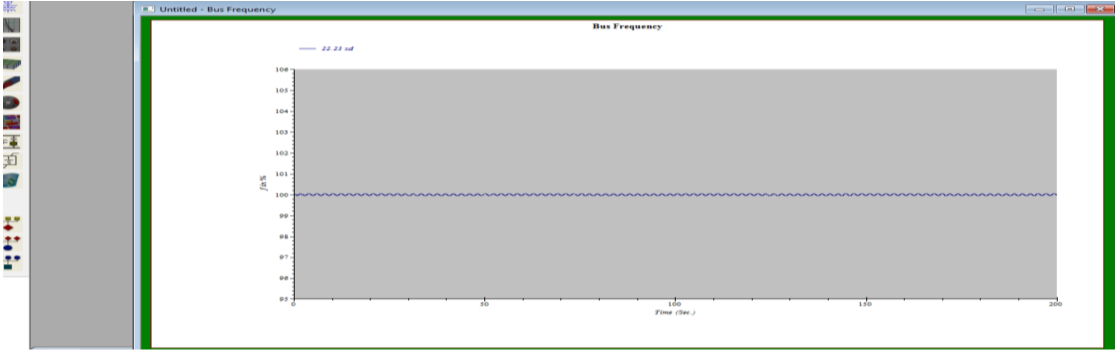
APPENDIX B2

PRESENTATION OF BUS VOLTAGE ANGLE



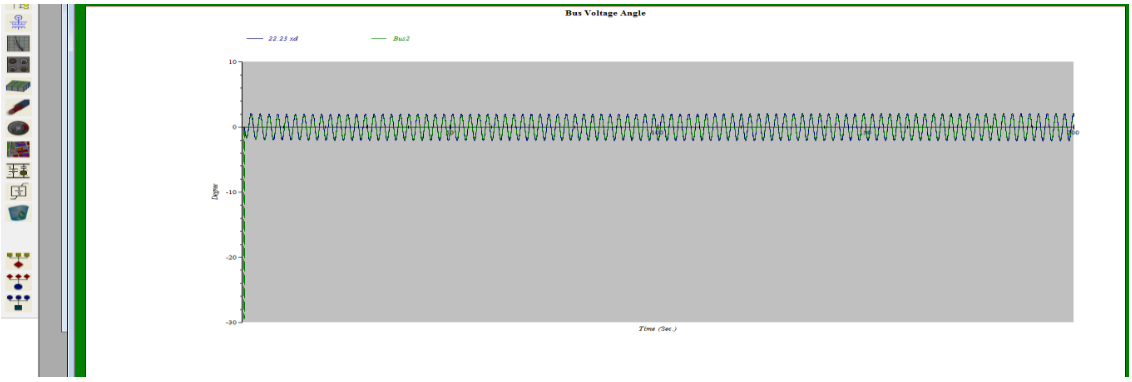
APPENDIX B3

PRESENTATION OF GENERATOR BUS FREQUENCY



APPENDIX B4

PRESENTATION OF BUS VOLTAGE ANGLE BETWEEN THE GENERATOR AND BUS 2



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