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Research Article

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Analysis of the Response of Nigerian 330kv medium Transmission Line

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Abstract This research work analyses the behaviour of the Nigerian 330kV medium transmission line network to controlled signals. To carry out this work successfully, the medium transmission line network was modelled using Laplace transform in the S-domain. The state space equations for the lines in the network was also obtained. The network was tested for stability using the Eigen values for the state variables. The Unit-step signals and the Impulse signal were injected into the medium transmission line network. The response of the network was obtained. The work was based on the effect of varying shunt capacitance on the medium transmission line.

It was observed that for a capacitance of 0.0000015pu on the medium transmission line, the settling time was 0.059sec and the steady state time was 0.08sec.this was the best time recorded.

Keywords Medium Transmission Line, Unit Step Signal, Impulse Signal, Shunt Capacitance.

Introduction

In the power system, fault is one of the system problems that occur in the system. These faults are overcurrent in the circuits mainly due to a short circuit [1]. A short circuit in a power system is clearly not a steady state condition. Such an event can start a variety of different dynamic phenomena in the system, and to study these, dynamic models are needed. However, when it comes to analysing the fault currents in the system, steady state (static) models with appropriate parameter values can be used. A fault current consists of two components, a transient part, and a steady state part, but since the transient part can be estimated from the steady state one, fault current analysis is commonly restricted to the analysis of the steady state fault currents [2].

It is not practical to design and build electrical equipment or networks so as to completely eliminate the possibility of failure in service. It is therefore an everyday fact of life that different types of faults occur on electrical systems, however infrequently, and at random locations [3].

The Concept of Controllability and Observability of a System

According to [4-6] controllability involves determining the state vector from the input vector and also involves the system and input matrices. For a system to be controllable, the determinant of the controllability matrix must exist.

Observability is concerned with finding the state vector from the output vector and thus involves the system and output matrices. Hence for a system to be observable and controllable, their determinant matrices must exist.

Modelling of a 330kv Medium Transmission Line

The medium transmission line is a line whose length exceeds 250 km .This line circuit is modelled using the π-configuration and complex impedance (Z). Figure 1 shows the equivalent circuit for a medium transmission line.

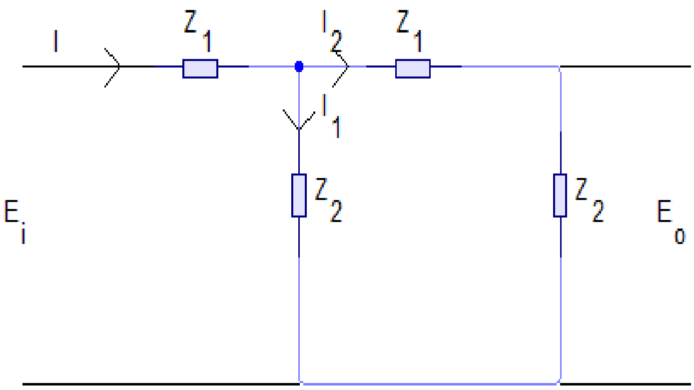

Figure 1: Equivalent Circuit for a Long Transmission line

$Z_1 = \dfrac{R+Ls}{2}$ 1

$Z_2 = \dfrac{1}{Cs}$ 2

$Z_2 I_1 = (Z_1 + Z_2) I_2$ 3

$I_1 + I_2 = I$ 4

Using current divider rule

$I_1 = \dfrac{Z_1 + Z_2}{Z_1 + 2Z_2} I$ 5

$I_2 = \dfrac{Z_2}{Z_1 + 2Z_2} I$ 6

$E_1(s) = Z_1 I + Z_2 I_1 = \left[Z_1 + Z_2 \left(\dfrac{Z_1 + Z_2}{Z_1 + 2Z_2} \right) \right] I$ 7

$E_0(s) = Z_2 I_2 = Z_2 \left(\dfrac{Z_2}{Z_1 + 2Z_2} \right) I$ 8

Equation 7 can be written as follows;

$E_1(s) = \dfrac{Z_1(Z_1 + 2Z_2) + Z_2(Z_1 + Z_2)}{Z_1 + 2Z_2}$ 9

The transfer function is written as

$\dfrac{E_o(s)}{E_i(s)} = \dfrac{Z_2^2}{Z_1(Z_1 + 2Z_2) + Z_2(Z_1 + Z_2)}$ 10

$= \dfrac{\left(\dfrac{1}{CS}\right)^2}{\left(\dfrac{R+LS}{2}\right)\left[\left(\dfrac{R+LS}{2}\right) + 2\left(\dfrac{1}{CS}\right)\right] + \dfrac{1}{CS}\left[\dfrac{R+LS}{2} + \dfrac{1}{CS}\right]}$ 11

$= \dfrac{1}{CS\left[\left(\dfrac{R+LS}{2}\right)^2 + \left(\dfrac{R+LS}{CS}\right) + \left(\dfrac{R+LS}{CS}\right) + \dfrac{R+LS}{2CS} + \dfrac{1}{C^2S^2}\right]}$ 12

$$= \frac{1}{\left[CS\left(\frac{R+LS}{2}\right)^2 + \frac{3}{2}(R+LS) + \frac{1}{CS} \right]} \quad 13$$

$$= \frac{4CS}{CL^2S^4 + 2RLCS^3 + (C^2R^2 + 6LC)S^2 + 6RCS + 1} \quad 14$$

Methodology

The state space equation for the transmission line in study is first obtained to check if the system or medium transmission line can be controlled and observed. If such medium transmission line passes the test for controllability and observability, control signals such as the unit-step and ramp input signals are introduced to the medium transmission line. The medium transmission line response is observed to obtain the settling time and steady state value. The capacitance of the medium transmission line is varied during the simulation and the settling time and steady state value is observed. The root-locus diagram for the network is also plotted to observe the stability of the medium transmission lines.

Simulation Results and Analysis

Analysis of Medium Transmission Lines

Jebba GS to Oshogbo

The State space equation at C=0.0000005 is

$$\begin{bmatrix} \dot{X}_1 \\ \dot{X}_2 \end{bmatrix} = 1.0*10^{11} \begin{bmatrix} 0 & -3.7 \\ 0 & 0 \end{bmatrix} \begin{bmatrix} X_1 \\ X_2 \end{bmatrix} + \begin{bmatrix} 1 \\ 0 \end{bmatrix} u \quad 15$$

$$y = 1*10^{11}\begin{bmatrix} 0 & 3.7 \end{bmatrix} \quad 16$$

The determinant of the controllability and observability matrices exist hence it can be controlled and observed. The stability of the line can be represented with root locus diagram.

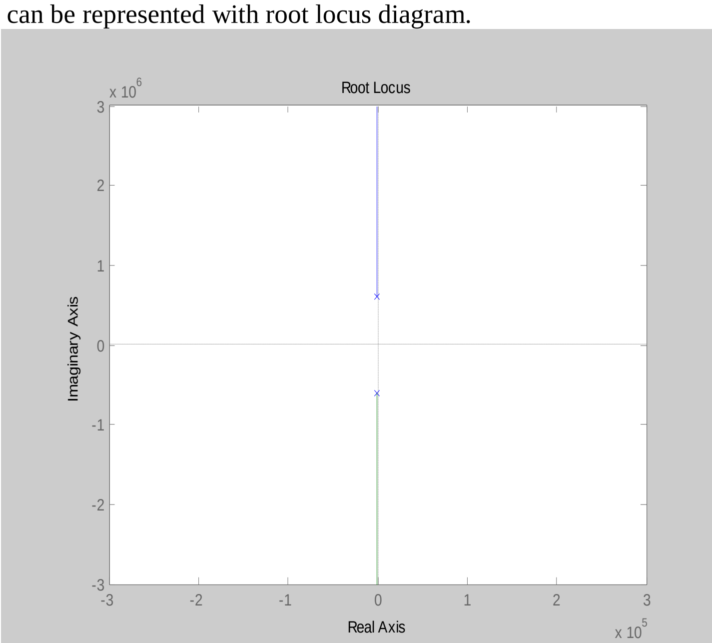

Figure 2: Root-Locus diagram at C = 0.0000005 for JebbaGS-Oshogbo

From the diagram the poles are not located in the positive half of the s-plane hence the system the step response curve is shown in Figure 3.

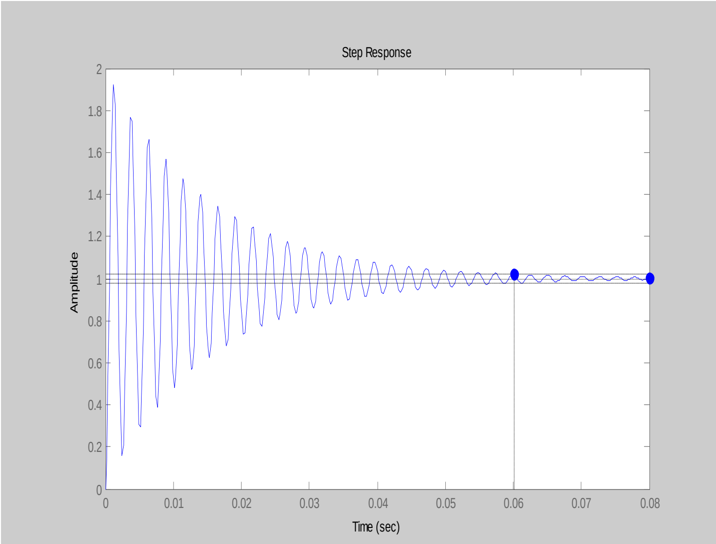

Figure 3: Step response curve at 0.0000005 for JebbaGS-Oshogbo

From the curve, the settling time is 0.06sec and the steady state time is 0.08sec. The impulse response is show in Figure 4.

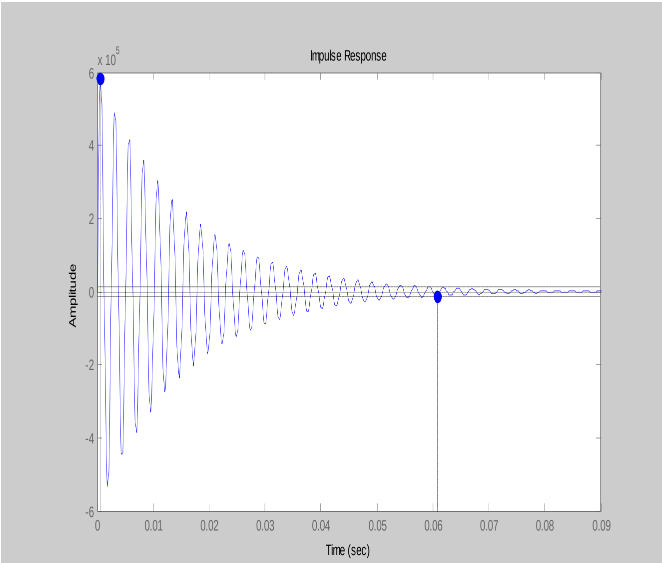

Figure 4: Impulse response at C=0.0000005 for JebbaGS-Oshogbo

The settling time with the impulse signal is 0.61sec.

The State space equation at C=0.0000010 is

$$\begin{bmatrix} \dot{X}_1 \\ \dot{X}_2 \end{bmatrix} = 1.0*10^{11} \begin{bmatrix} 0 & -1.85 \\ 0 & 0 \end{bmatrix} \begin{bmatrix} X_1 \\ X_2 \end{bmatrix} + \begin{bmatrix} 1 \\ 0 \end{bmatrix} u \quad (17)$$

$$y = 1*10^{11} [0 \quad 1.85] \quad (18)$$

The determinant of the controllability and observability exist hence it can be controlled and observed. The stability of the line can be represented with root locus diagram.

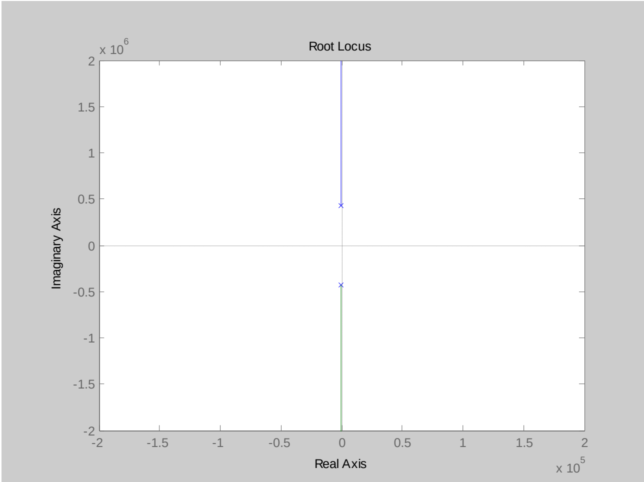

Figure 5: Root Locus Diagram at C=0.0000010 for JebbaGS-Oshogbo

From the diagram the poles are not located in the positive half of the s-plane hence the system.

The step response curve is shown in Figure 6.

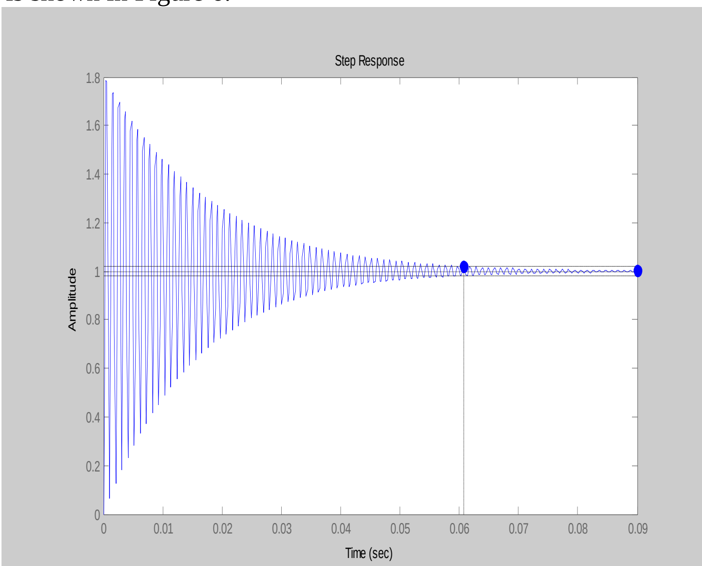

Figure 6: Step response at C=0.0000010 for JebbaGS-Oshogbo

From Figure 6, the settling time is 0.061sec and the steady state time is 0.09sec.

The impulse response curve is shown in Figure 7.

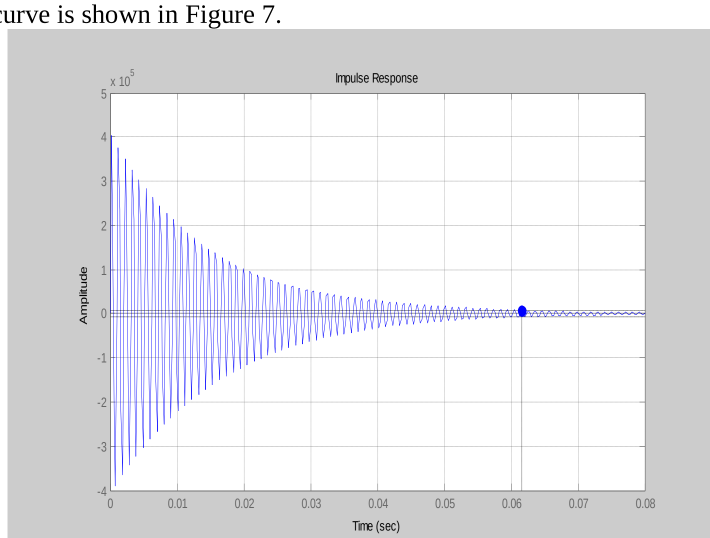

Figure 7: Impulse response at C=0.0000010 for JebbaGS-Oshogbo

The settling time is 0.062 sec.
The State space equation at C=0.0000015 is

$$\begin{bmatrix} \dot{X}_1 \\ \dot{X}_2 \end{bmatrix} = 1.0*10^{11}\begin{bmatrix} 0 & -1.23 \\ 0 & 0 \end{bmatrix}\begin{bmatrix} X_1 \\ X_2 \end{bmatrix} + \begin{bmatrix} 1 \\ 0 \end{bmatrix}u \quad (19)$$

$$y = 1*10^{11}\begin{bmatrix} 0 & 1.23 \end{bmatrix} \quad (20)$$

The determinant of the controllability and observability matrices exist hence the system can be controlled and observed.
The root-locus diagram is shown in Figure 8

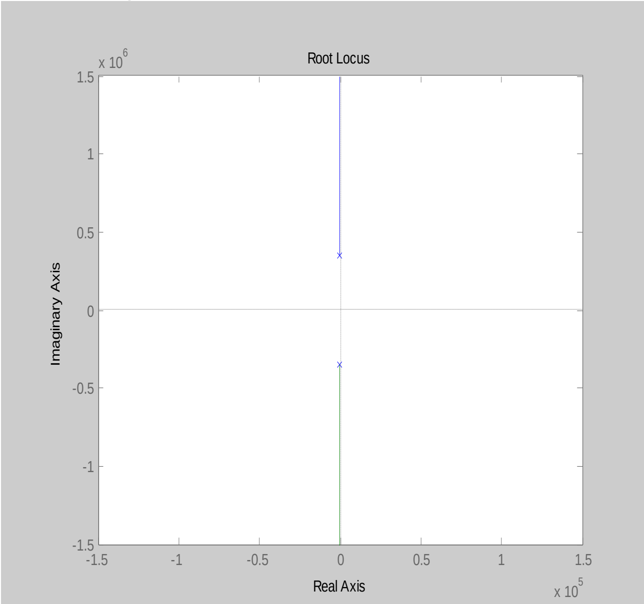

Figure 8: Root-Locus diagram at C=0.0000015 for JebbaGS-Oshogbo

The roots of the characteristic equation are both having negative real numbers that is the poles are located in the left hand side of the s-plane.
The step response of the system is illustrated in Figure 9

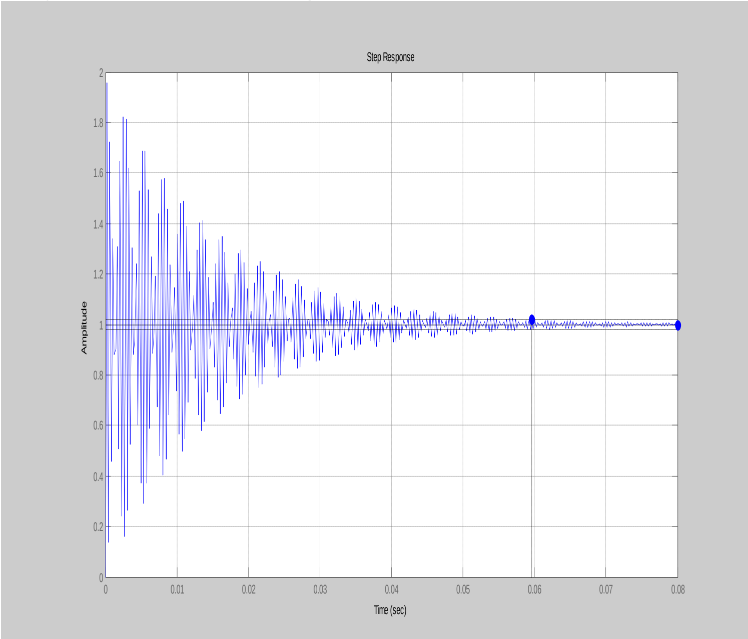

Figure 9: Step response at C=0.0000015 for JebbaGS-Oshogbo

From the figure, it can be seen that the settling time is 0.059sec and the steady state time is 0.08sec.

The impulse response is shown in Figure 10.

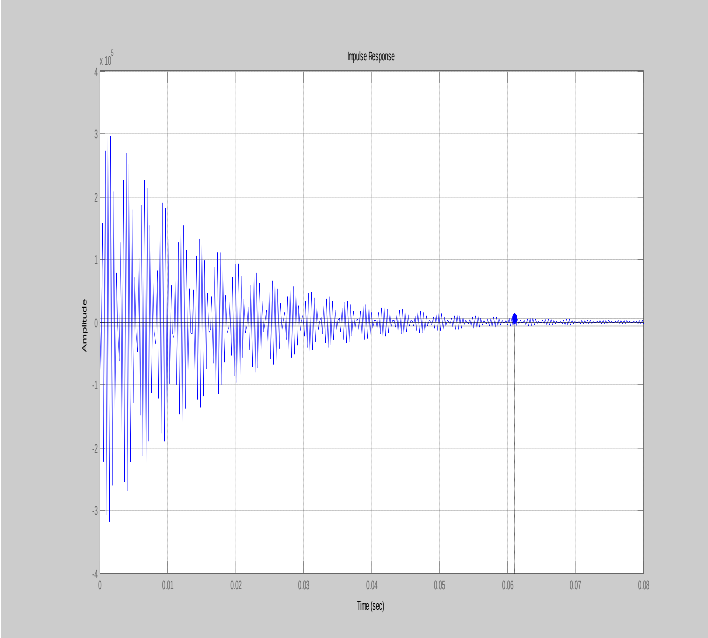

Figure 10: Impulse response at C=0.0000015 for JebbaGS-Oshogbo

The settling time with the impulse signal is approximately 0.061sec.

The State space equation at C=0.0000020 is

$$\begin{bmatrix} \dot{X}_1 \\ \dot{X}_2 \end{bmatrix} = 1.0*10^{10}\begin{bmatrix} 0 & -9.26 \\ 0 & 0 \end{bmatrix}\begin{bmatrix} X_1 \\ X_2 \end{bmatrix} + \begin{bmatrix} 1 \\ 0 \end{bmatrix}u \qquad 21$$

$$y = 1*10^{10}\begin{bmatrix} 0 & 9.26 \end{bmatrix} \qquad 22$$

The determinant of the controllability and observability matrices exist hence the system can be controlled and observed.

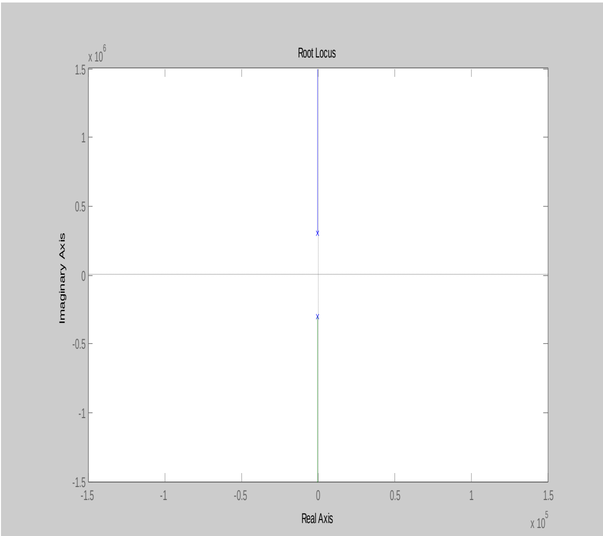

Figure 11: Root-Locus diagram at C=0.0000020 for JebbaGS-Oshogbo

The roots of the characteristic equation are both having negative real numbers that is the poles are located in the left hand side of the s-plane. Hence the system is stable with the capacitance.

The step response is shown in Figure 12.

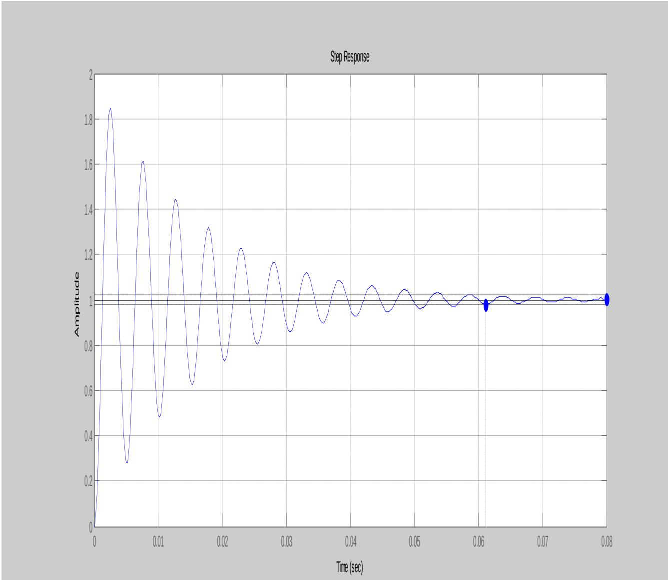

Figure 12: Step Response at C=0.0000020 for JebbaGS-Oshogbo

The settling time for the system is approximately 0.062sec and the steady state time is 0.08sec.
The impulse response is shown in Figure 13.

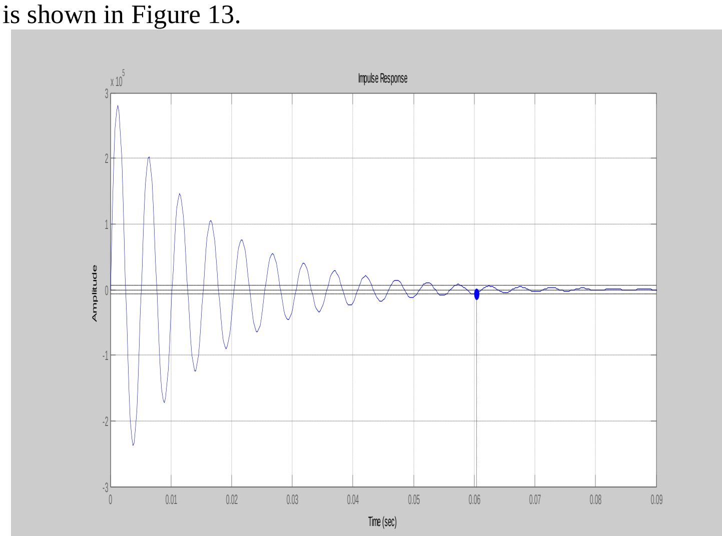

Figure 13: Impulse Response at C=0.0000020 for JebbaGS-Oshogbo

The settling time for the system under impulse signal is approximately 0.0607sec.
The State space equation at C=0.0000025 is

$$\begin{bmatrix} \dot{X}_1 \\ \dot{X}_2 \end{bmatrix} = 1.0*10^{10}\begin{bmatrix} 0 & -7.41 \\ 0 & 0 \end{bmatrix}\begin{bmatrix} X_1 \\ X_2 \end{bmatrix} + \begin{bmatrix} 1 \\ 0 \end{bmatrix}u \quad 23$$

$$y = 1*10^{10}\begin{bmatrix} 0 & 7.41 \end{bmatrix} \quad 24$$

The determinant of the controllability and observability matrices exist hence the system can be controlled and observed.
The root-locus diagram is shown in Figure 14

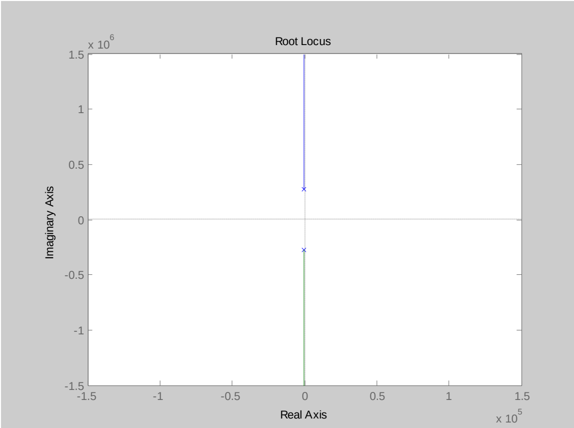

Figure 14: Root-Locus diagram at C=0.0000025 for JebbaGS-Oshogbo

The roots of the characteristic equation are both having negative real numbers that is the poles are located in the left hand side of the s-plane. Hence the system is stable with the capacitance.

The step response of the line is shown in Figure 15.

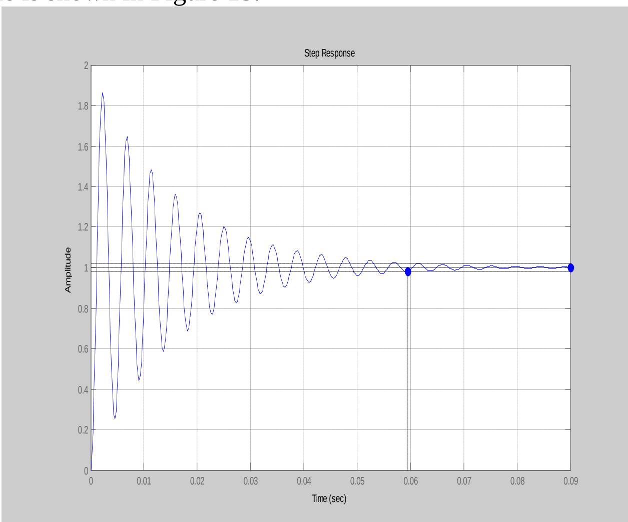

Figure 15: Step response diagram at C=0.0000025 for JebbaGS-Oshogbo

The settling time is approximately 0.059sec and the steady state is at 0.09sec.

The impulse response is shown in Figure 16.

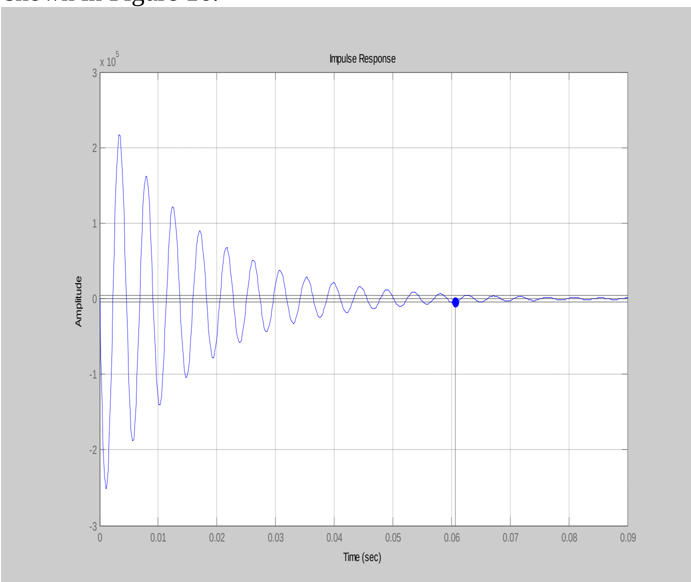

Figure 16: Impulse response diagram at C=0.0000025 for JebbaGS-Oshogbo

The settling time for the impulse signal is approximately 0.061sec.
The State space equation at C=0.0000030 is

$$\begin{bmatrix} \dot{X}_1 \\ \dot{X}_2 \end{bmatrix} = 1.0*10^{10}\begin{bmatrix} 0 & -6.17 \\ 0 & 0 \end{bmatrix}\begin{bmatrix} X_1 \\ X_2 \end{bmatrix} + \begin{bmatrix} 1 \\ 0 \end{bmatrix}u \quad 25$$

$$y = 1*10^{10}\begin{bmatrix} 0 & 6.17 \end{bmatrix} \quad 26$$

The determinant of the controllability and observability matrices exist hence the system can be controlled and observed.
The root-locus diagram is shown in Figure 17.

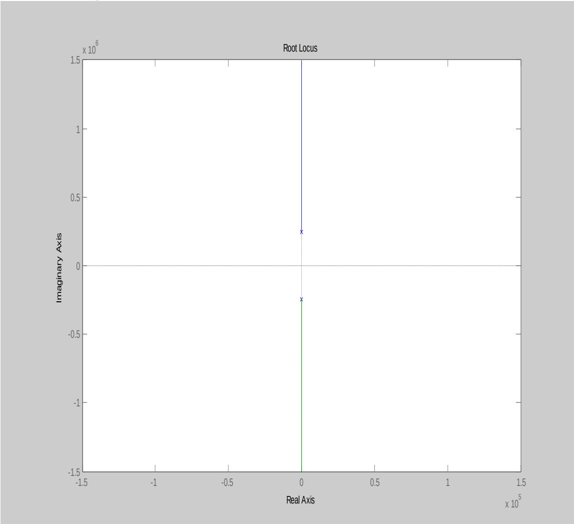

Figure 17: Root-Locus diagram at C=0.0000030 for JebbaGS-Oshogbo

The roots of the characteristic equation are both having negative real numbers that is the poles are located in the left hand side of the s-plane. Hence the system is stable with the capacitance.
The step response of the line is shown in Figure 18.

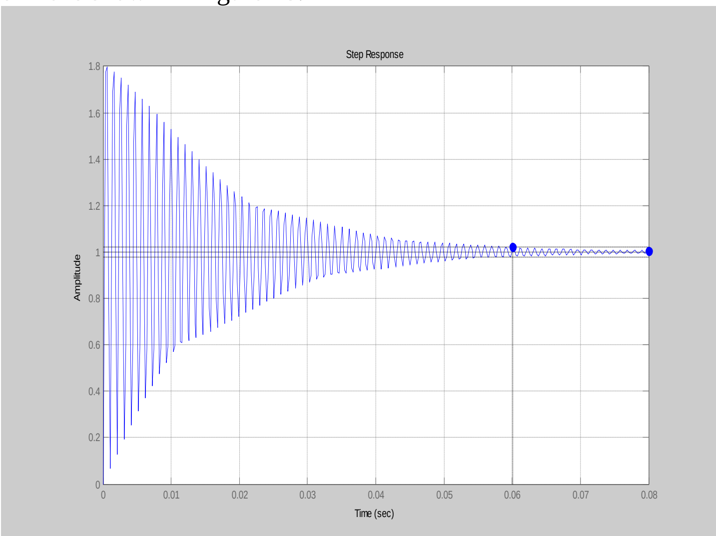

Figure 18: Step response diagram at C=0.0000030 for JebbaGS-Oshogbo

The settling time is approximately 0.06sec and the steady state is at 0.08sec.
The impulse response is shown in Figure 19.

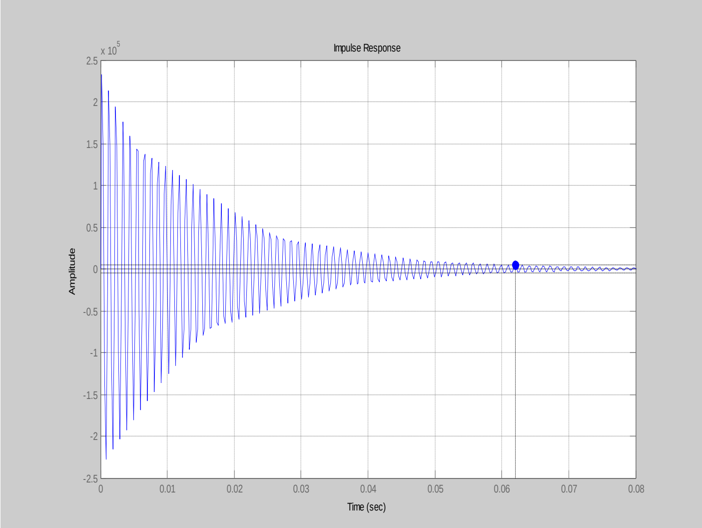

Figure 19: Impulse response diagram at C=0.0000030 for JebbaGS-Oshogbo

The settling time for the impulse signal is approximately 0.062sec.

From the step response plotted, it was observed that at C=0.0000015, the settling time and the steady state time were the fastest.

The other medium transmission lines follow the same pattern of analysis and are not repeated.

Conclusion

This research work analyses the behaviour of the Nigerian 330kV medium transmission line network to controlled signals. To carry out this work successfully, the medium transmission line network was modelled using Laplace transform in the S-domain. The state space equations for the lines in the network was also obtained. The network was tested for stability using the Eigen values for the state variables. The Unit-step signals and the Impulse signal were injected into the medium transmission line network. The response of the network was obtained. The work was based on the effect of varying shunt capacitance on the medium transmission line.

It was observed that for a capacitance of 0.0000015pu on the medium transmission line, the settling time was 0.059sec and the steady state time was 0.08sec.this was the best time recorded.

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