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Steady-State Stability Study of Power Transmission Network Using Simple Series Impedance Method

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ABSTRACT: This research work examined the steady-state stability of disturbances of the transmission line, and various kinds of fault that occurs on the electric power system transmission line using the simple series impedance method. A typical 330KV real line data (parameters) from the Odukpani transmission line station was used to model the power system transmission line in MATLAB R2016a. Simulations were performed on the power transmission line modelled with the line parameters and obtained graphical results from the model. The analysis of three (3) phase short-circuits faults including (phase A, phase B; phase C respectively) in a Matlab coded environment. The results of the simulated fault condition show that there is a strong need for short-circuit fault clearing time which should be quick for relays and circuit breakers responses (sensitivity and selectivity-based). The revelation of the finding also shows that system instability will be restored for improvement at fault clearing time before 0.09s. The effective and reliable operation of protective relay coordination is strongly recommended in the generating station which should be based on 'selectivity' and 'sensitivity' for fast discrimination of the circuit breaker action in the case of fault reoccurrence.

KEYWORDS: Steady-State Stability, Transmission Network, Nigeria Electricity Grid, Matlab/Simulink.

i. INTRODUCTION

The purpose of a transmission network is to transfer electrical energy from generation units at various locations to the distributions system which ultimately supplies the load. Transmission lines also interconnect neighbouring utilities which permit not only economic dispatch of power within regions during the normal condition, but also the transfer of power between regions during emergencies [1]. All transmission lines in a power system exhibit the electrical properties of resistance, inductance, capacitance and conductance, this line parameters cause 'voltage drop and losses along the line. Therefore, the stability of the line depends on this parameter and the occurrence of the fault. The short transmission line considers resistance and inductance, when the length of the transmission line increases, the line charging current becomes appreciable and shunt capacitance must be considered alongside the series resistance R and the inductance L. These parameters are essential for the development of the transmission line models used in power system analysis [1]. The resistance R is because the energy conductor offers opposition to the flow of current, the inductance L is because the current-carrying conductor is surrounded by the magnetic lines of force, the capacitance C is because the conductor carrying current forms a capacitor with the earth which always at lower potentials than the conductor and the air between them forms a dielectric medium. The effect of line resistance is that it causes voltage drop (IR volts) and power loss (I^2R watts) in the line.

The effect of line inductance is to cause a voltage drop in the line in quadrature with the current flowing in the conductor, which is equal to $2\pi fLI$ volts where f is supply frequency in Hz, L is the inductance per conductor in Henries and I is the current flowing through the conductor in amperes. The effect of line capacitance is to produce a current; called the charging current, which is in quadrature with the voltage. This component of current in the conductor has a maximum value at the sending end of the line and decreases continuously as the receiving end of the line approaches zero. The magnitude of charging current I_C at the sending end is given by $2\pi fCV_s$, where f is the supply frequency in Hz, C is the capacitor per conductor in farads and V_s is the voltage at the sending end to neutral in volts [3].

II. POWER SYSTEM OPERATIONAL SUSTAINABILITY

In recent times, the management of power systems has proven to be more difficult than in the past. This is due to recent increased competition (existing power systems are required to provide the same service at a lower cost), environmental constraints and other factors have conspired; thus, limiting the expansion of the transmission network [4].

The deregulation and unbundling of the power sector have witnessed a sudden increase in the demand for electricity with economic consideration as a top priority. The modern deregulated electricity environment has driven utilities, around the world, to operate the power systems closer to the stability thresholds to ensure more efficient utilization of transmission networks [5]. This development has opened a new opportunity for power system operators, whereby at the same time, putting the system under considerable pressure to strike a balance between more profit on one hand and fear of possible loss of the system on the other hand. Critical analysis of the recent widespread occurrence of power outages (worldwide) showed that a blackout is recorded whenever the sequence of normal contingencies exceeds the acceptable security limits and reliability margins [6]. It can also be noted that large power system failure is a rare event that is difficult to predict; so also, much tedious to control. To maintain the stability of the power system, there are two very important parameters which are namely: the fault clearing time (FCT) and critical clearing time (CCT). The FCT is defined as the time at which fault is cleared after the occurrence of the fault; always recorded in (seconds). Whereas, the CCT is the fault clearing time at which the system is critically stable, also measured in seconds [7].

Review on Voltage Stability of the Nigerian Electricity Grid

In [10] the researchers performed a voltage stability analysis of the Nigerian power grid. They employed a distributed generation system, where the electricity is added from different units in the system. They found that distributed generation in the country creates unique problems in the form of voltage control, maintaining power quality, and reducing the possible faults. Their analysis revealed that the voltage profile can be improved when the current faults are analyzed and the system is set up in the form of distributed generation which follows the available buses in the system. They found that the bus, which lies closest to the power distribution centre works the best when compared to other options.

In [11] the authors performed a survey in which they researched the flexible alternating currents transmission system (FACTS) controllers that can be implemented on the 330KV transmission line in Nigeria. The survey scrutinized various publications that discussed these systems and ensured that it is possible to compare the performance of SVC, UPFC, and other FACTS Controllers for use on the power grid of Nigeria. The review performed shows that the problems of the grid system will be greatly reduced, especially with the application of different FACTS with each providing specific benefits. While in [12] the authors also performed a case study of the 330KV line in Nigeria. They found with the help of the Power World Simulator that the grid is highly stable, and can quickly develop cascaded faults once it faces an isolated incident of loss of quality of power. Voltage stability becomes difficult to maintain in such circumstances. There is a need to modify the current network and add shunt compensation and network strengthening to improve the performance levels of the current 330KV Nigerian grid network. Idris and others [13] found that voltage stability improvements are possible by installing static VAR compensators that can improve the weak bus of the network.

Osahenwemwen and other engineers [14] performed research in which they evaluated both the 330KV and the 132KV power systems for a year for the entire 24-hour period. They found that the average loss of power in the 132KV line is around 2.76KV, while it is around 4.725KV for the 330KV line. The system provides an average of 22.5 amperes of current. The observation reveals that the losses increase as a higher power is sent through the current transmission system, while the conductor size and the covered distance also play a role in determining the electrical power loss during the transmission.

Enemouh and others [15] argued that using the V-Q Sensitivity method, it is possible to predict the voltage instability, which is present in the interconnected electric power system in Nigeria. They described that their calculations show the Maiduguri, Gombe, Kano, and Jos as the system buses that have successive high V-Q values. The Maiduguri Bus is at the highest risk of suffering from voltage instability. The improvement is possible by integrating the available power grids and ensuring that equipment is used to improve the voltage stability of the system. Samuel and others [16] performed research in which they found that system collapses can affect the perception of electrical power and can often produce a situation, where voltage instability is commonly present in a system, like the Nigerian grid system, which often varies in terms of the voltage amplitude and phase difference.

Overview of Power System Stability

The power system consists of some synchronous machines operating in synchronism. For the continuity of the power system, they must maintain perfect synchronism under all steady-state conditions. When the disturbance occurs in the system, the system develops a force due to which it becomes normal or stable [8,9]. The ability of the power system to return to its normal or stable conditions after being disturbed is called stability. Disturbances of the system may be of various types like sudden changes of load, the sudden short circuit between line and ground, line-to-line fault, all three-line faults, switching, etc. [9].

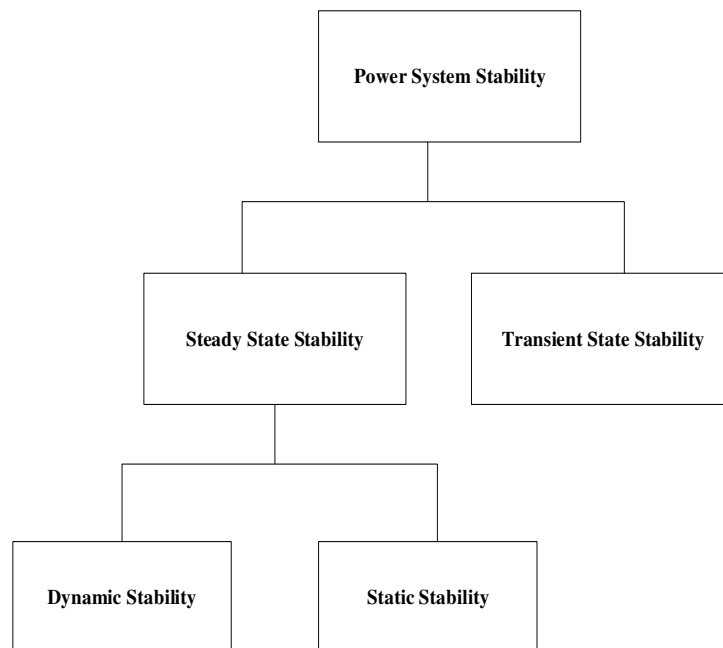


Figure 2.0. Power System Stability of a Transmission Line

The stability of the system mainly depends on the behaviour of the synchronous machines after a disturbance. The stability of the power system is mainly divided into two types depending upon the magnitude of disturbances [9].

- i) Steady-state stability
- ii) Transient stability

Steady-state stability – It refers to the ability of the system to regain its synchronism (speed & frequency of all the networks are the same) after slow and small disturbance which occurs due to gradual power changes. Steady-state stability is subdivided into two types [9];

Dynamic stability – It denotes the stability of a system to reach its stable condition after a very small disturbance (disturbance occurs only for 10 to 30 seconds). It is also known as small-signal stability. It occurs mainly due to the fluctuation in load or generation level.

Static stability – It refers to the stability of the system that obtains without the aid (benefit) of automatic control devices such as governors and voltage regulators.

III. MATERIALS AND METHODS

Materials used

The power supply network from Niger Delta Power Holding Company Limited (NDPHC), and Calabar generating Company Limited Calabar Itu Road Odukpani through a transmission line of 330KV and length of 74km to adiabio transmission substation, at Odukpani mains network data were collected and transmission company of Nigeria (TCN) for analysis and investigation for the study case.

Method of Analysis

Considering the activities of power systems whether steady-state, the behaviour of the electrical network will be determined for a given loading and operating condition of the system. This means that power flow problems will be formulated to monitor the existing state of the system. It is a requirement to consider the efficiency of the power system at all times for purpose of planning, design, and reconfiguration of the power system. This work will strongly consider the application of a short transmission line and MATLAB/SIMULINK will be used to draw and design and analyze the electrical network from the supply system to the study case.

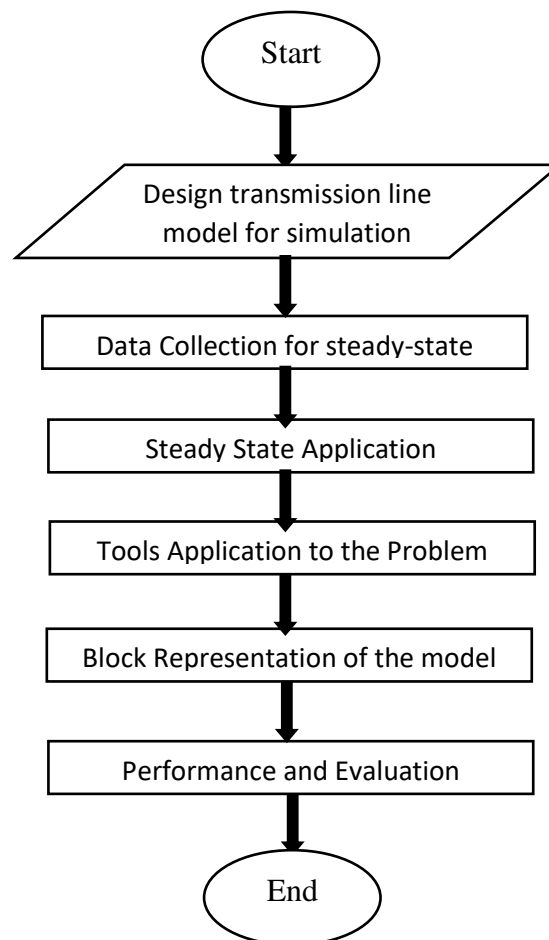


Figure 3.1: Flow chart of the study

Development of Model of the Power System Transmission Line Model

The 330kv transmission line model considered is a single line diagram with a total length of 74km as shown below. The model was developed using MATLAB/SIMULINK.

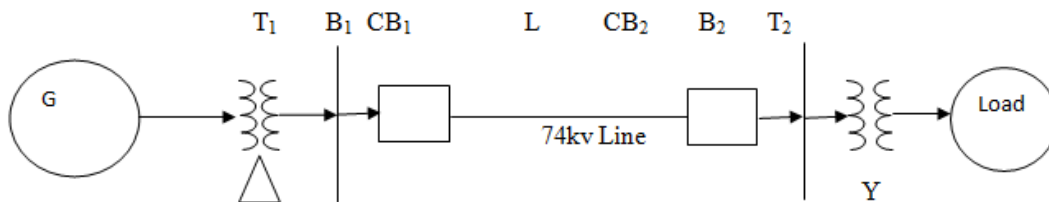


Figure 3.2: one line diagram of the network.

Table 3.1 System data from the transmission network

Network Component	MVA	Voltage Rating KV	R_{PU}	X_{PU}
G	150	15	1.726	1.726
T ₁	150	15/330	1.72	1.72
T ₂	150	330/132	0.008	0.007
T _L	150	330	0.37	0.13

Generalized Circuit Constants

The transmission line is a 4-terminal network, with two input terminals where power enters the network and two output terminals where the power leaves the network. Therefore, the input voltage (V_s) and input current (I_s) of 3-phase circuit constants of a transmission line can be expressed as [17,18]



Figure 3.3: Two-port representation of a transmission line.

Where;

V_s = Sending end voltage per-phase

I_S = Sending end current

V_R = Receiving end voltage per-phase

I_R = Receiving end current

$$V_S = AV_R + BI_R \dots\dots\dots (3.1)$$

$$I_S = CV_R + DI_R \dots\dots\dots (3.2)$$

With receiving end open-circuited,

Receiving end current I_R is Zero,

Therefore, from equations (3.1) and (3.2).

$$A = V_S/V_R \dots\dots\dots (3.3)$$

$$\text{And } C = I_S/V_R \dots\dots\dots (3.4)$$

With receiving end short-circuited,

Receiving end voltage V_R is Zero,

Therefore from equations (3.1) and (3.2).

$$B = V_S/I_R \text{ and } \dots\dots\dots (3.5)$$

$$D = I_S/I_R \dots\dots\dots (3.6)$$

Short Line Model

The capacitance will be ignored without much error since the lines are less than 80km (50miles) long.

$$Z = (r + j\omega L) l \dots\dots\dots (3.7)$$

$$= R + jX \dots\dots\dots (3.8)$$

Where r and L are the per-phase resistance and inductance per unit length, respectively, and l is the line length. The short line model on a per-phase basis is shown below [19].

V_S and I_S are the phase voltage and current at the sending end of the line, and V_R and I_R are the phase voltage and current at the receiving end of the line.

Referring to figure 2.1: a three-phase load with apparent power S_R (3ϕ) is connected at the end of the transmission line, the receiving end current is obtained by

$$I_R = S_R^* (3\phi) / 3V_R^* \dots\dots\dots (3.9)$$

The phase voltage at the sending end is

$$V_S = V_R + ZI_R \dots\dots\dots (3.10)$$

Since the shunt capacitance is neglected, the sending end and the receiving end current are equal i.e.

$$I_S = I_R \dots\dots\dots (3.11)$$

From equation (3.10) and (3.11)

$$A = 1, B = Z, C = 0, D = 1 \dots\dots\dots (3.12)$$

Regulation and Efficiency of a Transmission Line

Voltage regulation of the line is the percentage change in voltage at the receiving end of the line (expressed as a percent of full-load voltage) in going from no-load to full-load [18,19].

$$\text{Percentage } V_R = \frac{|V_{R(NL)}| - |V_{R(FL)}|}{|V_{R(FL)}|} \times 100 \dots\dots\dots (3.13)$$

At no-load $I_R = 0$ and from (3.1)

$$V_{R(NL)} = \frac{V_S}{A} \dots\dots\dots (3.14)$$

For a short line $A = 1$ and $V_{R(NL)} = V_S$

Once the sending end voltage is calculated the sending end power is obtained by

$$S_{S(3\phi)} = 3V_S I_S^* \dots\dots\dots (3.15)$$

The total line loss is then given by

$$S_{L(3\phi)} = S_{S(3\phi)} - S_{R(3\phi)} \dots\dots\dots (3.16)$$

And the transmission line efficiency is given by

$$\eta = \frac{P_{R(3\phi)}}{P_{S(3\phi)}} \dots\dots\dots (3.17)$$

Where $P_{R(3\phi)}$ and $P_{S(3\phi)}$ are the total real power at the receiving end and sending end of the line.

SIMULATION MODEL

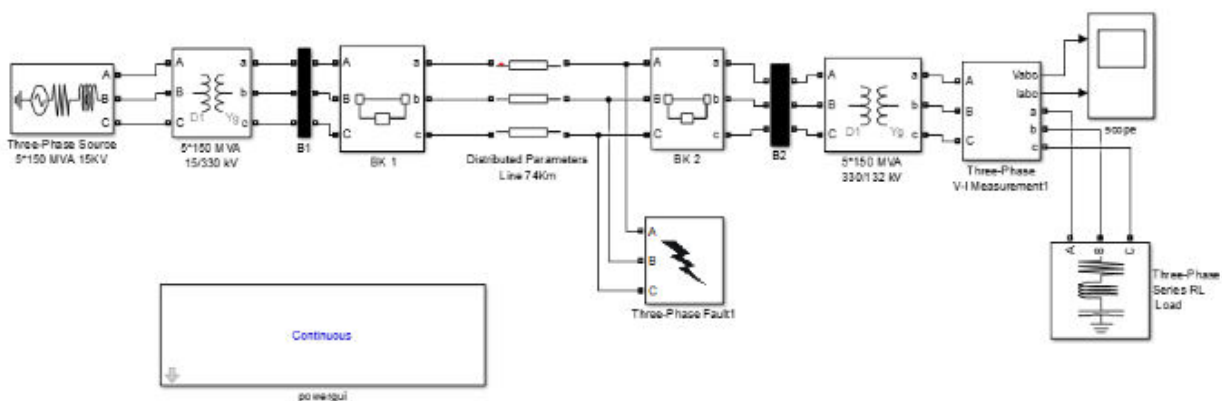


Figure 3.4. Simulation Model of the Network

IV. SIMULATION RESULTS AND DISCUSSION

Simulation Results:

Results of Short-Circuit Fault Simulations – Phase-A only

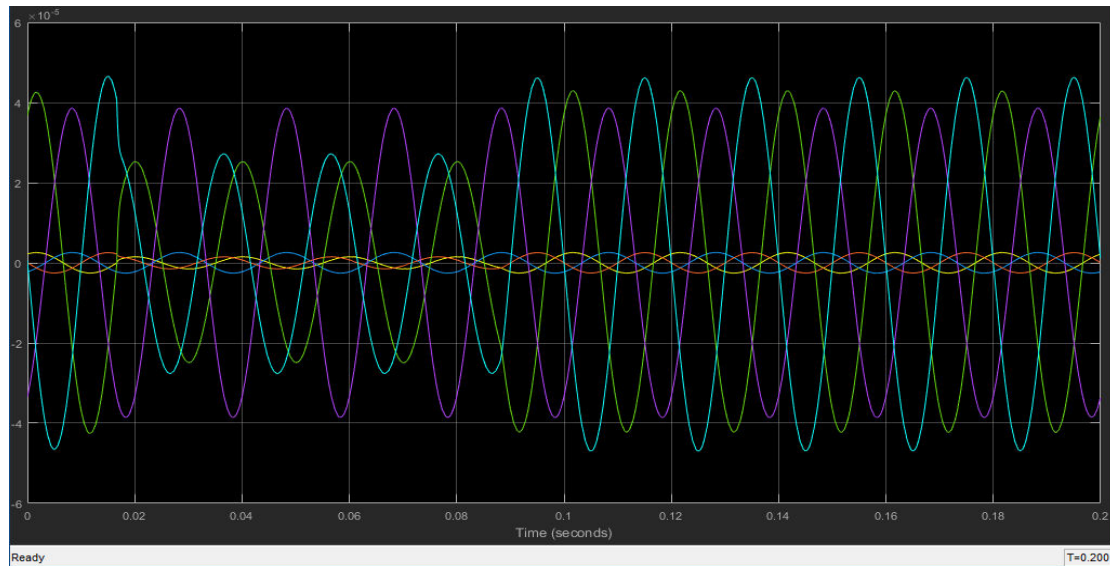


Figure 4.1: Voltage and Current Response of the Transmission Network with a Fault at Phase A-Terminal

The results of a single short circuit fault for Phase-A by activating only Phase-A using the Fault simulator block while considering the generator voltage responses at all phases. From the voltage and current responses above, Phase A and B experienced an abnormally fluctuation while Phase C maintain its normal waveform. The fault started at 0.02s and was active for a duration of 0.09s before being cleared by the breakers but if it had persisted and the voltages on Phase A and B continues to collapse as seen from the plot, then the system would have been beyond its stability limit. This means that the fault is cleared at $t=0.1s$.

From the observation, quick response harmonic resistance breakers are needed for this kind of fault clearance as the breakers staggered for about 0.09s before finally clearing the fault and the system restored to equilibrium.

Results of short-circuit fault simulations – Phase-B only

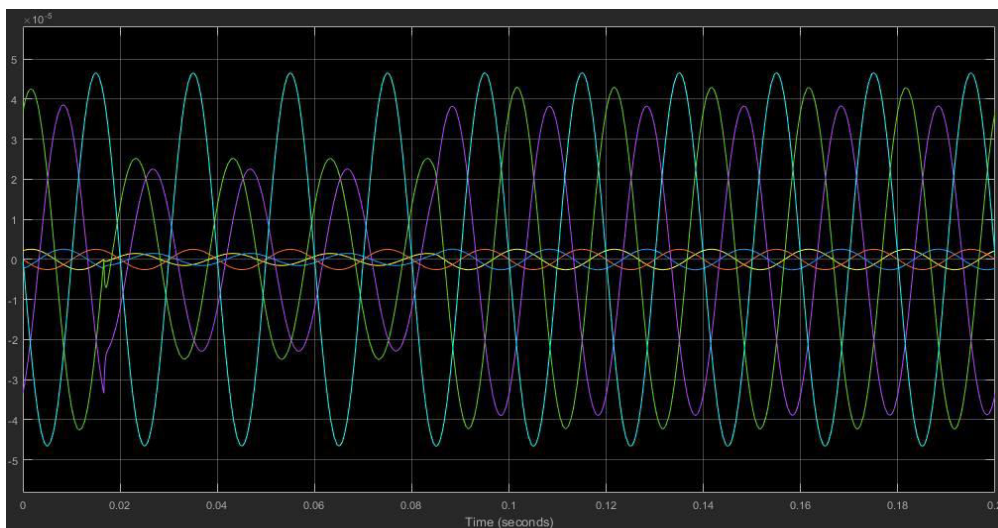


Figure 4.2: Voltage and Current Response of the Transmission Network with a Fault at Phase B-Terminal

The results of a single short circuit fault by activating only Phase-B using the Fault simulator block as shown, considering the voltage and current responses at all phases. From the result shown Phase A and C experienced low voltage while Phase B maintain a normal voltage waveform. The fault duration was about 0.09s before the breakers cleared the fault. This is almost consistent with the analysis made in Fig. 4.1 in terms of the breaker requirements.

Results of short-circuit fault simulations – Phase-C only

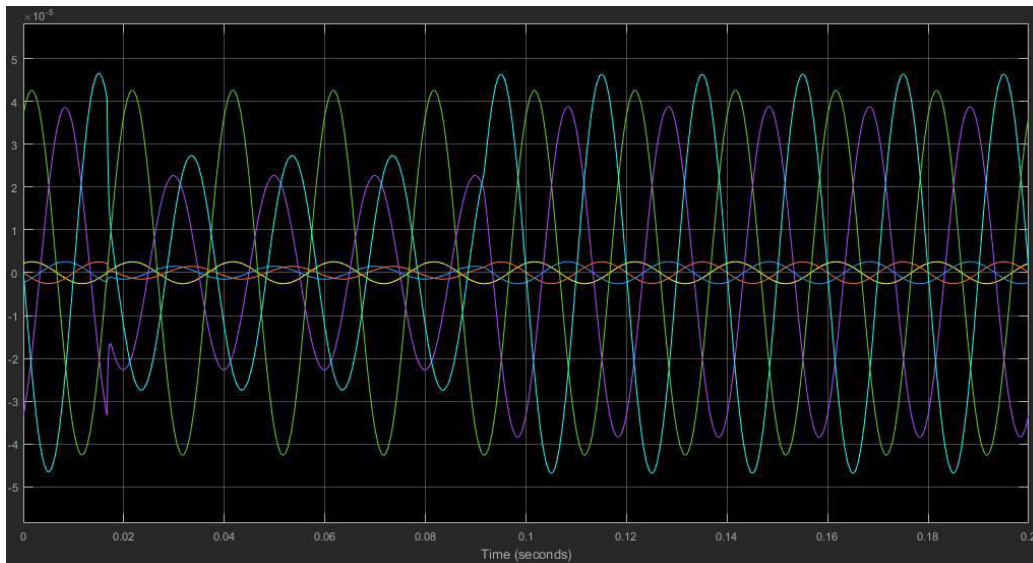


Figure 4.3: Transient Voltage Response of the Transmission Network with a Fault at Phase C-Terminal.

The results of a single short circuit fault by activating only Phase-C using the Fault simulator block are, as shown above, considering the voltage and current responses at all phases. Phase C and B experienced an abnormally low voltage while phase A maintain its normal waveform. Be for the breakers cleared the fault. The fault duration was about 0.09s. This situation must be avoided by ensuring faster breaker operation.

Results of short-circuit fault simulations – Phase-A, B, and C.

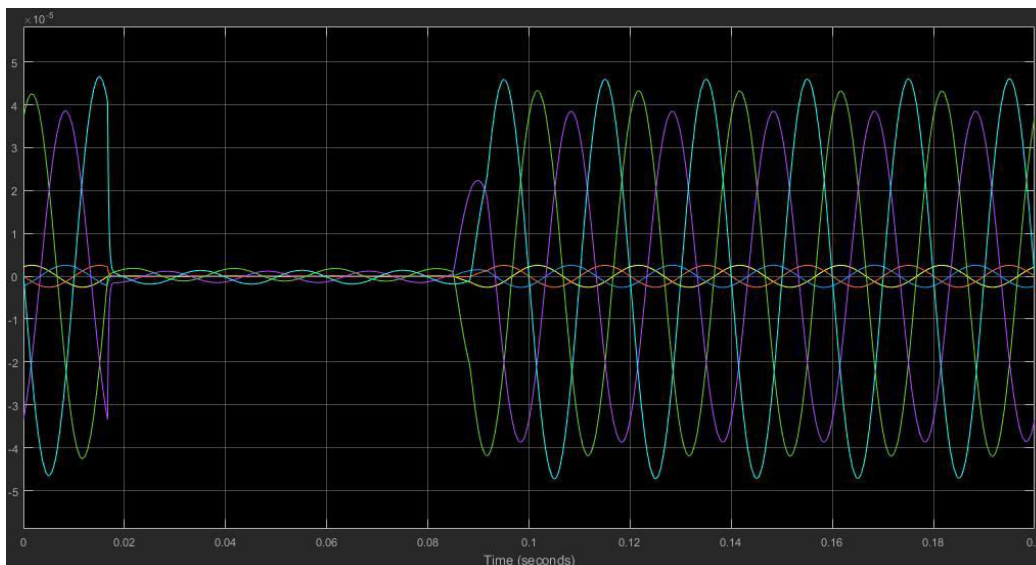


Figure 4.4: Transient Voltage Response of the Transmission Network with a Fault at Phase A, B, and C-Terminal.

All the phases experienced a very low voltage and collapse at the instance of fault at 0.02s where fluctuation continues until the breakers cleared the fault at 0.1 where the system returns to its steady-state condition. It is therefore advisable to use a faster breaker on this type of fault.

V. DISCUSSION

After the MATLAB simulation for stability, it was observed that the voltage and current waveforms experience some fluctuation in their signal waveform during the period of fault occurrence. The circuit breaker intercepted the short circuit currents thereby isolating the healthy part of the lines from the faulted part restoring a sinusoidal waveform signal on the line, indicating a fault free line sinusoidal signal, after the circuit breaker isolated the fault.

VI. CONCLUSION

In the Transient analysis model using the Simple series impedance method, the activities of the power transmission lines are implemented in Matrix-Laboratory (Matlab) environment; to investigate and justify whether the 330KV network from the Odukpani transmission network is responding to quick selectivity relay action for fast discrimination of the circuit breaker before, during and after the initiation of faults occurrence in the form of overload or perturbation, lighting initiation including faults due to phases etc. Which may not be healthy for transmission system operation and performance. The analysis and investigation show that a fault protection scheme should have a lower clearing time for effective operating performance. It is also evident that a programmed time setting of the protective relay within 0.09 seconds will clear the fault immediately.

Automated and efficiently programmed protective relay schemes on a real-time basis should be integrated to monitor and scan the power system network, particularly the transmission network, with the view to enhancing the sequential operation of the relay action to enhance effective performance at all times.

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