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MODELING AND EVALUATION OF CALABAR TRANSMISSION LINE NETWORK FOR LOAD FLOW AND TRANSIENT STABILITY ANALYSIS FOR FUTURE GRID EXPANSION

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Abstract: The Calabar transmission network, which consists of 41 buses and 56 lines, was subjected to load flow studies and transient stability analyses. During a standard simulation of load flow analysis, buses 9, 50, and 54 had voltages of 66.681%, 66.96%, and 66.655%, respectively. However, after compensating the afflicted buses, the voltages on these buses improved by 16.89%, resulting in 96.112%, 98.887%, and 103%, respectively. Without compensators, the total network losses during normal load flow simulation are 16.511MW and 4004.872 Mvar. When compensation is applied, the overall network losses increase to 19.211MW and 2348.110 Mvar. Some transient cases were examined; these cases are 3-phase faults on bus 3 at 5 seconds. 50% fault on line 34 cleared after 15 seconds. ETAP 19.0 is utilized as a simulation tool since it has a superior network analysis performance. The purpose of this article is to analyze the Calabar transmission line network, with the results being used effective planning and extension energy sustainability. This work is being done in response to the energy issues in the area in order to improve performance and coordination. The Newton Raphson technique of load flow is being investigated the job because of its advantages of better and shorter iteration to solution

Keywords: Transient Stability, Load Flow, Power System Stability, Transient Stability Methods.

INTRODUCTION

The power system is divided into three stages: generation, transmission, and distribution. In terms of generation, synchronous generators are used more frequently. The voltage level is then changed by transformers before transmission to decrease currents in the line and thus power losses. Transformers step down voltages for distribution purposes. [1,2,7,9]. Because the system is designed to deliver a constant and consistent power source. However, inevitable events like as lightning and human/animal accidents do occur, resulting in faults of varying magnitude. Generator disturbance produces system in-balance in both generation and distribution due to network problems. However, if these flaws are not corrected within a short period of time, they cause equipment deterioration, which leads to instability. This can be avoided by installing protective equipment in the network for the perfect scheme, which will prevent the spread of fault energy to the rest of the network. Some protective mechanism installations are required for an effective protection system. It is necessary to implement a mechanism. These can be avoided by installing protective equipment in the network for the perfect scheme, which will prevent the spread of fault energy to the rest of the network. Some protective mechanism installations are required for an effective protection system. [3, 4, 5,10] The occurrence of a failure can generates network instability, which can cause a computer to lose synchronism. A load flow analysis is required to assess the power system's transient stability. If the system cannot be sustained until the fault is resolved. The fault then destabilizes the entire system. Demonstrate how transient and load flow can affect the network and how they can be cleared by limiting their impact on the network. Because stability aids in the system's continual generation and transfer. Direct approaches determine stability without having to solve the system differential equations in detail. [3, 11, 14] The early work of Magnusson and Aylett, who employed the energy function to reach stability, sparked substantial interest in this method. The transient energy technique was then represented using a ball rolling on the inner surface of a cylinder formed by the equation describing the system's transient energy, as shown in. The region of stability is represented by the area inside the bowl, while the region of instability is represented by the area outside. The bowl rim symbolizes the highest elevation and thus the most potential energy for the transverse projection induced by the fault energy. A well-established method for evaluating synchronous machine transient performance and control techniques is mathematical modelling of synchronous machines. [12, 13, 18].

2. DEVELOPING LOAD FLOW EQUATION MODEL

$$P_p - j\,Q_p = V^*_p\, I_p \qquad 1$$

$$\Rightarrow I_p = P_{p\,-}\, jQ_p \qquad 2$$

Now the nodal current equations for a n-bus system can be written as

$$I_p = \sum_{q=1}^{n} Y_{pq} V_q, \quad p = 1,2,\ldots\ldots..n; \qquad 3$$

$$I_p = Y_{pp} V_p + \sum_{\substack{q=1\\ q\neq p}}^{n} Y_{pq} V_q \qquad 4$$

$$\Rightarrow V_p = \frac{I_p}{Y_{pp}} - \frac{1}{Y_{pp}} \sum_{\substack{q=1\\ q\neq p}}^{n} Y_{pq} V_q \qquad 5$$

Now,

$$V_p^* I_p = P_p - jQ_p \qquad 6$$

$$\Rightarrow I_p = \frac{P_p - jQ_p}{V_p^*} \qquad 7$$

Substituting for Ip in the above equation,

$$V_p = \frac{1}{Y_{pp}}\left[\frac{P_p - jQ_p}{V_p^*} - \sum_{\substack{q=1\\ q\neq p}}^{n} Y_{pq} V_q\right], \quad p=1,2\ldots\ldots\ldots n \qquad 8$$

We substitute Ip by active and reactive power, because the quantities are usually specified in a power system.

2.1 LOAD FLOW EQUATION SOLUTION METHODS

The final equations derived in the previous section are the load flow equations where bus voltages are the variables.

It can be seen that these equations are nonlinear and they can be solved using iterative methods like:

2.2 NEWTON-RAPHSON (N-R) METHOD

Consider the solution of a set of simultaneous non-linear equations of the form:

[F(x)] = [0]

Where: [F(x)] is a vector of functions: f_1 --- f_n in the variables x_1 --- x_n. 9

The expression described above will not become equal zero until the N-R process has converged, assuming the initial set of values x_1, x_2, --- x_n.

where the x's is voltage magnitude and phase angle for all load buses and voltage phase angles for all generator buses, that is, angles at all buses except slack and $|V|$ for all PQ buses. [4, 8]

The equations for load flow problem which can be solved by using N-R method can be derived as:

$$P_p - jQ_p = V_p^* I_p = V_p^* \sum_{q=1}^{n} Y_{pq} V_q \qquad 10$$

Let,

$$V_p = e_p + jf_p \quad \text{and} \quad Y_{pq} = G_{pq} - jB_{pq} \qquad 11$$

$$P_p - jQ_p = (e_p + jf_p)^* \sum_{q=1}^{n} \left(G_{pq} - jB_{pq}\right)\left(e_q + jf_q\right) \qquad 12$$

$$= (e_p - jf_p) \sum_{q=1}^{n} \left(G_{pq} - jB_{pq}\right)\left(e_q + jf_q\right) \qquad 13$$

Separating the real and imaginary parts, we have:

$$P_p = \sum_{q=1}^{n} [e_p\left(e_q G_{pq} + f_q B_{pq}\right) + f_p(f_q\, G_{pq} - e_q B_{pq})] \qquad 14$$

$Q_p = \sum_{q=1}^{n}[f_p(e_q G_{pq} + f_q B_{pq}) - e_p(f_q G_{pq} - e_q B_{pq})]$ 15

Also,

$|V_p|^2 = e_p^2 + f_p^2$ 16

The three sets of equations above are the load flow equations for the N-R method and we can see that they are non-linear in terms of real and imaginary components of nodal voltages. The quantities on the left-hand side i.e., Pp, Qp is for a load bus and Pp and |Vp| is for a generator bus are specified and ep and fp are unknown quantities. [3, 9, 16,]

For an n-bus system, the number of unknowns is (2n-1). Thus, if bus 1 is taken as the slack bus, the unknowns are $e_2, e_3, .., e_{n-1}, e_n$ and $f_2, f_3, .., f_{n-1}, f_n$.

Thus to solve all these variables, we need to solve all the 2(n-1) equations.

The Newton-Raphson method helps us to replace a set of nonlinear power-flow equations with a linear set, using Taylor's series expansion.

The mathematical background for this method is as follows:

Let the unknown variables be (x1, x2…, xn) and the quantities specified be y1, y2,…, yn These are related by the set of non-linear equations

$Y_1 = f(x_1, x_2, \ldots\ldots\ldots x_n)$ 17

$Y_2 = f(x_1, x_2, \ldots\ldots\ldots x_n)$ 18

$Y_n = f(x_1, x_2, \ldots\ldots x_n)$ 19

To be able to solve the above equations, we apply approximate solution $(x_1^0, x_2^0, \ldots, x_n^0)$.

Here, the 0 in the superscript implies the zero[th] iteration in the process of solving the above equations. By assuming a flat voltage profile i.e Vp=1.0+j0.0 for P=1,2,3…,n; except the slack bus, which is satisfactory for almost all practical systems.

Linearizing the equation about the initially assumed values. We then expand the first equation $y_1 = f_1$ and the results for the following equations.

Assuming $\Delta x_1^0, \Delta x_2^0, \ldots \Delta x_n^0$ as the corrections required for $x_1^0, x_2^0, \ldots x_n^0$ Respectively for the next better solution. The equation $y_1 = f_1$ will be

$Y_1 = f(x_1^0 + \Delta x_1^0, x_2^0 + \Delta x_2^0, \ldots\ldots\ldots, x_n^0 + \Delta x_n^0)$ 20

$= f(x_1^0, x_2^0, \ldots\ldots x_n^0) + \Delta x_1^0 \frac{\partial f_1}{\partial x_1} + \Delta x_2^0 \frac{\partial f_1}{\partial x_2} + \ldots\ldots + \Delta x_n^o \frac{\partial f_1}{\partial x_n} + \Phi_1$ 21

Where Φ_1 is function of higher order of Δx^8 and higher derivatives which are neglected according to N-R method. In fact, this is the assumption which needs the initial solution close to the final solution. After all the equations are linearized and arranged in a matrix form, we get:

$$\begin{bmatrix} y_1 - f_1(x_1^0 + \Delta x_1^0, x_2^0 + \Delta x_2^0, \ldots, x_n^0 + \Delta x_n^0) \\ y_2 - f_2(x_1^0 + \Delta x_1^0, x_2^0 + \Delta x_2^0, \ldots, x_n^0 + \Delta x_n^0) \\ . \\ . \\ . \\ y_n - f_n(x_1^0 + \Delta x_1^0, x_2^0 + \Delta x_2^0, \ldots, x_n^0 + \Delta x_n^0) \end{bmatrix} = \begin{bmatrix} \frac{\partial f_1}{\partial x_1} & \frac{\partial f_1}{\partial x_2} \ldots & \frac{\partial f_1}{\partial x_n} \\ \frac{\partial f_2}{\partial x_1} & \frac{\partial f_2}{\partial x_2} \ldots & \frac{\partial f_2}{\partial x_n} \\ & . & \\ & . & \\ & . & \\ \frac{\partial f_n}{\partial x_1} & \frac{\partial f_n}{\partial x_2} \ldots & \frac{\partial f_n}{\partial x_n} \end{bmatrix} \begin{bmatrix} \Delta x_1^0 \\ \Delta x_2^0 \\ . \\ . \\ . \\ \Delta x_n^0 \end{bmatrix} \quad 22$$

B = J.C

Here the matrix J is called the Jacobian matrix. The solution of the equations requires calculation of the vector B on the left hand side, which is the difference of the specified quantities and calculated quantities at $(x_1^0, x_2^0, \ldots x_n^0)$. Similarly the Jacobian is calculated at this assumption. Solution of the matrix equation gives $(\Delta x_1^0, \Delta x_2^0, \ldots, \Delta x_n^0)$ and the next better solution is obtained as follows:

$x_1^1 = x_1^0 + \Delta x_1^0$

$x_2^1 = x_2^0 + \Delta x_2^0$.

$x_n^1 = x_n^0 + \Delta x_n^0$

The better solution is now available and it is $(x_1^1, x_2^1, \ldots x_n^1)$

With these values the iteration process is repeated till:

(1) The largest element in the left column of the equations is less than the assumed value, or

(2) The largest element in the column vector is less than assumed value.

Temporarily assuming that all buses except bus 1, are PQ buses. Thus, the unknown parameters consist of the $(n - 1)$ voltage phasors, $V_2, . . ., V_n$. In terms of real variables, these are:
Angles $\theta_2, \theta_3, . . ., \theta_n$ $(n - 1)$ variables
Magnitudes $|V_2|, |V_3|, . . ., |V_n|$ $(n - 1)$ variables
The linearized equations thus become,

$$\begin{bmatrix} \Delta P_2 \\ \Delta P_3 \\ . \\ . \\ \Delta P_n \\ \Delta Q_2 \\ \Delta Q_3 \\ . \\ . \\ \Delta Q_n \end{bmatrix} = \begin{bmatrix} \frac{\partial P_2}{\partial e_2} & \frac{\partial P_2}{\partial e_3} & \cdots & \frac{\partial P_2}{\partial e_n} & \frac{\partial P_2}{\partial f_2} & \frac{\partial P_2}{\partial f_3} & \cdots & \frac{\partial P_2}{\partial f_n} \\ \frac{\partial P_3}{\partial e_2} & \frac{\partial P_3}{\partial e_3} & \cdots & \frac{\partial P_3}{\partial e_n} & \frac{\partial P_3}{\partial f_2} & \frac{\partial P_3}{\partial f_3} & \cdots & \frac{\partial P_3}{\partial f_n} \\ & & & . & & & & \\ & & & . & & & & \\ & & & . & & & & \\ \frac{\partial P_n}{\partial e_2} & \frac{\partial P_n}{\partial e_3} & \cdots & \frac{\partial P_n}{\partial e_n} & \frac{\partial P_n}{\partial f_2} & \frac{\partial P_n}{\partial f_3} & \cdots & \frac{\partial P_n}{\partial f_n} \\ \frac{\partial Q_2}{\partial e_2} & \frac{\partial Q_2}{\partial e_3} & \cdots & \frac{\partial Q_2}{\partial e_n} & \frac{\partial Q_2}{\partial f_2} & \frac{\partial Q_2}{\partial f_3} & \cdots & \frac{\partial Q_2}{\partial f_n} \\ \frac{\partial Q_3}{\partial e_2} & \frac{\partial Q_3}{\partial e_3} & \cdots & \frac{\partial Q_3}{\partial e_n} & \frac{\partial Q_3}{\partial f_2} & \frac{\partial Q_3}{\partial f_3} & \cdots & \frac{\partial Q_3}{\partial f_n} \\ & & & . & & & & \\ & & & . & & & & \\ \frac{\partial Q_n}{\partial e_2} & \frac{\partial Q_n}{\partial e_3} & \cdots & \frac{\partial Q_n}{\partial e_n} & \frac{\partial Q_n}{\partial f_2} & \frac{\partial Q_n}{\partial f_3} & \cdots & \frac{\partial Q_n}{\partial f_n} \end{bmatrix} \quad (23)$$

Let Psp , Qsp and |Vsp| be the specified quantities at the bus p. Now, assuming a flat voltage profile, the value of P,Q and |V| at various buses are calculated.

Then,

$$\Delta P_p = P_{sp} \quad (24)$$

$$\Delta Q_p = Q_{sp} - Q_p^0 \quad (25)$$

$$|V_p|^2 = |V_{sp}|^2 - |V_p^0|^2 \quad (26)$$

Where the superscript zero implies that the value calculated corresponding to initial assumption i.e zeroth iteration.

After calculating the Jacobian matrix and the residual column vector corresponding to the initial solution, the desired increment vector can be calculated by using any standard technique.
The next desired solution would be:

$$e_p^1 = e_p^0 + \Delta e_p^0 \quad (27)$$

$$f_p^1 = f_p^0 + \Delta f_p^0 \quad (28)$$

We use these voltage values in the next iteration. This process keeps repeating and the better estimates for the voltages of the buses will be:[1, 12, 21]

$$e_p^{k+1} = e_p^k + \Delta e_p^k \quad (29)$$

$$f_p^{k+1} = f_p^k + \Delta f_p^k \quad (30)$$

3.0 RESULT PRESENTATION

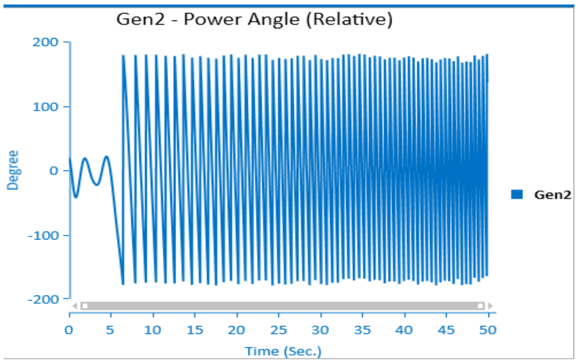


Fig. 1: generator 2 power angle plot

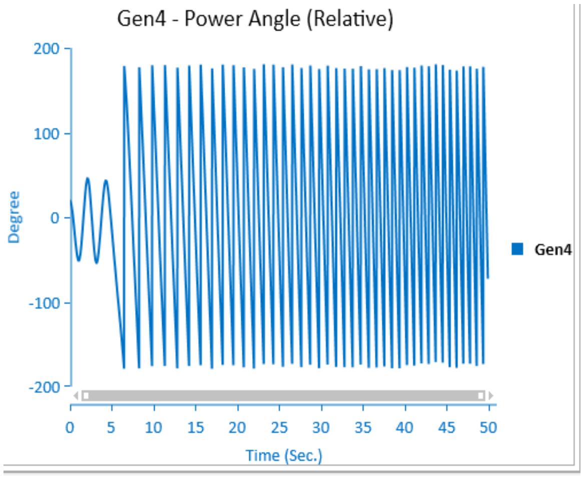


Fig. 2: graph of power angle for generator 4

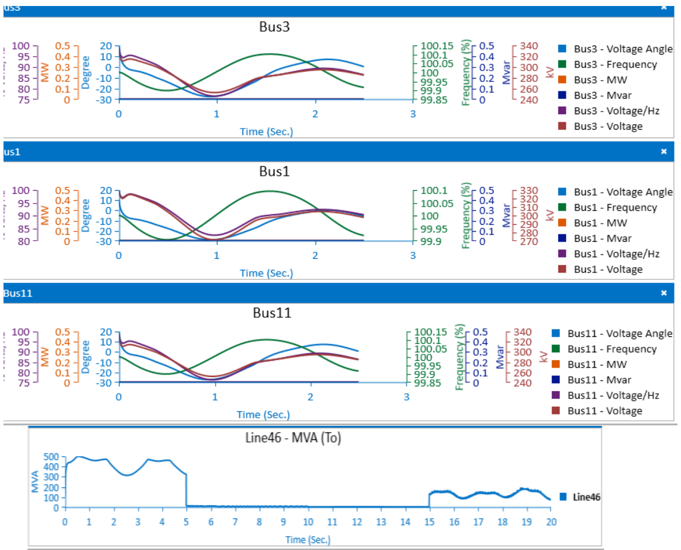


Fig. 3: graph of voltage angle, voltage and frequency for bus 3.

Fig. 4: graph of line 46 wave forms.

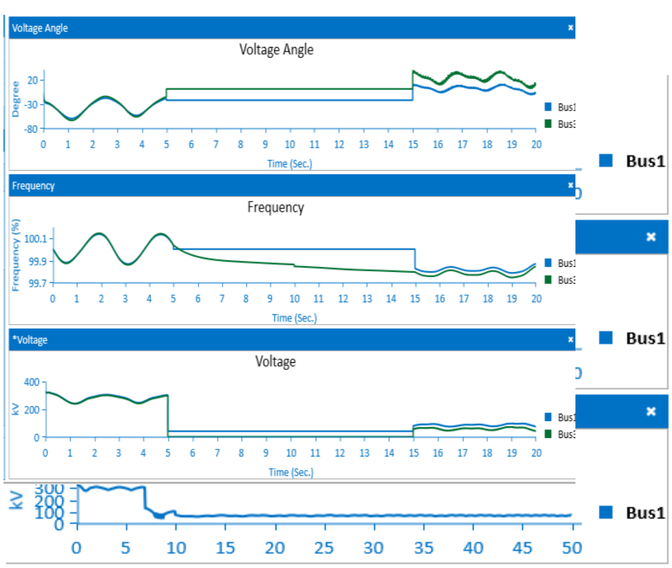
Fig. 5: graph of voltage angle, voltage and frequency for bus 1

Fig. 6: graph of voltage angle, voltage and frequency

Fig. 7: graph of line 46, 34 and line 1

Fig. 8: graph of bus 3 wave forms

Fig. 9 graph of line 34 wave forms.



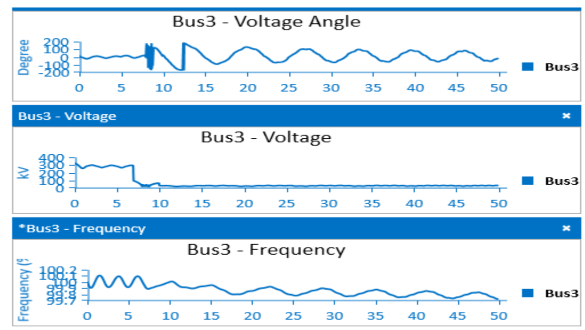
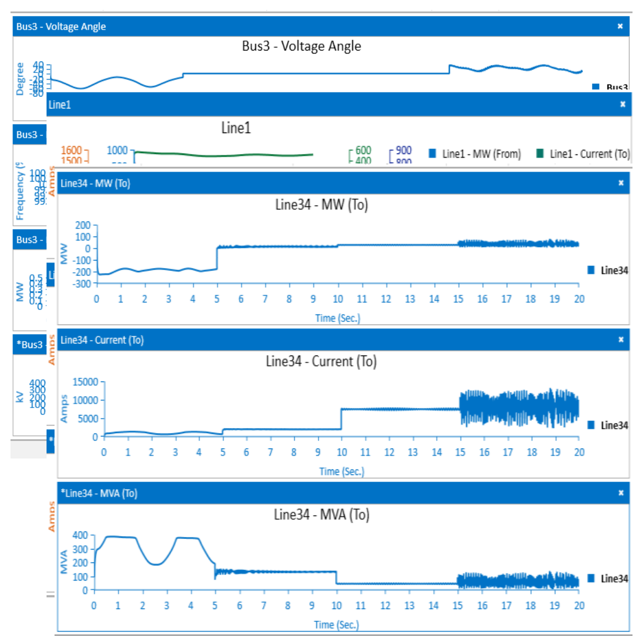


Fig. 10: graph of line 46 wave forms.



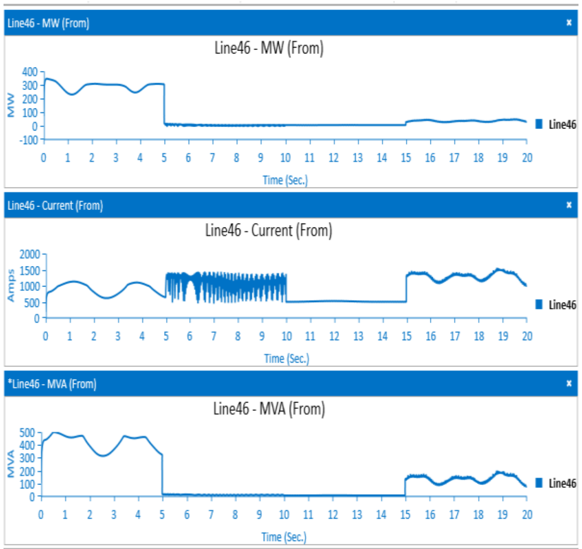


Fig. 11: graph of bus 1 wave forms.

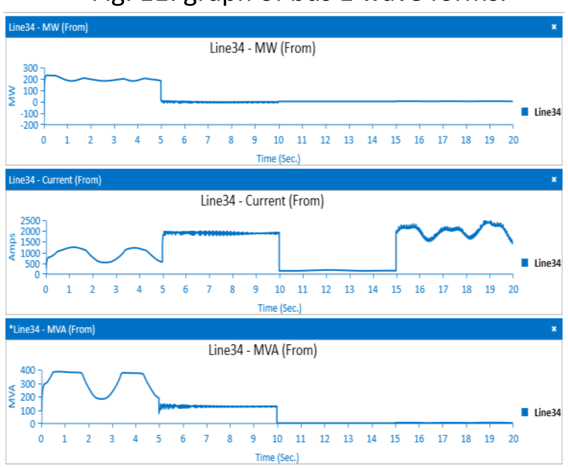


Fig. 12: graph of line 34 wave form

4.0 DISCUSSION OF RESULTS

The load flow analysis was done on the Calabar transmission network which comprises of Adiabo sub station and flour mill injection station. These are the two major transmission network in the area as shown in the Etap model fig. 13. It contains 41 buses, 56 branches, two generators and two grids lines. These grids lines are Itu line 132KV and Odukpani power plant line 330KV.

Setting the simulations time to 20 sec., the Etap load flow analysis were simulated and the result obtained reveals that at bus 9, bus 54 and bus 50 has a bus voltages below the voltage limit of ±5 (100V) %. When compensated the buses with static var compensators (SVC), the bus voltages improved to 96.112%, 98.887% and 103% respectively. Thus increasing the total voltages on the network.

The transient stability analysis conducted on the same network as shown in fig. 4.4 with different faults conditions. The cases are:

i. 3 phase faults on bus 3 at 5 sec. fault cleared at 15 sec
ii. 50 % fault on line 34 at 10 sec.
iii. Generator 4 has voltages impact of 10 % at 10 sec.
iv. Line to line to ground fault at line 46.

The impact of the three phase faults on the network really affect the currents/voltage waveforms of others line on the network especially those that are closed by.

The line to line to ground faults its impacts on the network are shown in fig 4.15 and 4.16. Its reveals that, at 5sec where faults occur, the plots shows that the MW from the line 46. The wave form returned to zero and lasted for 10sec after which the faults as cleared at 15sec and the system trying to return back to its normal form but not exact. Its current waveform clearly shows the impact. The faulted waveform returned to normal after which the fault were completely cleared.

5.0 Conclusion

On transient stability analysis, the impact of the faults on the network as reflected on fig. 4.6, fig. 4.7, fig. 4.8 etc. at the point of faults, the impact generated affect all the lines and some busses, this is depending on the types of faults (3 phase fault) and it locations on the network, its durations also determined its impact on the network and finally when the faults is being cleared. The quicker the responds to fault the better the network. Any fault on the network that lasted for more than a specific period, the effect of the faults can cause a serious damages to the entire network depending on the types and the locations of the faults on the network. Thus the transient stability analysis reveals the impact of faults on the network.

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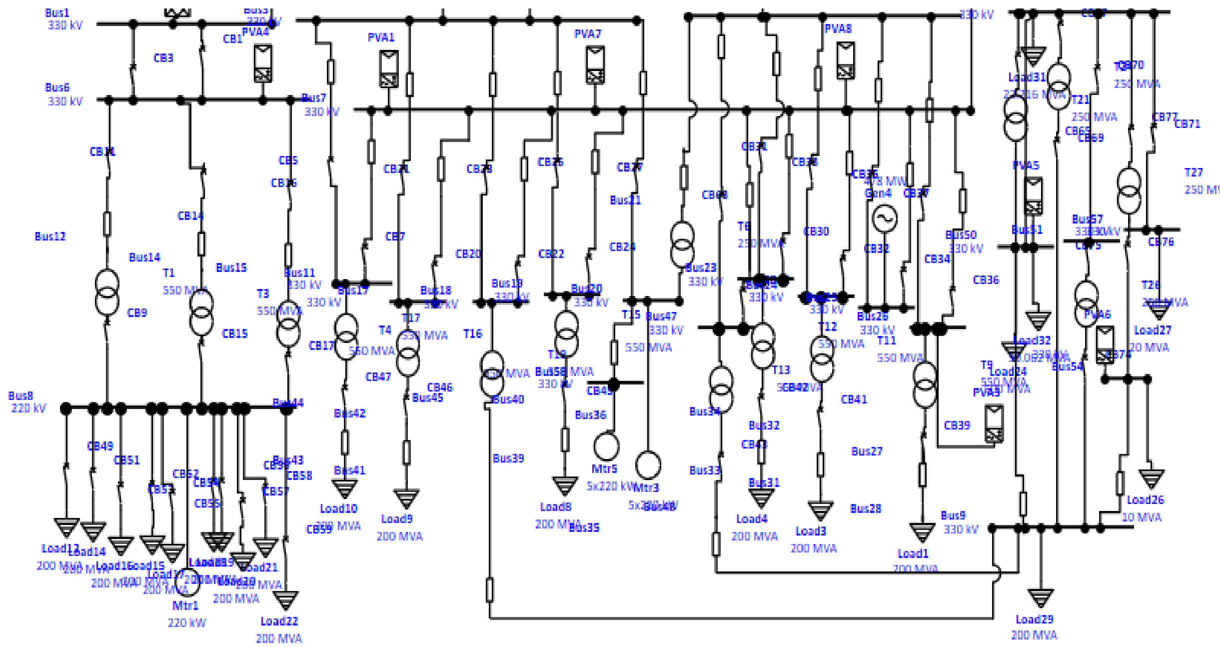

Fig. 15: Etap model of the Calabar transmission and sub-transmission.