Simulink model for outage studies in power transmission system

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Abstract: This thesis presents the simulink model for outage studies in a power transmission system. The study involved the development of simulink model for all necessary components in power system. Consequently, several outages considering line or generator outages were performed on the system, to evaluate the impacts of these events to system stability. In realizing the possible events, an IEEE 9-bus system was utilized as the test specimen. Responses for voltage, current and active and reactive power profiles were monitored with and without line and generator outages.

I. Introduction

The steady state operating mode of a power system is balanced 3-phase ac. However due to sudden external or internal changes in the system, this condition is disrupted. When the insulation of the system fails at one or more points or a conducting object comes in with a live point, a short circuit or fault occurs. The causes of faults are numerous lightning, heavy winds, trees falling across lines and other. A fault involving all the three phases is known as symmetrical (balanced) fault while one involving only one or two phases is known as unsymmetrical (unbalance) fault. Single line to ground, line to line and double line to ground faults are known as unsymmetrical faults [2].

The occurrence of fault will cause currents of high value to flow through the network to the faulted point. The amount of current may be much greater than the designed thermal ability of the conductors in the power lines or machines feeding the fault. As a result, temperature rise may cause damage by annealing of conductors and insulation charring. In addition, the low voltage in the neighborhood of the fault will cause equipment malfunction [3].

Faults in balanced systems can be solved using symmetrical components, but the derivations are rather cumbersome. Distribution power systems are normally unbalanced. Several proposals have been specifically described to deal with fault analysis on distribution systems, which may include single phase, two-phase and untransposed three-phase feeders [7-11].This paper presents the simulation studies of probabilistic outages in power system. IEEE 9-bus system [6] developed in simulink was used as the test specimen.

2. Methodology

In order to implement the simulation studies for several probabilistic outages due to faults, the methodology involve the following activities:-

i. Development of simulink model for the power transmission system.
ii. The components such as transmission lines, transformers, generators and loads are connected in three phase [6].
iii. The scope connected at each bus to record the output waveform.
iv. Put three phase fault component at transmission lines and circuit breaker at generator.
v. Three waveforms such voltage, current and active and reactive power versus time at each scope were recorded.
vi. Implementation of possible outages namely:-
    - Three phase fault
    - Double line to ground fault
    - Line to line fault
    - Single line to ground fault
    - Generator outage
vii. Analysis of results.

3. Three phase fault

Three-phase faults are unique in that they are balanced, that is, symmetrical in the three phases. A fault condition is a sudden abnormal alteration to the normal circuit arrangement. The circuit quantities, current and voltage, will alter, and the circuit will pass through a transient state to a steady state. In the transient state, the initial magnitude of the fault current will depend upon the point on the voltage wave at which the fault occurs. The decay of the transient condition, until it merges into steady state, is a function of the parameters of the circuit elements [4]. The transient current may be regarded as a d.c exponential current superimposed on the symmetrical steady state fault current. In a.c machines, owing to armature reaction, the machine reactance pass through 'sub transient' and 'transient' stages before reaching their steady state synchronous values. For this reason, the resultant fault current during the transient period, from fault inception to steady state also depends on the location of the fault in the network relative to that of the rotating plant. In a system containing many voltage sources, or having a complex network arrangement [5].

A three phase fault has all three phases connected to each other and to ground. It is a symmetrical one; even with the fault, the network is still symmetric.

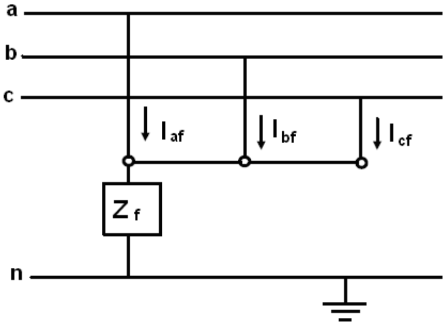


Figure 1: Illustrates the pictorial representation of a three phase fault

To analyze it, we denote fault currents in phases a, b, and c as $I_{af} < 0^{o}$, $I_{af} < -120^{o}$, $I_{af} < 120^{o}$. Then the zero positive negative currents are computed as

$$\underline{I}_S = \begin{bmatrix} I_s^0 \\ I_s^+ \\ I_s^- \end{bmatrix} = \underline{A}^{-1} \underline{I}_{abc} = \frac{1}{3}\begin{bmatrix} 1 & 1 & 1 \\ 1 & \alpha & \alpha^2 \\ 1 & \alpha^2 & \alpha \end{bmatrix}\begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix} \quad (1)$$

$$= \frac{1}{3}\begin{bmatrix} 1 & 1 & 1 \\ 1 & \alpha & \alpha^2 \\ 1 & \alpha^2 & \alpha \end{bmatrix}\begin{bmatrix} I_{af}\angle 0^\circ \\ I_{af}\angle -120^\circ \\ I_{af}\angle 120^\circ \end{bmatrix} = \begin{bmatrix} 0 \\ I_{af} \\ 0 \end{bmatrix}$$

This result shows what we already knew. Only positive sequence currents flow for a 3-phase (symmetric) fault. So we use only positive-sequence network to analyze this fault [1].

3.1. Single line to ground fault.

A single phase fault, or more commonly known as a single-line-to-ground (SLG) fault, has one phase connected to ground.

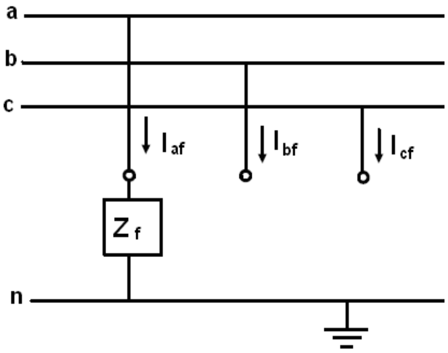


Figure 2: Illustrates the pictorial representation of a single line to ground fault at phase ‘a’.

To analyze a SLG fault, denote fault currents in phases a, b, and c as I_{af}, 0, and 0. Then the zero positive negative currents are computed as:

$$\begin{bmatrix} I_0 \\ I_1 \\ I_2 \end{bmatrix} = \frac{1}{3}\begin{bmatrix} 1 & 1 & 1 \\ 1 & a & a^2 \\ 1 & a^2 & a \end{bmatrix}\begin{bmatrix} I_a \\ 0 \\ 0 \end{bmatrix} = \frac{1}{3}\begin{bmatrix} I_a \\ I_a \\ I_a \end{bmatrix} \quad (2)$$

$I_{bf}=I_{cf}=0$ (3)
$V_f=Z_f * I_{af}$ (4)
$V_0+V_1+V_2=Z_f(I_0 + I_1 + I_2)$ (5)
From (4) and (2)
$I_1=I_2= I_0$ (6)
$V_0+V_1+V_2=Z_f * 3I_0$ (7)
From (6) and (7) can be satisfied by interconnecting the sequence network in series as shown in figure 3.
$I_1=I_2= I_0= V_f / (Z_0+Z_1+Z_2 +3Z_f)$ (8)
Transform (8) to phase domain
$I_a=I_0+I_1+I_2=3 I_1$ (9)
$I_b= I_0+a^2I_1+aI_2=0$ (10)
$I_c= I_0+aI_1+a^2I_2=0$ (11)

It is observed that the same current is flowing in all three sequence networks. The circuit connection for which this is true is a series connection of the positive, negative, and zero-sequence circuits [1].

To satisfy the voltage and current boundary conditions, the sequence networks should be connected in series as shown in figure 3.

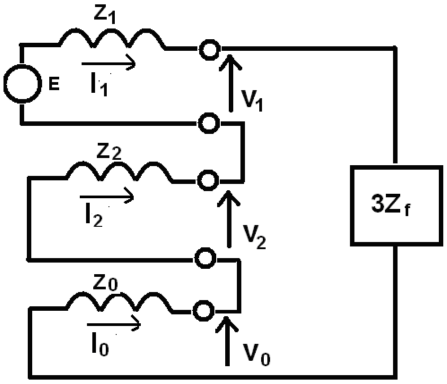


Figure 3: Equivalent circuit representation for single line to ground fault.

3.2. Line to line fault

A line-to-line (LL) fault has one phase connected to another. Assuming phase b is connected to phase c, we have $I_{af} = 0$, $I_{cf} = -I_{bf}$.

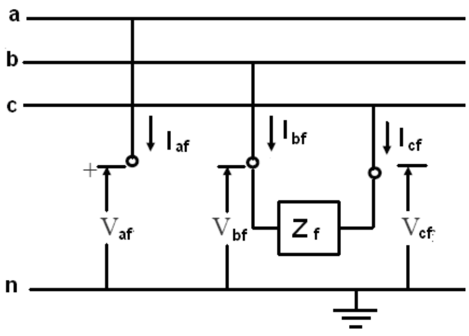


Figure 4: Illustrates the pictorial representation of line to line fault.

To analyze a (LL) fault, denote fault currents in phases a, b, and c as 0, I_{bf}, and $-I_{bf}$. Then the zero positive and negative currents are computed as

$$\begin{bmatrix} I_0\\ I_1\\ I_2\end{bmatrix} = \frac{1}{3}\begin{bmatrix}1&1&1\\ 1&a&a^2\\ 1&a^2&a\end{bmatrix}\begin{bmatrix}0\\ I_b\\ -I_b\end{bmatrix} = \frac{1}{3}\begin{bmatrix}0\\ [a-a^2]I_b\\ [a^2-a]\,I_b\end{bmatrix} \quad (12)$$

$I_{af}=0$ (13)

$I_{bf}=-I_{cf}$ (14)

$(V_0+a^2V_1+aV_2)-(V_0+aV_1+a^2V_2)$

$= Zf\,(I_0+a^2I_1+aI_2)$ (15)

Noting From (11) that $I_0=0$ and $I_1=-I_2$ simplifies to

$(a^2-a)V_1=(a^2-a)\,I_1Z_f+(a^2-a)\,V_2$

Or $V_1=V_2+Z_fI_1$ (16)

Therefore from (12) and (16) fault condition in sequence domain line to line fault

$I_0=0$

$I_1=-I_2$

$V_1=V_2+ZfI_1$

Note also that

$I_a= I_0+I_1+I_2=0$ (17)

$I_c= I_0+aI_1+a^2I_2=(a-a^2)I_1=-I_b$ (18)

It is observed that the zero sequence circuit is dead, but positive and negative sequence currents are equal in magnitude but opposite in direction! The circuit connection for which this is true is one where the positive sequence terminals are directly connected to the negative sequence terminals [1].

To satisfy the voltage and current boundary conditions, the sequence networks should be connected as shown in figure 5.

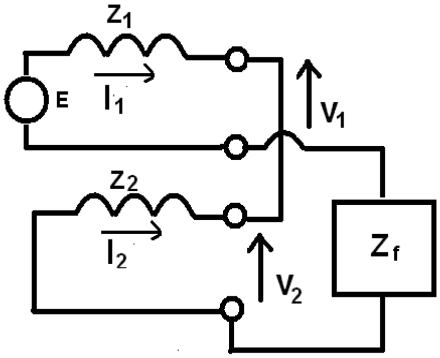


Figure 5: Equivalent circuit representation for line to line fault.

3.3. Double line to ground fault

A double line to ground fault has two phases connected together to the ground. Assuming phase b and phase c connected together to the ground, we have $I_{af}=0$,

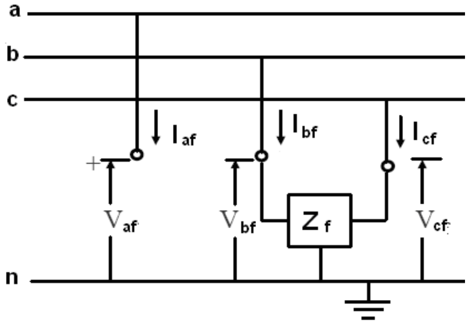


Figure 6: Illustrates the pictorial representation of double line to ground fault.

Fault condition in the phase domain (DLG)

$I_{af}= 0$ (19)

$V_{bf}= V_{cf}$ (20)

$I_0+I_1+I_2=0$ (21)

From equation (20)

$V_0+a^2V_1+aV_2=V_0+aV_1+a^2V_2$ (22)

Voltage boundary conditions

$V_{bf}=(I_{bf}+I_{cf})\,Z_f$ (23)

$V_{bf}=V_{cf}$ (24)

From equation (23)

$V_0+a^2V_1+aV_2=(2I_0+a^2I_1+aI2+aI_1+a^2I_2)\,Z_f$

Fault condition in the sequence domain DLG fault

$I_0+I_1+I_2=0$

Thus $V_1=V_2$

Thus $V_0-V_1=3Z_fI_0$

Considering the voltage and current boundary conditions, the sequence networks are connected as shown in figure 7.

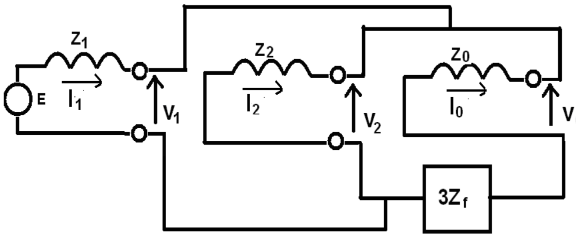


Figure 7: Equivalent circuit representation for double line to ground fault.

3.4. Generator outage

Generator outage is one of the probabilistic outages in a transmission system. Consider a 4-bus system with two generators and two loads busses shown in figure 8.

From the figure, if let say generator 2 is on outage, generator 1 will have to supply electricity to the generator 2 entire system. This scenario will load the entire system to experience stress condition, which will cause possible breakout. In this study, the generator outage is simulated to observe the impact to voltage transient response.

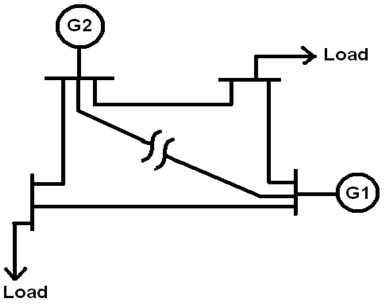


Figure 8: A simple 4-Bus System.

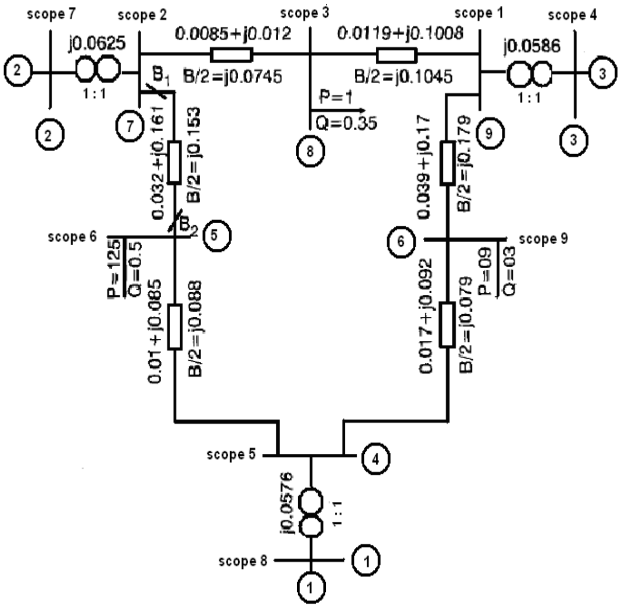


Figure 9: Single line diagram for IEEE 9-bus system.

4. Result

In this study five categories of fault or outages formed as probabilistic outages were implemented on the system. Since the system was developed in simulink, therefore corresponding response for the respective outage can be monitored or recorded.

4.1. Effect of outage to generator

When a short circuit occurs on the system powered by a generator, the generator continues to produce voltage at the generator terminals as the field excitation is maintained and the prime mover drives the generator at normal speed. The generated voltage causes a large magnitude fault current flow from the generator to the short circuit point. The flow of fault current is limited only by the generator impedance and the impedance of circuit between the generator and short circuit. In case of a short circuit at the generator terminals, the fault current is limited by generator impedance only.

4.2. Effect of outage to transformer

The fault current delivered by a utility system depends on the impedance of the generators and the impedance of power system to the terminals of the supply transformer. Supply transformers deliver fault current from the power system generators. Transformers change the system voltage and magnitude of current. The fault current delivered by a transformer depends on the transformer secondary voltage and impedance, the impedance of the upstream section of power system to the terminals of the transformer and the impedance of the circuit from the transformer to the short circuit point

4.3. Pre-Fault Simulation

Result for pre-fault condition was recorded first before any one of the probabilistic outages is conducted. Scopes connected at corresponding to in order buses are measure voltage, current and active and reactive power versus time. The simulation type is continuous mode with simulation time between 0s to 0.04s. During this period of time, the scopes recoded all waveforms. Pre-fault results for simulation are shown in figure 10 to figure 14. From the figure, it is observed that the voltage, current, active and reactive power is in stable condition without any presence of transient.

4.4. Three phase fault

Figure 10 illustrate the results for three phase fault occurrence at bus 7. The fault resistance for all faults is 1000 ohms and the transition time for fault occurs is between 0.01667s to 0.025s. From the figure, it is observed that, between 0.01667s to 0.025s the voltage at all phases drastically drop to 0V. In the mean time, the current in each phase overshoot above the nominal value. On the other hand, the active and reactive power responses demonstrate transient effect due to the fault occurrence.

4.5. Double line to ground fault

Figure 11 illustrate the results for double line to ground fault occurrence at bus 7. The fault resistance for all faults is 1000 ohms and the transition time for fault occurs is between 0.01667s to 0.025s. From the figure, it is observed that, between 0.01667s to 0.025s the voltage at phase ‘b’ and phase ‘c’ drastically drop to 0V. In the mean time, the current at phase ‘b’ and phase ‘c’ overshoot above the nominal value. On the other hand, the active and reactive power responses demonstrate transient effect due to the fault occurrence.

4.6. Line to line fault

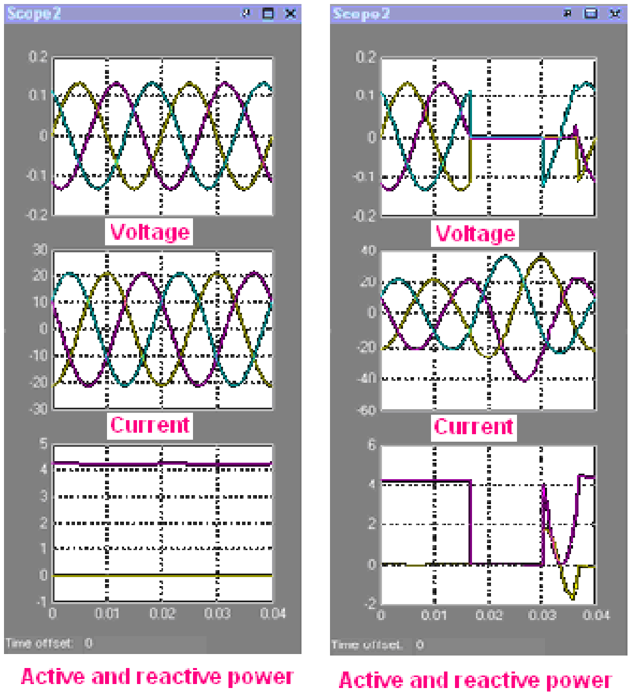
Figure 12 illustrate the results for line to line fault occurrence at bus 7. The fault resistance for all faults is 1000 ohms and the transition time for fault occurs is between 0.01667s to 0.025s. From the figure, it is observed that, between 0.01667s to 0.025s the voltage at phase ‘b’ and phase ‘c’ demonstrate transient effect. In the mean time, the current at phase ‘b’ and phase ‘c’ overshoot above the nominal value. On the other hand, the active and reactive power responses demonstrate transient effect due to the fault occurrence.

4.7. Single line to ground fault

Figure 13 illustrate the results for single line to ground phase fault occurrence at bus 7. The fault resistance for all faults is 1000 ohms and the transition time for fault occurs is between 0.01667s to 0.025s. From the figure, it is observed that, between 0.01667s to 0.025s the voltage at phase ‘a’ drastically drops to 0V. In the mean time, the current in at phase ‘a’ overshoot above the nominal value. On the other hand, the active and reactive power responses demonstrate transient effect due to the fault occurrence.

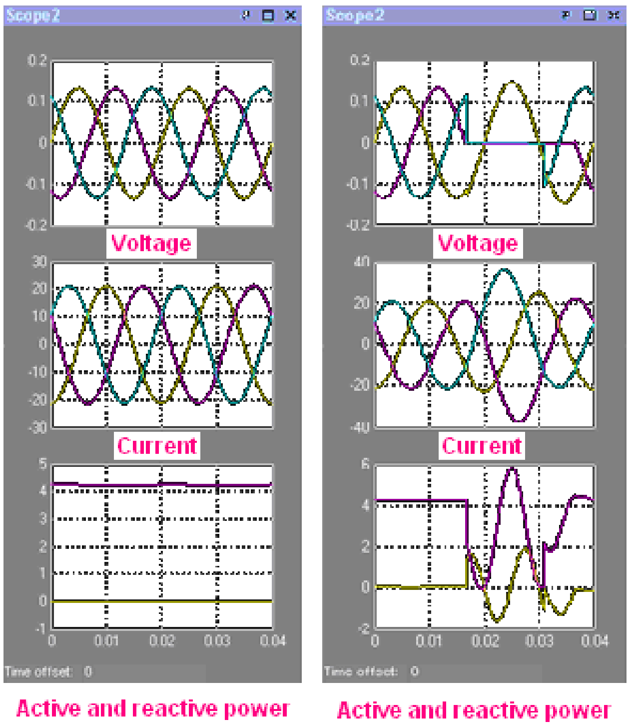
4.8. Generator 2 outage

Figure 14 illustrate the results for generator 2 outage. From the figure, it observed that, between 0.01667s to 0.025s when generator 2 experiences that outage, the voltage at bus 2 drop to 0V. Consequently when the circuit breaker is closed the voltage returned to high level again with transient effects before the response reached steady state. On the other hand, the current drop to zero from its steady state value. When the circuit breaker is closed, the current response return to its original value with transient phenomena before it returns to steady state. The response for active and reactive power drop to zero from its steady state condition when outage occurs. Consequently, when the circuit breaker is closed responses for active and reactive power return to their steady state condition initiated with transient response.



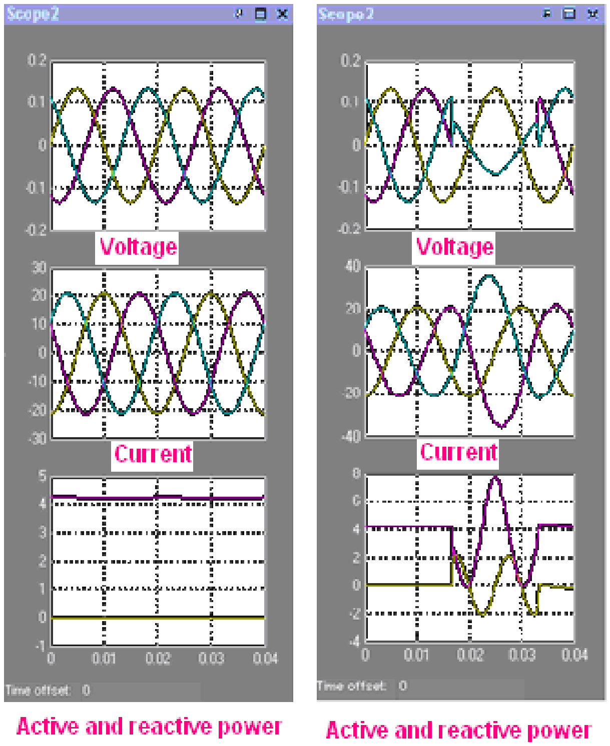
Before **After**

Figure 10: Result for three phase fault at bus 7



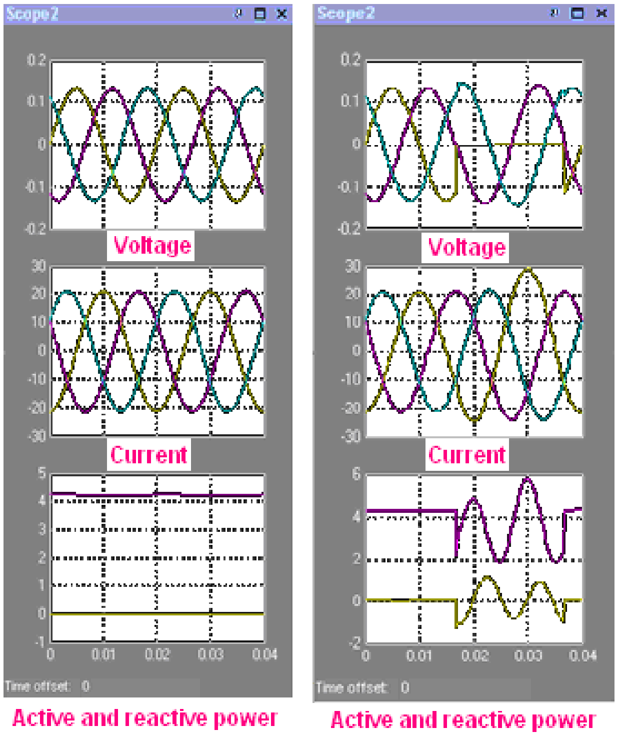
Before After

Figure 11: Result for double line to ground fault at bus 7



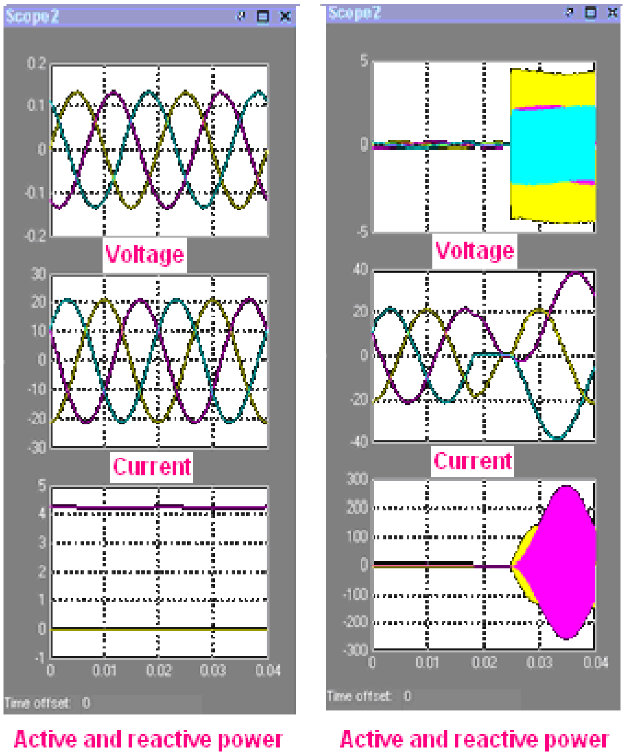
Before After

Figure 12: Result for line to line fault at bus 7



Before After

Figure 13: Result for single line to ground fault at bus 7



Before After

Figure 14: Result for generator 2 outage

5. Conclusion

Probabilistic outages in a small transmission system were presented. The study involves three phase fault, single line to ground fault, double line to ground fault, line to line fault and generator outage. Result obtained from the simulink modeling indicated that simulink is a suitable model to represent the power system.

6. Future Development

For future development it is suggested that Matlab simulink software can be used for any simulation study because it has been tested and prove that this Matlab simulink software will give the acceptable results. Moreover, it can be implemented to a smaller or bigger power system making it a flexible and affordable simulation technique.

7. Acknowledgement

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9. Appendix

8.1 Generators

Generator 1: 16500V, 50Hz
Generator 2: 18000V, 50Hz
Generator 3: 13800V, 50Hz

8.2 Transformers

Transformer 1: 16500/230000V
Transformer 2: 18000/230000V
Transformer 3: 13800/230000V

8.3 Loads

Load 1: 125MW+50MVar
Load 2: 100MW+35MVar
Load 3: 90MW+30MVar

8.4 Impedance

All impedance is in p.u

Bus 7 to bus 8: 0.0085+j0.072
Bus 8 to bus 9: 0.0119+j0.1008
Bus 7 to bus 5: 0.032+j0.153
Bus 5 to bus 4: 0.01+j0.085
Bus 6 to bus 4: 0.017+j0.092
Bus 9 to bus 6: 0.039+j0.14

$S_{base:}$ 100MVA