

The general steps that would be required to create a new power system model, perform a simulation, analyze results and briefly description of each module is shown as following:

- File Manager: This module allows the user organize many projects and cases which ultimately will be created into the database.
- Draft: This module allows the user to graphically sketch power system circuit to be simulated. And all parameters associated with the particular component are entered into the special menu associated with the component's icon.
- T-line/Cable: Two special modules have been written to handle the complex computations which is required to generate data for the overhead transmission line modules and cable modules.
- Run Time: This module allows the user to monitor and interact with the power system simulation by two way, one is the EMTDC simulation that runs until simulation finish time is reached and the other one is real time digital simulator (RTDS). Simulation runs until the operator decides to stop it. Graphical icons of meters, sliders and also the simulation by initiating a fault sequence through a push buttons are used on interface. The run time cover the operation of EMTDC with on line graphical output displays under run time. When the data input file and the DSDYN and DSOUT subroutines have been assembled automatically by Draft or manually by the user, Run time will compile and link DSDYN and DSOUT subroutines to EMTDC, run, display output, allow for SNAPSHOT files to be written, enable restarts from SNAPSOT files and provides for on line adjustment for parameters during the run with graphical icons of potentiometers, push buttons and switches.
- Multi Plot: This module is used to plot and directly analyze (by Fourier analysis, rms values, harmonic distortion etc.) the data generated by the EMTDC simulation and allows multiple graphs to be combined and displayed on a common page [21].

3.1.1 Typical Studies Using PSCAD/EMTDC

EMTDC is software based electromagnetic transient simulation tool which can be accessed through PSCAD. The user is able to assemble virtually and conceive

power system by using building blocks available from supplied libraries, or from user generated components. One of EMTDC's strengths lines is its ability to model complex power systems which may include HVDC transmission schemes and their associated controls with relative ease. The simulation of studies routinely conducted using EMTDC include [23-24]:

1. General power system electromagnetic transient studies
2. DC transmission configuration and controls
3. Effect of FACTS devices
4. Synchronous and induction machine torsion effects and self excitation
5. Static compensators
6. Non-linear control systems
7. Transmission line and cables
8. Transformer saturation studies such as ferroresonances and core saturation instability
9. Development of new control system concepts
10. Steep front surge analysis.

3.1.2 What PSCAD/EMTDC can be used for

One of the ways to understand the behavior of a complicated system is to study its response when subjected to disturbances or parametric variations. Simulation is one way of producing these responses. In power systems, these responses can be studied by observing either the time domain instantaneous values, time domain rms values, or the frequency components of response.

PSCAD/EMTDC is the most suitable of simulating the time domain instantaneous response, also popularly known as electromagnetic transients of electrical systems. Following are some of the common components used in system studied using PSCAD/EMTDC [22-24]:

- Resistors (R), inductors (L) and capacitors (C)
- Mutually coupled windings such as transformer
- Distributed frequency dependent transmission lines and cables
- Current and voltage sources
- Switches and breakers

- Diodes, thyristors and GTO's
- Analogue and digital control functions
- AC machines, exciters, governors, stabilizers and inertial models
- Meters and measuring functions
- Generic DC and AC controls
- HVDC, SVC, and other FACTS devices

The power of EMTDC is tremendously increased by its state of the art PSCAD graphical user interface. PSCAD allows the user to assemble the circuit, run the simulation, analyze the results, and manage the data in a completely integrated graphical environment. Together, PSCAD/EMTDC is a very efficient tool for electromagnetic transient simulation of power systems.

3.2 Equipments Modeling in PSCAD/EMTDC Program

3.2.1 Transmission Line Modeling

There are three basic transmission line modeling techniques in EMTDC: Pi sections, the Bergeron Model, and Frequency-Dependent Line Models. The requirements of the study will determine which of the three models is suitable.

A simple Pi section model will give the correct fundamental impedance, but cannot accurately represent other frequencies unless many sections are used (which is inefficient). It also cannot accurately represent the frequency dependent parameters of a line (such as skin effect). It is suitable for very short lines where the traveling wave models cannot be used.

The Bergeron model represents the L and C elements of a Pi section in a distributed manner (not using lumped parameters like Pi sections). It is roughly equivalent to using an infinite number of Pi sections except that the resistance is lumped (1/2 in the middle of the line, 1/4 at each end). Like Pi sections, it also accurately represents the fundamental frequency. It also represents impedances at other frequencies, except that the losses do not change. This model is suitable for studies where the fundamental frequency load-flow is most important (i.e. relay studies).

The Frequency-Dependent Line Model represents the frequency dependence of all parameters. This model takes longer to run than the Bergeron model, but is

necessary for studies requiring a very detailed representation of the line over a wide frequency range. Frequency dependent models can be solved using modal techniques or using the more advanced phase domain techniques.

The most accurate of these is the frequency dependent model, which represents all frequency dependent effects of a transmission line, and should be used whenever in doubt. When using Bergeron model, impedance/admittance data can also be entered directly to define the transmission corridor, for frequency dependent models detailed conductor information (i.e. line geometry, conductor radius) must be given.

In this thesis selects the frequency dependent model is used for the modeling of 500 kV transmission system Nam Theun 2 – Roi Et 2 , the description of this model is shown in chapter 2 section 2.2.4.2 [22-24].

3.2.1.1 The Frequency Dependent Line Model

The Frequency Dependent Line Model is based on the theory developed in [9]. In order to arrive at the time domain formation of the line equations, it is convenient to first work in the frequency domain, where an exact solution for a given frequency is possible.

Consider the following circuit of a transmission line as seen from the terminations: as show in Figure 3.2.

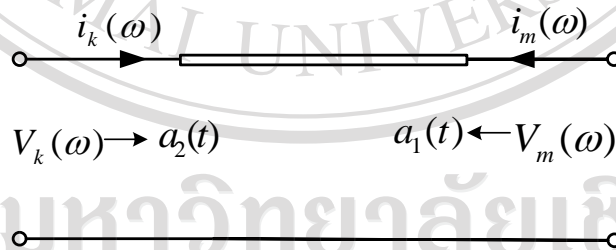


Figure 3.2 The traveling wave frequency dependent line model [22].

For a given frequency, the voltage and currents at one end of the line may be represented in terms of the voltage and current at other end by :

$$V_k(\omega) = \cosh[\gamma(\omega).l].V_m(\omega) - Z_c(\omega).\sinh[\gamma(\omega).l].i_m(\omega), \quad (3.1)$$

$$i_k(\omega) = \frac{\sinh[\gamma(\omega).l]}{Z_c(\omega)}.V_m(\omega) - \cosh[\gamma(\omega).l].i_m(\omega), \quad (3.2)$$

where:

$$\gamma(\omega) = \sqrt{Y(\omega).Z(\omega)} \quad : \text{Propagation constant}$$

$$Z_c(\omega) = \sqrt{Z(\omega) / Y(\omega)} \quad : \text{Surge impedance}$$

$$Y(\omega) = G + j\omega C \quad : \text{Shunt admittance of the line}$$

$$Z(\omega) = R + j\omega L \quad : \text{Series impedance of the line}$$

G is shunt conductance, R is resistance, L is inductance and C is capacitance of the line.

By introducing the forward and back ward traveling wave functions F_k and B_k in the node k from Figure 3.3,

$$F_k(\omega) = V_k(\omega) + Z_c(\omega).i_k(\omega), \quad (3.3)$$

$$B_k(\omega) = V_k(\omega) - Z_c(\omega).i_k(\omega), \quad (3.4)$$

and similarly at node m ,

$$F_m(\omega) = V_m(\omega) + Z_c(\omega).i_m(\omega), \quad (3.5)$$

$$B_k(\omega) = V_m(\omega) - Z_c(\omega).i_m(\omega). \quad (3.6)$$

Substituting equation (3.4) into Equation (3.3) gives:

$$F_k(\omega) = 2.V_k(\omega) - B_k(\omega), \quad (3.7)$$

And similarly,

$$F_m(\omega) = 2.V_m(\omega) - B_m(\omega), \quad (3.8)$$

For equation (3.1) and (3.2) (and their equivalents at node m) can now be expressed in terms of the forward and backward traveling functions.

$$B_k(\omega) = A(\omega).F_m(\omega), \quad (3.9)$$

$$B_m(\omega) = A(\omega).F_k(\omega), \quad (3.10)$$

where :

$$A(\omega) = \frac{1}{\cosh[\gamma(\omega).l] + \sinh[\gamma(\omega).l]} = e^{-\gamma(\omega)l}, \quad (3.11)$$

The time domain form of $A(\omega)$ is the function $a_1(t)$ shown in Figure 3.2. Under these conditions $a_1(t)$ is directly related to the voltage at node m and $a_2(t)$ to the voltage at node k . If such an equivalent network can be found, the new $a_1(t)$ weighting function will have only the first spike and the function $a_2(t)$ will become zero.

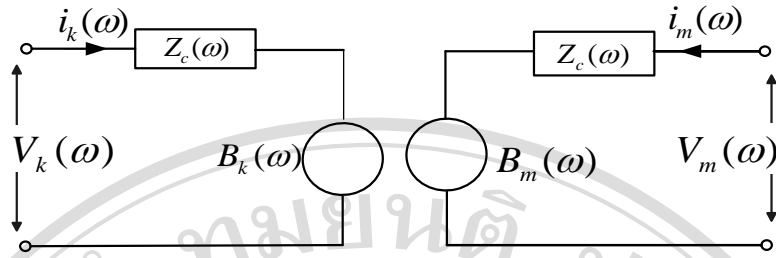


Figure 3.3 Frequency Dependent equivalent line model [22].

Equation (3.9) and (3.10) relate the source $B_k(\omega)$ with the m side quantities $V_m(\omega)$ and $B_m(\omega)$.

Introducing in node k ,

$$B_k(\omega) = A(\omega) \cdot [2 \cdot V_m(\omega) - B_m(\omega)], \quad (3.12)$$

And similarly in node m

$$B_m(\omega) = A(\omega) \cdot [2 \cdot V_k(\omega) - B_k(\omega)], \quad (3.13)$$

The time domain form of Equation (3.12) and (3.13) is given by the convolution integrals

$$b_k(t) = \int_{\tau}^t a_1(u) \cdot f_m(t-u) \cdot du. \quad (3.14)$$

and

$$b_m(t) = \int_{\tau}^t a_1(u) \cdot f_k(t-u) \cdot du \quad (3.15)$$

The Equation (3.14) and (3.15) it can be seen that value of b_k and b_m at time step t are completely defined from the past history values of functions f_k and f_m , as the long as the integration step Δt of the network solution is smaller than τ . Fortunately, the convolution can be computed in a recursive form suitable for time domain solution. The traveling time is calculated using the imaginary term β of the propagation constant. This equation is still in a very inconvenient form for a time domain solution because with each time step, more and more terms of the convolution integral must be evaluated. Fortunately, the convolution can be computed in a recursive form suitable for time domain solution.

With the reference to the PSCAD/EMTDC line model, the selected transmission line models are transposed frequency dependent phase model based on traveling time and characteristic impedance of the line. The 500 kV double circuit lines between

NTN 2 - RE 2 with 304.5 km length of the line is divided into two parts. The 135 km line from NTN 2 – SVJ with 795 MCM ACSR of conductor is divided into 5 sections, the 169.5 km line from SVJ-RE 2 with 1,272 MCM ACSR of conductor is divided into 13 sections. It is illustrated in Appendix B, Figure B.2.2 - B.2.3.

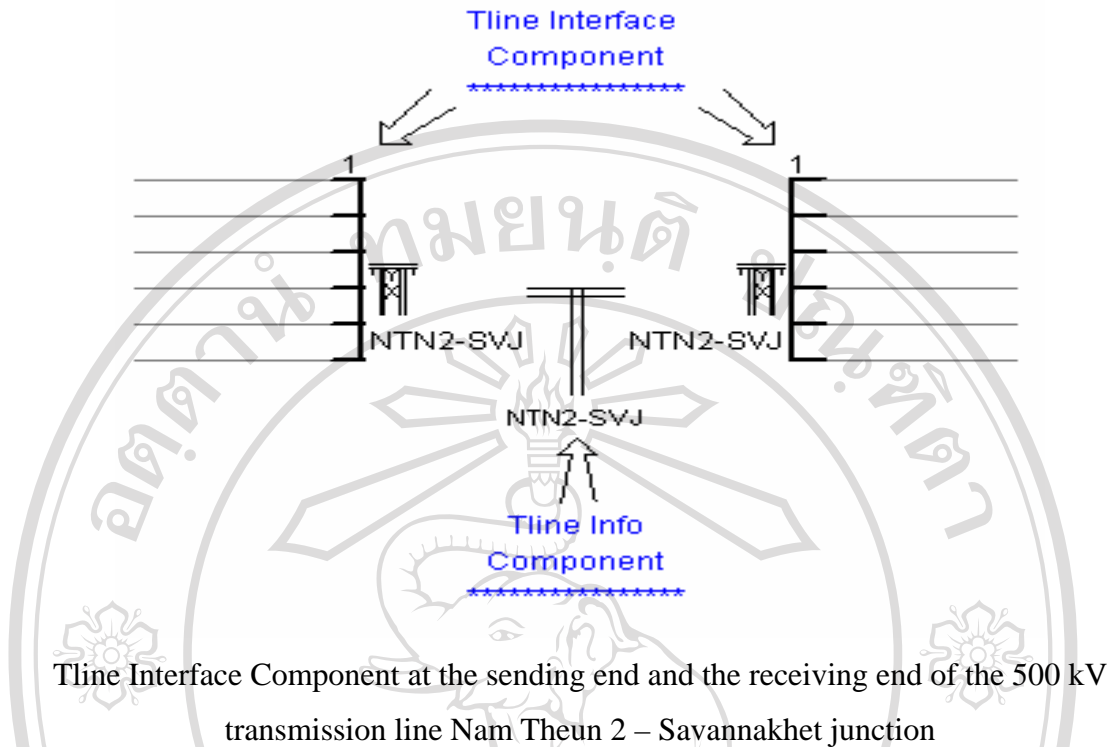
The input data required by each section for example; section length, phase transformation data, tower configuration and ground conductivity are shown in table 3.1.

Table: 3.1 Data input for transmission line model.

<ul style="list-style-type: none"> ◆ Tower configuration <ul style="list-style-type: none"> - Relative X position of tower center on right of way - Shunt conductance - Number of conductors - Show graphic of conductor sag - Is this circuit ideal transpose - How many ground wires - Estimate ground wires 	<ul style="list-style-type: none"> ◆ Symbol <ul style="list-style-type: none"> (m) (s/m) (Yes/No) (Yes/No) (Yes/No) (Yes/No)
<ul style="list-style-type: none"> ◆ Conductors data <ul style="list-style-type: none"> - Conductor radius - Conductor DC resistance - Sag of all conductor - Number of sub-conductors in a bundle - Bundle configuration (Symmetrical or non symmetrical) - Show bundle graphics - Horizontal coordinate and height distance - Phase/Node connection information 	<ul style="list-style-type: none"> (m) (Ω/km) (m) (Yes/No) (Yes/No) (X/Y)
<ul style="list-style-type: none"> ◆ Ground wires data <ul style="list-style-type: none"> - Number of ground wires - Ground wires radius - Ground wires DC resistance - Sag of all ground wires - Horizontal coordinate and height distance 	<ul style="list-style-type: none"> (m) (Ω/km) (m) (X/Y)
<ul style="list-style-type: none"> ◆ Other data <ul style="list-style-type: none"> - Length of line - Tline interface component and Tline info Component - Steady state frequency - Ground resistivity 	<ul style="list-style-type: none"> (km) (Hz) (Ω)

The data preparation and input data in the selected transmission model can be explained. For the 500 kV double circuits from Nam Theun 2 substation to Savannakhet junction (NTN 2 – SVJ), the representation is shown in Figure 3.5 with the following step.

- Select the Tline Interface Component and TlineInfo Component from Master Library
- Name the circuit as NTN 2-SVJ for both Tline Interface Component and TlineInfo Component
- Assign the line parameter for TlineInfo Component and tower configuration according to the existing of 500 kV transmission line Nam Theun 2 – Roi Et 2 substation.



Tline Interface Component at the sending end and the receiving end of the 500 kV transmission line Nam Theun 2 – Savannakhet junction

Line Model General Data

Name of Line: NTN2-SVL

Steady State Frequency [Hz]: 50.0

Length of Line [km]: 135

Number of Conductors: 6

Frequency Dependent (Phase) Model Options

Travel Time Interpolation: On

Curve Fitting Starting Frequency: 0.5

Curve Fitting End Frequency: 1.0E6

Maximum Order of Fitting for YSurge: 20

Maximum Order of Fitting for Prop. Func.: 20

Maximum Fitting Error for YSurge: 0.2

Maximum Fitting Error for Prop. Func.: 0.2

General Line Geometry Data Input

Tower: NTN2-SVJ05 Tower Centre 40 [m]
 Conductors: 795 ACSR/GA --> Ground_Wires: 74.57mm² OHGW

Cond. #	Connection Phasing #	X (from tower centre)	Y (at tower)	GW. #	Connection Phasing #	X (from tower centre)	Y (at tower)
1	1	7.3 [m]	62.1 [m]	1	Eliminated	7.55 [m]	70 [m]
2	2	7.65 [m]	51.1 [m]	2	Eliminated	-7.55 [m]	70 [m]
3	3	8.25 [m]	40.1 [m]				
4	4	-7.3 [m]	62.1 [m]				
5	5	-7.65 [m]	51.1 [m]				
6	6	-8.25 [m]	40.1 [m]				

Mid-Span Sag: ↑

10 [m] for Conductors

8 [m] for Ground Wires

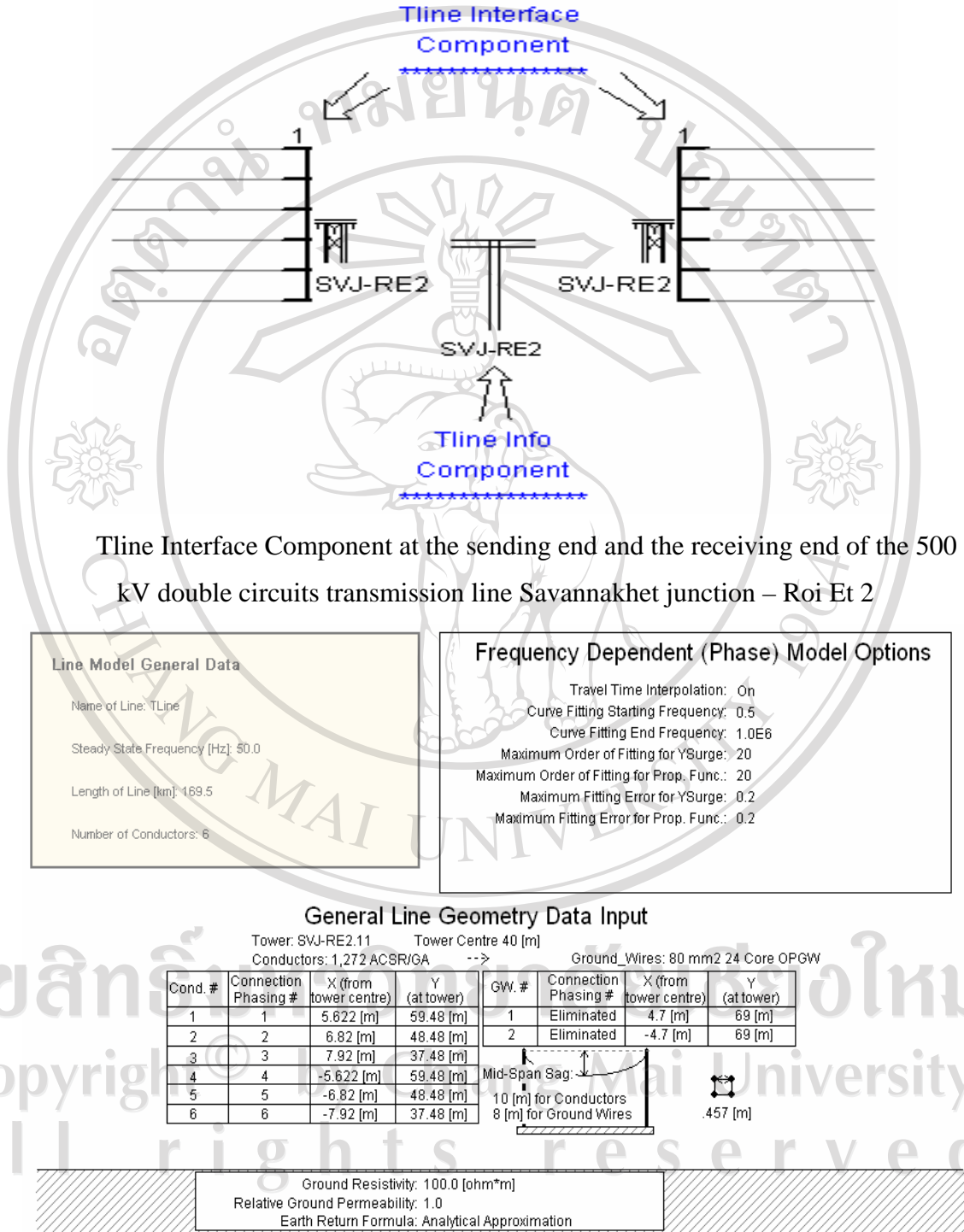
457 [m]

Ground Resistivity: 100.0 [ohm*m]
 Relative Ground Permeability: 1.0
 Earth Return Formula: Analytical Approximation

Edit parameter of Tline Info Component for the 500 kV

Figure 3.4 Tline Interface and Tline Info Component for Nam Theun 2 – Savannakhet Junction model.

The 500 kV double circuits from Savannakhet junction to Roi Et 2 substation, (SVJ – RE2) can also be represented as shown in Figure 3.5 with the similar step.



Edit parameter for Tline Info SVJ-RE2

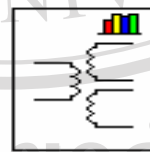
Figure 3.5 Tline Interface and Tline Info Component for Savannakhet Junction – Roi Et 2 model.

3.2.2 Transformer modeling

The thesis there is two selected transformer models. The single phase model is used for single phase step up power transformer at Nam Theun 2 substation and step up power from generator 18 kV connecting with single phase step up power transformer 18/ 525 kV. The three phases model is used for three phases step down power autotransformer at Roi Et 2 substation and step down power from line 525 kV - 230 kV-22 kV via the Roi Et 2 substation.

Transformer models as shown in Figure 3.6 are represented in detail with the following information required for the PSCAD/ EMTDC transformer components:

- Transformer MVA rating.
- Winding configuration and winding voltage.
- Transformer tap change range and normal setting.
- Leakage reactance between windings (this information can be obtained from the load flow data used in system operating studies, if not readily available from the name plate data).
- Knee point of transformer core saturation characteristic in per unit of rate flux or voltage.
- Estimated saturated air core reactance of transformer and winding it is based on.
- Based operation frequency



Transformers

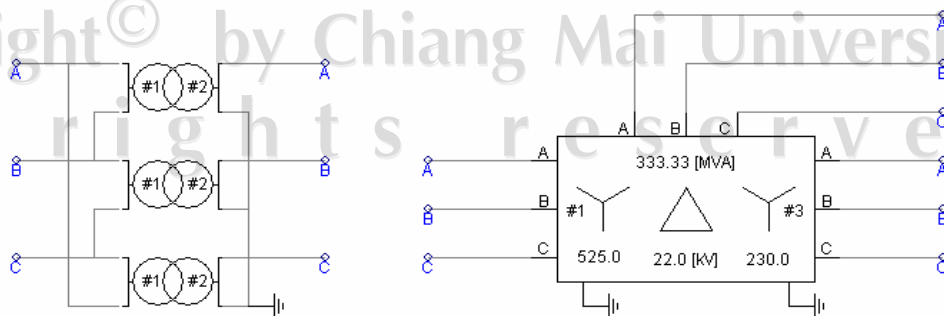


Figure 3.6 Single and three phases transformer model in PSCAD/EMTDC.

3.2.3 Generator modeling

The generator can be represented by the infinite source series with subtransient impedance matrix. The subtransient matrix can be built by the same procedure as the three phases transformer as following:

- Positive sequence impedance (X_1)
- Negative sequence impedance (X_2)
- Zero sequence impedance (X_0)
- Base MVA (three phases)
- Base voltage (L-L rms)
- Source impedance type

Build the matrix $[X]$ from the short-circuit input reactance. The matrix contains 3×3 sub-matrixes of the form.

$$\begin{bmatrix} X_s & X_m & X_m \\ X_m & X_s & X_m \\ X_m & X_m & X_s \end{bmatrix}, \quad (3.15)$$

where X_s is the self reactance of each phase, and X_m is the mutual reactance among the three phases. As in any other network three-phase network component, from Figure 3.7, these self and mutual reactances are related to the positive and zero sequence values X_1 and X_0 by:

$$X_s = \frac{(X_0 + 2X_1)}{3}, \quad (3.16)$$

$$X_m = \frac{(X_0 - X_1)}{3}. \quad (3.17)$$

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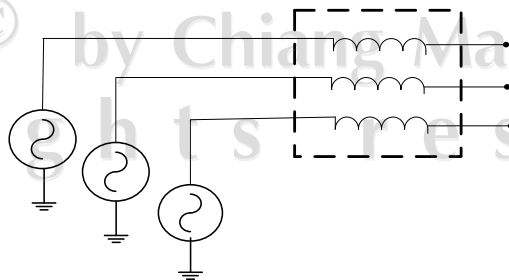


Figure 3.7 Three phases X- matrix source.

3.2.4 Surge Arrester Modeling

Zinc oxide or metal oxide surge arresters are highly non-linear resistance, with an almost infinite slope in the normal voltage region and almost horizontal slope in the overvoltage protection region. The common form of the exponential function, describing the protective characteristic of arrester, is as follows:

$$I = k \cdot \left(\frac{V}{V_{ref}} \right)^m, \quad (3.18)$$

where V_{ref} is the reference voltage used to prevent the numerical overflow of the exponential term for large voltage values, k and m are constant values (typical value for m equal 20 to 30).

Surge arrester is characterized with a nonlinear voltage versus resistance characteristic. The model will be presented by entering points on the V-I characteristic, or the default characteristic may be applied. It is suitable for designing switching surge, temporary overvoltage protection as shown in Figure 3.8.



Surge Arrester Model

The figure shows two screenshots of the 'Surge Arrester Model' dialog box in PSCAD/EMTDC. The left screenshot displays the 'Configuration' tab, and the right screenshot displays the 'I-V Characteristic' tab.

Configuration Tab:

- Arrester Name: Line Arrester
- Arrester Voltage Rating: 911.0 [kV]
- # of Parallel Arrester Stacks: 1.0
- Enable Non-linear Characteristic: 1
- I-V Characteristic:
 - Default
 - User defined (table)
 - User defined (external data file)

I-V Characteristic Tab:

X	Y
X1	0.1 kA
X2	0.3 kA
X3	0.5 kA
X4	0.8 kA
X5	1 [kA]
X6	2 [kA]
X7	3 [kA]
X8	4 [kA]
X9	6 [kA]
X10	8 [kA]
X11	10 [kA]
Y1	0.78 [p.u.]
Y2	0.8 [p.u.]
Y3	0.82 [p.u.]
Y4	0.84 [p.u.]
Y5	0.85 [p.u.]
Y6	0.87 [p.u.]
Y7	0.91 [p.u.]
Y8	0.94 [p.u.]
Y9	0.96 [p.u.]
Y10	0.98 [p.u.]
Y11	1.08 [p.u.]

File name: datafile

Pathname to the datafile is given as:

- relative pathname
- absolute pathname

Figure 3.8 Surge arrester model in PSCAD/EMTDC.

3.2.5 Circuit Breaker Modeling

The circuit breakers are modeled as simple time controlled switches in the PSCAD/EMTDC program as shown in Figure 3.9. The program allows various options to vary the closing time ranging from one-shot deterministic closings to multiple shot statistical closings. For the statistical switching simulations, the characteristics of the mechanical operating parts are modeled by a random pole spreading with a standard deviation for the three phase breaker operating times. Randomly generated switch closing times varying are also used to account for random operation at any point on the power frequency waveform.

The component allows simulation of single phase circuit breaker operation. The “Open” and “Close” resistance of the breaker is specified along with its initial state. If the input is 0, the breaker will close. If the input 1, the breaker will open. The breaker current may be labeled and monitored via an output channel if desired. A pre-insertion and post-insertion resistor may be represented if required. The data input for circuit breaker model is shown in table 3.2.

Table: 3.2 Parameter input for circuit breaker model.

<ul style="list-style-type: none"> ◆ Configuration - Breaker name (the name should be the same as the output signal label of the breaker logic component. - Open possible if current flowing - Use pr-insertion resistance 	<ul style="list-style-type: none"> ◆ Symbol (Yes/No) (Yes/No)
<ul style="list-style-type: none"> ◆ Breaker main data - Breaker close resistance - Breaker open resistance (Enter large value than close resistance) 	<ul style="list-style-type: none"> (Ω) (Ω)
<ul style="list-style-type: none"> ◆ Pre-Insertion data - Pre-insertion resistance : - Time delay for closing breaker - Time delay for bypassing pre-insertion 	<ul style="list-style-type: none"> (sec.) (sec.)

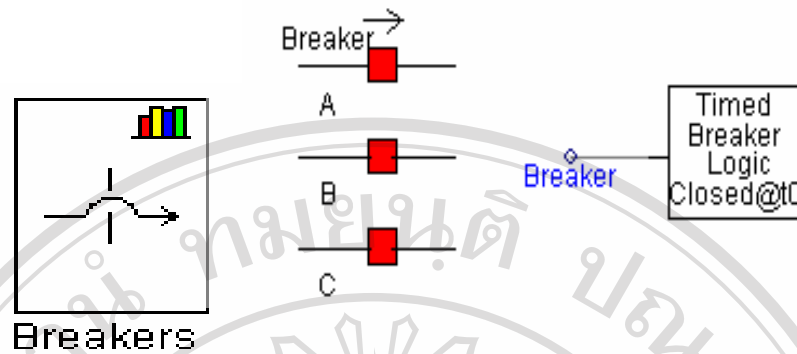


Figure 3.9 Circuit breaker models in PSCAD/EMTDC.

3.2.6 Shunt Reactor Modeling

Shunt Reactors in the studied 500 kV system are modeled by simple lumped element. The locations of shunt reactors are identified. The neutral reactors are installed in the neutral of the shunt reactors as presented in Figure 3.10.

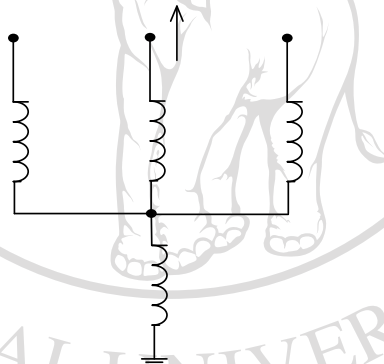


Figure 3.10 Configuration of line connected shunt reactors with a neutral reactor.

The shunt reactance value of 3×55 Mvar line shunt reactor at Nam Theun 2 side per circuit and 2×55 Mvar line shunt at Roi Et 2 side per circuit can be calculated from the rate capacity with based voltage 525 kV as following Equation (3.19):

For shunt reactor rate of Mvar.

$$\text{Reactance } X = \frac{(\text{Voltage}[kV])^2}{\text{Rate}(Mvar)} \quad (3.19)$$

3.2.7 Load Modeling

The external grid connecting with autotransformer 525/230/22 kV at Roi Et 2 substation are considered in load model. The external equivalent network is employed to reduce the rest of the Roi Et 2 substation 500/230 kV. The complete external network will be reduced to a voltage source behind a Thevenin equivalent matrix of Z_{eq} . The Z_{eq} is obtained by initializing a three phases fault at the respective bus and obtaining the sequence impedances at the faulted bus. The equivalent source from Appendix A.9 is used for this study. The magnitude and phase angles of all voltage sources are found from a load flow program.

3.3 Initial Condition of PSCAD/EMTDC Program

There are generally two ways to start a simulation: start from time $t = 0.0$ with no initial conditions or start with pre-calculated initial conditions imposed on some or all elements. In this study, starting a simulation with initial conditions is achieved by using a Snapshot File. This can be accomplished in program by taking a snapshot at a time just previous to the switch opening. Subsequent runs could be started from this snapshot file, which would have stored, among other values, the current flowing in the inductor at the time of the snapshot. All studied cases start at steady state condition by the used of snapshot feature.

3.4 The Accuracy of the Models

To analysis of the studied system with the simulation, the models must be verified. All these sophistications in the simulation techniques increase considerably the complexity and potential value of the studies, but this of little practical use without accurate “input” data related to the transient behavior of actual system elements. Therefore, the verification of the model is very important and in this thesis, the accuracy of the model is checked for validity with the following cases:

- Comparison with TNA case study for line energizing of the Mae Moh 3 to Tha Ta Ko circuit 1 [6-8].
- Comparison with line energization overvoltage study report of EGAT on the 500 kV transmission line Nam Theun 2 to Roi Et 2 project [2].

3.4.1 Comparison with TNA case study for line energizing of the Mae Moh 3 to Tha Ta Ko circuit 1

The switching overvoltage of 500 kV Mae Moh 3 (MM 3) to Tha Ta Ko (TTK) circuit 1 in case of line energization was taken from TNA case study to compare with the result. The purpose is to check the accuracy of the selected models and the reference case (MM 3 – TTK) is quite similar to the studied system (NTN 2 – RE 2) [6-8]. The network of MM 3 – TTK circuit 1 is shown in Figure 3.11.

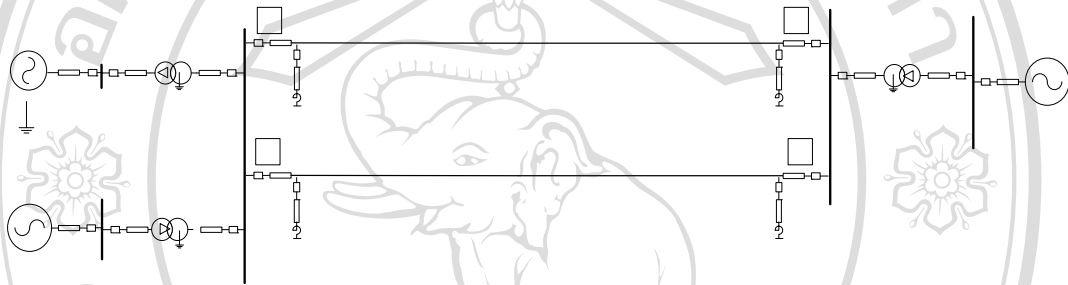


Figure 3.11 Single line diagram Mae Moh 3 – ThaTaKo circuit 1.

All equipments are represented in 500 kV transmission line Mae Moh 3 to ThaTaKo circuit 1 with the following detail:

- Generator model is the basic Thevenin voltage sources, three phases X-matrix and short circuit impedance.
- Transformers model: Each transformer is represented in detail with this exiting information: MVA rating, winding configuration and voltage, tap change ranges and normal setting, leakage reactance between windings. Knee point of transformer core saturation characteristic in per unit of rate flux or voltage, and estimated saturated air core reactance.
- Transmission line model: The selected transmission line models are distributed parameter models based on the traveling time and characteristic impedance of the line. The section of 500 kV line Mae Moh 3 – ThaTaKo are presented by untransposed frequency dependent line model.

AC Voltage
Source

525 kV

230 kV

300 MVA

>

110 Mvar

<

18 kV

370 MVA

90 Mvar

Mae Moh 3 (MM 3)

Thermal Power Plant

Line 1 500 kV

MM 3-TTK

Line 2 500 kV MM 3 -

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- Circuit breaker model: the locations of the circuit breakers that will be switched are identified on the studied system. Other parameters of the circuit breaker are determined.
- Arresters models: the installed location and rating of surge arresters are provided. The maximum ratings and particular the energy absorption capability is determined with this study.
- Shunt reactors models: the location of shunt reactors is identified. This is included whether they are line connected or bus connected.

3.4.2 Results of the Studies

The line energization study in case of 500 kV transmission line Mae Moh 3 to Tha Ta Ko circuit 1 is shown in Figure 3.11.

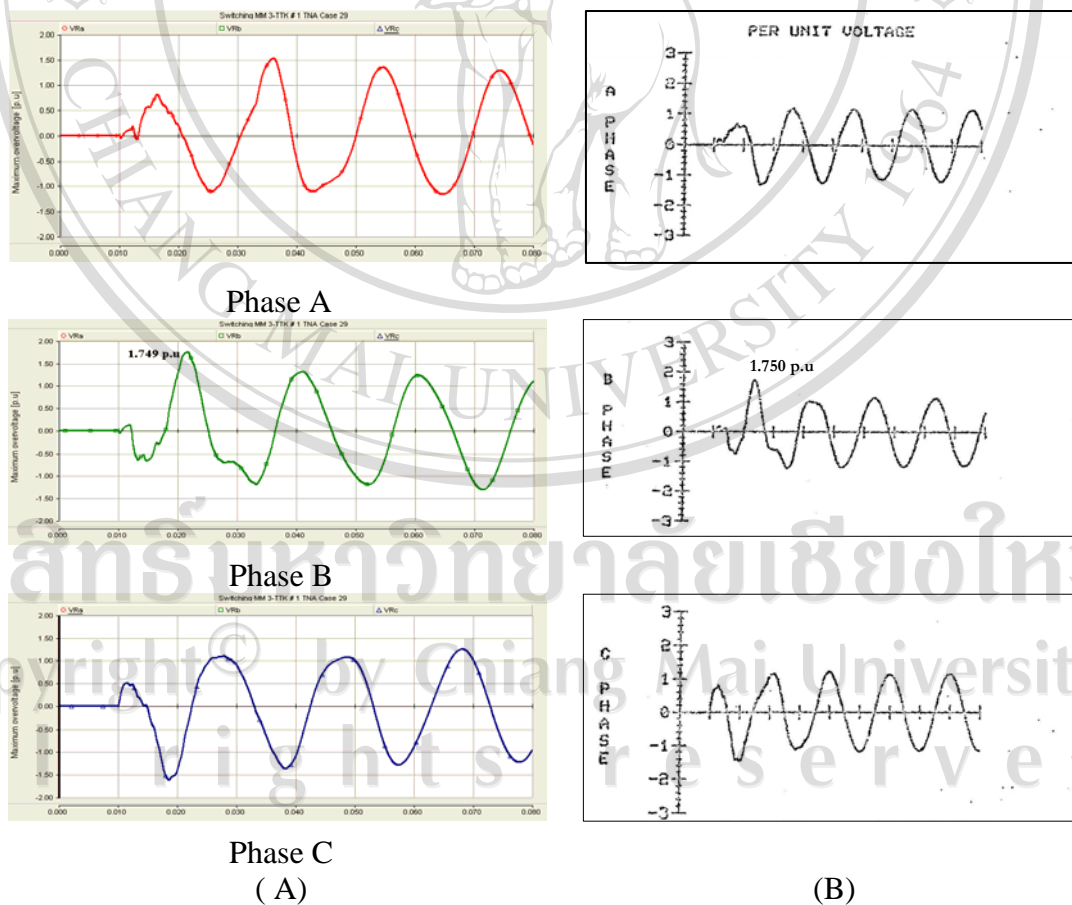


Figure 3.12 MM 3-TTK circuit 1 waveform from PSCAD/EMTDC (A) and TNA (B).

The TNA result and PSCAD/EMTDC result show relatively the similar waveform with the same condition for breaker operation as shown in Figure 3.12.

3.4.3 Comparison with line energization overvoltage study report of EGAT on the 500 kV transmission line Nam Theun 2 to Roi Et 2 project

The DigSILENT study is conducted to investigate the switching overvoltage occurring during switching of the line circuit breaker on each side of the 500 kV transmission line between Nam theun 2 project and EGAT's network at Roi Et 2 substation. The initial study is for EGAT planning development before the project starting [2]. The DigSILENT software program was used for the study. After confirmation of the selected model from the previous section, the studied system is represented with the existing parameter and information related to EGAT studied case. The simulation is performed in three steps as follows:

Step 1 : Prior to the switching action commencing , EGAT's system is in a normal steady state operating condition. All circuit breakers at both ends of these two circuits are opened and all generators at Nam Theun 2 Power Plant are off line.

Step 2 : All generators of Nam Theun 2 Power Plant are running at no load synchronous speed while all line circuit breakers at both ends of two circuits are still open.

Step 3 : One set of line circuit breakers on one circuit of the double circuit lines at Nam Theun 2 end is closed.

Table: 3.3 Simulation results from DigSILENT and PSCAD/EMTDC program

Detail	DigSILENT simulation of EGAT	PSCAD/EMTDC simulation
Energized from Nam Theun 2 Power Plant		
Maximum Overvoltage (kV)	-817.219	-817.030
Point	Receiving end at RE 2	Receiving end at RE 2
Phase	C	C
Time closing of CB (sec)	0.020	0.020

The receiving end voltage from EMTDC simulation was recorded and compared with the corresponding result of DigSILENT simulation. The comparison values are shown in table 3.3.

The waveform of DigSILENT and PSCAD/EMTDC simulation are shown in Figure 3.13 and 3.14. The waveform of the voltage at the receiving end Roi Et 2 substation from both simulations are almost identical with similar highest voltage.

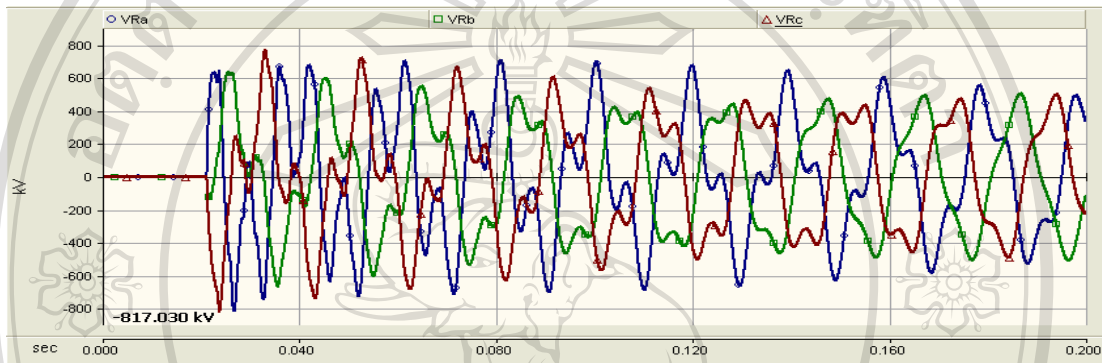


Figure 3.13 The voltage waveform of PSCAD/EMTDC simulation.

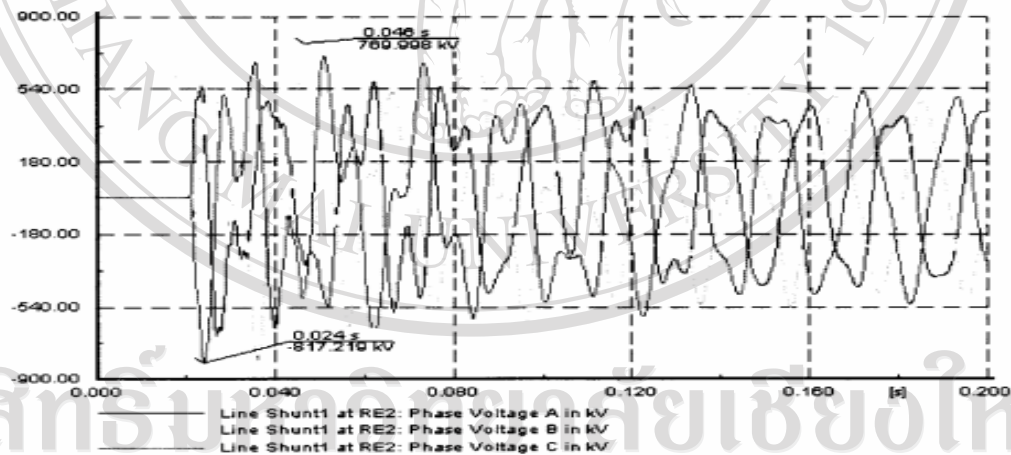


Figure 3.14 The voltage waveform of Dig SILENT simulation.

3.5 Conclusion for the Accuracy of the Models

The accuracy of the PSCAD/EMTDC modeling program of the system components as well as lines, transformers, generators, circuit breakers, shunt reactors, surge arresters, loads are presented by taking into account the saturation of transformer, shunt reactor and surge arresters. The raw data has to be converted to the suitable value before input to the program.

The accuracy of the model with TNA case Mae Moh to Tha Ta Ko, the results from simulation are similar. This comparison is taking the selected equipments model and methodology of the studied for improvement of the selected model in case of Nam Theun 2 to Roi Et 2.

The accuracy of the model with comparison of line energization overvoltage study report of EGAT on the 500 kV transmission line Nam Theun 2 to Roi Et 2 project, the simulations from PSCAD/EMTDC and DigSILENT program are in good agreement.

In case of the model verification, it can be concluded that the analysis of transient overvoltage used PSCAD/EMTDC program in case of Mae Moh to Tha Ta Ko the maximum overvoltage are the same values. Comparison with line energization study report of EGAT on Nam Theun 2 to Roi Et 2, the maximum overvoltages from both are similarly. The simulation had the identical system configuration as the reference case. The voltage waveforms are almost identical, the comparisons give satisfactory results, further confirming the accuracy of the simulation model and used parameters. Therefore, the selected models in this thesis are accuracy and can be used for analysis of the proposed system.