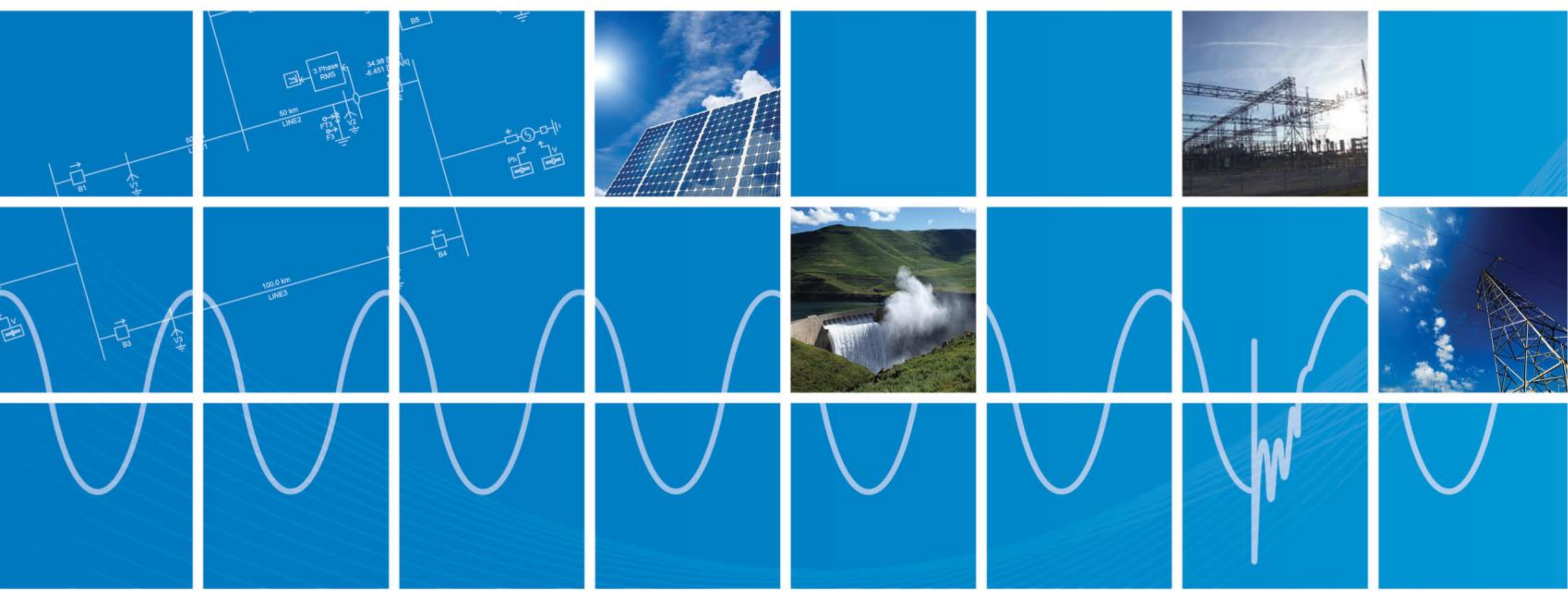
PSCAD Cookbook

Line Energizing Studies

Written for v4.5

Revision 1, August 13, 2018



Powered by Manitoba Hydro International Ltd.
211 Commerce Drive
Winnipeg, Manitoba
R3P 1A3 Canada
mhi.ca

Contents

6. Line Energizing Study

6.1 Energizing a Transmission Line Study

Motivation

This study is used to illustrate the key points to be considered in a line energizing study. The PSCAD 'Multiple-Run' component is used to time the instant at which the three poles of the circuit breakers are closed.

System Overview

A typical high voltage ac network consisting of 400 kV and 115 kV transmission lines is shown in Figure 1.

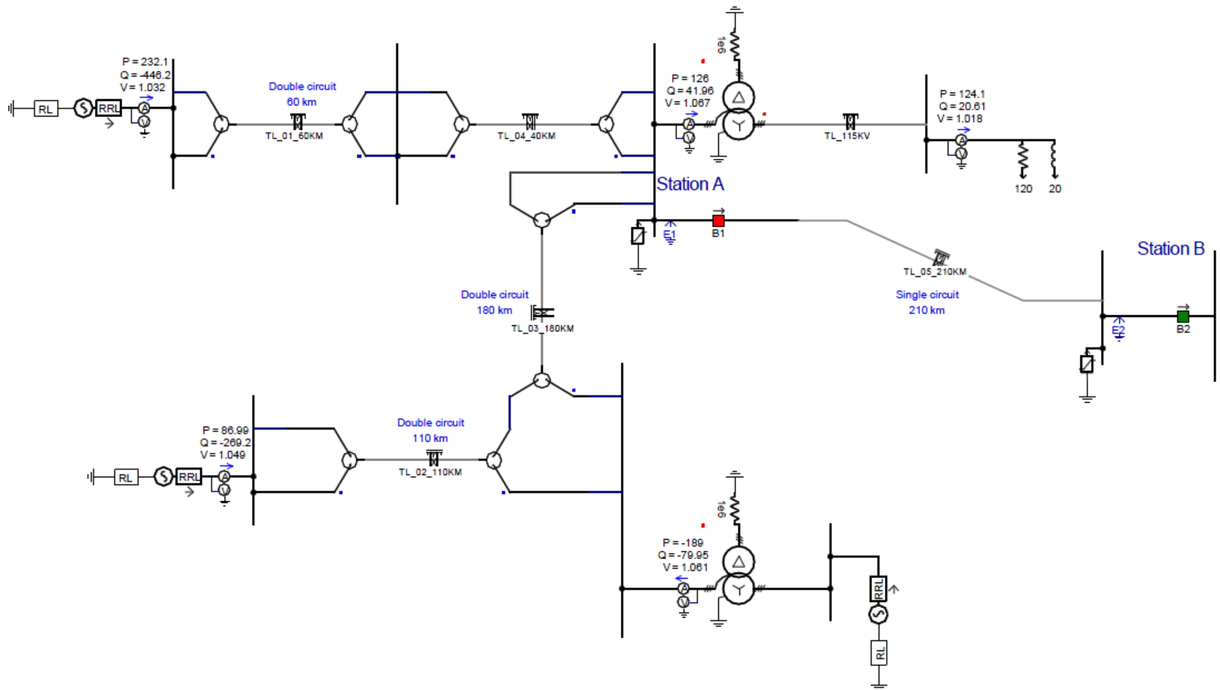


Figure 1: High Voltage ac Network

The 210 km single circuit line (400 kV) between Station A and Station B is the focus of the line energizing study. The line is energized from Station A. The circuit breaker at Station B is open. Thus, E2 (Figure 2) is the open end voltage of the energized line.

Page 1

Important features of the network model are as follows:

- The network details up to two buses away from Station A are included in the model. The rest of the system is represented by Thevanin's equivalence voltage sources.
- The transmission lines are represented by detailed 'frequency dependent' line models.
- The surge arresters at Station A as well as the line end surge arrester at Station B are included in the model.

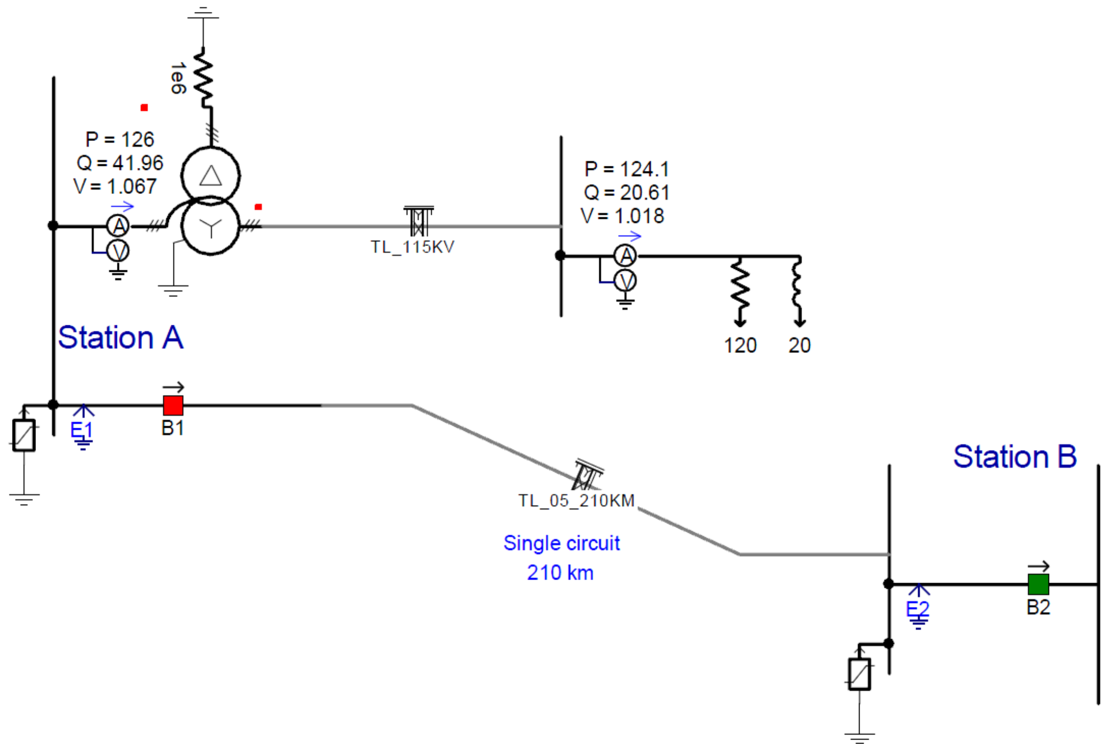


Figure 2: The 210 km Line between Station A and Station B

Network equivalence

The parameters of the voltage source(s) representing the 'remote' buses must accurately represent the fault current contribution from the 'remote' system. As well, the voltage magnitude and the phase angle must correspond to the specific system operating condition (i.e. load flow condition). As such, we proceed as follows:

- We enter the positive and zero sequence impedance of the 'remote' system calculated based on the fault levels.
- We enter the voltage source magnitude and phase angle corresponding to the system operating condition.

Note

Prior to performing the energizing study, the correct steady-state power flow in different parts of the network should be verified (i.e. conduct a comparison with known power flow conditions).

Page 2

Transmission Line data

Typical data corresponding to a 400 kV line is used in this example simulation (see Figure 3 and Table 1).

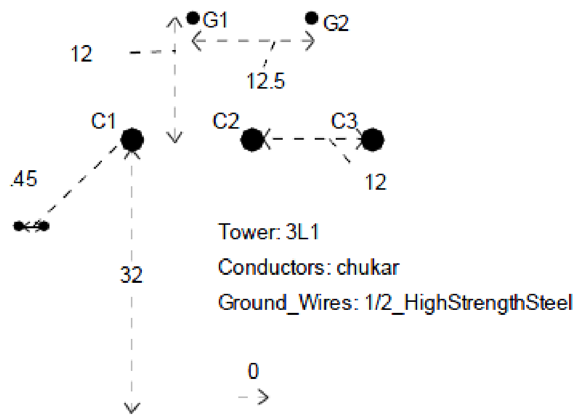


Figure 3: Conductor Heights and Spacing

Conductor Specifications	
Conductor outer radius	0.015 m
Conductor DC resistance	0.06 Ohms/km
Sub conductors per bundle	2 (symmetrical)
Bundle spacing	0.45 m
Ground wire radius	0.005 m
Ground wire DC resistance	0.06 Ohms/km

Table 1: Conductor Data

Page 3

Surge Arrester

The surge arrester characteristics used in this example are listed in Table 2. The rated voltage of the surge arresters (connected from line to ground) in this example is 335 kV. This is typical for a 400 kV system. The PU voltage of Table 2 is based on the surge arrester rated voltage. Slope of the V-I Characteristic curve must reduce as current increase.

V [PU]	I [kA]
1.1	0.00001
1.6	0.0001
1.7	0.001
1.739	0.002
1.777	0.038
1.815	0.65
1.853	1.27
1.881	1.9
1.91	2.56
1.948	3.5
3.2	200

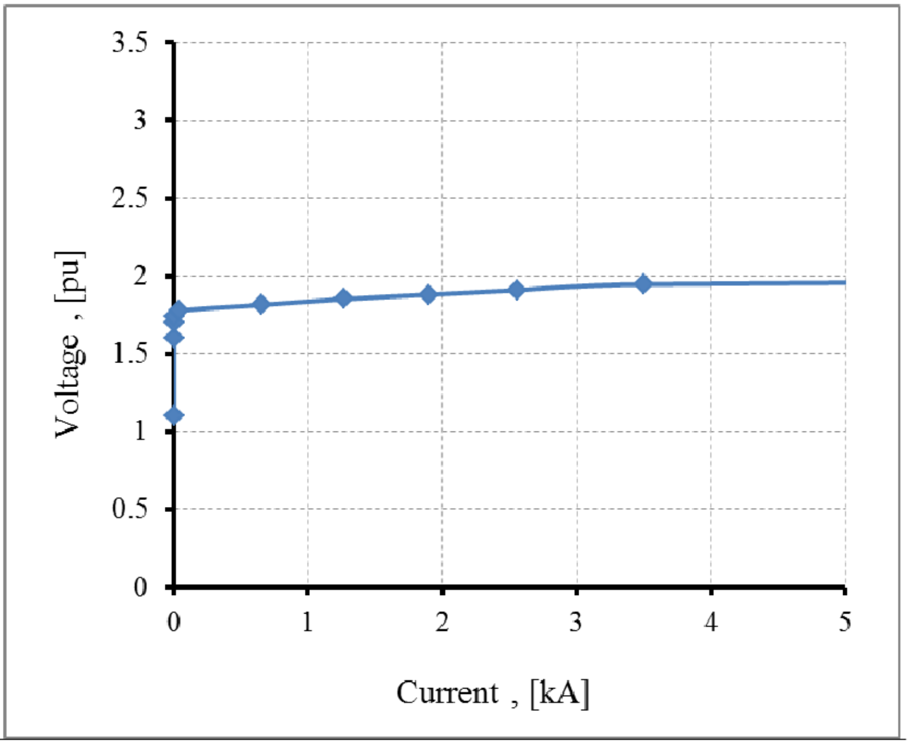


Table 2: Surge Arrester Data

Page 4

Objective

The main objectives of a line energizing study are to demonstrate the following:

- The peak switching overvoltage is less than the ratings of the substation switching surge insulation levels.
- The energy dissipation in the surge arrester during the switching surge is within the surge arrester energy rating.

Simulation Results

In this study, the multiple-run component of PSCAD is used to energize the line at different points on the voltage waveform. All three breaker poles close at the same instant. Thus, the pre-strike phenomenon of an individual breaker pole is not implemented in this example.

The multiple-run unit is set up to repeat the simulation 106 times. On each run, the breaker B1 closes at a different point on the voltage waveform.

The simulation results shown in Figure 4 are for the worst case, in which the line end voltage (E2) attains its largest peak value (approximately 600 kV or 1.85 PU). It can be noted that the surge arrester energy dissipation is around 70 kJ. These values must be compared with relevant equipment ratings.

It should be noted that the transients at Station A bus are less severe than at the remote end of the line.

The statistical summary of the line energizing results (i.e. multiple runs) is given in Table 3.

Page 5

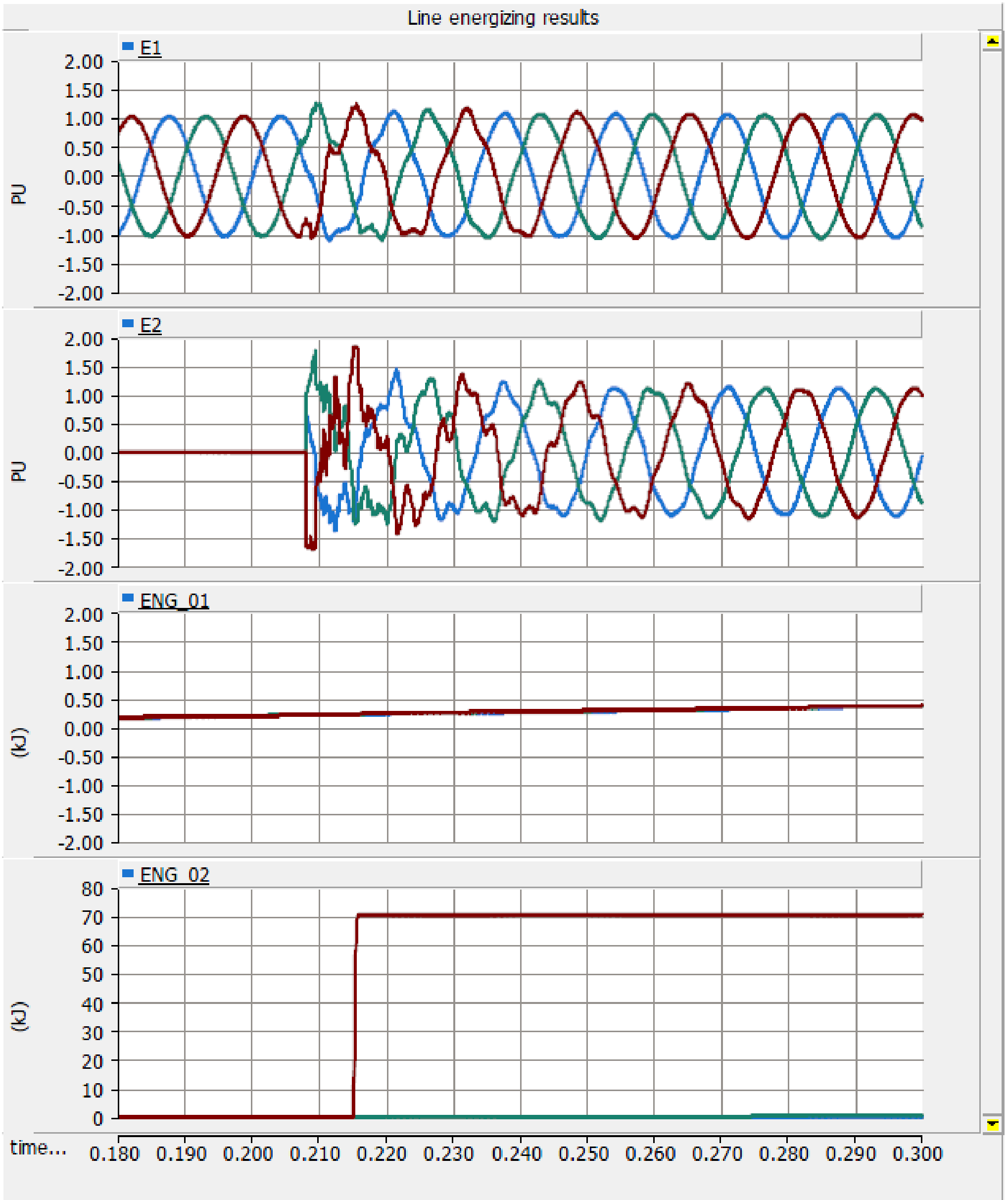


Figure 4: Simulation Results - Worst Case is Shown

Values	E2_PEAK
Minimum	596.5688726
Maximum	601.0333557
Mean	599.0005888
Std Dev	1.506022295
2% Level	595.9075971
98% Level	602.0935805

Table 3: Statistical Summary of the Line Energizing Study

The values displayed in Table 3 are described as follows:

- Minimum and Maximum: These are minimum and maximum values observed in the study sample (i.e. peak overvoltage - raw data).
- Mean and Std. Dev.: These are the mean value and the standard deviation of the data sample.
- 2% level: Statistically, 2% of line switching events will results in peak over- voltage levels less than this value.
- 98% level: Statistically, 98% of line switching events will results in peak over- voltage levels less than this value.

Hints

The following are some helpful hints during this study:

- Use the ‘Snapshot’ feature to speed up the multiple-run simulations.
- Disable graphic animations during multiple runs to speed up the simulation.

Discussion

This study considers energizing the line when it is fully de-energized. However, the worst case is more likely when the line is energized (re-energized), when there is ‘trapped charge’ on the line. This is addressed in Section 6.2.

PSCAD

Refer to PSCAD case: LineSwitchStudy01.pscx

Page 7

6.2 Re-Energizing With Trapped Charge on the Line Study

Motivation

This study is used to illustrate the key points to be considered in a line re-energizing study. The PSCAD 'Multiple-Run' component is used to time the instant at which the three poles of the circuit breakers are closed.

System Overview

The network model and the details are as listed in Section 6.1.

Note

Prior to performing the energizing study, the correct steady-state power flow in different parts of the network should be verified (i.e. perform a comparison with known power flow conditions).

Objectives

The main objectives of a line re-energizing study are to demonstrate that:

- The peak switching overvoltage is less than the ratings of the substation switching surge insulation levels.
- The energy dissipation in the surge arrester during the switching surge is within the surge arrester energy rating.

Simulation Results

In this study, the multiple-run component of PSCAD is used to re-energize the line at different points on the voltage waveform. All three breaker poles close at the same instant. Thus, the pre-strike phenomenon of an individual breaker pole is not implemented in this study.

The multiple-run unit is set up to repeat the simulation 106 times. On each run, the breaker closes at a different point on the voltage waveform.

Page 8

It should be noted that the line is re-energized while there is trapped charge on the line. In the simulation, the following steps are followed (see Figure 5):

- The line is initially energized (breaker B1 is initially closed).
- Breaker B1 is opened at 0.19 s. Since the breaker interrupts the current at a current zero crossing, point of wave opening of B1 is not necessary at this step.
- Breaker B1 is re-closed at time 'BRK_SIG'. The instant 'BRK_SIG' is set via the multiple-run component.

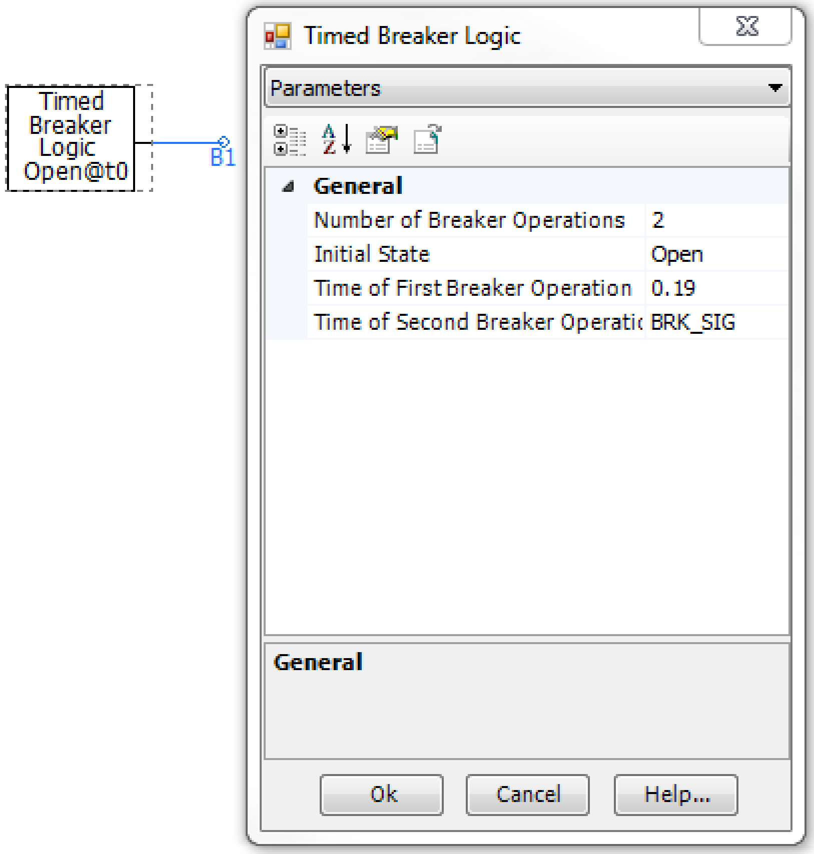


Figure 5: Settings for Breaker B1

The statistical summary of the line energizing results (i.e. multiple runs) is given in Table 4

Values	E2_PEAK
Minimum	482.0740655
Maximum	614.7404109
Mean	596.0793525
Std Dev	31.66879419
2% Level	531.0396000
98% Level	661.1191050

Table 4: Statistical Summary of the Line Energizing Study

The simulation results shown in Figure 6 are for the worst case, in which the line end voltage (E2) attains its largest peak value (approximately 620 kV or 1.86 PU). It can be noted that the surge arrester energy dissipation is around 480 kJ. These values are higher than the values observed during normal line energizing without any trapped charge on the line. The values must be compared with relevant equipment ratings.

It should be noted that the transients at Station A bus are less severe than at the remote end of the line.

Page 10

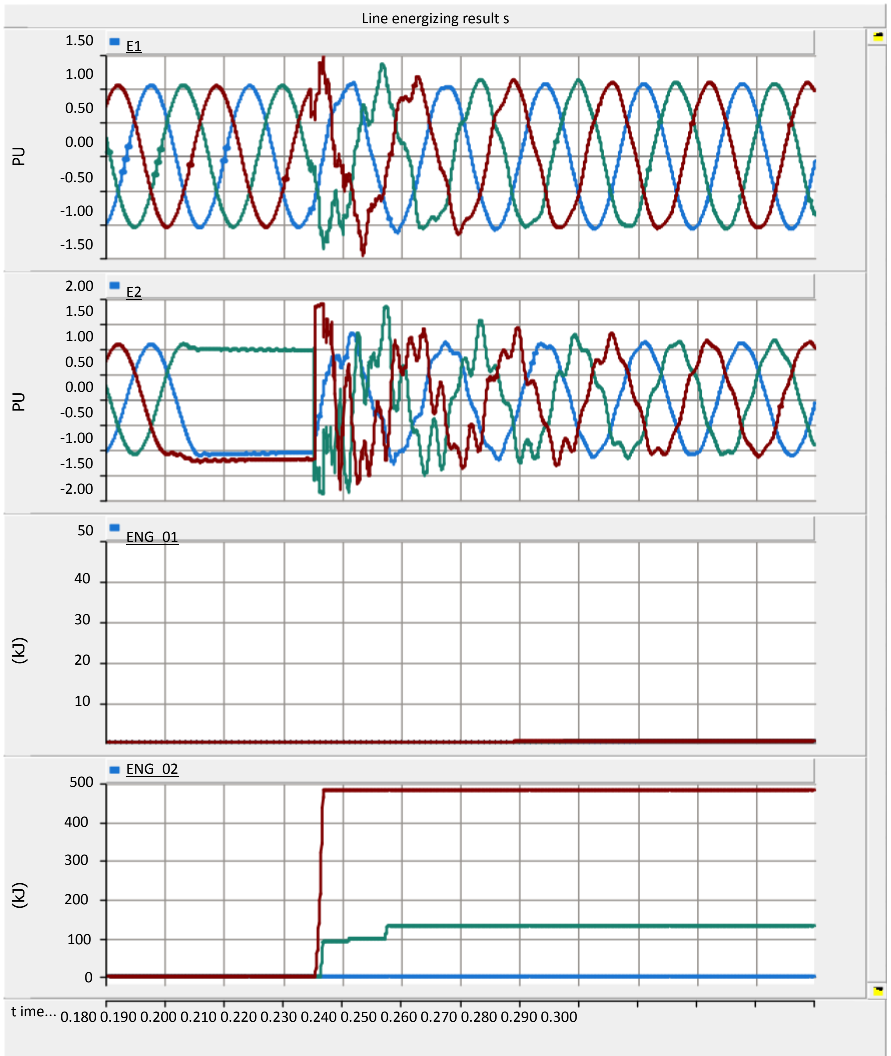


Figure 6: Simulation Results – Worst Case is shown

Hints

The following are some helpful hints during this study:

- Use the 'Snapshot' feature to speed up the multiple-run simulations.
- Make sure that the line has not discharged when the re-closing occurs.
- Disable graphic animations during multiple runs to speed up the simulation.

Page 11

Discussion

This example considers energizing the line when it carries the maximum trapped charge. This is most likely the worst case in terms of line energizing transients.

PSCAD

Refer to PSCAD case: *LineSwitchStudy02.pscx*

Page 12

6.3 Energizing of an Autotransformer from the HV Side Study – Harmonic Resonance Voltage Problems

Motivation

This study is used to illustrate the key points in energizing a large power transformer from the HV side and the harmonic resonance voltage problems associated with this.

System Overview

The following is similar to the network model and the details listed in Section 6.1. Note that a 500 MVA, 400/115/13.8 kV auto transformer is connected to the bus at Station B (see Figure 7). The transformer is not connected to any loads.

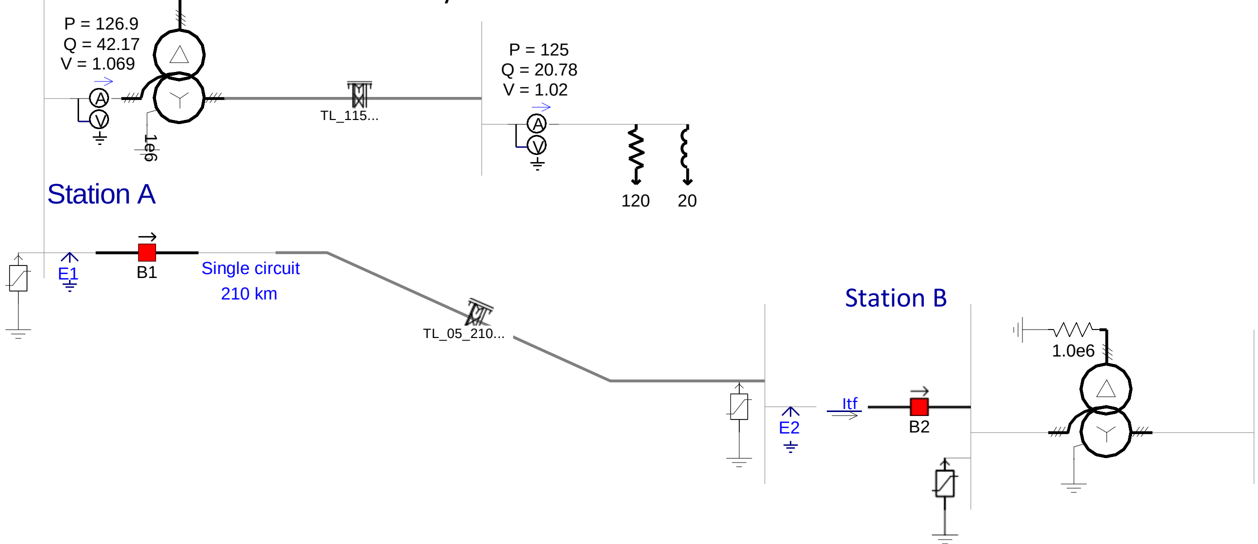


Figure 7: The 210 km Line between Station A and Station B with the Addition of the Auto Transformer

Note

Prior to performing the energizing study, the correct steady-state power flow in different parts of the network should be verified (i.e. conduct a comparison with known power flow conditions).

Page 13

Objective

The main objective of a large power transformer energizing study is to demonstrate that the resonant overvoltages are well damped and that the magnitudes do not violate temporary overvoltage capability of station equipment.

Simulation Results

The simulation results shown in Figure 8 show that inrush currents, which contain significant low order harmonics, are present. The low order harmonics can be seen in Figure 9. These low order harmonics can interact with the network, giving rise to sustained harmonic voltage problems.

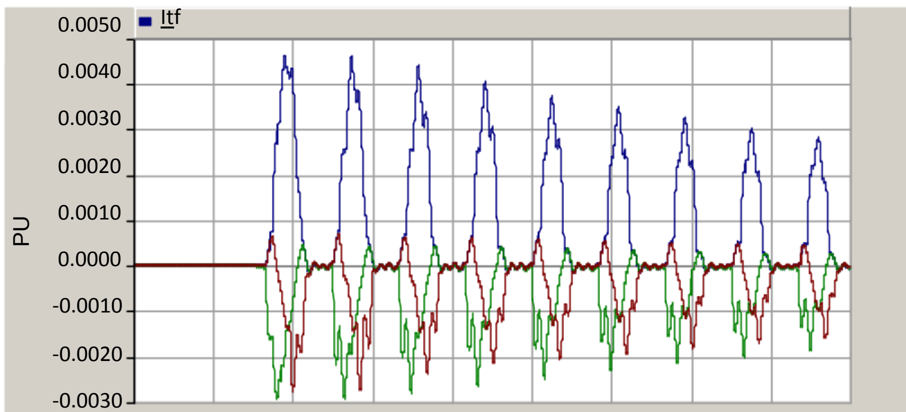


Figure 8: Inrush Currents at HV Side of Auto Transformer

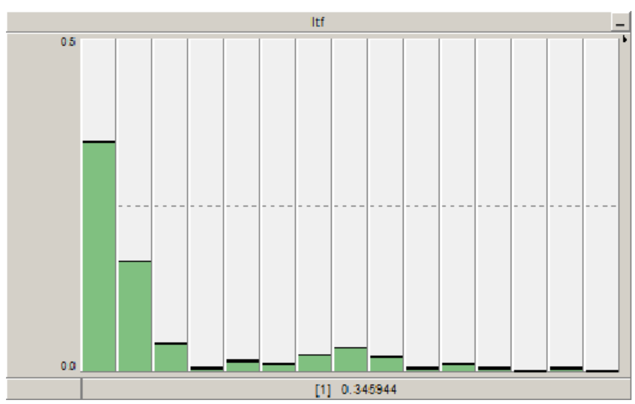


Figure 9: Inrush Current Harmonics

Page 14

The auto transformer energizing currents create temporary overvoltages (i.e. voltage magnification) at the HV side, which are shown for the worst case scenario in Figure 10. If the overvoltages are not properly damped, they may impact the equipment insulation (mitigation methods are discussed later in this section). The voltage (E2) magnitude reaches approximately 543kV (1.67 PU) and remains at around 532 kV (1.33 PU) for over half of a second.

The statistical summary of the line energizing results (i.e. multiple runs) is given in Table 5.

Values	E2_peak	Ift_peak
Minimum	503.5539292	0.3777435746
Maximum	547.5095128	1.634662293
Mean	522.9174694	1.115814744
Std Dev	12.94689663	0.4288404418
2% Level	496.3277942	0.2350841404
98% Level	549.5071447	1.996545347

Table 5: Statistical Summary of the Line Energizing Study

Page 15

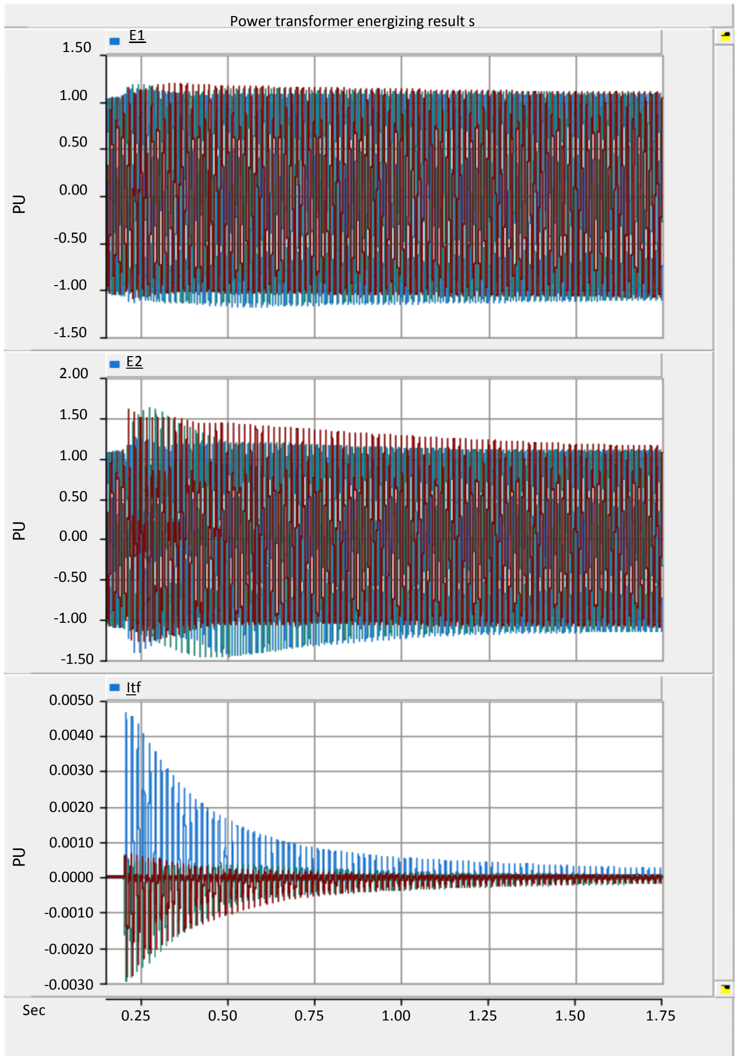


Figure 10: Power Transformer Energizing Results

The frequency scan at Station B is shown in Figure 11, and resonance points can be noted around 240 and 380 Hz (approximately the 4th and 6th). The high impedance at these resonance frequencies interacts with the corresponding harmonic currents, magnifying the temporary overvoltages (TOV).

Page 16

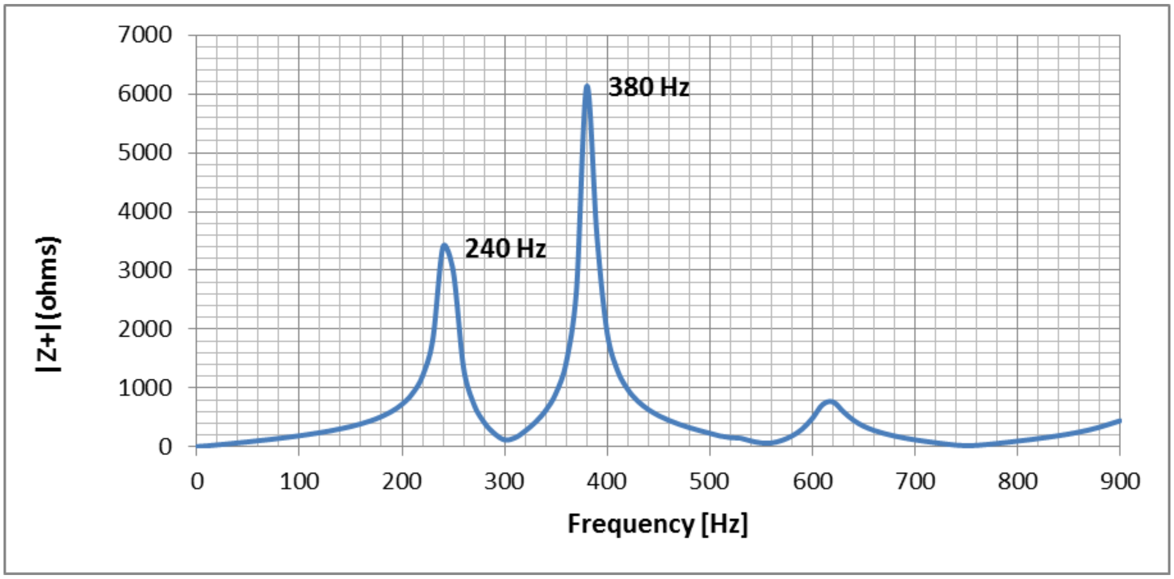


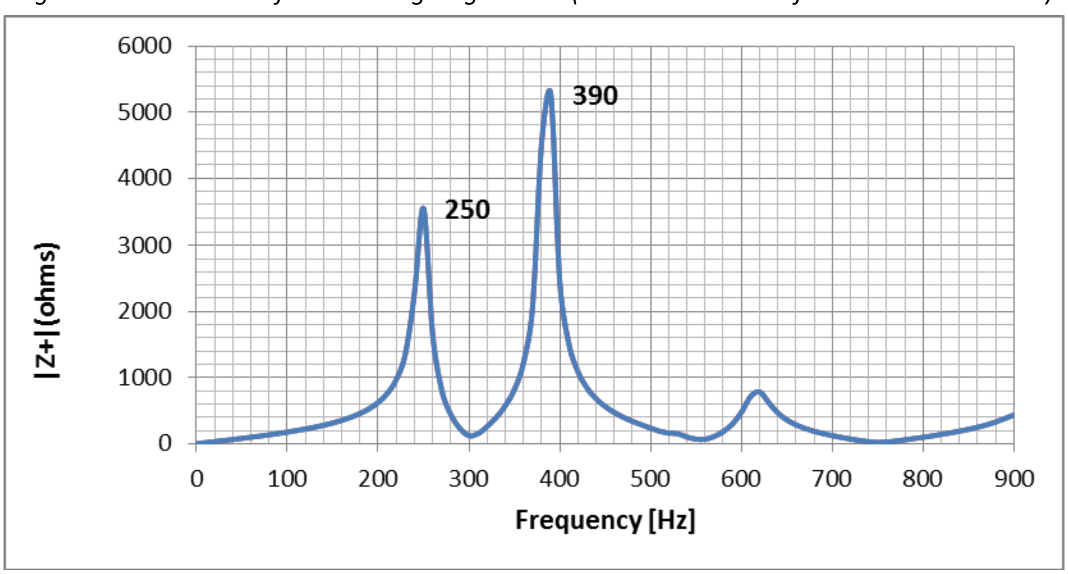
Figure 11: Harmonics Impedance Spectrum (as seen from 400 kV Bus)

In general cases, possible mitigation methods are as follows:

- Add a small load on the tertiary winding.
- Reconfigure the system to move the network resonance points. For example, add a 120 VAR reactor (if available) to the bus at Station B, or rearrange the number of lines connected to a bus.
- Synchronize the closing of the breaker (close to a voltage peak).

The simulation results from Figure 12 show that adding a 120 VAR reactor to the bus at Station B did reduce the voltage transients. It also shifted the harmonic impedance spectrum to slightly higher frequencies, as shown in Figure 13.

Figure 12: Power Transformer Energizing Results (with the addition of a 120 MVAR Reactor)



Page 17

Figure 13: Harmonic Impedance Spectrum (as seen from 400 kV Bus with the addition of the 120 MVAR Reactor)

Discussion

Based on the TOV observations, energizing the auto transformer from the 400 kV side is not recommended.

Mitigation methods must be considered.

PSCAD

Refer to PSCAD case: *AutoTransSwitchStudy03.pscx*

DOCUMENT TRACKING

Rev.	Description	Date
0	Initial	01/Jun/2013
1	Update to New Branding Guidelines	13/Aug/2018