






PSCAD

Switching Over Voltages (SOV)
Temporary Over Voltage (TOV)

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Outline

The study approach to SOV investigation, using the PSCAD/EMTDC simulation tool, is discussed in this webinar. The following topics are addressed:

- Switching over voltages and Temporary over voltages
- Power system modeling for switching studies
  - System model
  - Component models (transformers, breakers, shunt devices)
  - Surge arresters
- Simulation of switching events
  - Point-on-wave impact
  - Trapped charge on lines/cables
  - Line reactor impacts
- Transformer energizing transients
- Coupled line resonance examples
- PSCAD examples

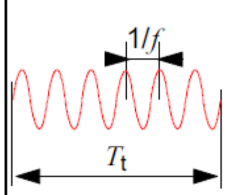
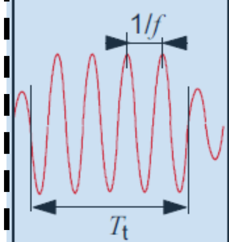
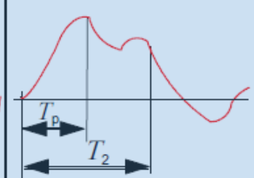
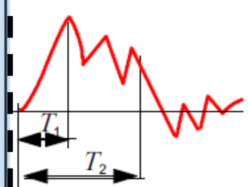
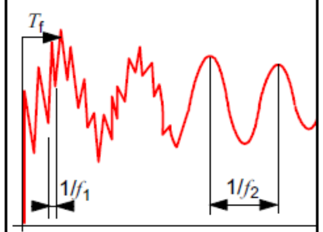
Objectives of a switching study:

- Determine the over voltage levels due to switching events
- Verify equipment insulation levels will not be violated
- Verify surge arrester requirements and surge arrester ratings
- Identify potential network resonance issues

Types of studies:

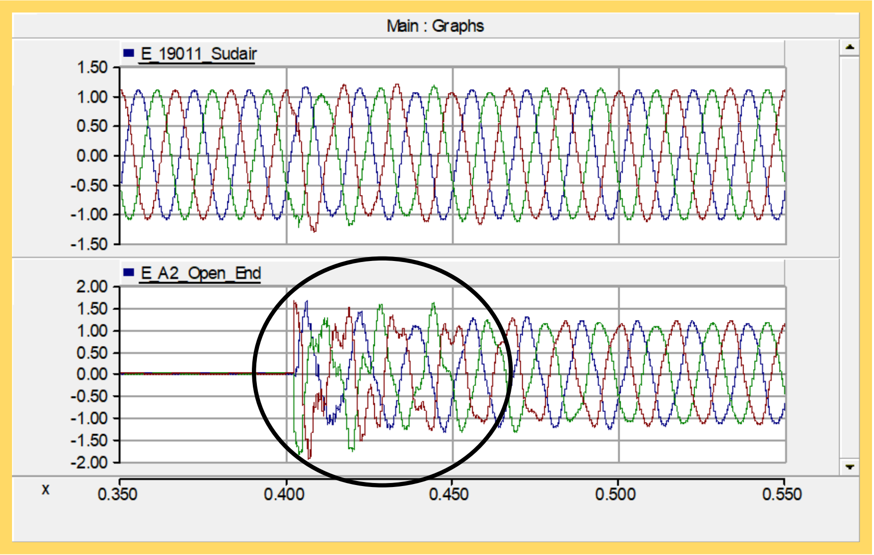
- Switching frequency over voltage studies (SOV)
- Temporary over voltage studies (TOV)
- Transformer energizing

SOV and TOV Frequency Spectrum

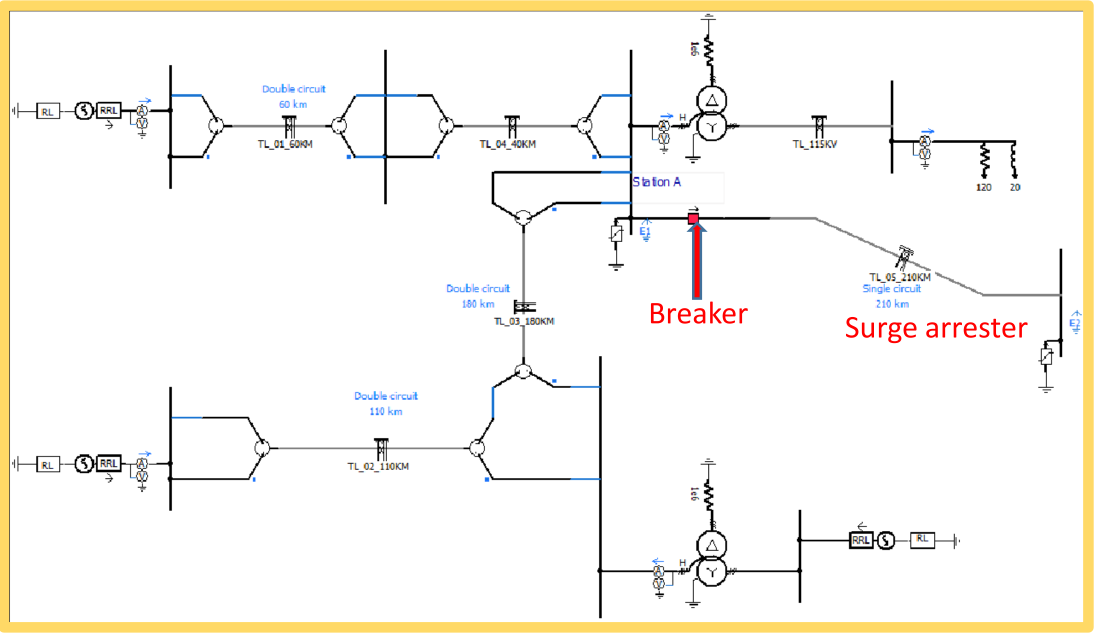
Class	Low frequency		Transient		
	Continuous	Temporary	Slow-front	Fast-front	Very-fast-front
Voltage or over-voltage shapes					
Range of voltage or over-voltage shapes	f = 50 Hz or 60 Hz T_t ≥3 600 s	10 Hz < f < 500 Hz 0,03 s ≤ T_t ≤ 3 600 s	20 µs < T_p ≤ 5 000 µs T_2 ≤ 20 ms	0,1 µs < T_1 ≤ 20 µs T_2 ≤ 300 µs	3 ns < T_f ≤ 100 ns 0,3 MHz < f_1 < 100 MHz 30 kHz < f_2 < 300 kHz

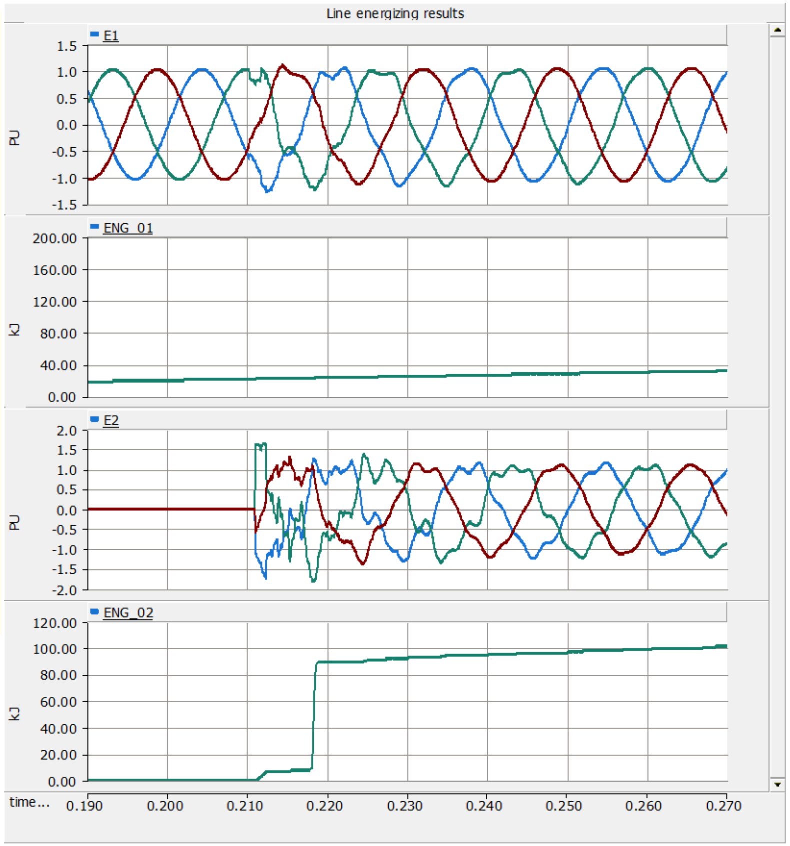
Switching Over Voltages (SOV)

- Switching over voltages (SOV) result from the operation of breakers and switches or due to faults in a power system.
- Switching actions lead to travelling waves on transmission lines, in addition to initiating oscillations in local L-C elements.
- Such travelling waves and local oscillations can appear as high frequency voltage transients in the network. The switching transient frequencies can reach up to a few kHz (say 500 Hz – 2 kHz)
- Typically SOVs are well damped (due to system losses and loads) – short duration

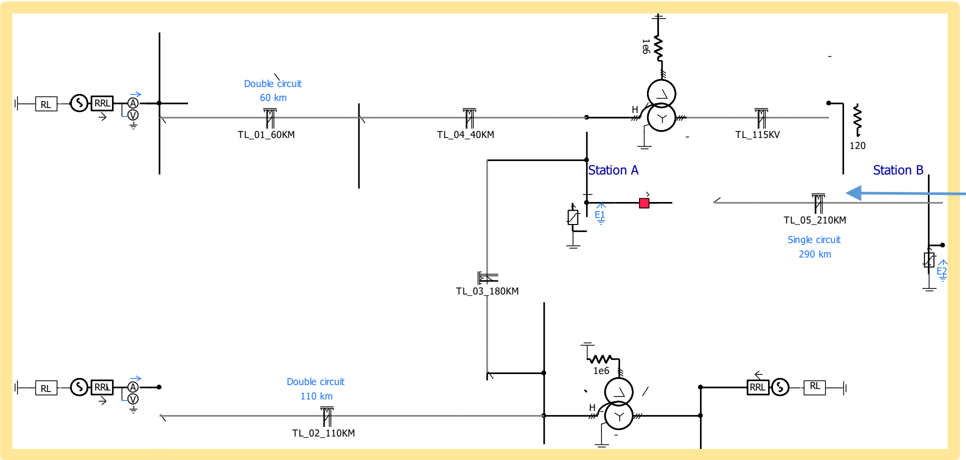


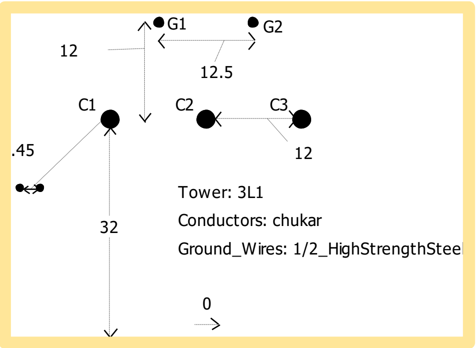
Travelling waves on Transmission Lines



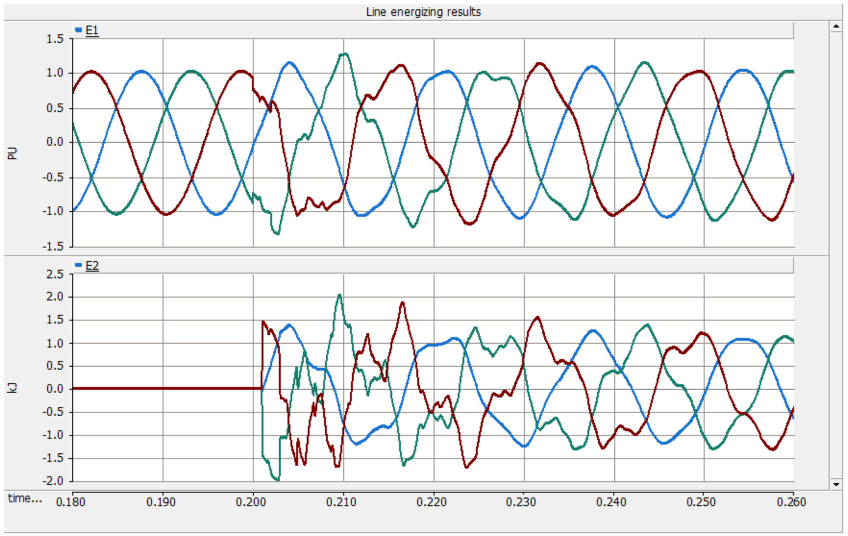


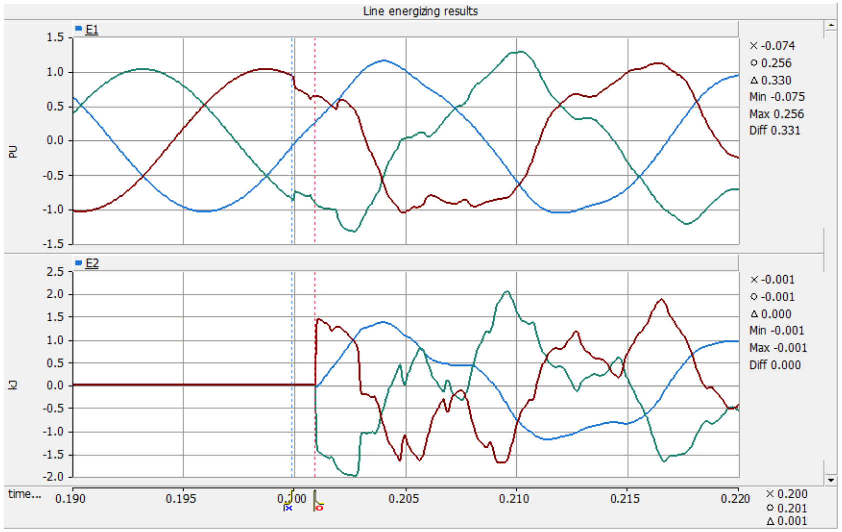
Travelling waves on Transmission Lines



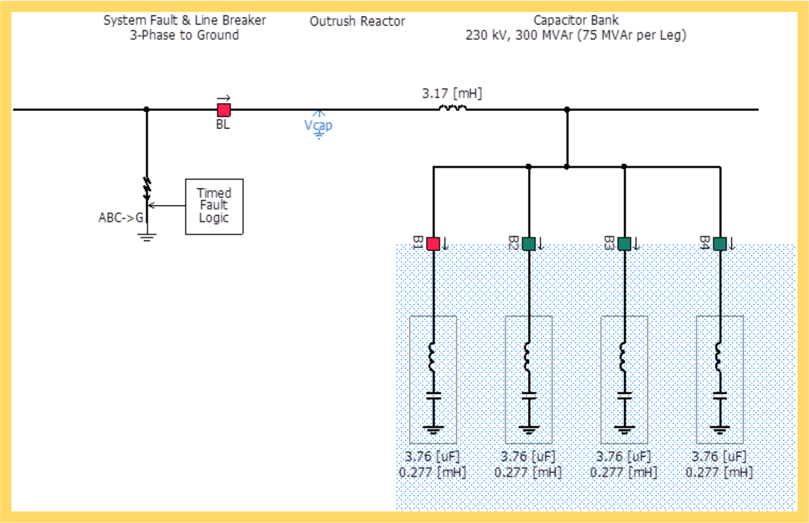


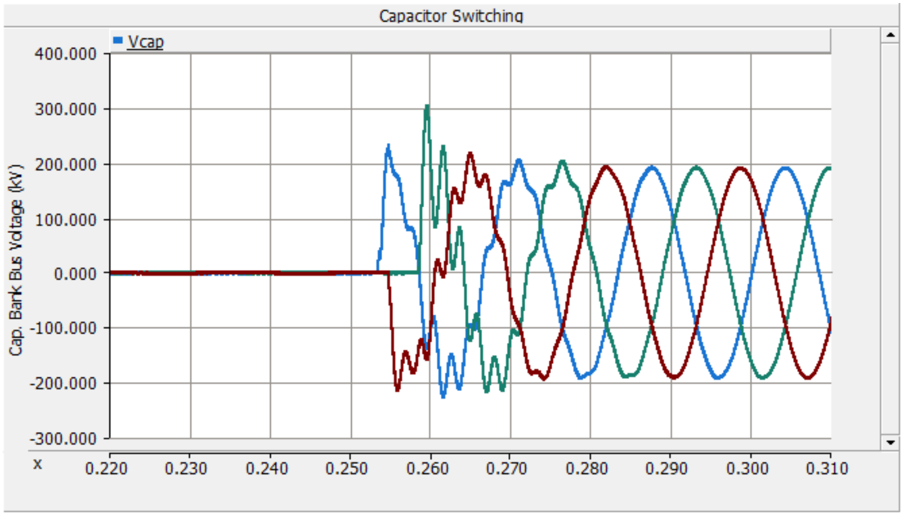
Line travel time (approx.). 1 ms





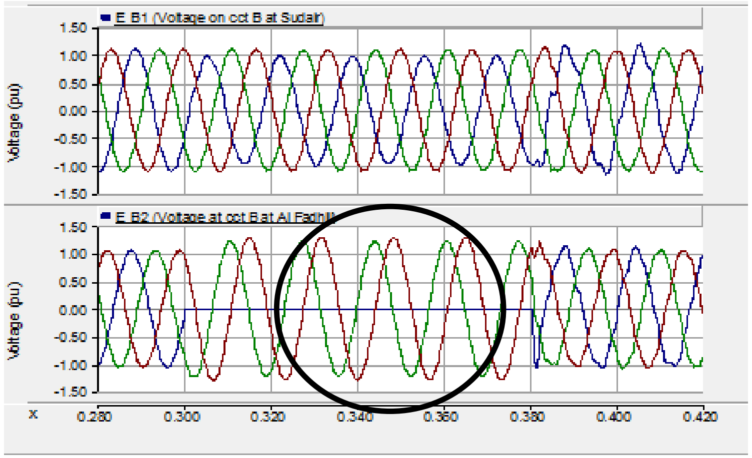
Local lumped L-C Oscillations

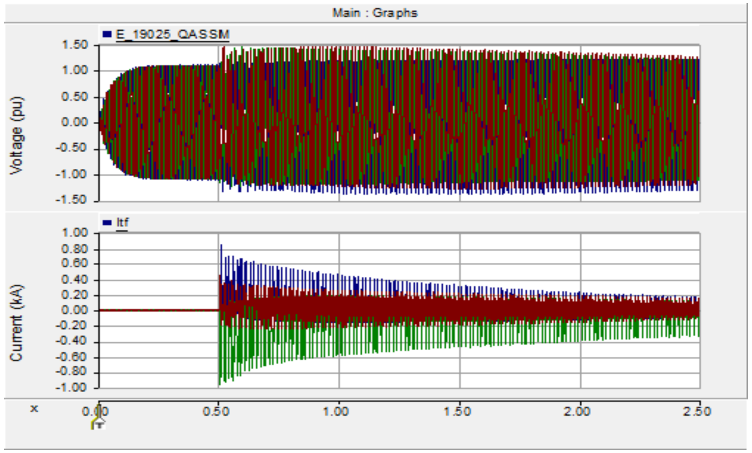




Temporary Over Voltages (TOV)

- Ferranti effect (Open end line voltage)
- Single line to ground faults
- Load rejection
- Transformer energizing
- Parallel line resonance



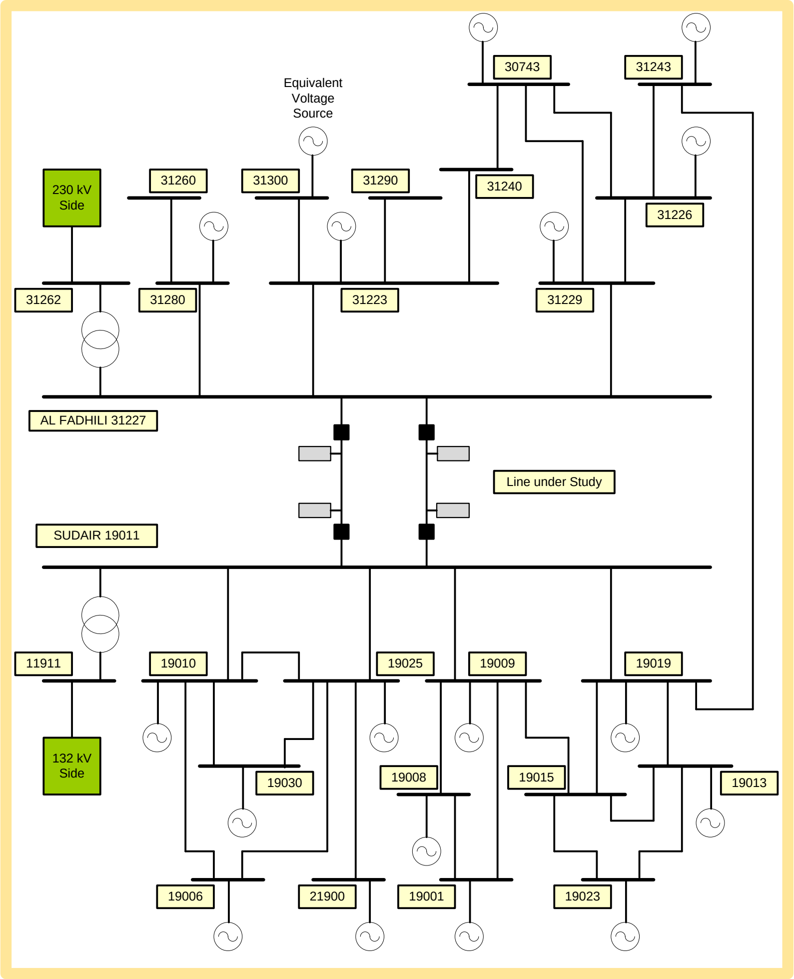


TOVs => power frequency/low order harmonics

PSCAD Modeling Considerations

380 kV System example:

System model captures details up to around 2-3 buses from the switching location.



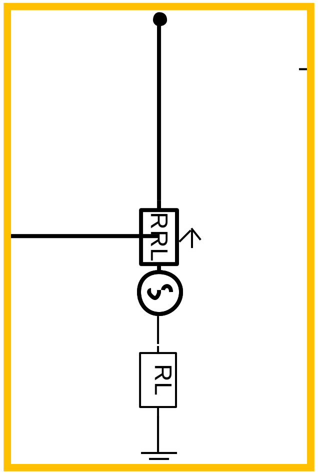
Modelling Considerations

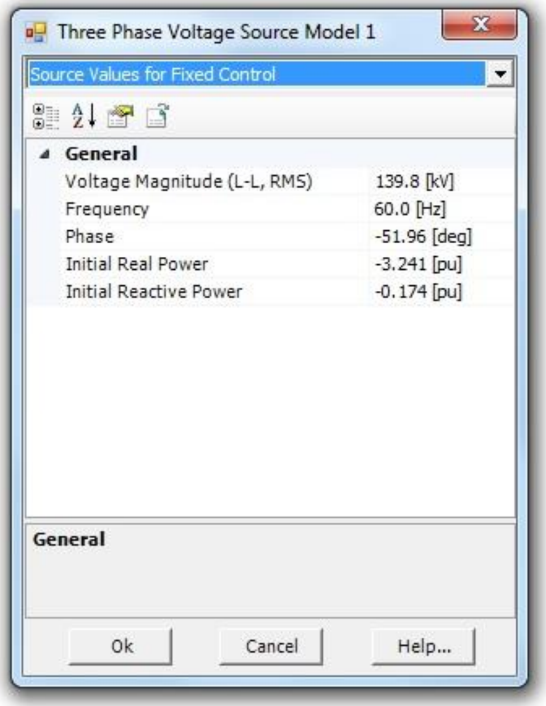
- System represented at least up to two buses away from point of interest
  - The impact of the fast transients are limited to a local area around the station
  - The transient itself is mainly influenced by the circuit elements (R-L-C) in close vicinity to where the disturbance (e.g. breaker action/fault) occurred
- Frequency dependent transmission line models – Travelling waves and damping due to line resistance
- Detailed transformer model including saturation data
- Shunt devices – Can influence network resonances
- Surge arrester non- linear characteristics- Main protective device limiting SOV
- Equivalent voltage source models to represent network boundaries/ generators/motors – fast transients die out relatively fast compared to mechanical dynamics of generators can influence SOV (in most cases)

Network boundary equivalence

Model data:

- Bus voltage & angle
- Positive sequence impedance
- Zero sequence impedance





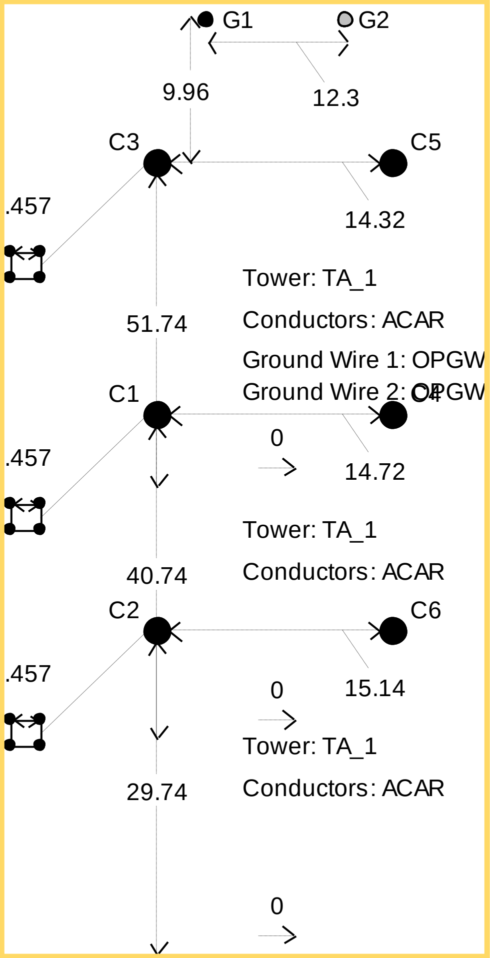
Tower / Line Details

- Geometrical arrangement of conductors
- Ground clearance
- Line sag

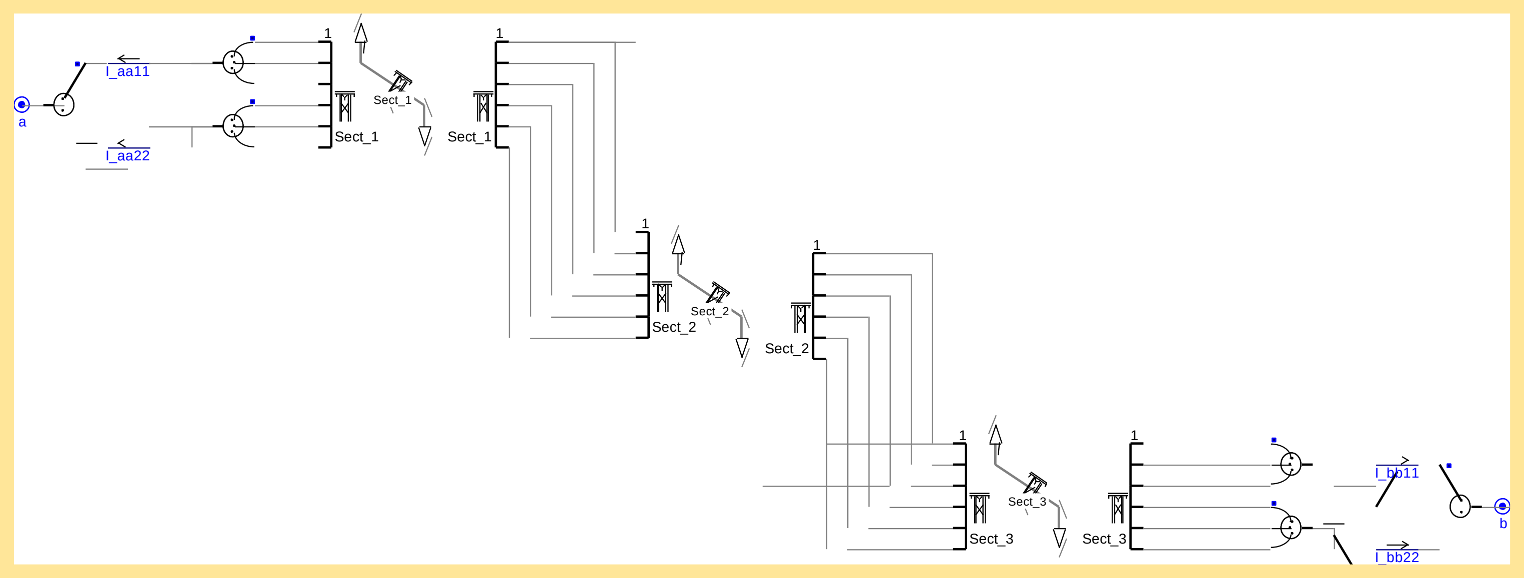
Conductor Data

- Conductor type
- Radius
- DC resistance
- Bundle data
- Ground wire data

	Conductor data	
	Parameter	Value
1	Conductor type	xxx
2	Outer radius (effective)	0.7025 [in]
3	DC resistance	0.0948 [ohm/mi]
4	Conductor sag	20 [ft.]
5	Bundle sub-conductors	2 [nos.]

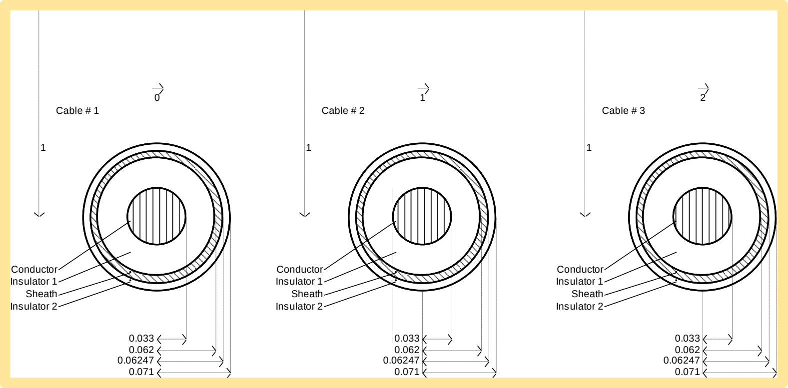


Line Transposition



Cable model

- Bergeron model
  - R,X,B (or Surge impedance and travel time)
- Frequency dependent model
  - Based on Cable design data



Bergeron Model Options

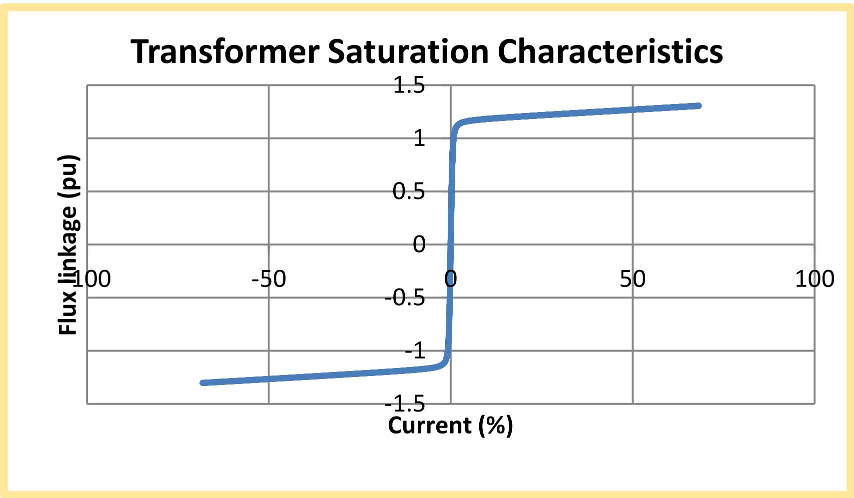
Travel Time Interpolation: On
Reflectionless Line (ie Infinite Length): No

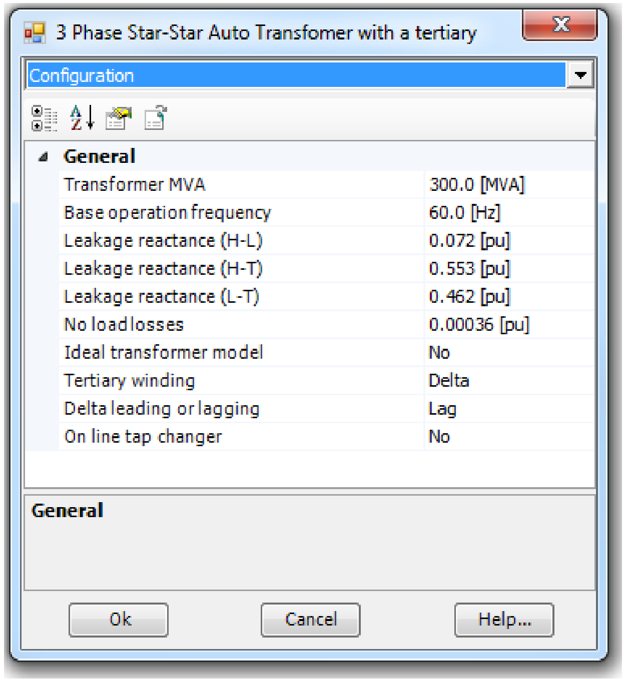
Manual Entry of Y,Z

+ve Sequence R:	0.000045e-3
+ve Sequence XL:	0.001278e-3
+ve Sequence B:	1.003e-3
0 Sequence R:	-estimated-
0 Sequence XL:	-estimated-
0 Sequence B:	-estimated-

Model data

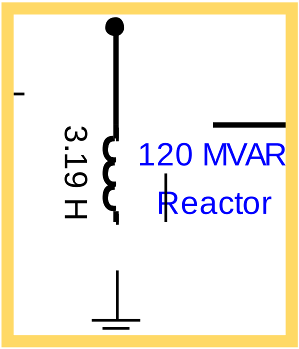
- General data
  - Ratings, impedance
- Saturation data

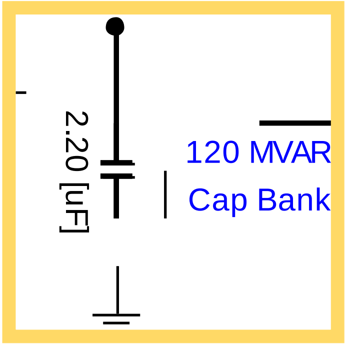




Shunt Devices

- Shunt reactor – with equivalent inductance (or as an non-linear inductor)
  - Single phase units
  - Three limbed core or five limbed core units
- Shunt capacitor – with equivalent capacitance
- Series compensation – with equivalent capacitance



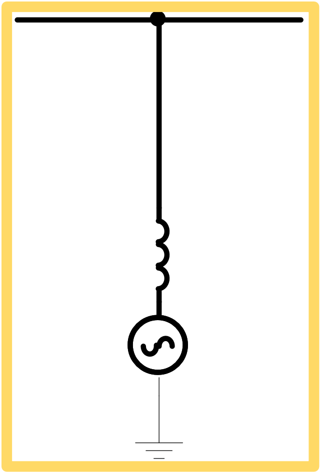


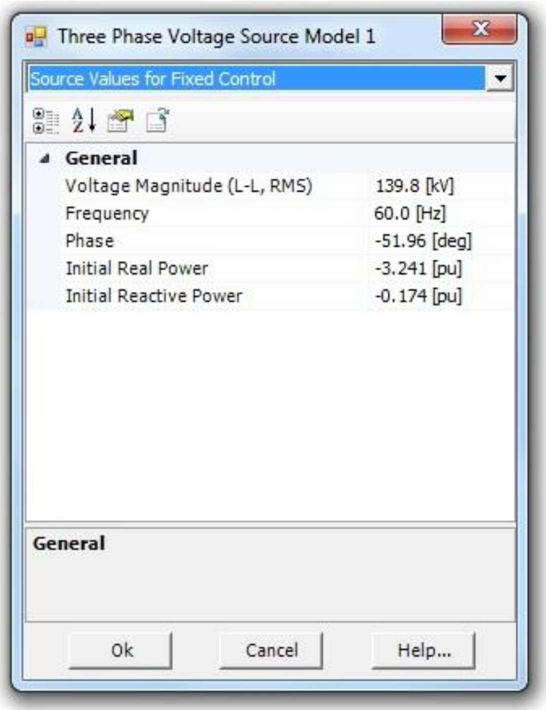
$$x = \frac{kV^2}{MVAr}$$

$$x = \omega L \text{ or } 1/\omega C$$

Model data

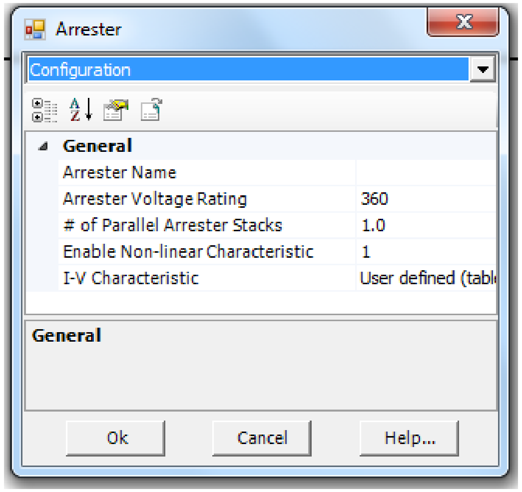
- Bus voltage & angle
- Positive sequence impedance (Xd”)
- Zero sequence impedance (if available)

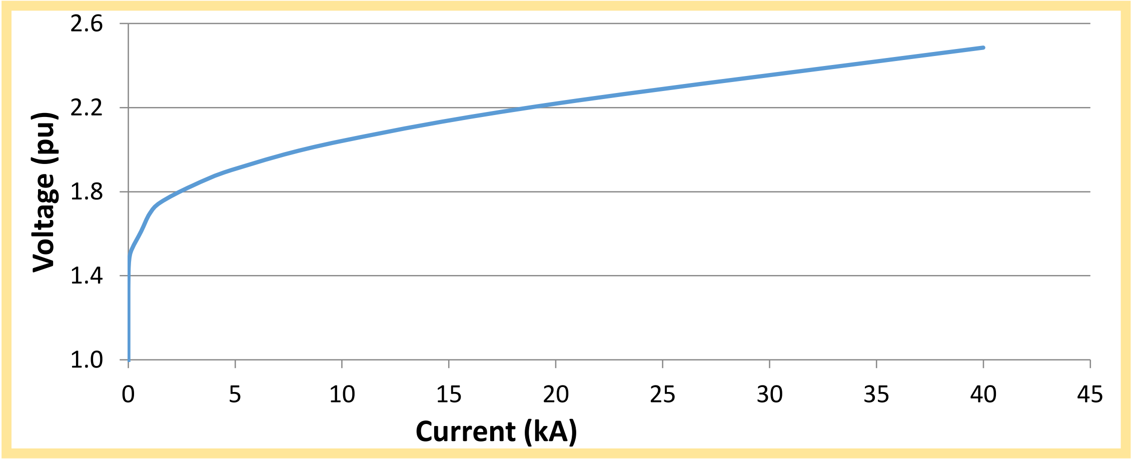




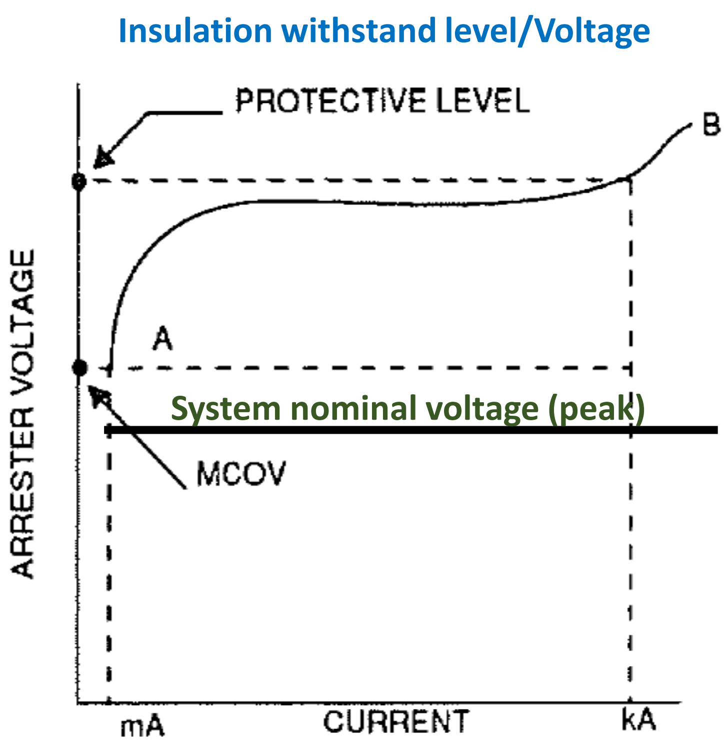
Model data

- Arrester rating – 360 kV
- V-I characteristic
- Energy absorption capability – 13 kJ/kV





Arrester Non linear VI characteristics



- Discharge voltage (protection level) is a function of the rise time of the current surge
- Faster surges result in a higher discharge voltage (ex. lightning)
- The discharge voltage for a switching surge could typically be 2% - 4% lower than that for a comparable (current peak) lighting surge.
- MCOV is typically 75% - 85% of the duty cycle 'voltage rating'.

Protective Ratio (PR) = (Insulation withstand level/Voltage at protected equipment)

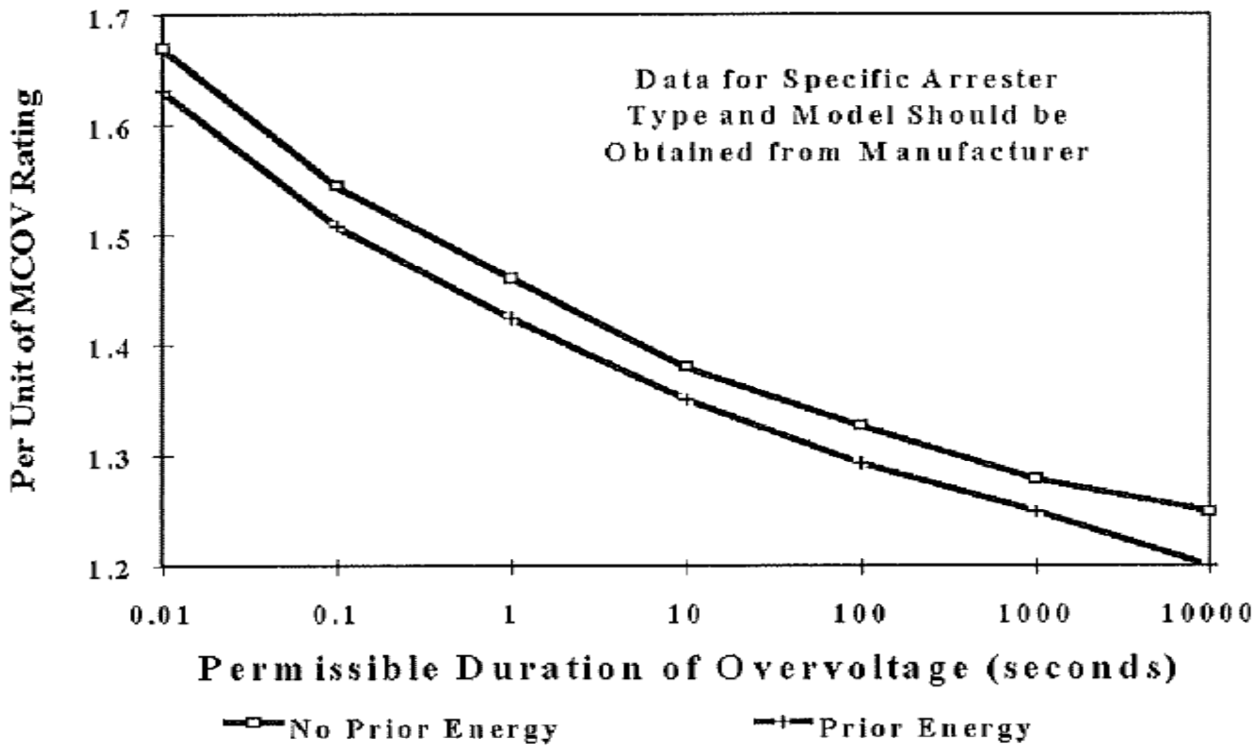
- ➢ Example: PR = BIL/Lightning Protective Level (LPL)

Protective Margin (PM) = (PR – 1).100

Arrester Coordination current

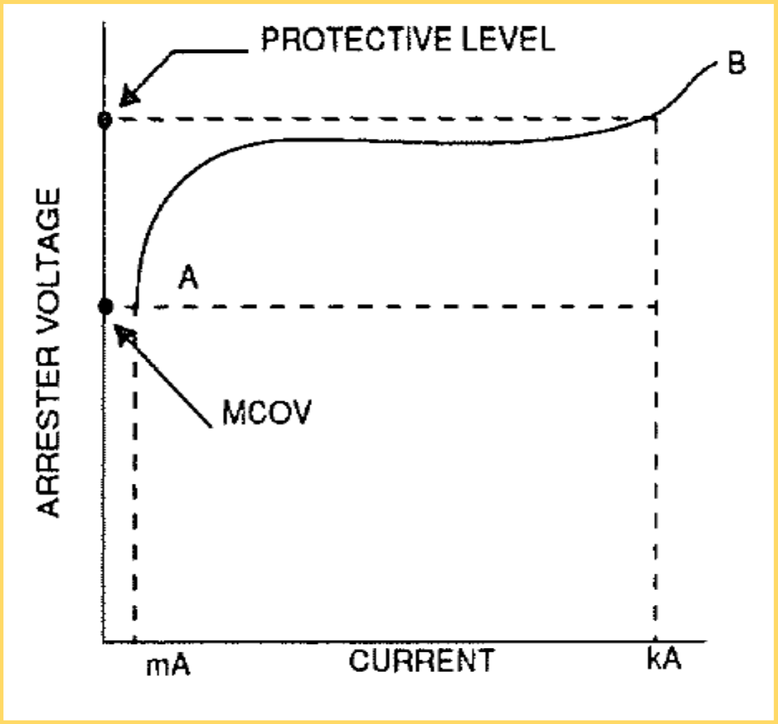
Maximum system voltage (kV)	Coordinating current (kA)
48.3	5
72	5
121	10
145	10
169	10
242	10
362	10
550	15
800	20

Arrester TOV Capability



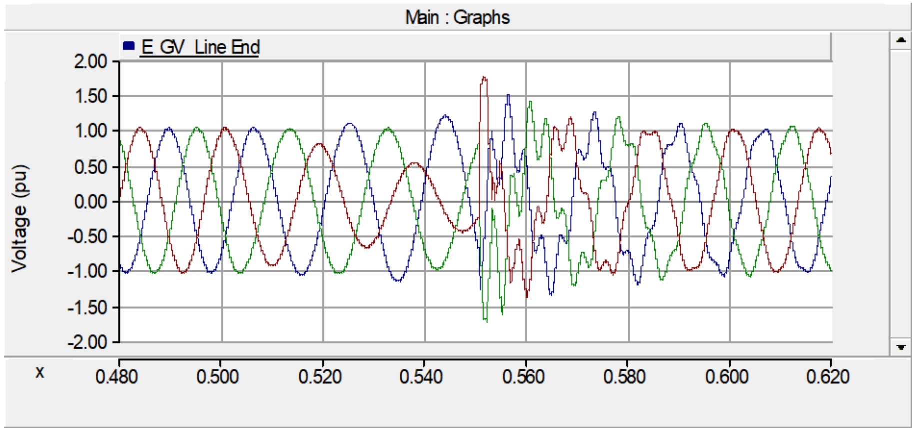
Provided by manufacturers as a data sheet item;

- kJ/kV (of arrester MCOV)
- kJ/kV (of arrester rating)



Arrester Energy = (V*I)* (duration of transient)

- How fast the transient gets damped out will determine (mainly) the energy dissipation of arrester



Model Validation

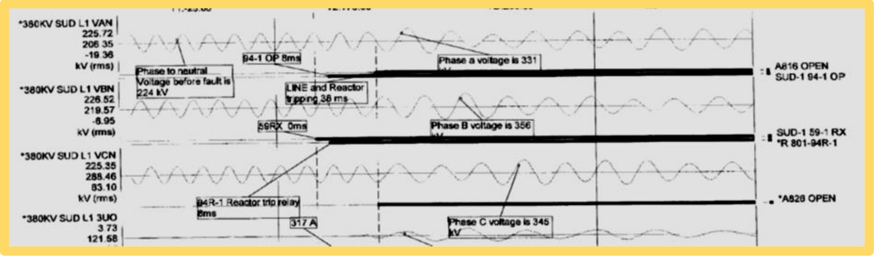
Active Power Flow

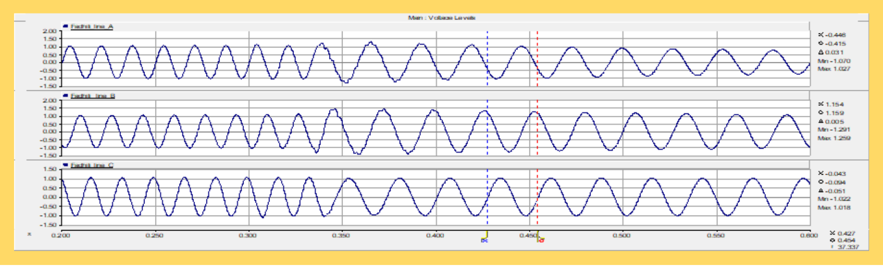
Bus number	PSCAD (MW)	PSSE (MW)
19001-19008	625	686
19001-19009	399	379
19001-19012	324	325
19001-19024	103	121
19001-19062	757	837
19001-18073&18003	434	436
19012-18088	647	650
19024-19008	405	409
19024-19061	210	203
19024-11924	237	238

Fault Level

Load Bus	PSCAD (kA)	PSSE (kA)
19001	47.7	46.9
19012	33.4	33.2
19024	48.0	46.9

Comparison with Field Data

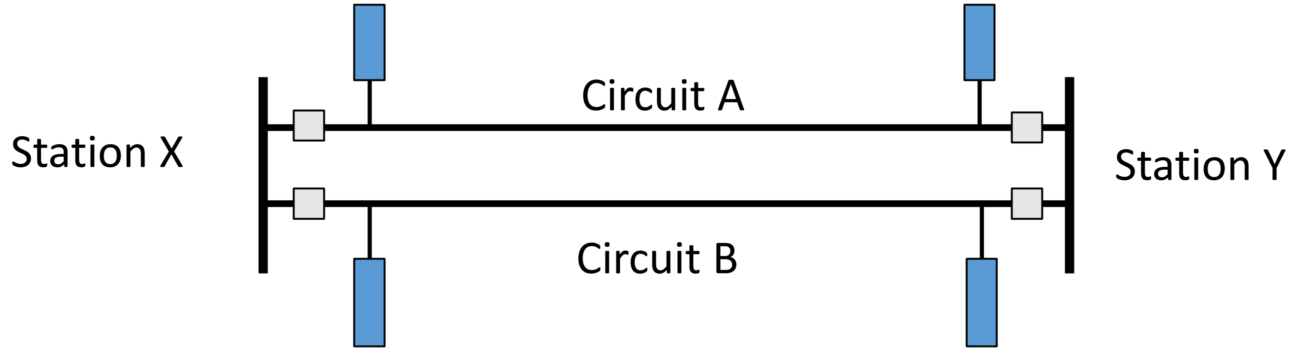




SOV Studies

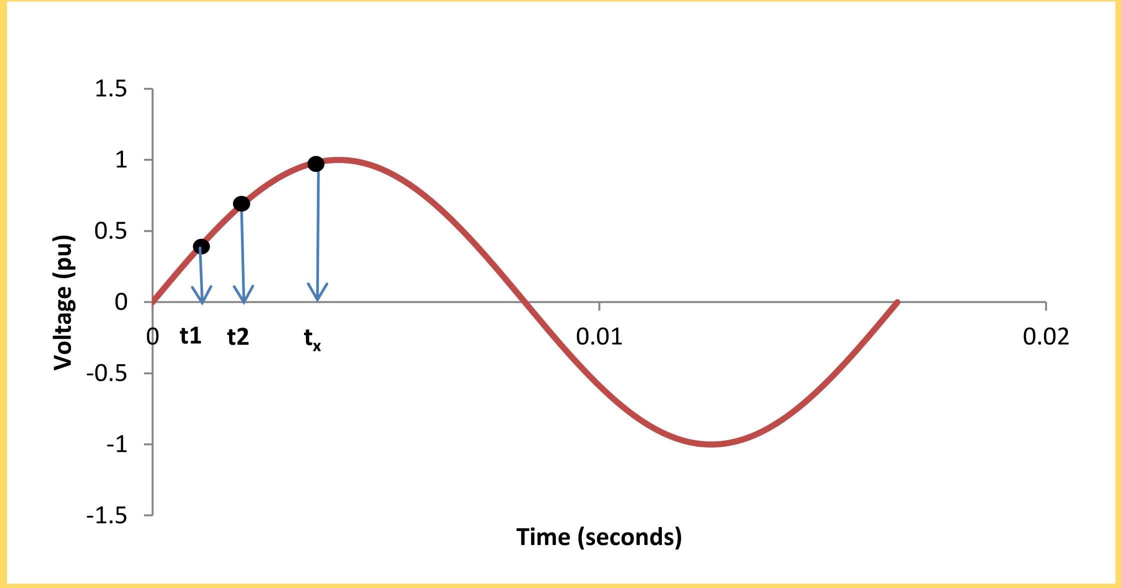
Simulation setup

- Point on wave impact - 100 points over a cycle
- Trapped charge on lines
- Network topology (credible scenarios)



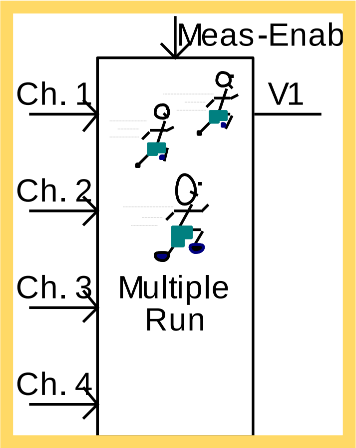
Point on Wave impact

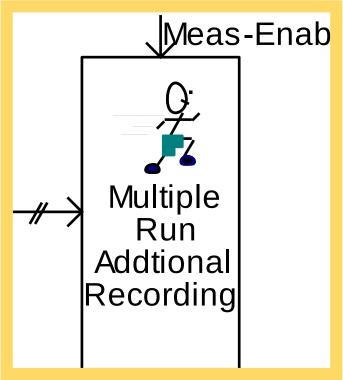
- Switching at different points over a 60 Hz cycle
  - 100 points over a cycle ⇨ 100 simulations
  - Breaker Pole Pre-Strike



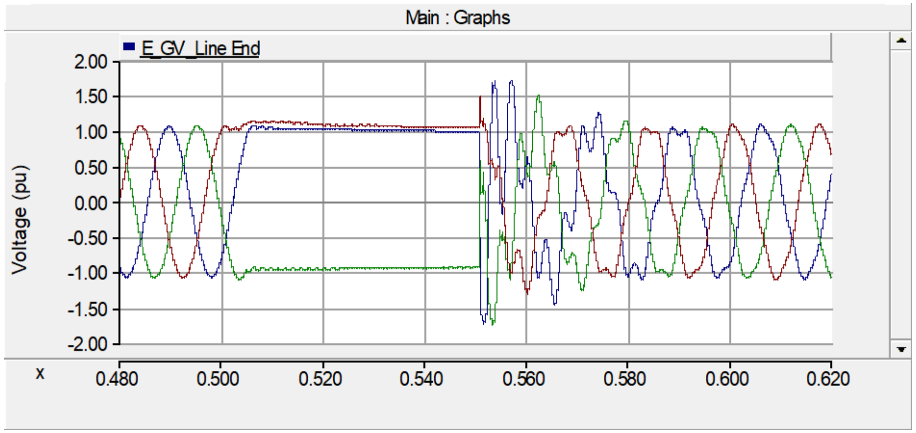
Point on Wave impact

- Switching at 100 different points over a 60 Hz cycle
  - Multiple Run component
  - Multiple Run additional recording



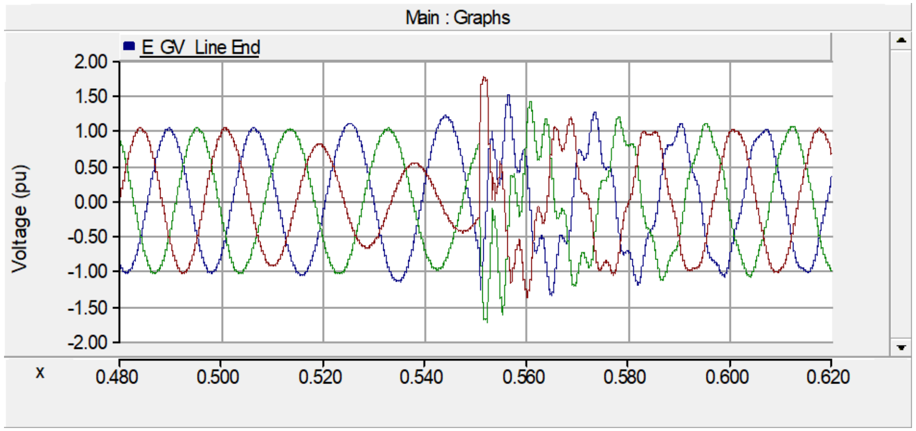


Trapped Charge



Simulation of trapped charge on transmission line

- Line reactor out of service



Simulation of trapped charge on transmission line

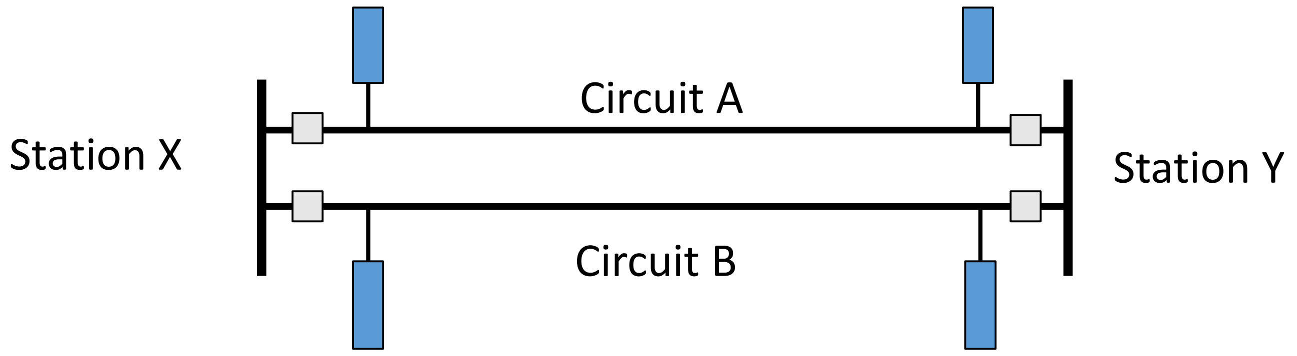
- Line reactor in service

Study Considerations - SOV

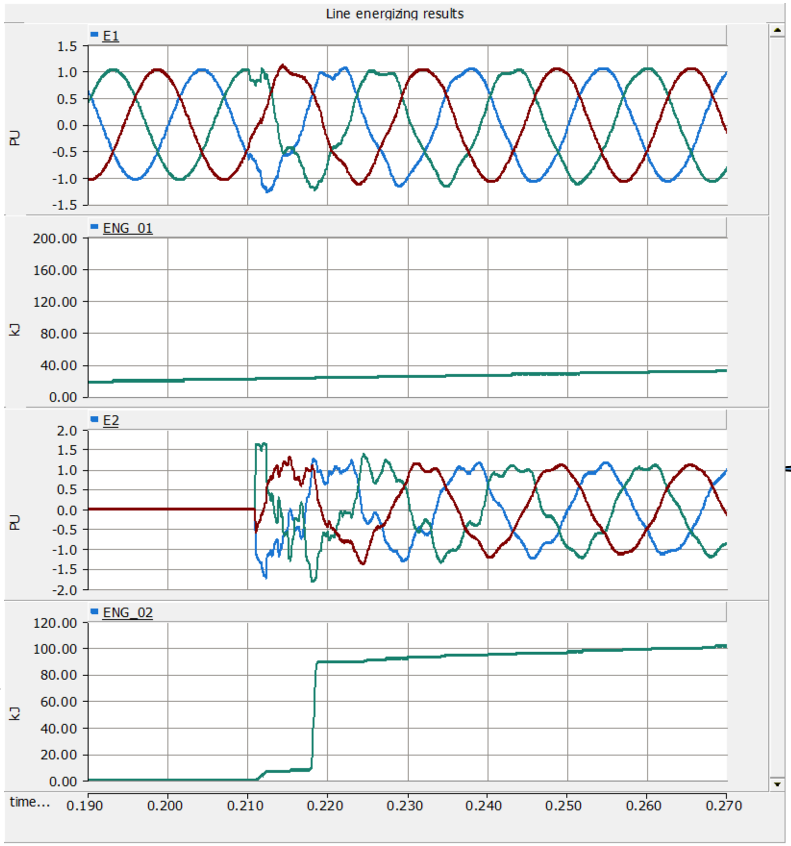
Credible Scenarios

- 10 -20 different scenarios for each line
  - 100 point on wave simulations for each scenario

Ex.
1) Reactors in service
2) Reactors out of service
3) Circuit B in service
4) Circuit B out of service



SOV Results



Voltage

Surge Arrester Energy

SOV Results - Statistical Summary

Line switching results

- E.g. Double circuit line
  - Circuit A energized from one end
  - Monitor voltages at two ends and at points along the line

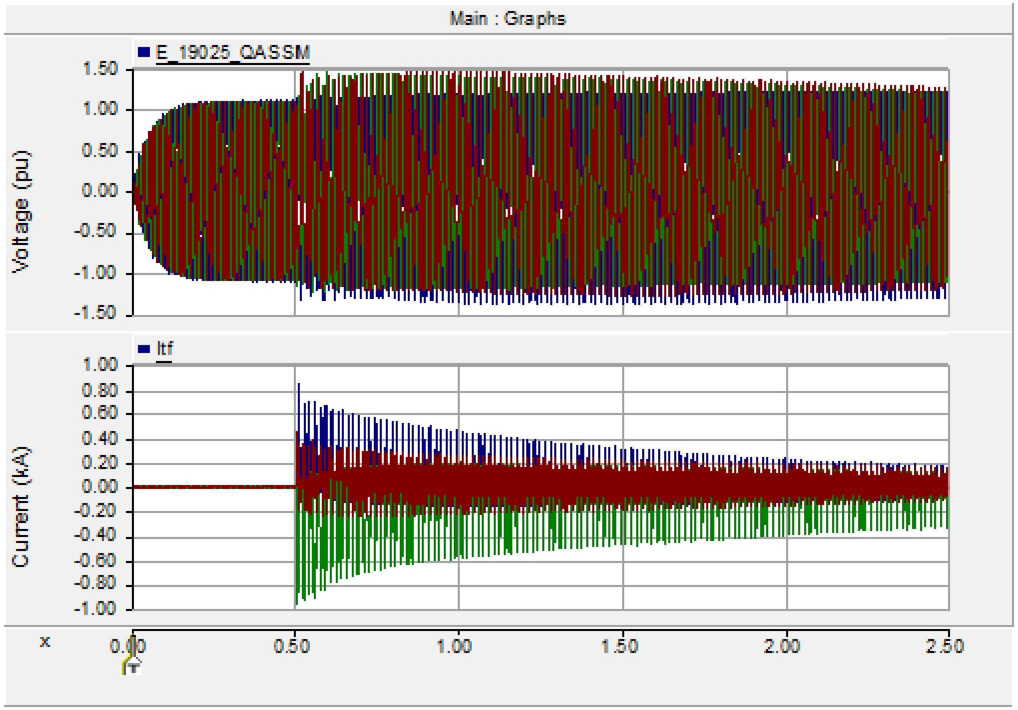
		Voltage in kV					
	Closing Time	E_19011	E_31227	E_A1	E_A2	E_B1	E_B2
Minimum:	0.4	441.6869422	328.437343	441.687283	648.5288508	41.0001304	53.75910884
Maximum:	0.4166	486.3028315	333.013673	486.303169	667.127313	78.50546719	84.10483459
Mean:	0.4083	469.2023583	330.033559	469.202736	656.3111978	64.56812464	73.44458982
Std Dev:	4.86E-03	12.5280621	1.01570766	12.5280421	5.347866178	12.1054595	8.943241286
2% Level:	0.398310918	443.472864	327.94755	443.473283	645.3280233	39.70655001	55.0774175
98% Level:	0.418289082	494.9318526	332.119567	494.932189	667.2943723	89.42969926	91.81176214

TOV - Harmonic Resonance following Transformer Energizing

Study Considerations - TOV

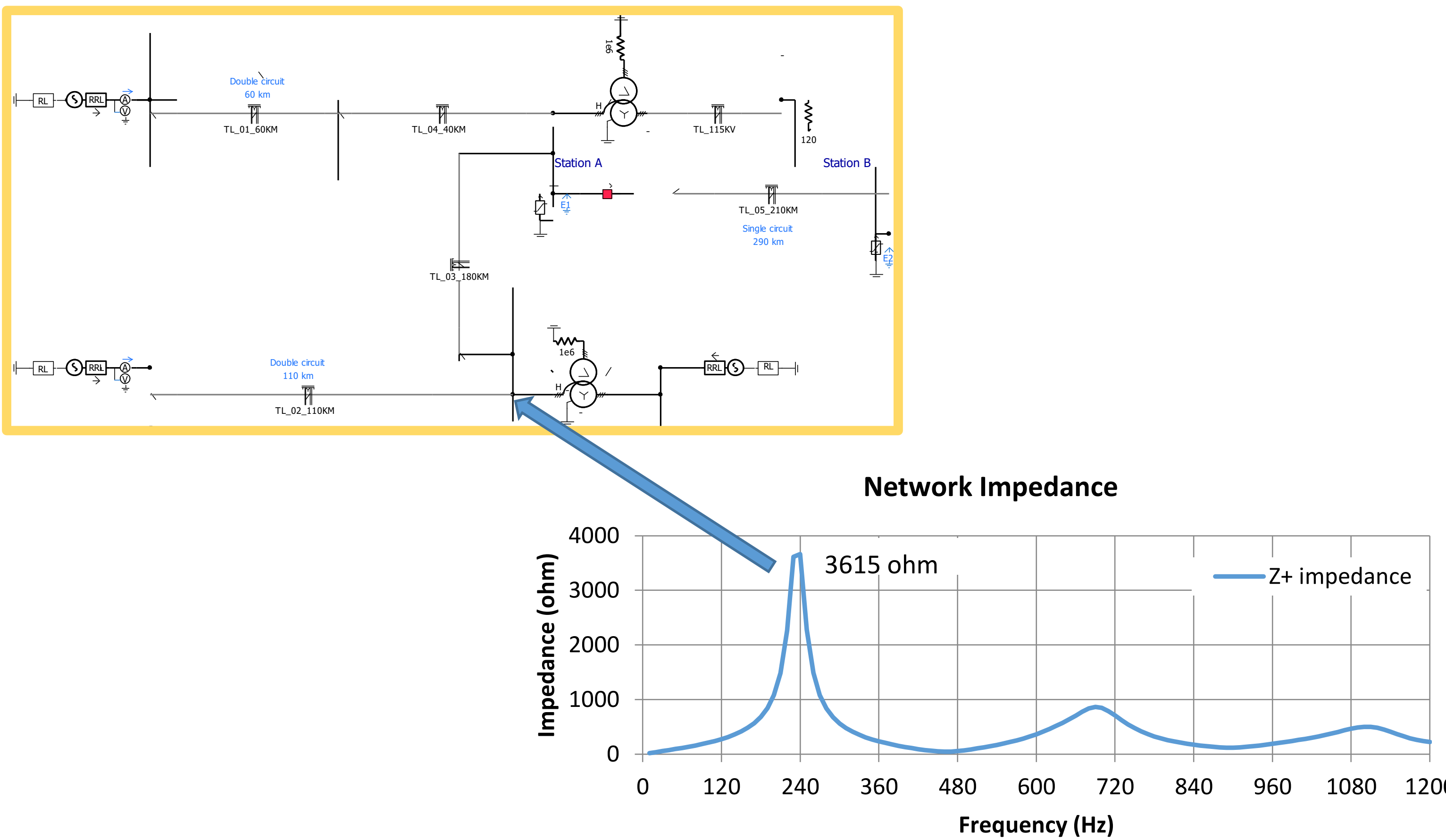
- Ferranti effect (Open end line voltage)
- Single line to ground faults
- Load rejection
- Transformer energizing
- Parallel line resonance

Transformer energizing



TOV – Transformer Energizing

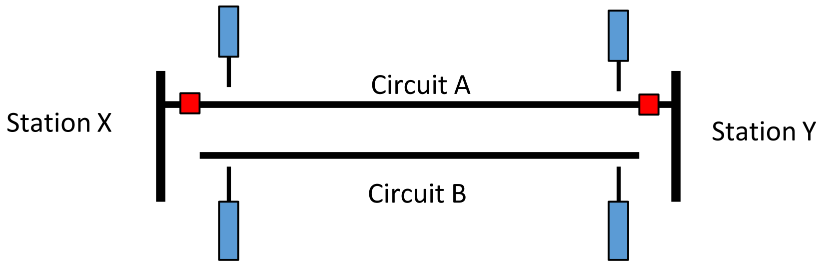
- Transformer inrush/magnetizing current - contains low order harmonics
- Network frequency scan – Parallel resonant points of network

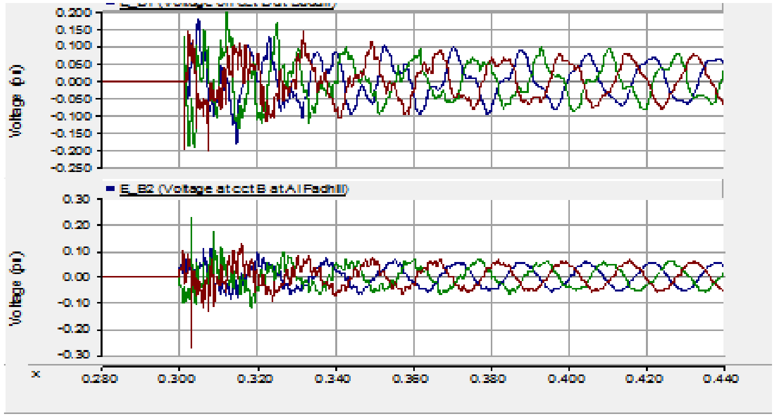


Parallel Line Resonance

Induced voltage on an open transmission line

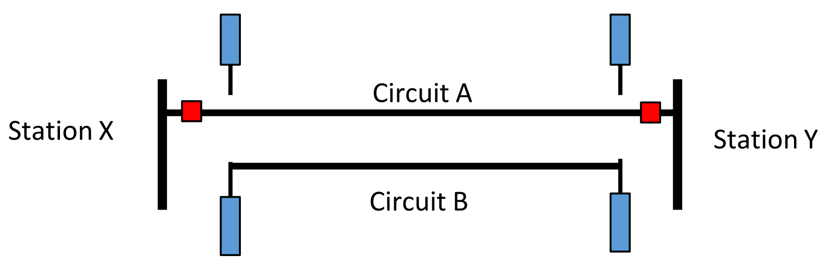
- Induced voltage on a de-energized line due to coupling between an energized parallel line on the same right of way
- De-energized line may be connected/ not connected to line reactors

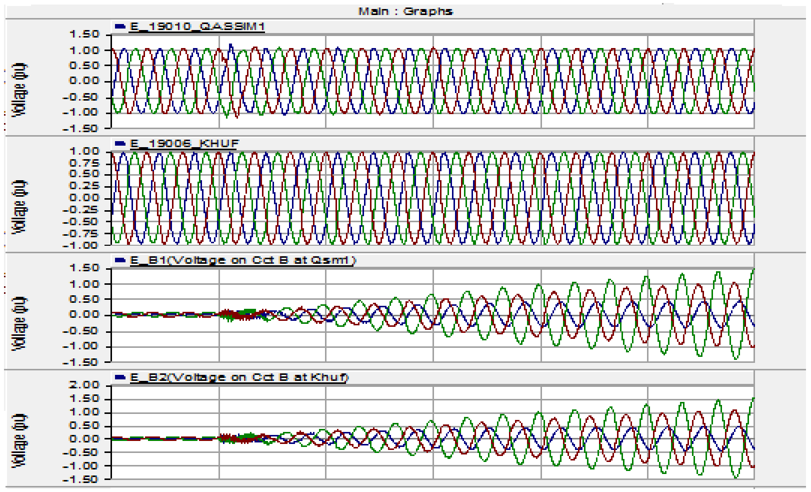




Induced voltage in transmission line

- Induced voltage on a de-energized line due to coupling between an energized parallel line on the same right of way
- De-energized line is connected to line reactors
- Induced voltage due to coupled resonance can be above 1 pu

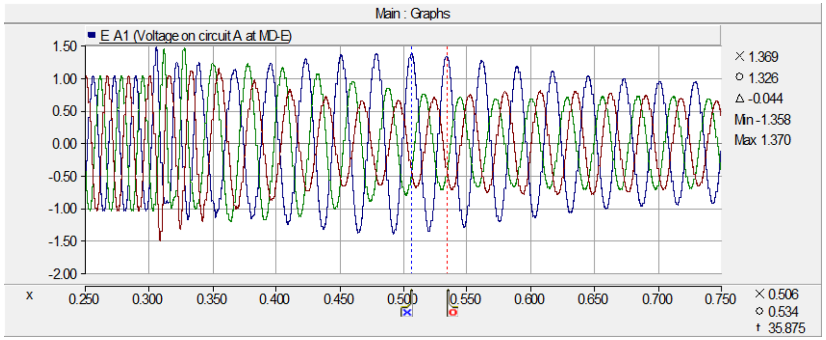


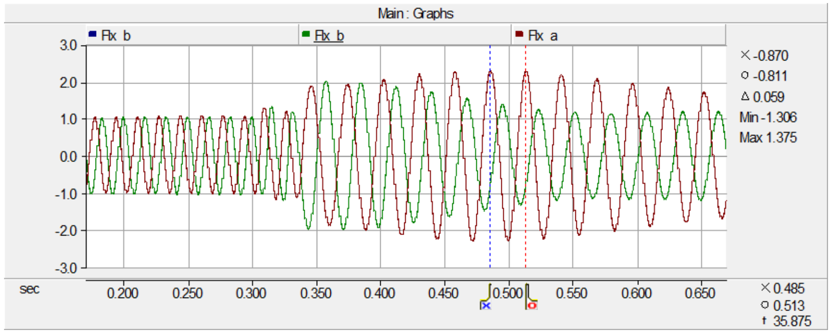


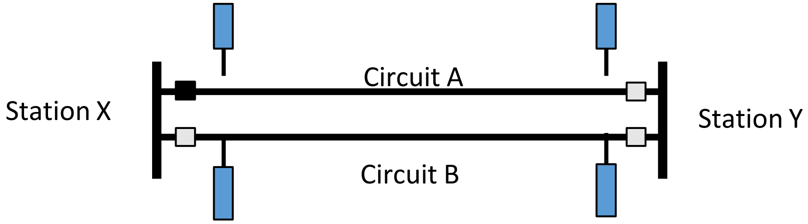
TOV – Open Line Resonance

Open line resonance

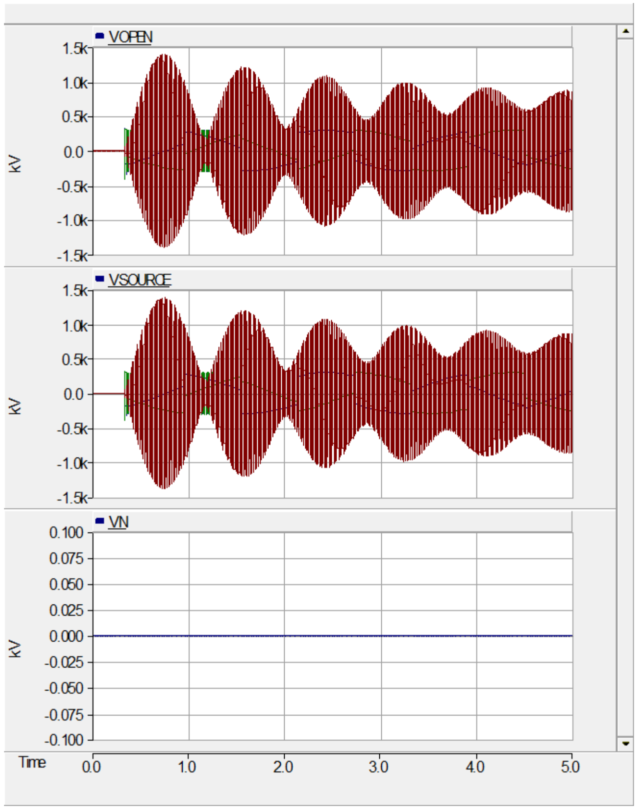
- Transmission line with line reactors
- Resonance results when line is tripped from both ends with reactors connected
  - Reactor/current transformer over fluxing issues
  - Avoid this condition through proper operational practices.
  - Low frequency oscillations



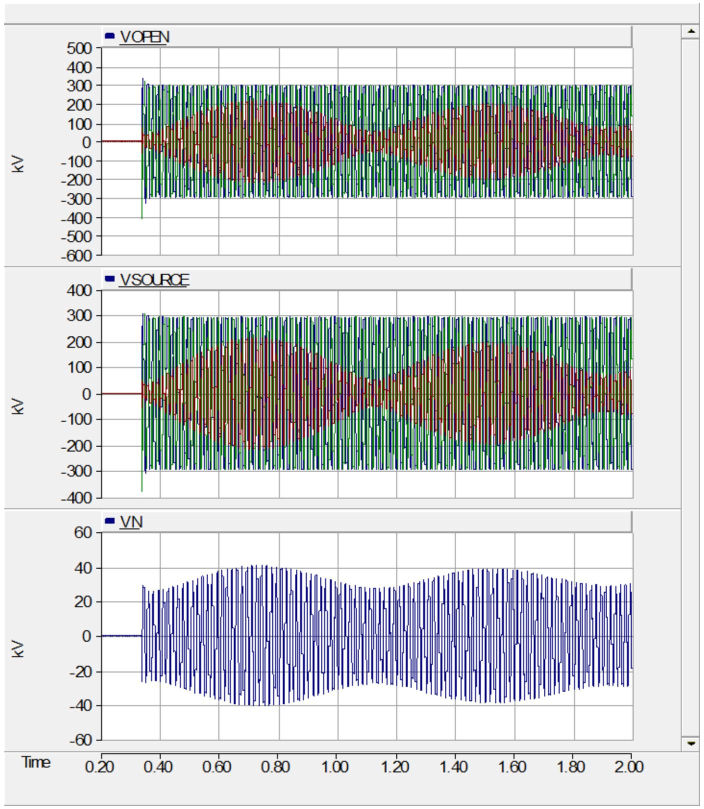




Breaker Stuck Pole Conditions



Without NGR



With properly sized NGR

- Transformer energizing
  - Voltage dips
  - Sympathetic inrush conditions
  - Harmonic resonance conditions

- Transmission line energizing
  - Impact of POW
  - Trapped charge
  - Line reactors

- Coupled line resonance conditions (over fluxing concerns)
  - Induced voltage
  - Open line resonance

- Cable energizing
  - Current zero miss condition

- Capacitor switching