TRAINING

Switching Over Voltages (SOV)

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Objectives of a switching study:

- Determine the over voltage levels due to switching events
- Determine equipment insulation levels
- Assessing surge arrester requirements and compliance
- Identify network resonance issues

Type of studies:

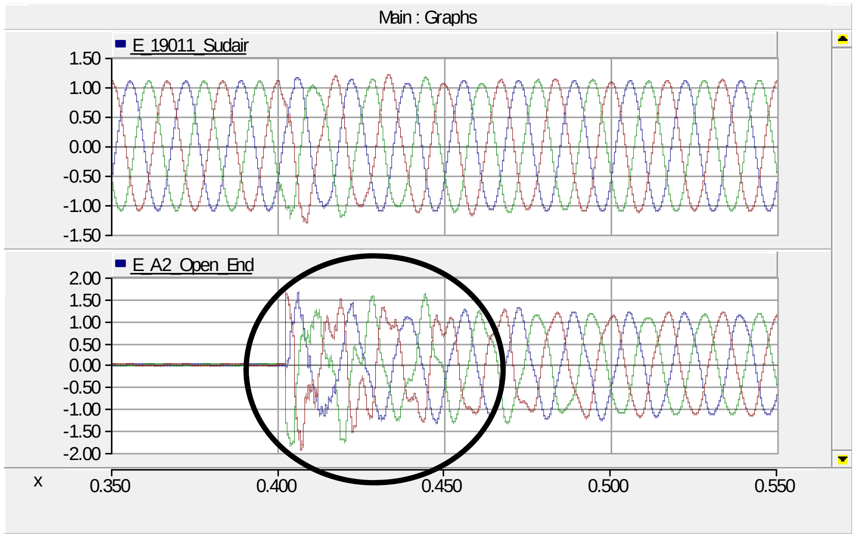
- Switching frequency over voltage studies
- Temporary over voltage studies

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



SOV and TOV Frequency Spectrum

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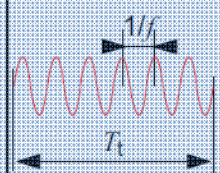
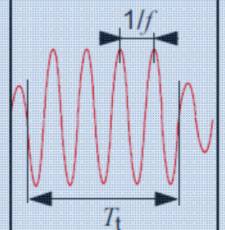
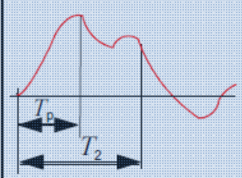
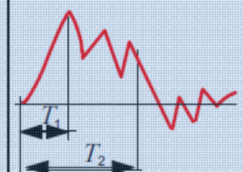
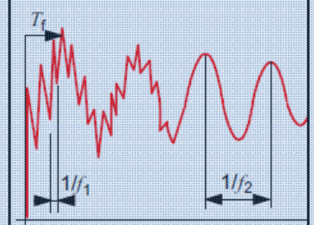
Class	Low frequency		Transient		
	Continuous	Temporary	Slow-front	Fast-front	Very-fast-front
Voltage or over-voltage shapes					
Range of voltage or over-voltage shapes	f = 50 Hz or 60 Hz $T_t \geq 3\ 600$ s	10 Hz < f < 500 Hz $0{,}03$ s $\leq T_t \leq 3\ 600$ s	20 µs < $T_p \leq 5\ 000$ µs $T_2 \leq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

Source: IEC Standard TR 60071-4 Insulation Co-ordination

Modelling Aspects:

- System represented at least up to two buses away from point of study
- Frequency dependent transmission line models
- Detailed transformer model including saturation data
- Shunt devices
- Surge arrester non- linear characteristics
- Equivalent voltage source models to represent network boundaries

PSCAD Network Model

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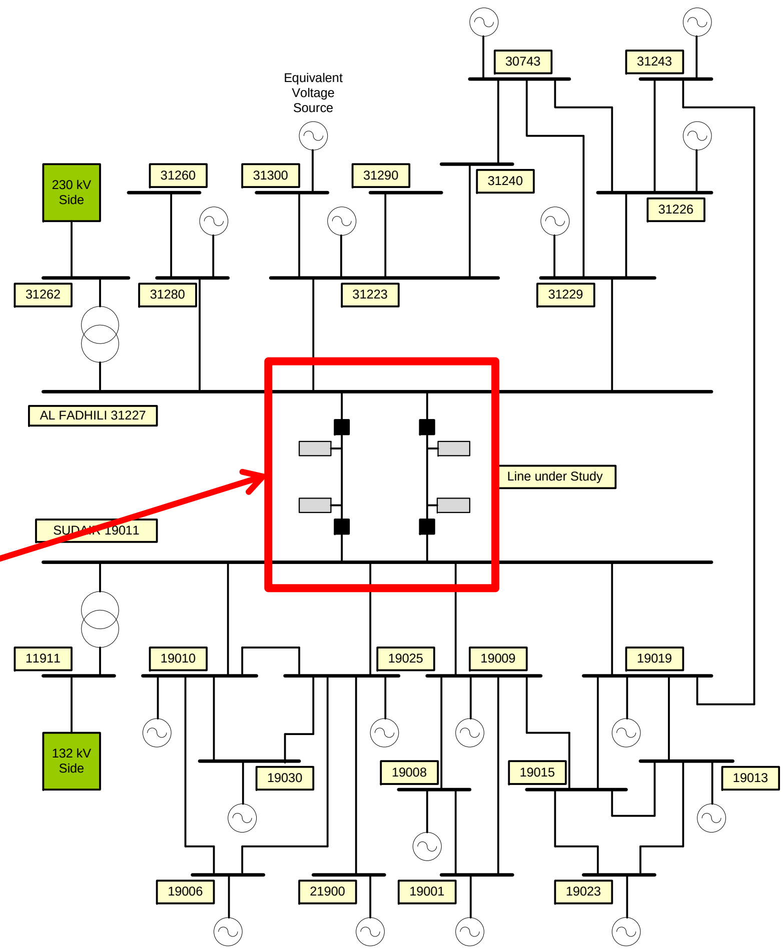
Model expands to at least two buses away from the stations under study

Ex. 380 kV System

Line under study

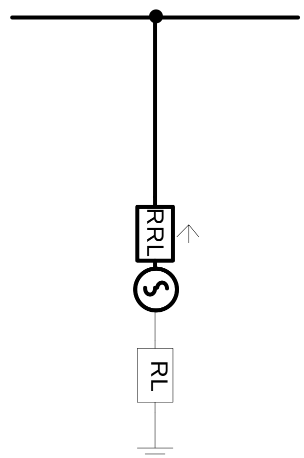


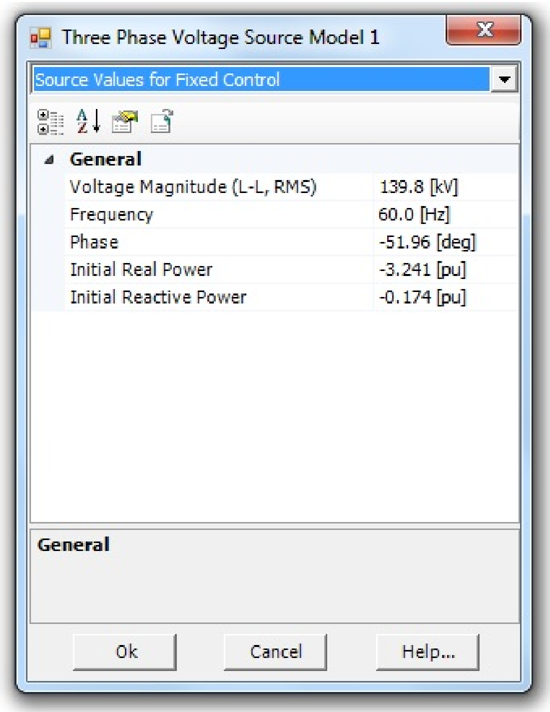
PSCAD Network Model

Network boundary equivalence

Model data

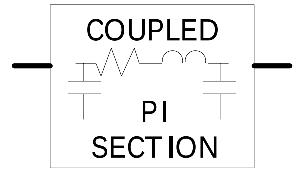
- Bus voltage & angle
- Real power & reactive power
- Positive sequence impedance
- Zero sequence impedance





Modelling type

- PI-section Model
  - Provide the correct fundamental frequency impedance, but do not provide an accurate full-frequency transient response.
  - Suitable for steady-state studies (such as a load flow).



- Bergeron Model
  - Represent the transmission line's travelling wave characteristics.
  - It is accurate only at the specified frequency and is suitable for studies where the specified frequency load-flow is most important (e.g. relay studies).

Bergeron Model Options

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

Modelling type

- Frequency-Dependent Model
  - Represent the transmission line's travelling wave characteristics.
  - It is accurate for all range of frequencies.

Frequency Dependent (Phase) Model Options

Travel Time Interpolation:	On
Curve Fitting Starting Frequency:	0.5 [Hz]
Curve Fitting End Frequency:	1.0E6 [Hz]
Total Number of Frequency Increments:	100
Maximum Order of Fitting for Yc:	20
Maximum Fitting Error for Yc:	0.2 [%]
Max. Order per Delay Grp. for Prop. Func.:	20
Maximum Fitting Error for Prop. Func.:	0.2 [%]
DC Correction:	Disabled
Passivity Checking:	Disabled

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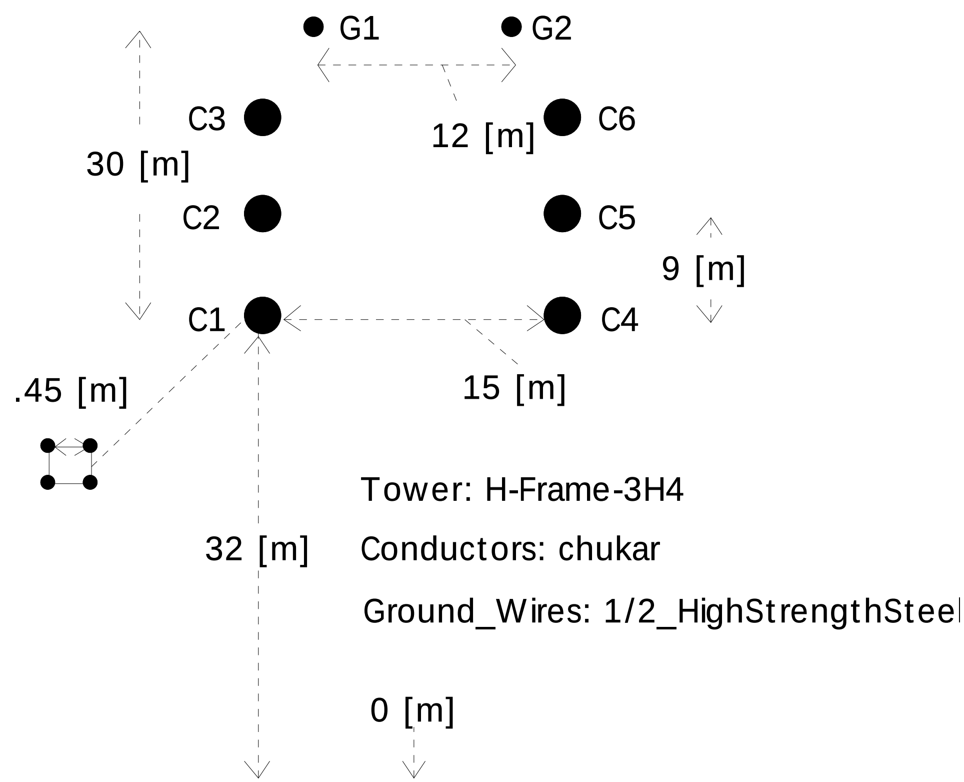
Tower cross section

- Geometrical arrangement of conductors
- Ground clearance
- Line sag



Conductor Data (illustrative)

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

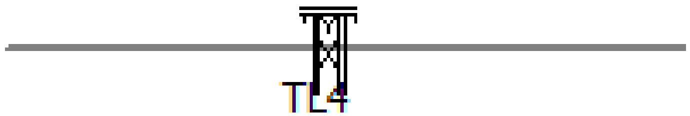
	Conductor data	
	Parameter	**Value**
1	Conductor type	xxx
2	Outer radius (effective)	0.590 [in]
3	DC resistance	0.9012 [ohm/mi]
4	Conductor sag	39 [ft.]
5	Bundle sub-conductors	2 [nos.]

Ground wire Data (illustrative)

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

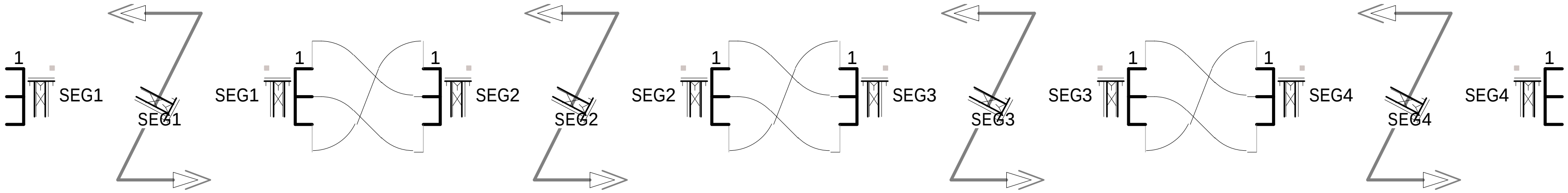
	Ground Wire data	
	Parameter	**Value**
1	Ground wire type	xxx
2	Outer radius (effective)	0.295 [in]
3	DC resistance	0.9656 [ohm/mi]
4	Conductor sag	32 [ft.]

Line Transpose Data



Untransposed 200 km line

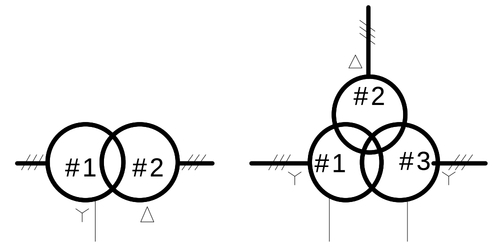
Transposed 200 km line in 4 segments (50 km each)

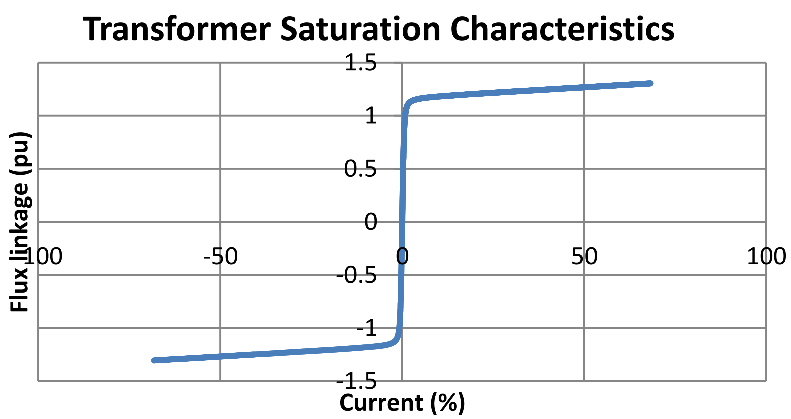


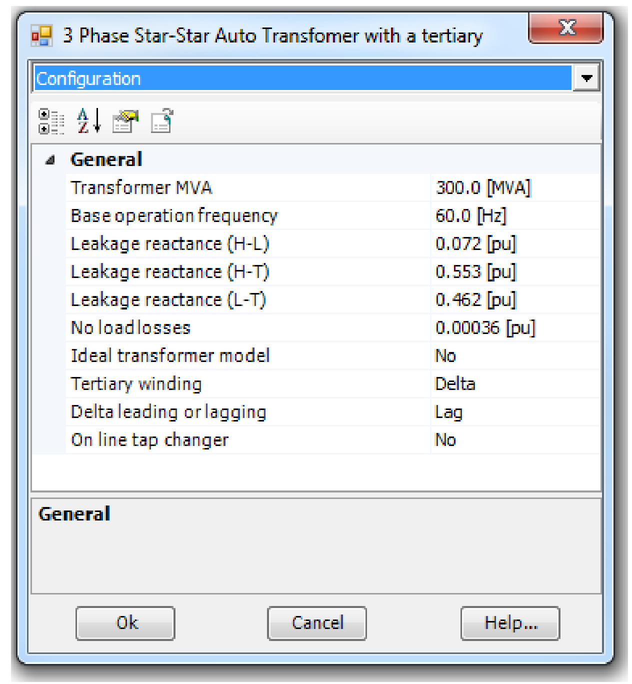
Transformer Model

Model data

- General Data
  - Ratings, impedance
- Saturation Data



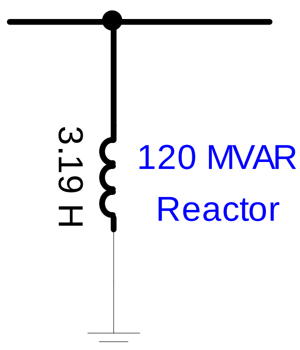


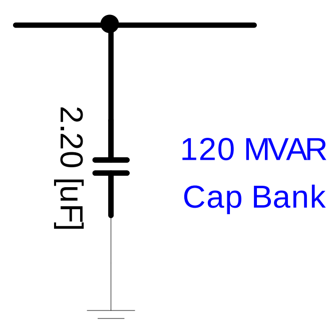


Shunt Devices

Model

- Shunt reactor – with equivalent inductance
- Shunt capacitor – with equivalent capacitance
- Series compensation – with equivalent capacitance





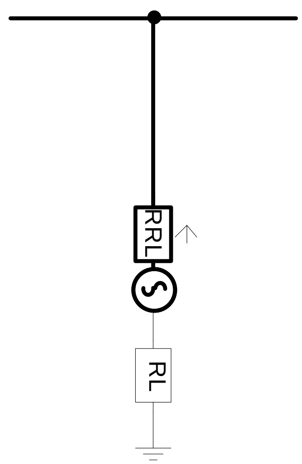
$$x = \frac{kV^2}{MVAr}$$

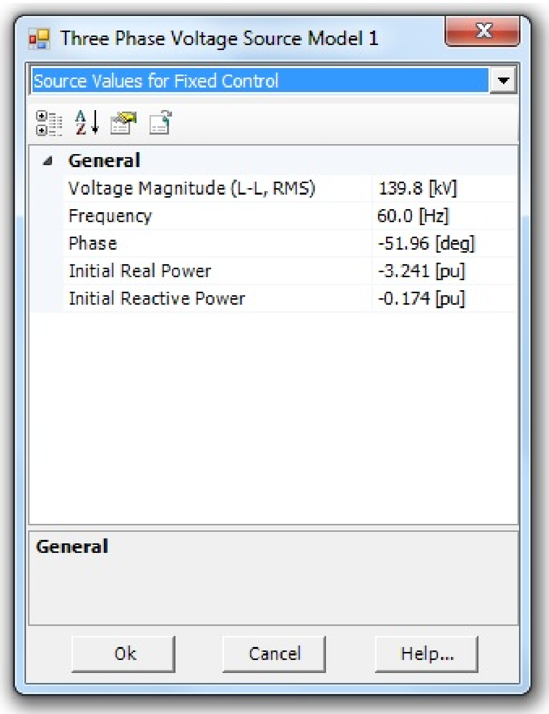
$$x = \omega L \text{ or } 1/\omega C$$

Generators and motors

Model data

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

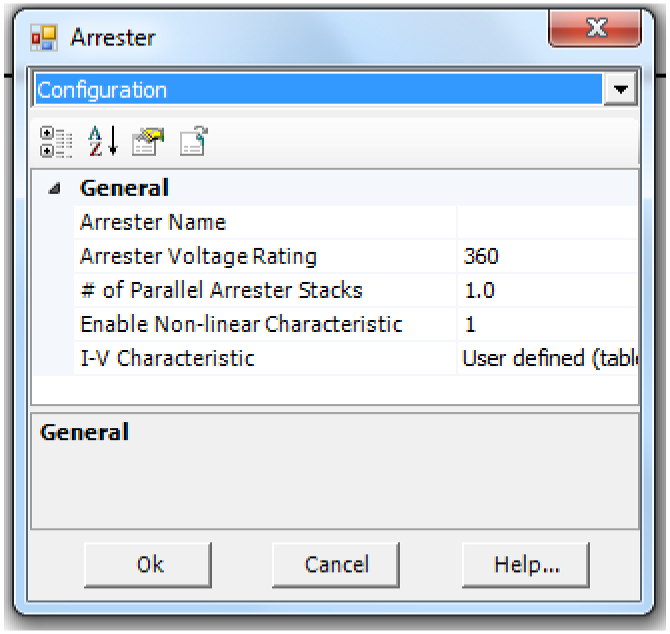


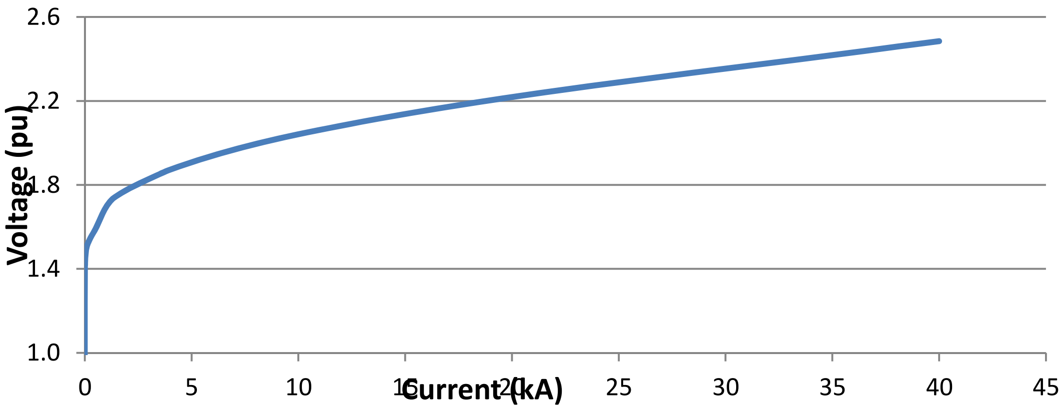


Surge Arrester

Model data

- Arrester rating i.e. 360 kV
- V-I characteristic
- Energy absorption capability i.e. 13 kJ/kV



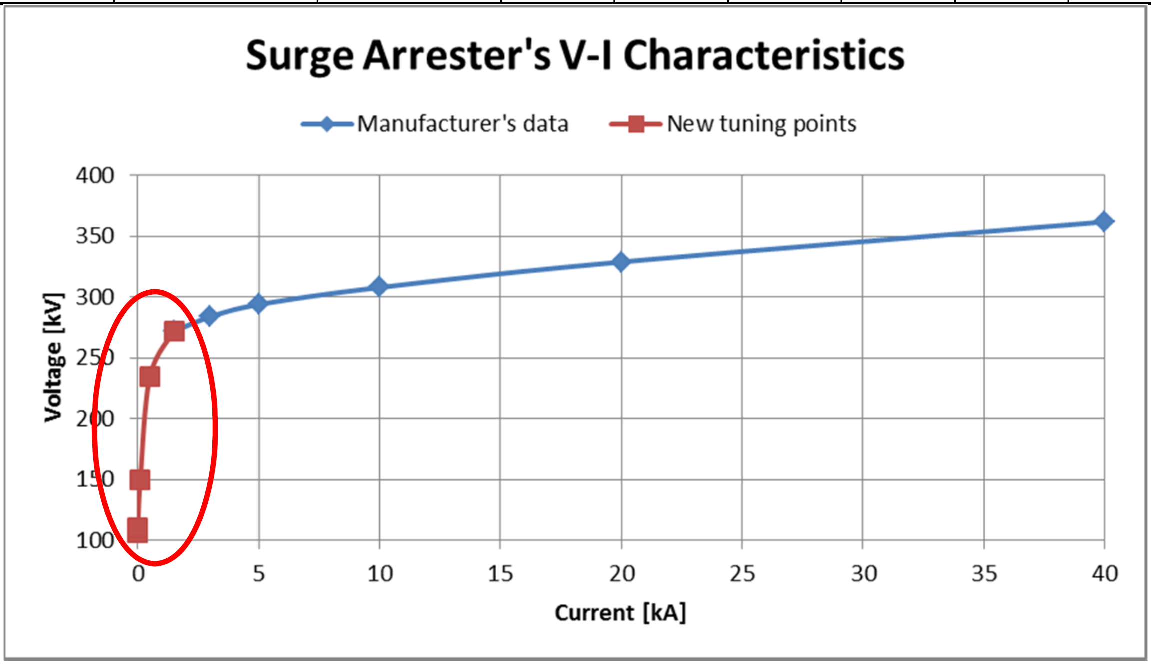


Surge Arrester

How to derive the surge arrester's characteristics from data sheet?

Typical manufacturer's data sheet
http://www.hubbellpowersystems.com/arresters/sub/hollowcore/station-312kv/

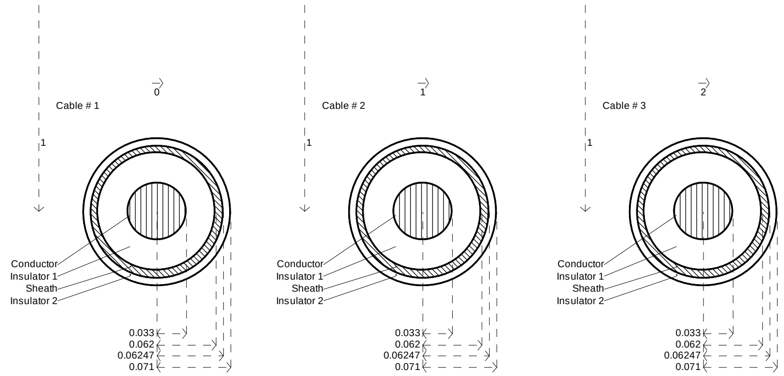
Duty Cycle Rating kV rms	Maximum Continuous Operating Voltage (MCOV) kV rms	Maximum 0.5μs Discharge Voltage kV	Maximum Switching Surge Protective Level (kV)	TOV Capability		Maximum Discharge Voltage using an 8/20 Current Wave-kV					
				1 sec kV rms	10 sec kV rms	1.5kA	3kA	5kA	10kA	20kA	40kA
132	106	334	261	126	121	272	284	294	308	329	362



Other models...

Cable model

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



Bergeron Model Options

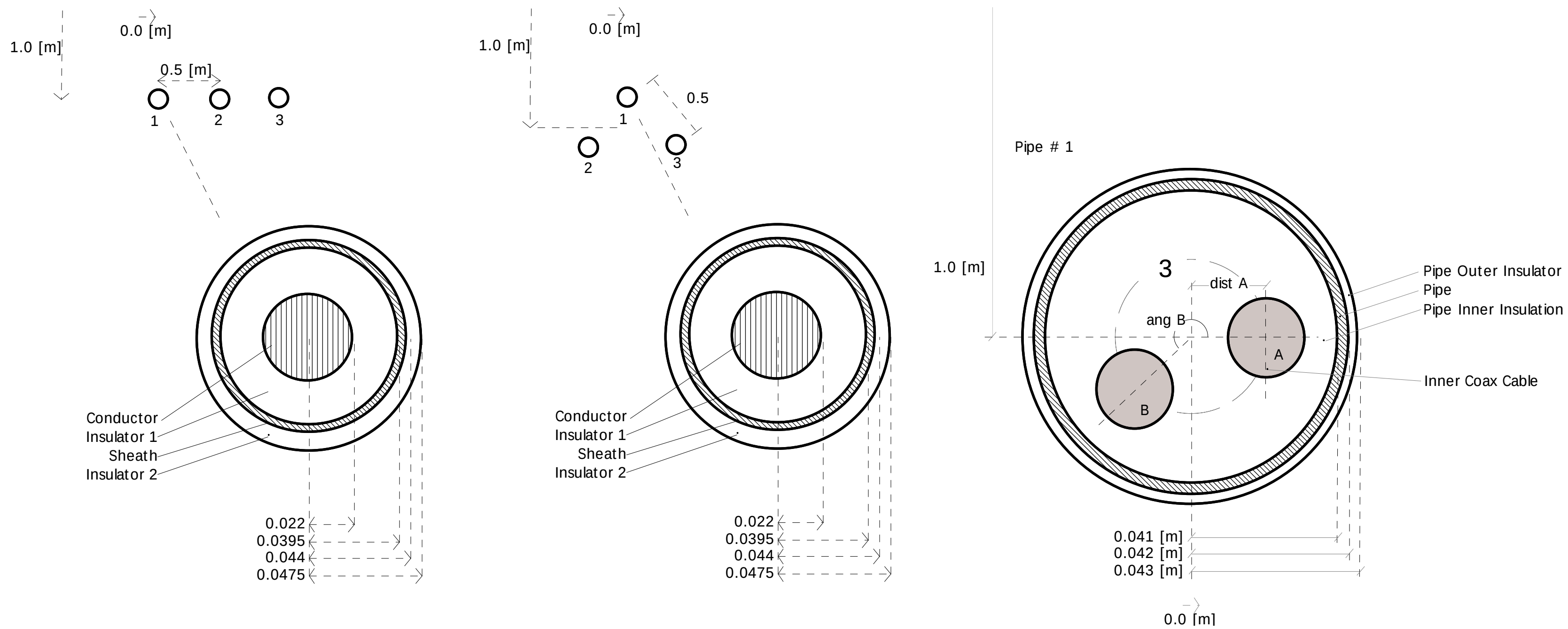
Travel Time Interpolation:	On
Reflectionless Line (ie Infinite Length):	No

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-

Cable model

- Pipe type
- Three cables flat or trefoil configuration



Model Validation

PSCAD model is validated against the load flow model on the following aspects

- Line power flows
  - Active power
  - Reactive power
- Source/ boundary equivalence power flows
  - Active power
  - Reactive power
- Fault levels
- Field results

Model Validation

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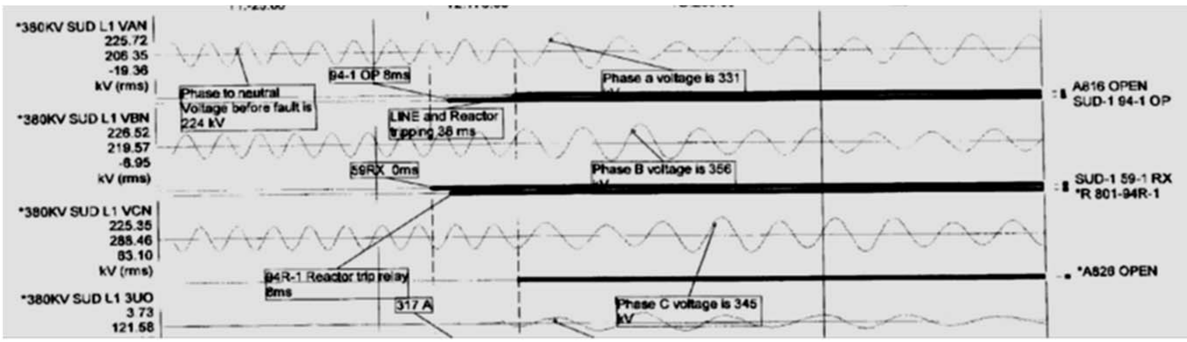
Active Power Flow

PSCAD [MW]	PSSE [MW]
685	686
382	379
324	325
118	121
834	837
434	436
647	650
405	409
207	203
237	238

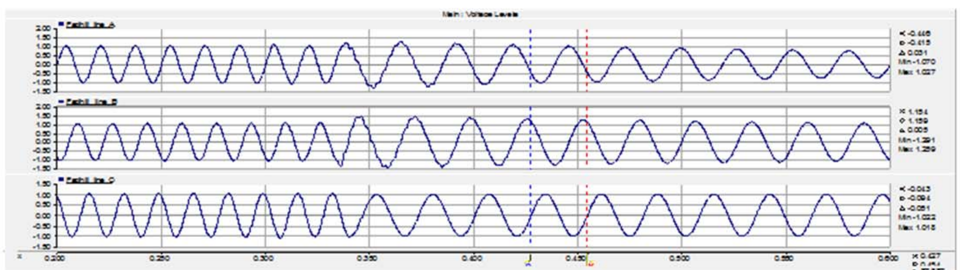
Fault Level

PSCAD [kA]	PSSE [kA]
47.7	46.9
33.4	33.2
47	46.9

Model Validation



Field



PSCAD

Simulation setup

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

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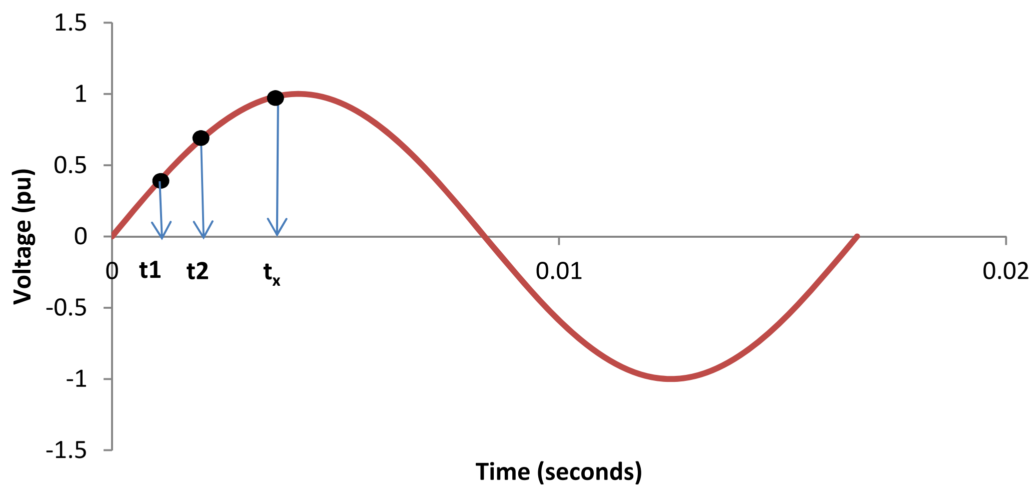
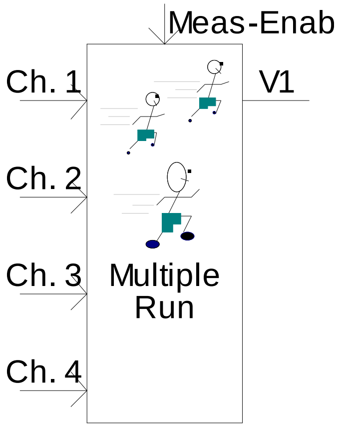
Point on wave impact

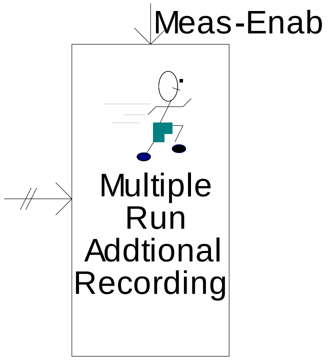
- Switching at different points over a 60 Hz cycle
  - 100 points over a cycle ➡ 100 simulations



Point on wave impact

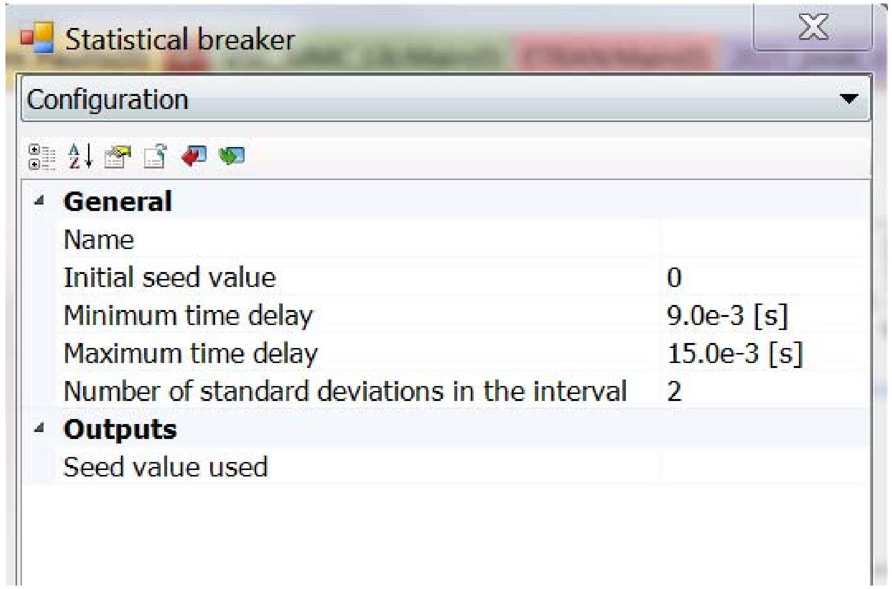
- Switching at 100 different points over a 60 Hz cycle
  - Multiple Run component
  - Multiple Run additional recording

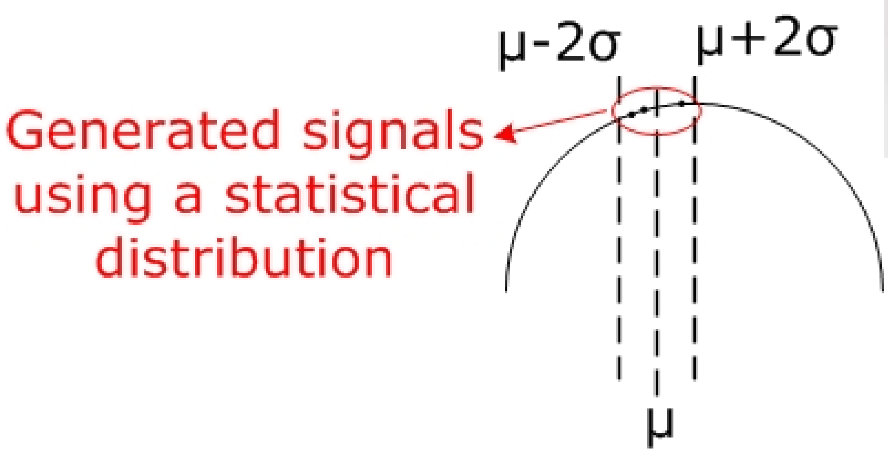


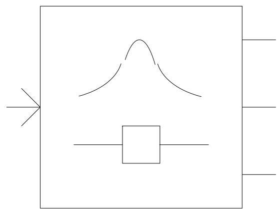


Statistical Breaker

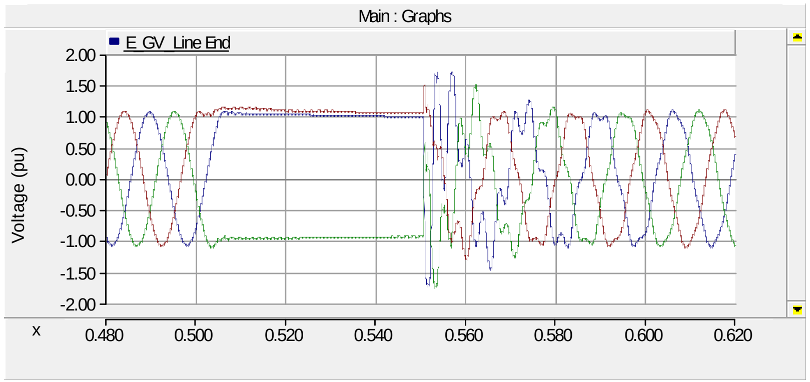
- Used in the single-pole operation of a 3-phase breaker, in a statistically distributed manner.







Trapped Charge

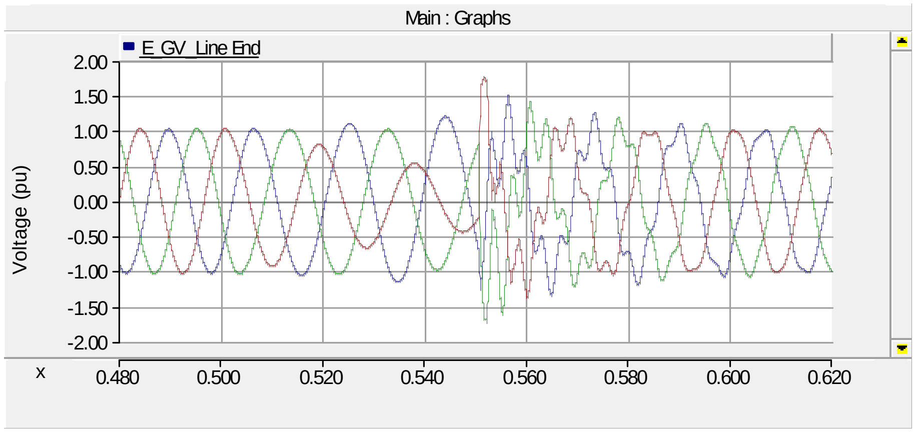


Simulation of trapped charge on transmission line

- Line reactor out of service

Simulation of trapped charge on transmission line

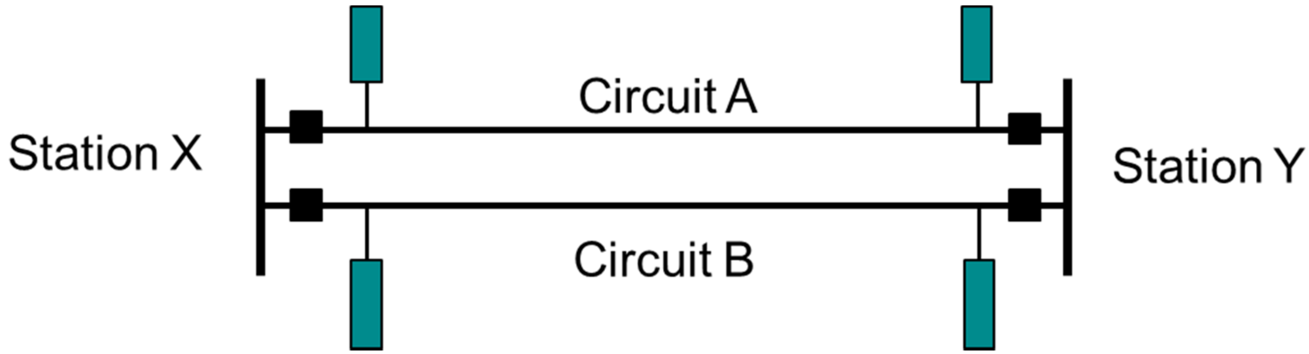
- Line reactor in service



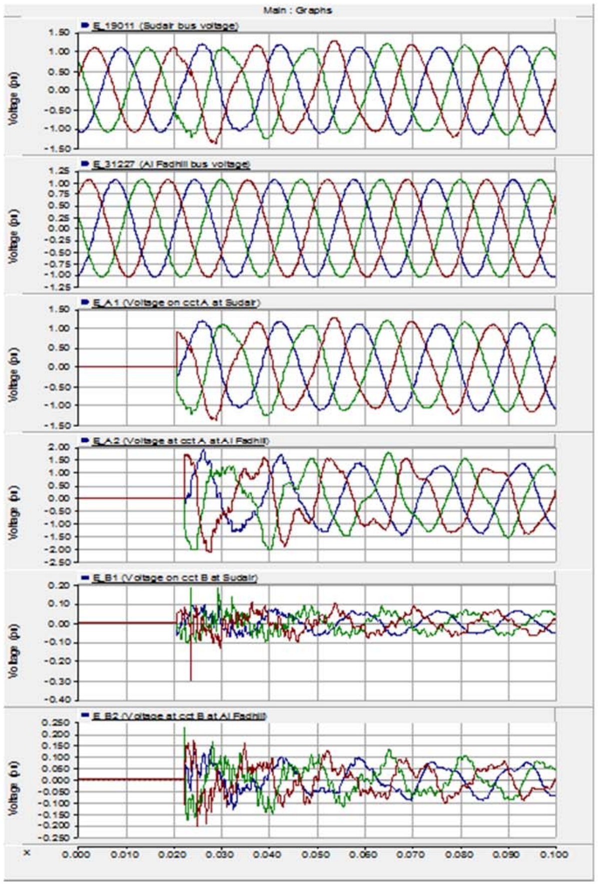
Credible Scenarios

- 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

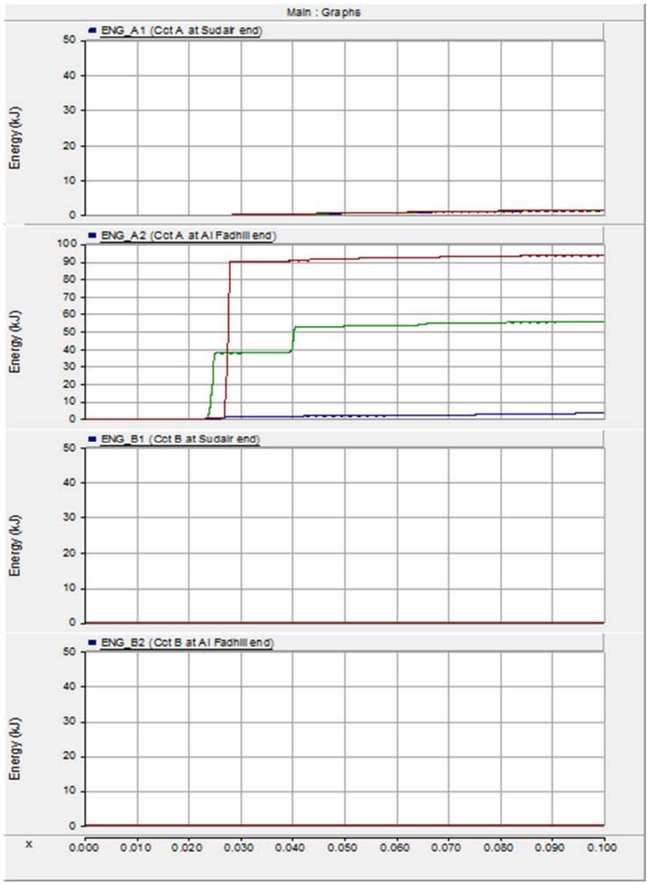


SOV Results



Voltage waveform

Surge Arrester Energy



Line switching result

- Ex. Double circuit line
  - Circuit A energized from one end
  - Monitor the open end

		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

Thank you