WEBINAR

Modelling Cables and Transmission Lines with PSCAD™/EMTDC™

Jeewantha De Silva, Lalin Kothalawala

Topics Covered

- Transmission line models in PSCAD

- Basic modeling of transmission lines/cables

- Features such as transposition, cross-bonding, mutual coupling, dc correction etc.
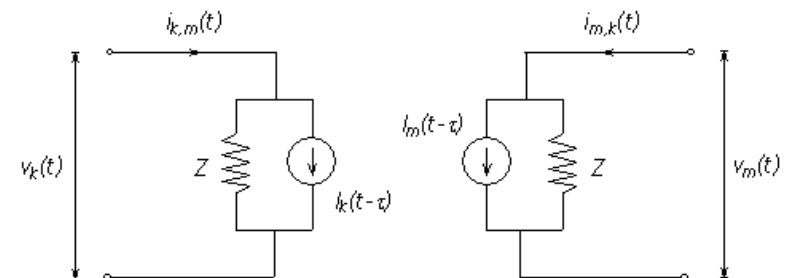
- Application examples

- Highly non-linear due to frequency dependence of conductors & ground path

- Two methods of representation

  - PI-section (lumped passive elements)
    - Short transmission lines
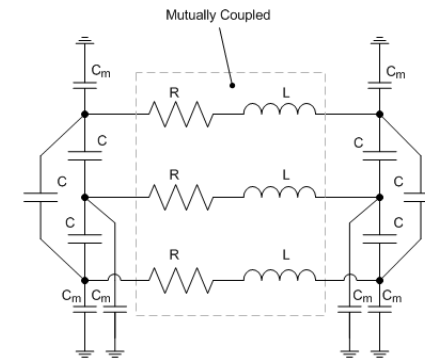
Coupled Π-Section Representation in PSCAD

  - Distributed parameter (traveling wave)
    - Bergeron
    - Frequency Dependent (Mode)
    - Frequency Dependent (Phase)

Bergeron Model

- Single frequency model – all parameters are derived at a specified frequency

- Distributed LC parameters (roughly equivalent to using an infinite number of PI Sections), except

- a lumped resistance (R) to approximate system losses: $\frac{1}{2}R$ in the middle and $\frac{1}{4}R$ at each end

- Used where the specified frequency is most important and also to model the lines few buses away from disturbance
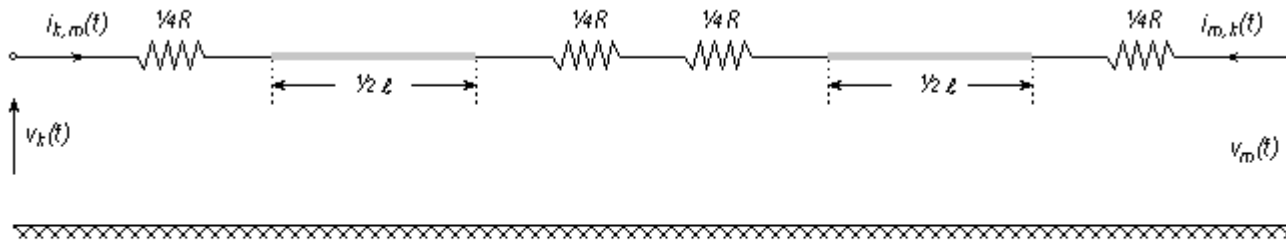

Figure 8-33 – Loss-Less Line with Lumped Resistance Included

Frequency Dependent (Mode) Model

- Distributed model based on modal transformation

Frequency Dependent (Phase) Model

- Accurately represents the frequency dependency and distributed nature of all parameters (DC to 1 MHz)

- Accurate for highly frequency dependent configurations such as vertically asymmetrical line geometry and underground cables

- Widely used in simulation studies

- Universal Line Model

- Direct formulation in the phase domain – avoid problems with modal transformation matrices

Transmission Line Models

Issue	Minimum Recommended Cable Model	importance of Detailed Models (Segments, Bonding, Grounding Frequency-Dependent (FD))
Phase unbalance and transposition	Bergeron (Unbalanced) Equivalent PI	Segments are important. FD is not important.
Harmonic frequency scans	Bergeron Equivalent PI	Segments are not important. FD is moderately important; cable parameters may be re-calculated for each frequency of interest if necessary.
TOV – Ground faults and clearing	Bergeron	Minimal; damping from other system components is more important.
TOV – Resonance	Bergeron	Minimal; damping from other system components is more important.
TOV – System islanding and load rejection	Bergeron	Minimal; damping from other system components is more important.
Ferroresonance	Bergeron	Minimal; damping from other system components is more important.
Harmonic sources and flows	Bergeron Equivalent PI	Segments are not important. FD is moderately important; cable parameters may be re-calculated for each frequency of interest.
Cable energization	Bergeron (at Target Frequency)	Segments are not important. FD is moderately important; this is usually the first case in which to apply an FD model.
Auto-reclosing overvoltages	Bergeron	Segments are not important. FD is moderately important, but power-frequency solution should not be compromised.
Discharge of the cable	Bergeron	Minimal.
Sheath overvoltages and protection	Bergeron (Unbalanced)	Segments are important. FD is moderately important.
DC offset / zero-miss effect	Bergeron	Minimal.
Current transformer (CT) saturation	Bergeron	Minimal.
Capacitive current interruption	Bergeron	Minimal.
Lightning overvoltage	Bergeron (Unbalanced, at Target Frequency)	Segments are important. FD is moderately important.
Shunt reactor restrike	Bergeron	Segments are not important. FD is moderately important.
Inductive coordination and EMI	Bergeron (Unbalanced) Equivalent PI	Segments are important. FD is not important.

Source : CIGRE WG C4.502 Power system technical performance issues related to the application of long HVAC cables

Long-line corrected RXB values

- RXB data is usually calculated as unit length parameters ($X = \omega L, B = \omega C$)

- Total RXB values for the entire line do not simply equal to per unit RXB multiplied by length due to the distributed nature of line parameters

- Long-line corrected RXB data represent effective RXB values for entire line

- Caution: Possibility of non-physical values

```
Positive Sequence (Long-Line Corrected)
................

Resistance      Rsq   [pu]:      0.335573149E-05
Reactance       Xsq   [pu]:      0.693356747E-04
Susceptance     Bsq   [pu]:      0.238202641E-03
Surge Impedance Zcsq  [pu]:      0.539516942

Zero Sequence (Long-Line Corrected)
............

Resistance      Rsq   [pu]:      0.636183683E-04
Reactance       Xsq   [pu]:      0.233582235E-03
Susceptance     Bsq   [pu]:      0.140496134E-03
Surge Impedance Zcsq  [pu]:       1.28940016
```

Conductor transposition

- Actual transposition
  - Each small line segment is modelled separately and transposed manually (very small time step)
  - E.g. Lightning studies, phase unbalanced study

- Ideal transposition
  - Single transmission model for entire line (large time step)
  - Options
    - Disabled
    - Enabled (all together)
    - Enabled (each group separately, zero sequence coupling between circuits)- sequence RXB data display
 - E.g. Transmission line with many transposed segments

Conductor elimination and bundling

- The earth wire/sheath voltage is assumed to be almost zero –typical approximation in many transient studies

- The earth wires/sheaths are mathematically eliminated

- Does NOT mean that the earth wire/sheath is neglected
  - The effect of earth wire/sheath is approximately considered (e.g. losses)

- Transmission line or cable interface should be changed accordingly

- E.g. earth wires, conducting layers (sheath) of short underground cable ,conductor bundles
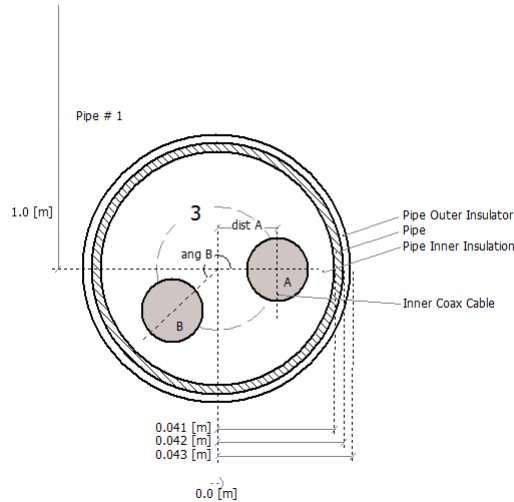
Cross-bonding of underground AC cables

- Minimize sheath losses due to circulating currents for AC cables
- Actual cross-bonding – each minor segment is separately modeled

- Ideal cross-bonding
  – Represent cross-bonded AC cable with many segments
  – Approximate method - single ideally cross-bonded model for entire line
  – Sheath is ideally transposed and eliminated
  – The cable interface should be changed accordingly

Coaxial cables
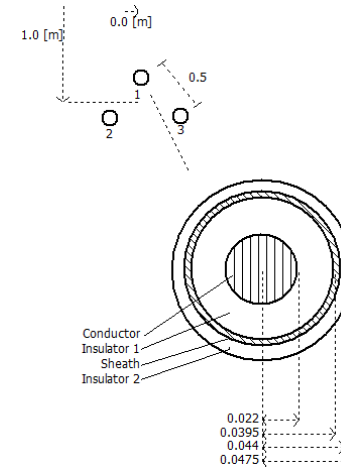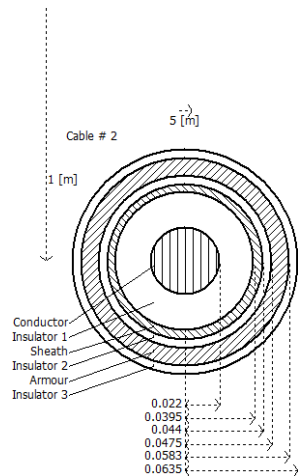
- Modelling of land cables
- Data is required for the Conductor, Sheath, Armour and Insulation Layers
- (dimensions and material properties)

- User friendly cable data entry method
  - typical cable parameters from datasheets
  - single-cable, two- cables or three-cables in flat or trefoil configurations
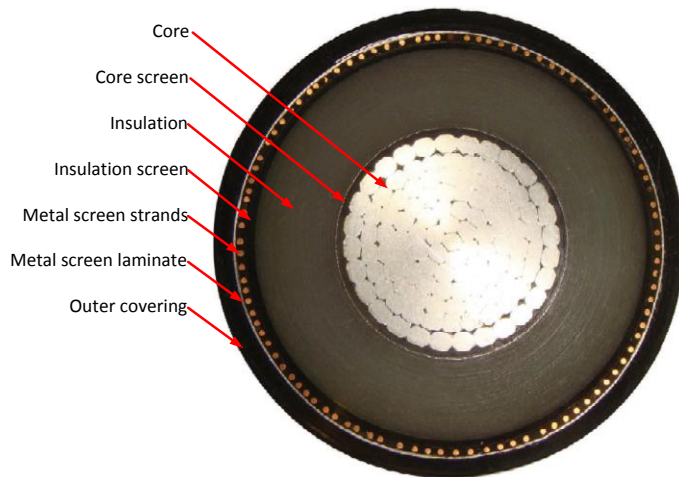 - Temperature corrections

Pipe-type cable

- Modelling of submarine cables
- Common pipe conductor encircling coaxial cables

- For all Cables
  - Aerial or underground cables can be modelled
  - Ideal cross-bonding/Conductor layer elimination
  - Mutual interaction between aerial and underground
  - Semi-conducting layer support

Practical cable modelling

Core inner radius	0 mm
Core outer radius	20.75 mm
Core material	Compact stranded Al
Core screen thickness	1.5 mm
Insulation radius	39.25 mm
Insulation material	XLPE
Insulation screen thickness	1 mm
Diameter of each metal screen strand	1.91 mm
Thickness of Metal screen laminate	0.8 mm
Outer covering outer radius	47.94 mm
Outer covering material	XLPE

Table 1: Cable data

Source : CIGRE WG C4.502 Power system technical performance issues related to the application of long HVAC cables

- Core conductor
  - Stranded/segmented design
  - Effective resistivity

$$\rho_c = \rho_c' \frac{\pi r_1^2}{A_c}$$

- Semi-conducting layers
  - High resistance and high relative permittivity (e.g. 1000)
  - Modelled as a part of insulation – effective permittivity value

$$\varepsilon_{r1} = \varepsilon_{rins} \frac{\ln(r_2 / r_1)}{\ln(b / a)}$$

- Wired sheath
  - Approximate by solid conductor (annulus) with effective outer radius

$$r_3 = \sqrt{\frac{A_s}{\pi} + r_2^2}$$

- Dual layer sheath
  - Approximate by solid conductor (annulus) with effective resistivity

Bjørn Gustavsen "Panel Session on Data for Modeling System Transients. Insulated Cables", Proc. IEEE. Power Engineering Soc. Winter Meeting , 2001.
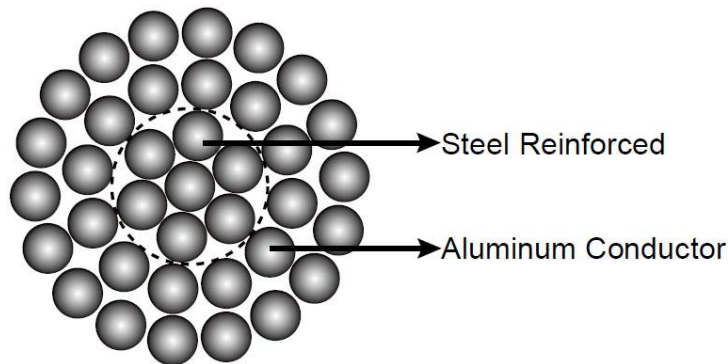
CIGRE WG C4.502 Power system technical performance issues related to the application of long HVAC cables

Mutual coupling between multiple towers

- **Mutual coupling between overhead line towers**
  - Model all coupled lines in the definition page

  Or

  - Using mutual coupling features

- **Mutual coupling between overhead lines and cables**
  - E.g. Induced voltage on pipe
  - Model both as cables in the cable definition page
  - Overhead line – aerial bare cables

Stranded conductor (e.g. ACSR)

- Neglect steel sub-conductors

- Optical ground wires – model as a stranded conductor neglecting optical part

DC correction algorithm for HVDC line and cables

- Improve accuracy at frequencies approaching dc for HVDC lines and cables

- Ensure accurate dc response

- Improve stability

- Phase model options> dc correction

- Functional form method

- Add residue/pole method
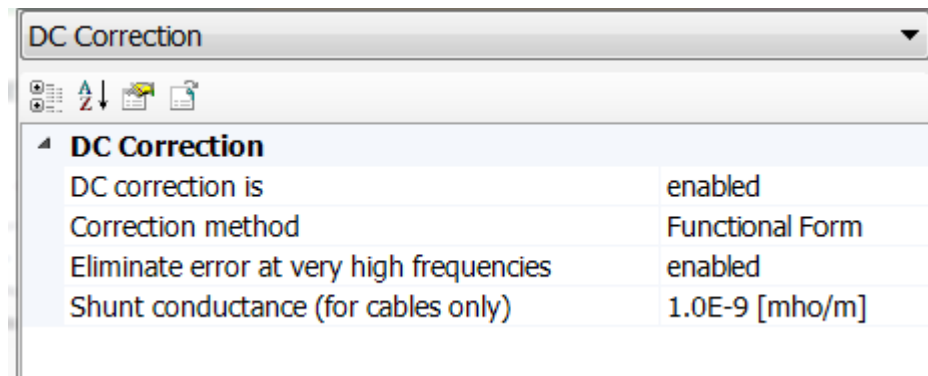
Improving stability

- Cause: Large ratios of residue/poles in transfer function
- Solution:
  - Phase model options> curve-fitting
  - Limit Large ratios of residue/poles (old method)
  - Two-sided recursive convolution algorithm (new PSCAD V4.6.0)
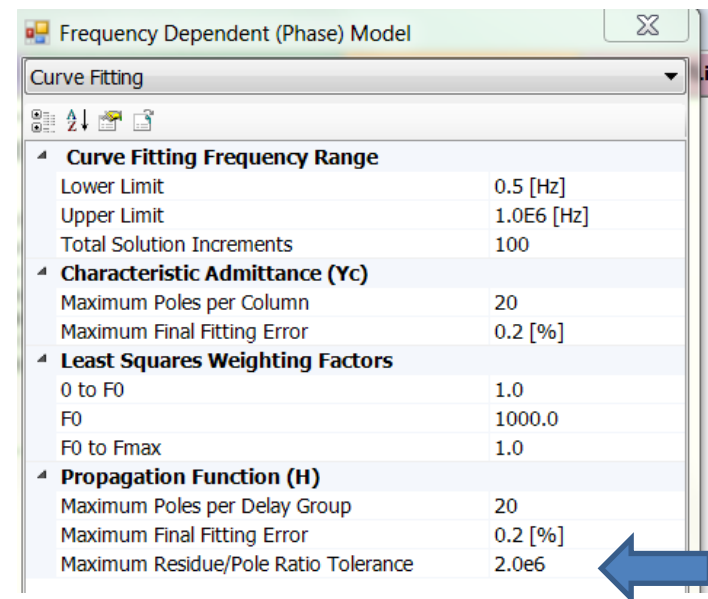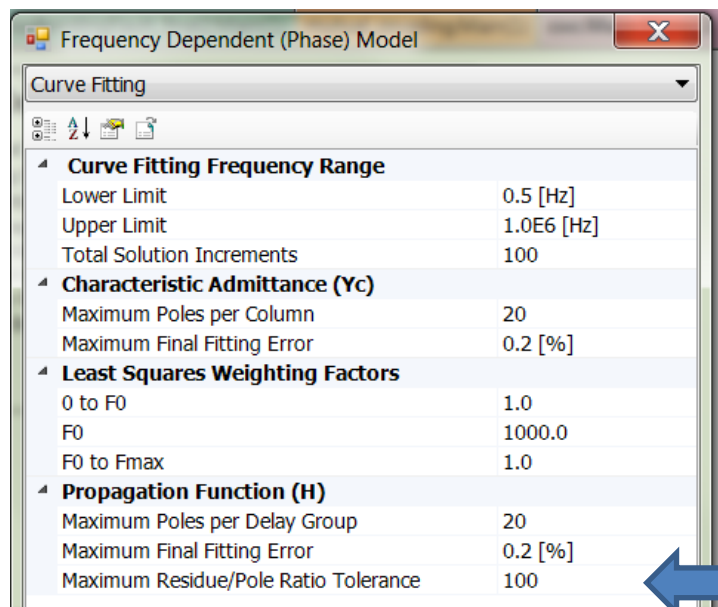
Improving stability

- Cause: Passivity violations
- Solution:
  - Phase model options> curve-fitting
  - Enable dc correction
  - Adequate shunt conductance
  - Reduce lower bound of fitting