Power Quality Studies Using Digital Simulation

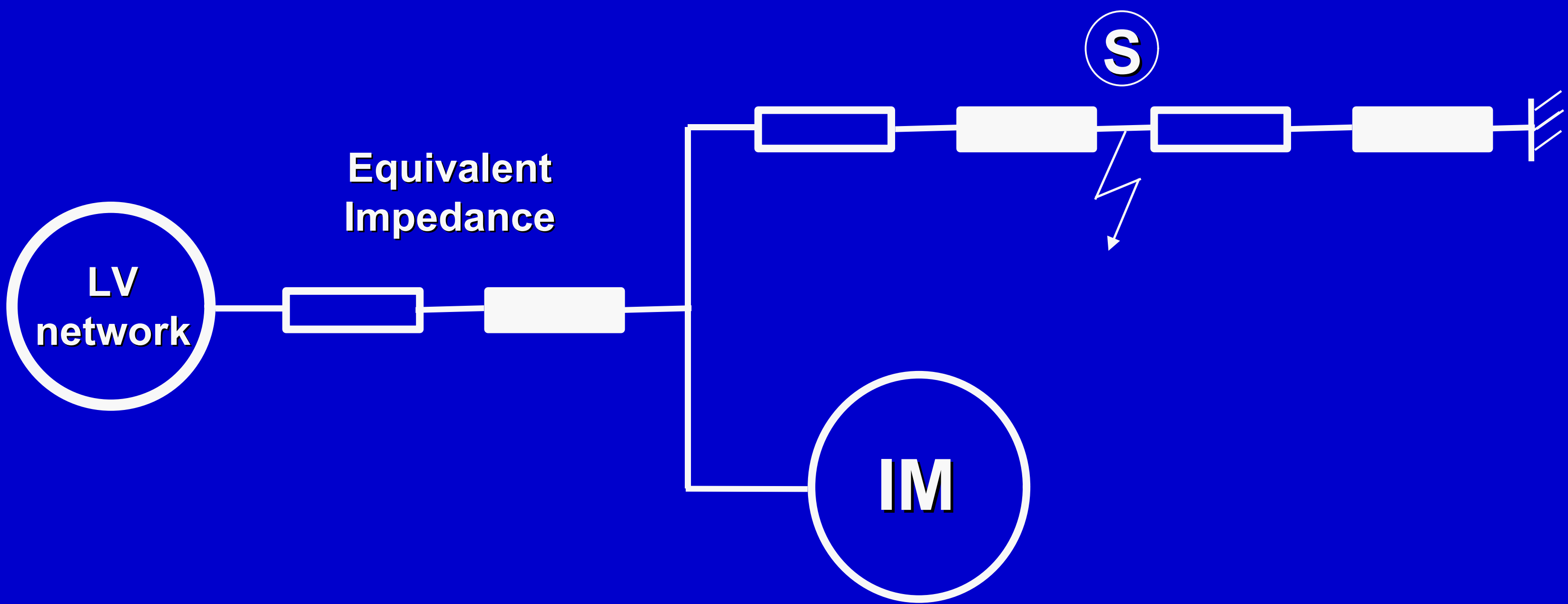
Illustrative Examples

Examples

- Voltage dip effects on three-phase induction motors
- Harmonic resonance. Passive filters
- Voltage dip calculations. Parametric studies
- Active filter simulation
- DVR Simulation
- Stochastic prediction of voltage dips

Three-Phase Induction Motor

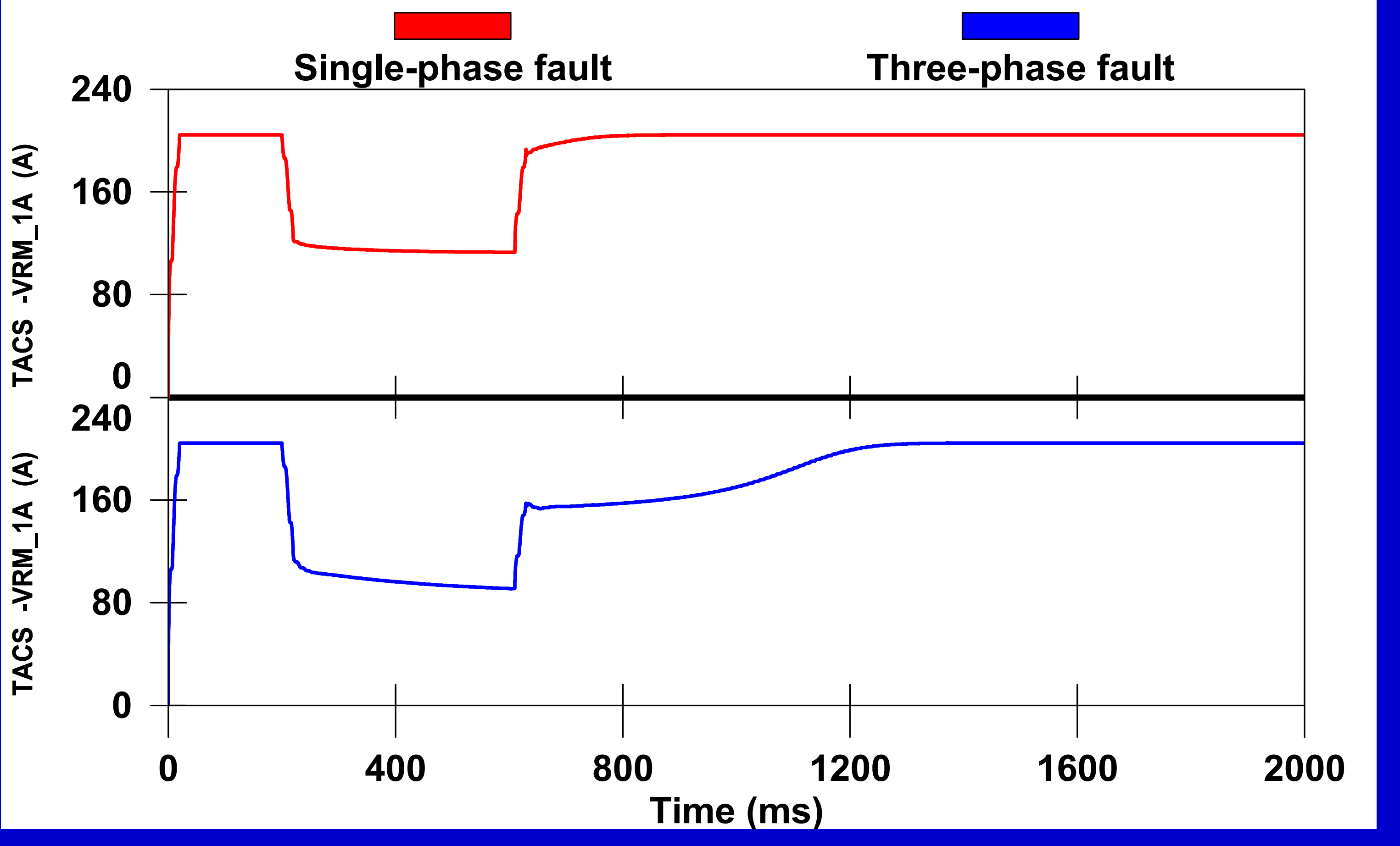
Voltage dip effects



Three-Phase Induction Motor

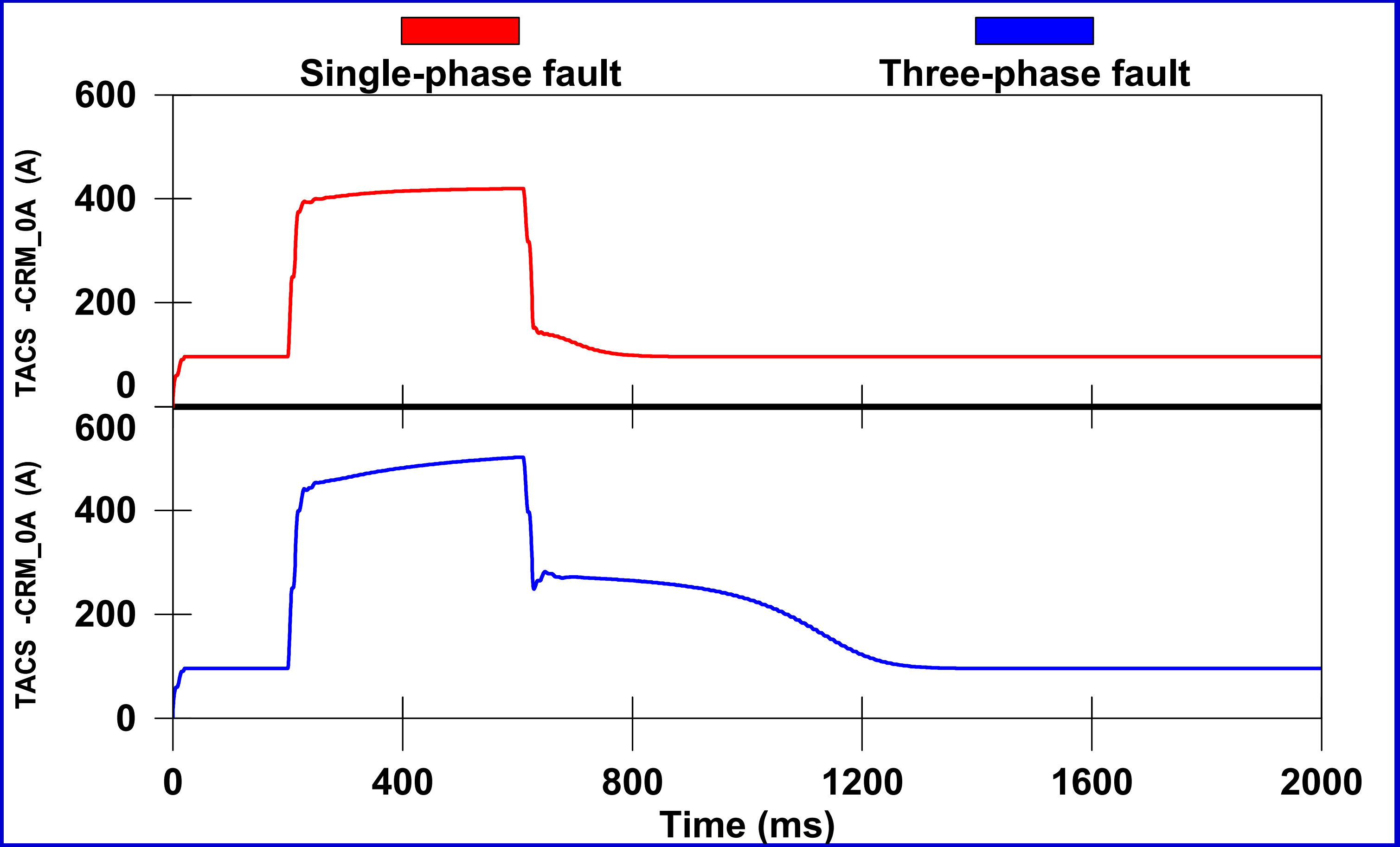
- Type of faults
  - single-phase-to-ground
  - three-phase-to-ground
- Calculation of
  - source and motor stator currents
  - voltages at motor terminals
  - rotor speed
  - electromagnetic torque
- Fault location : Node S

Three-Phase Induction Motor



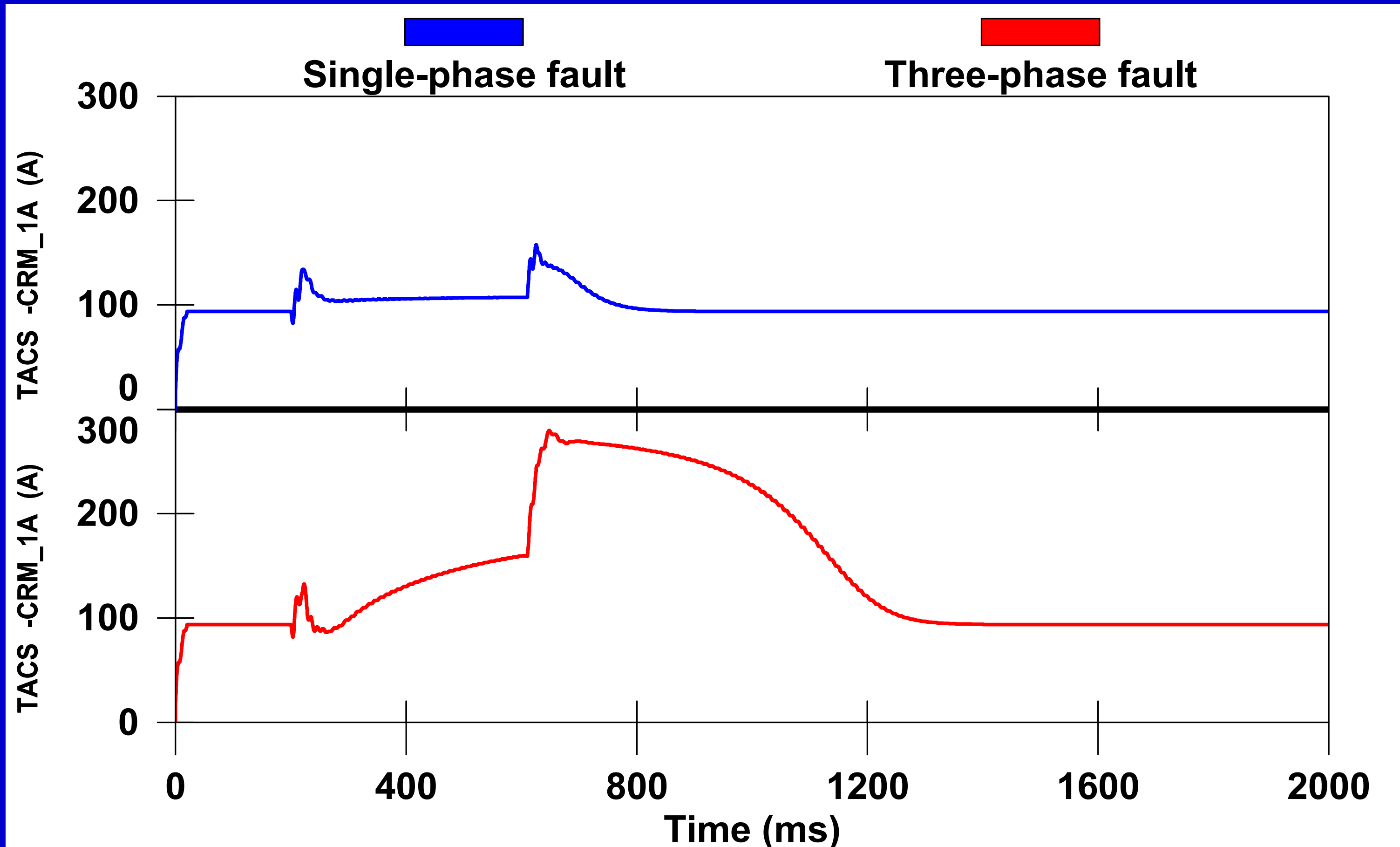
Terminal voltages

Three-Phase Induction Motor



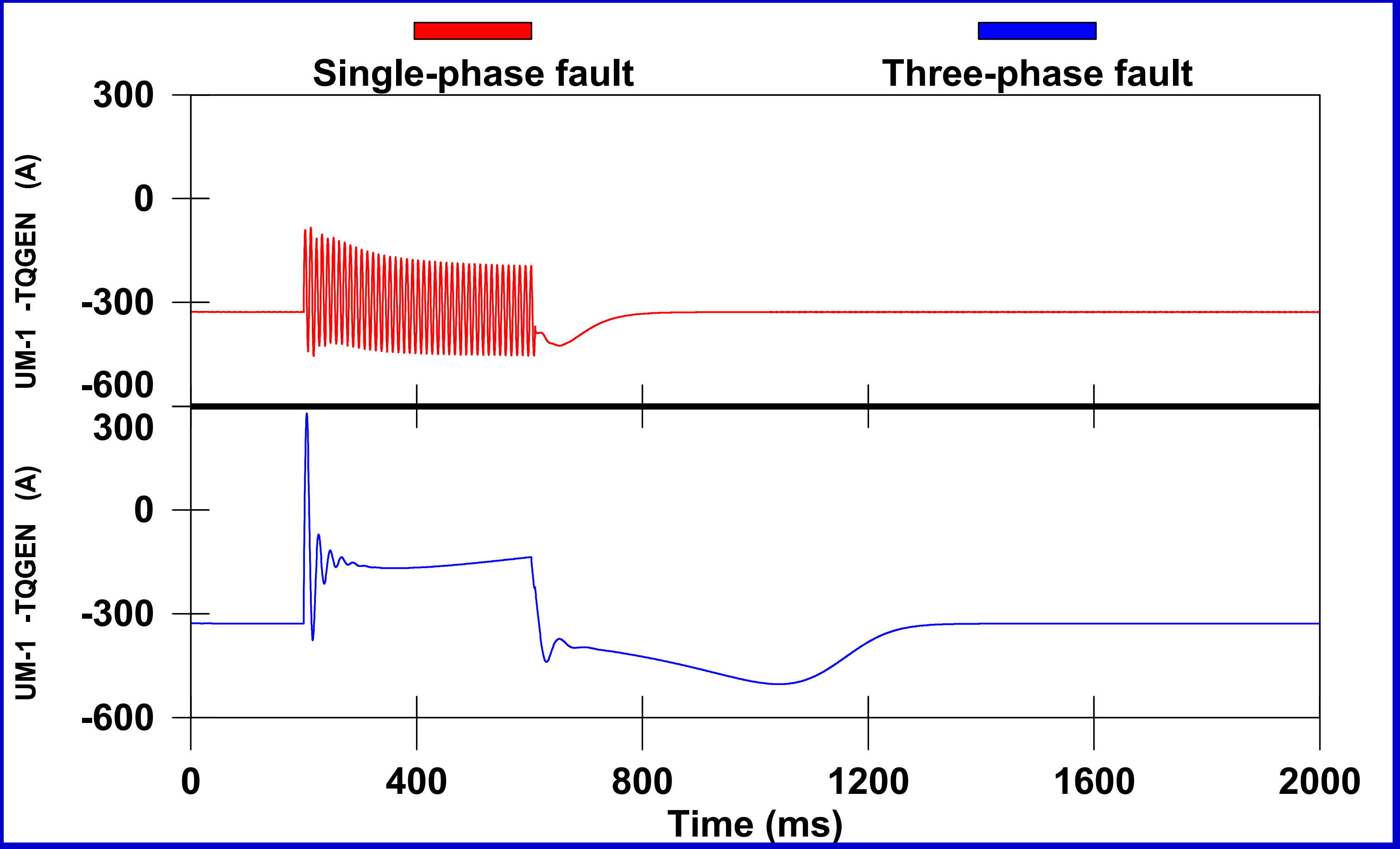
Source currents

Three-Phase Induction Motor



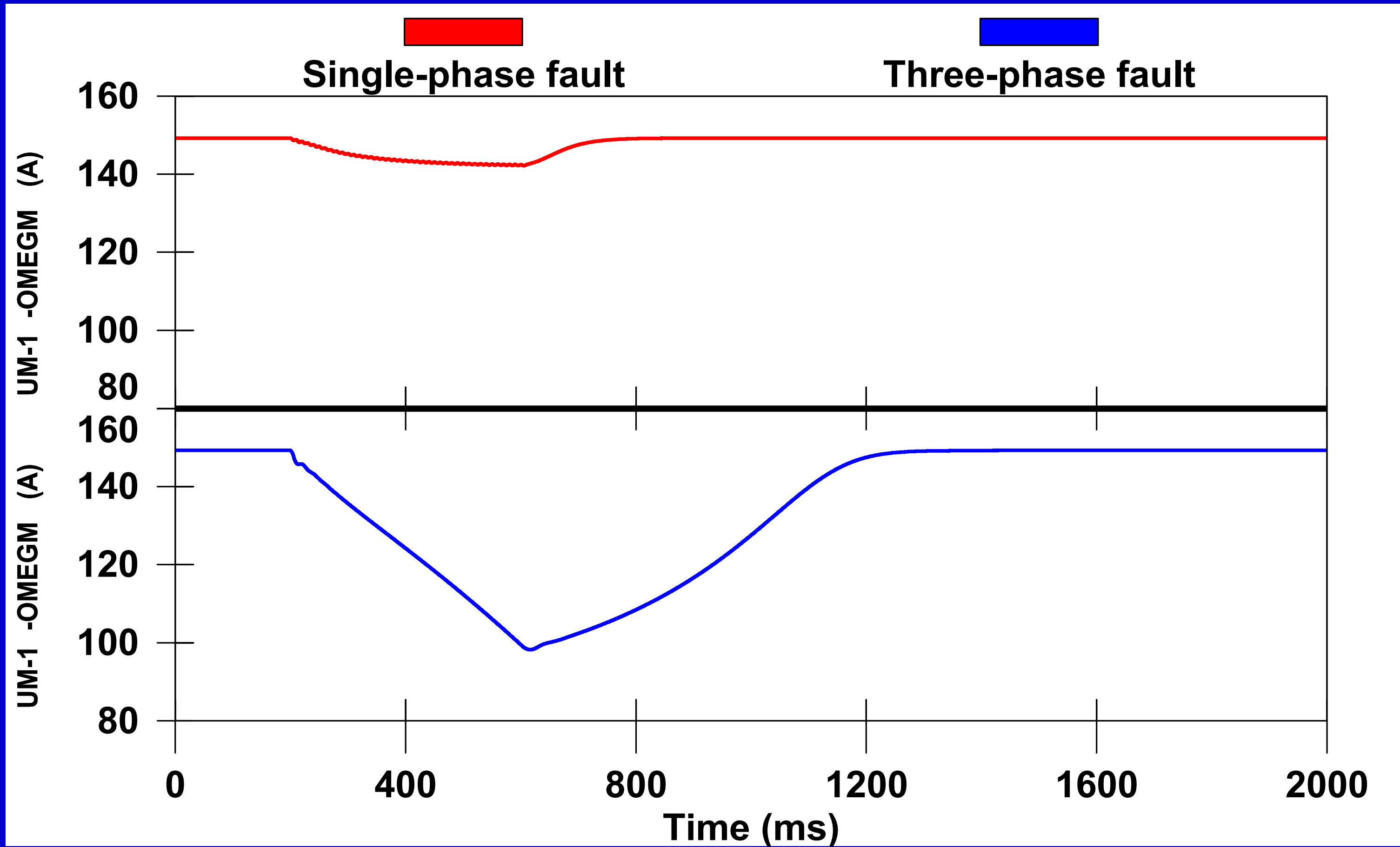
Stator currents

Three-Phase Induction Motor



Electromagnetic torques

Three-Phase Induction Motor



Rotor speeds

Harmonic Resonance

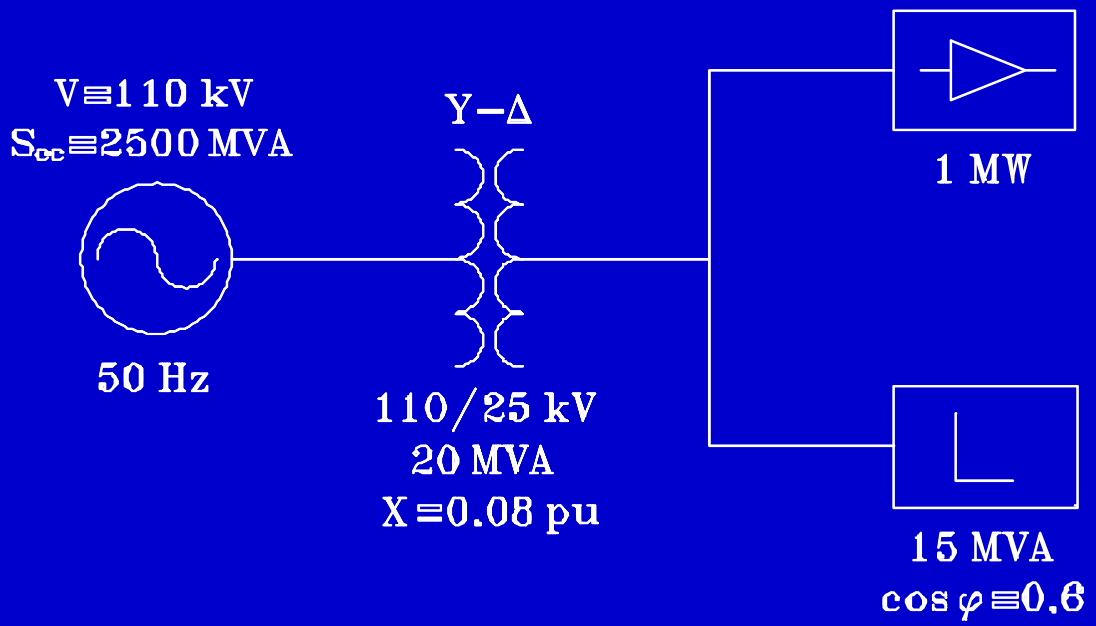
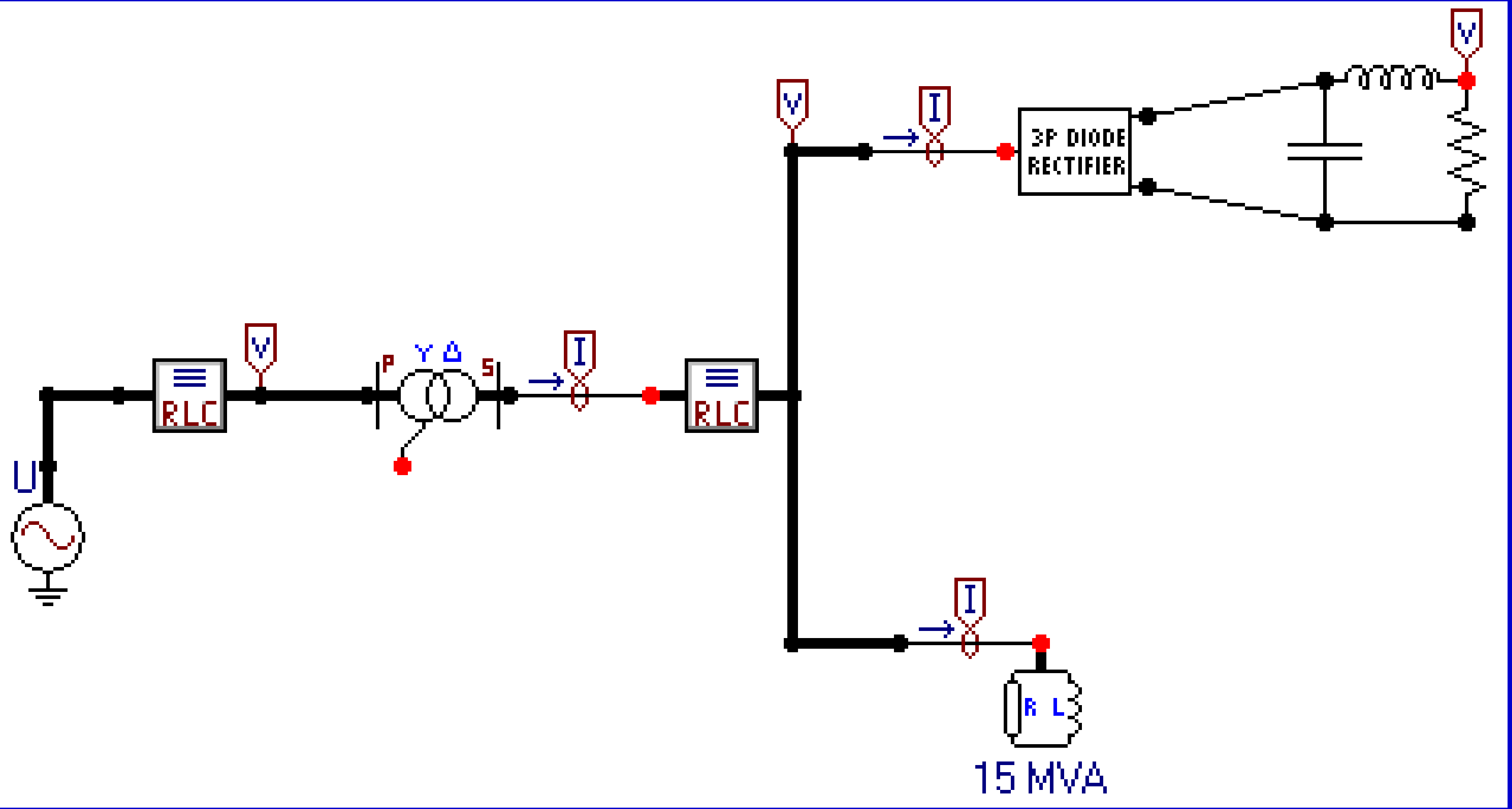


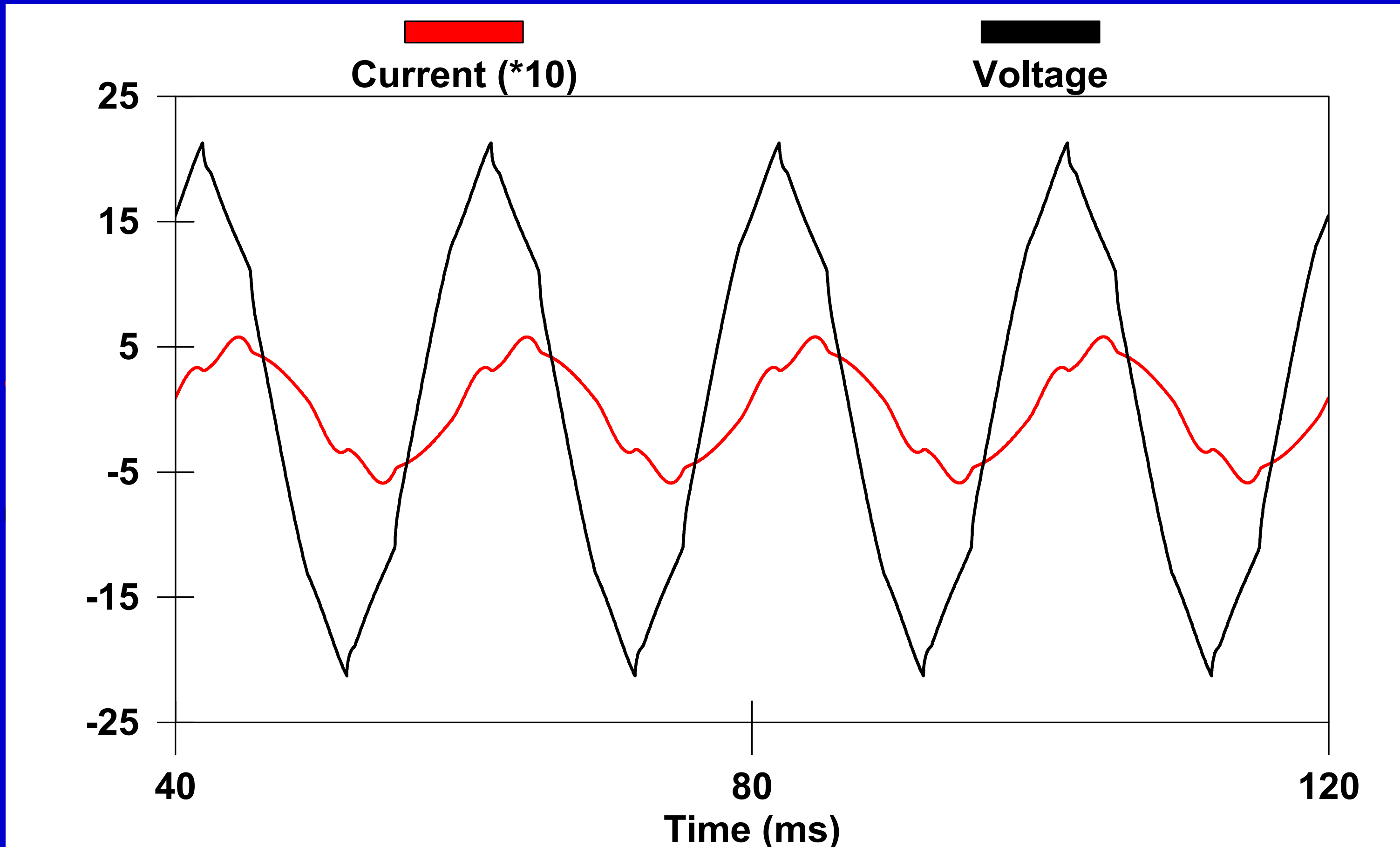
Diagram of the test case

Harmonic Resonance



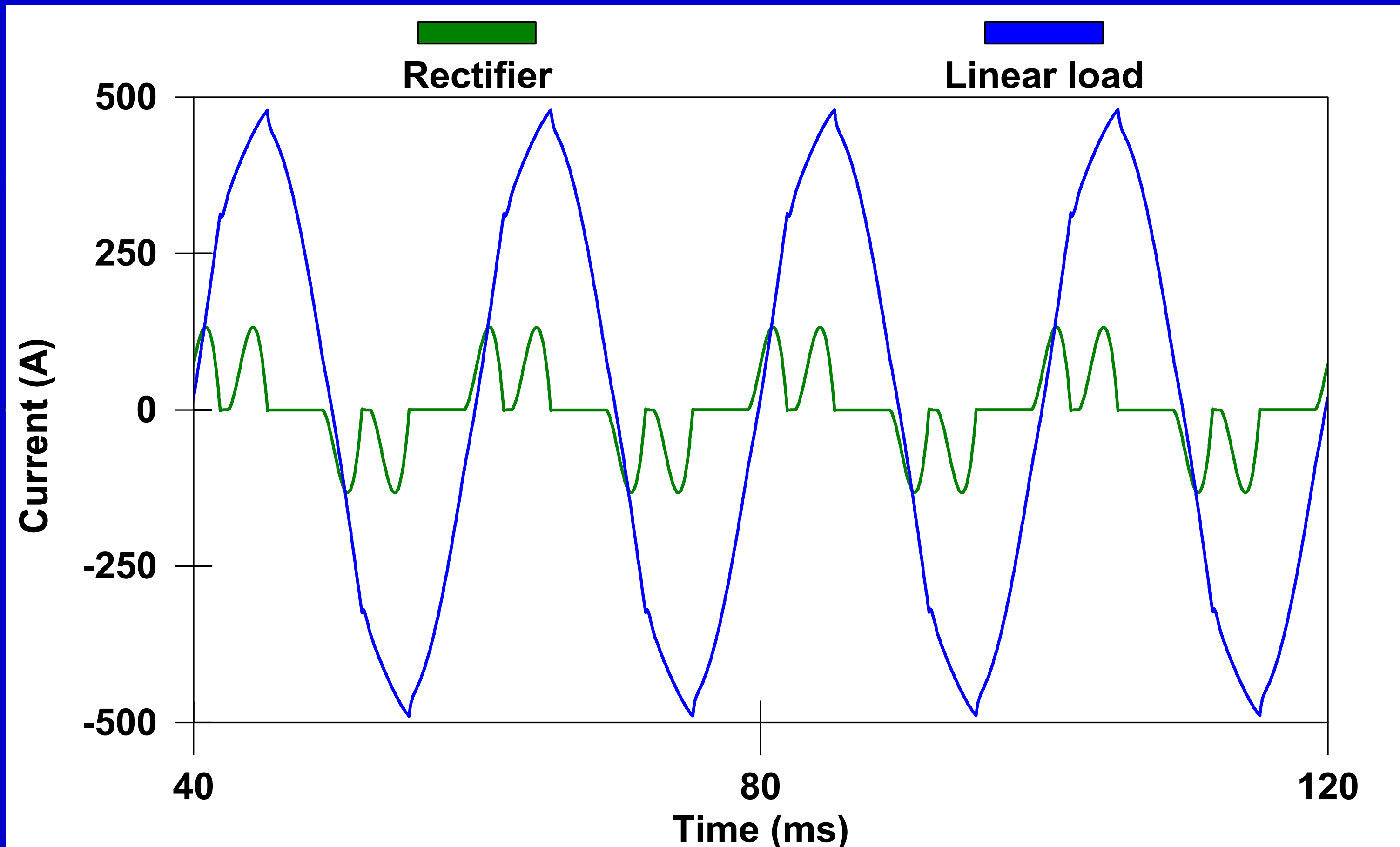
Initial configuration

Harmonic Resonance



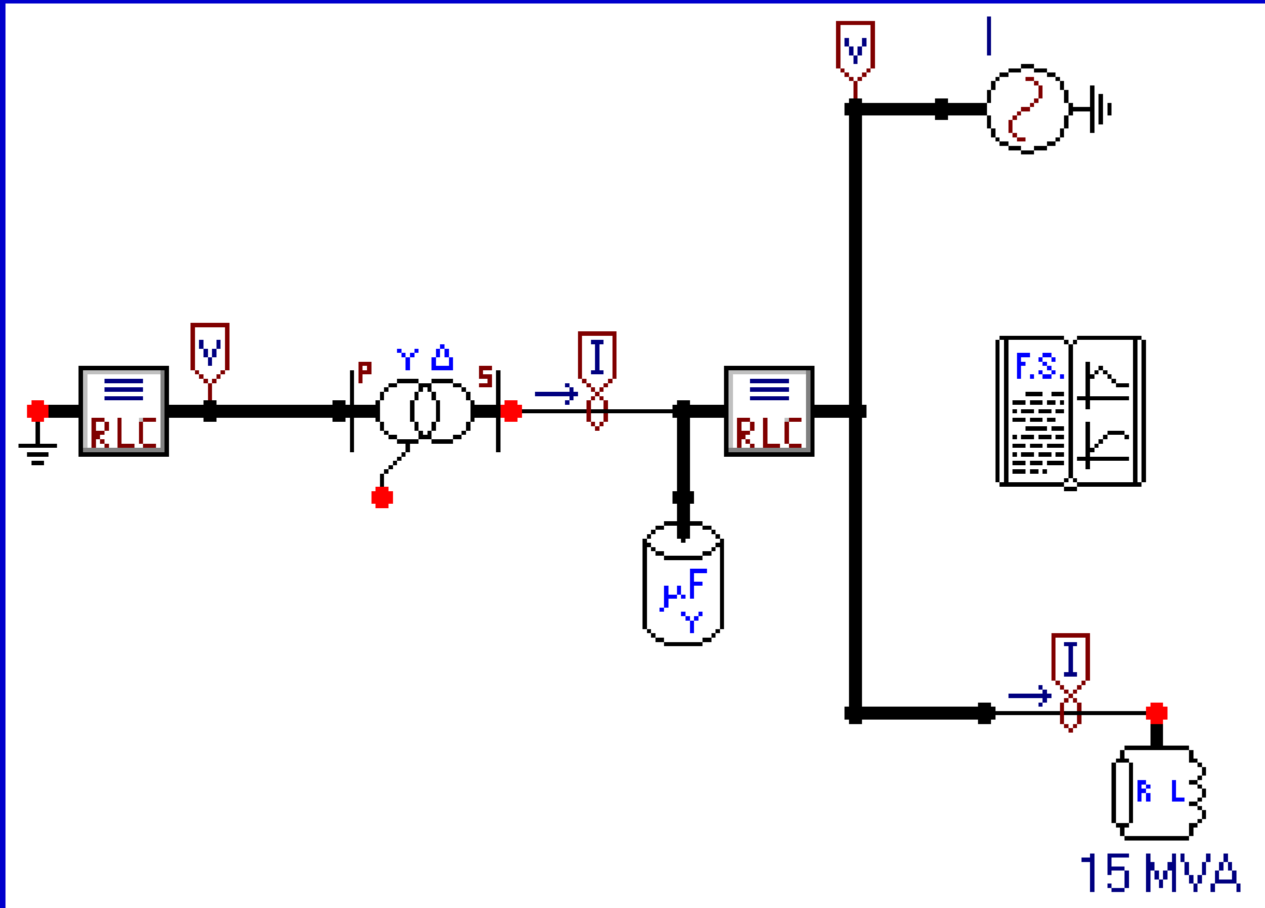
PCC voltage and current

Harmonic Resonance



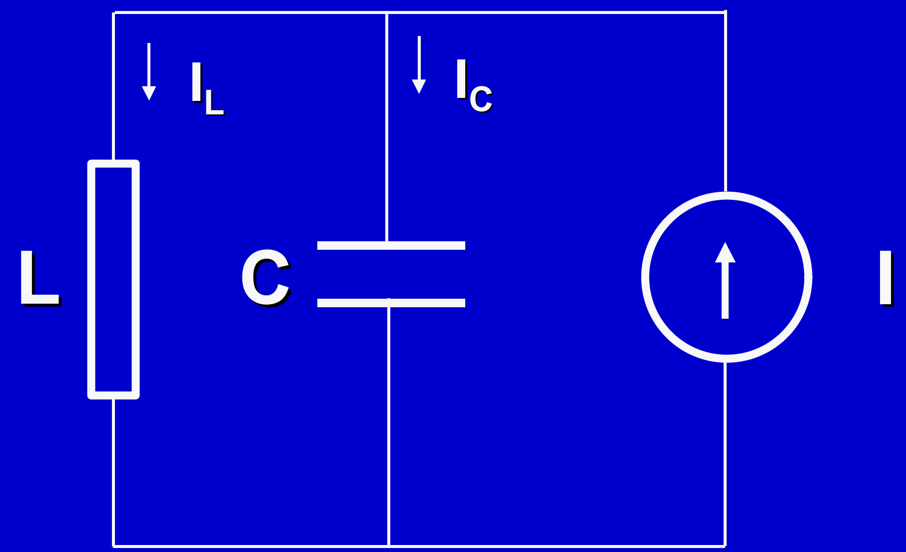
Rectifier and linear load currents

Harmonic Resonance



FREQUENCY SCAN after installing the capacitor bank

Harmonic Resonance

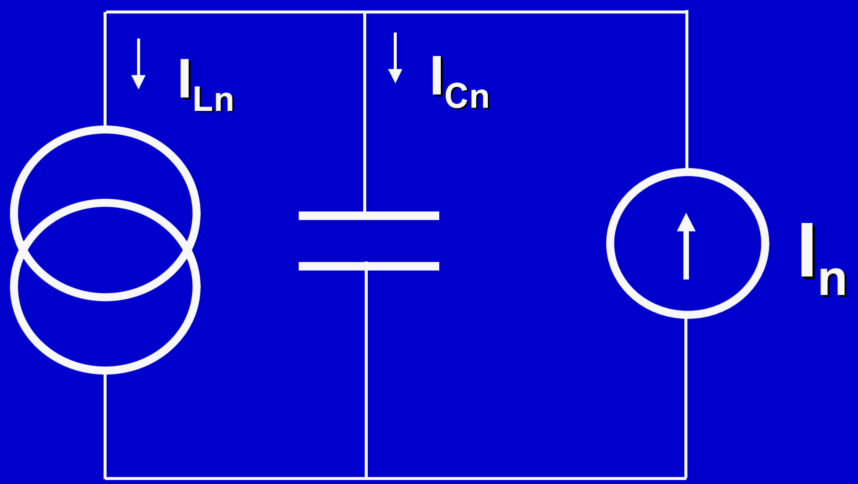


$$L = \frac{V^2}{\omega S_{cc}}$$

$$C = \frac{Q_c}{\omega V^2}$$

$$\omega_O = \frac{1}{\sqrt{LC}} = \omega \sqrt{\frac{S_{cc}}{Q_c}}$$

Harmonic Resonance



Example

High voltage : V = 110 kV ; Scc=2500 MVA

Transformer : 110/11 kV, 20MVA, 8%

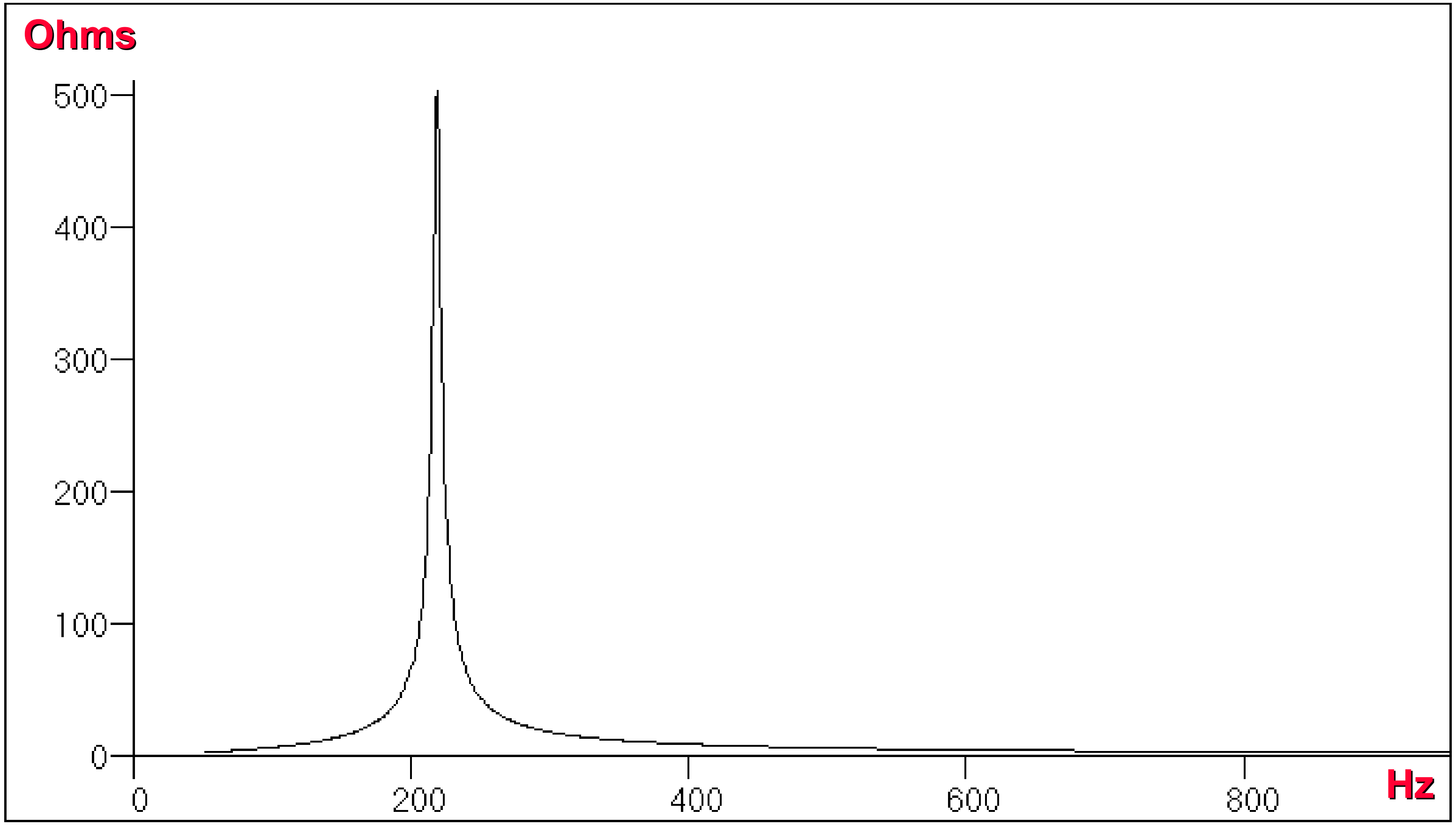
Capacitor bank : 11 kV, 12 MVA

HV+ Transformer = 20/2500 + 0.08 = 0.088

Capacitor bank = 20/12 = 1.667

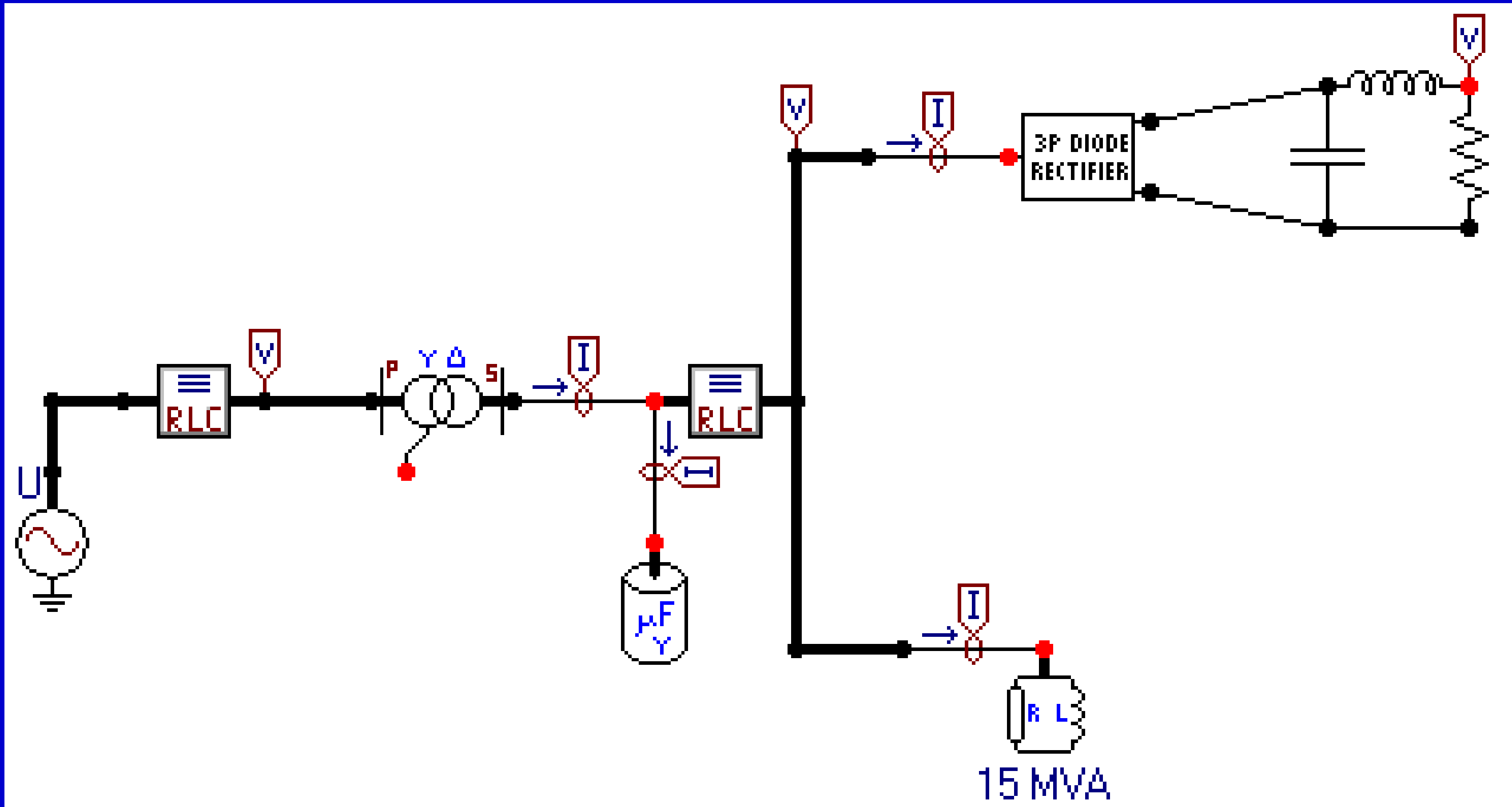
$$n = \sqrt{\frac{1.667}{0.088}} = 4.35$$

Harmonic Resonance



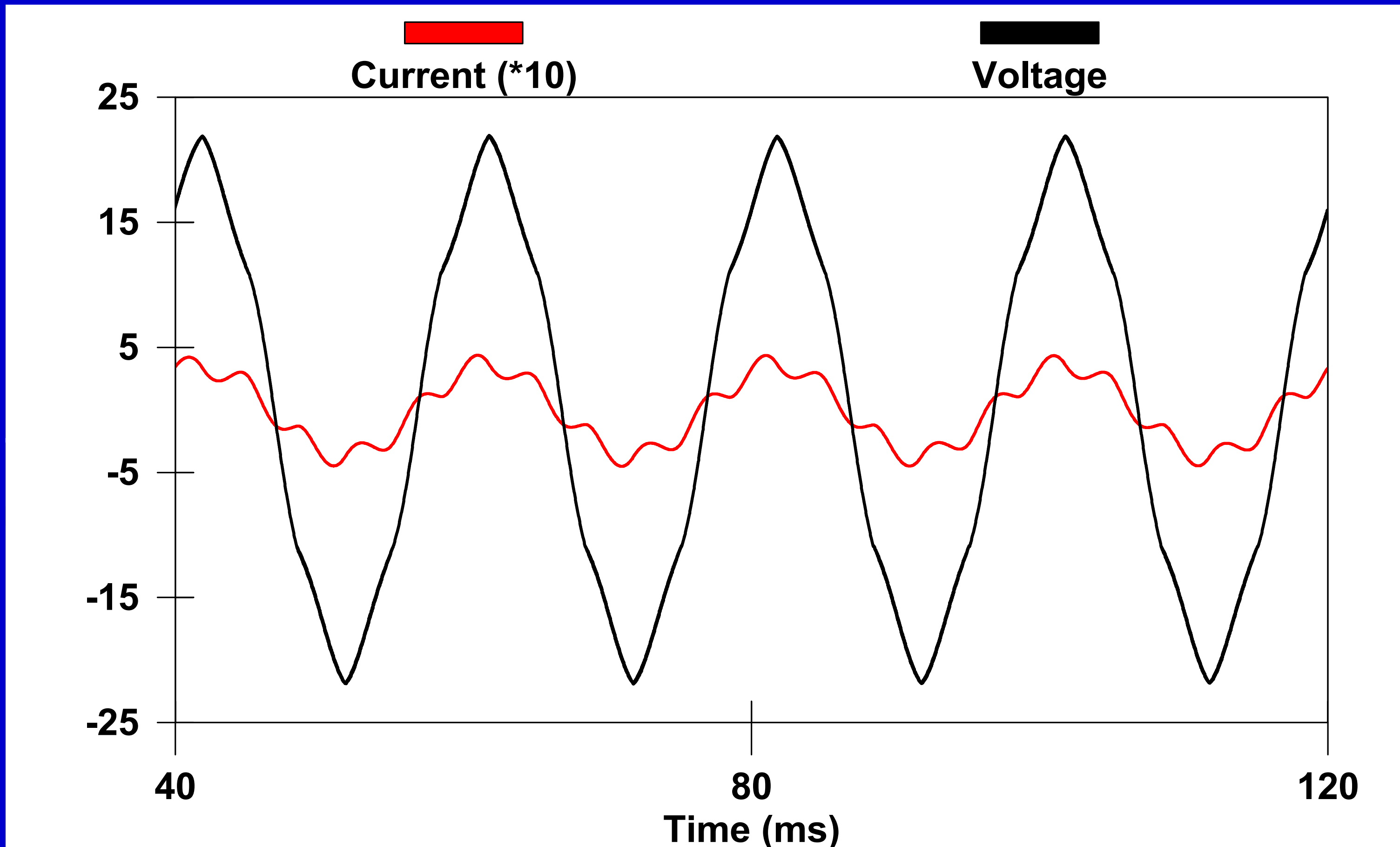
Frequency response after installing the capacitor bank

Harmonic Resonance



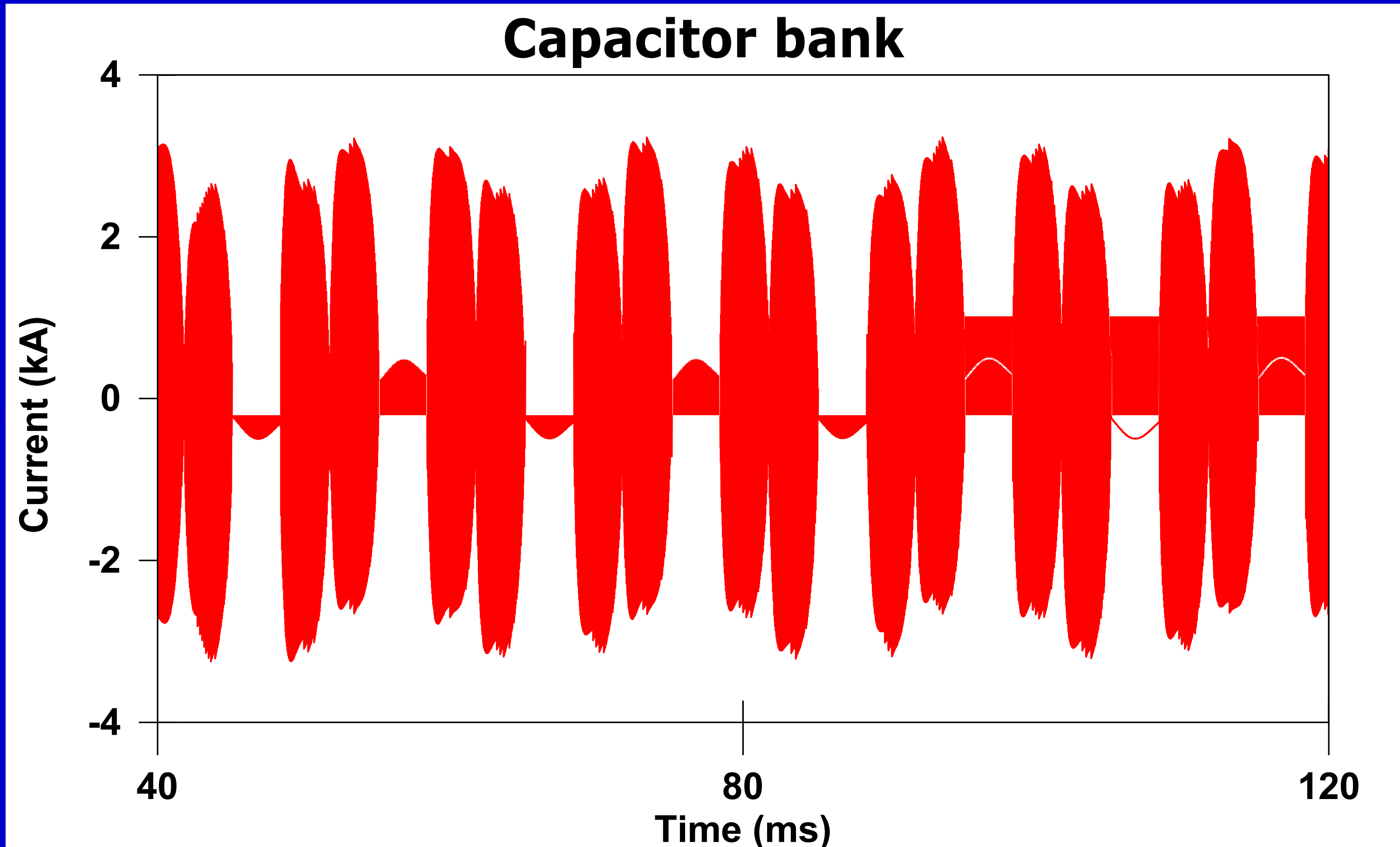
Transient simulation after installing the capacitor bank

Harmonic Resonance



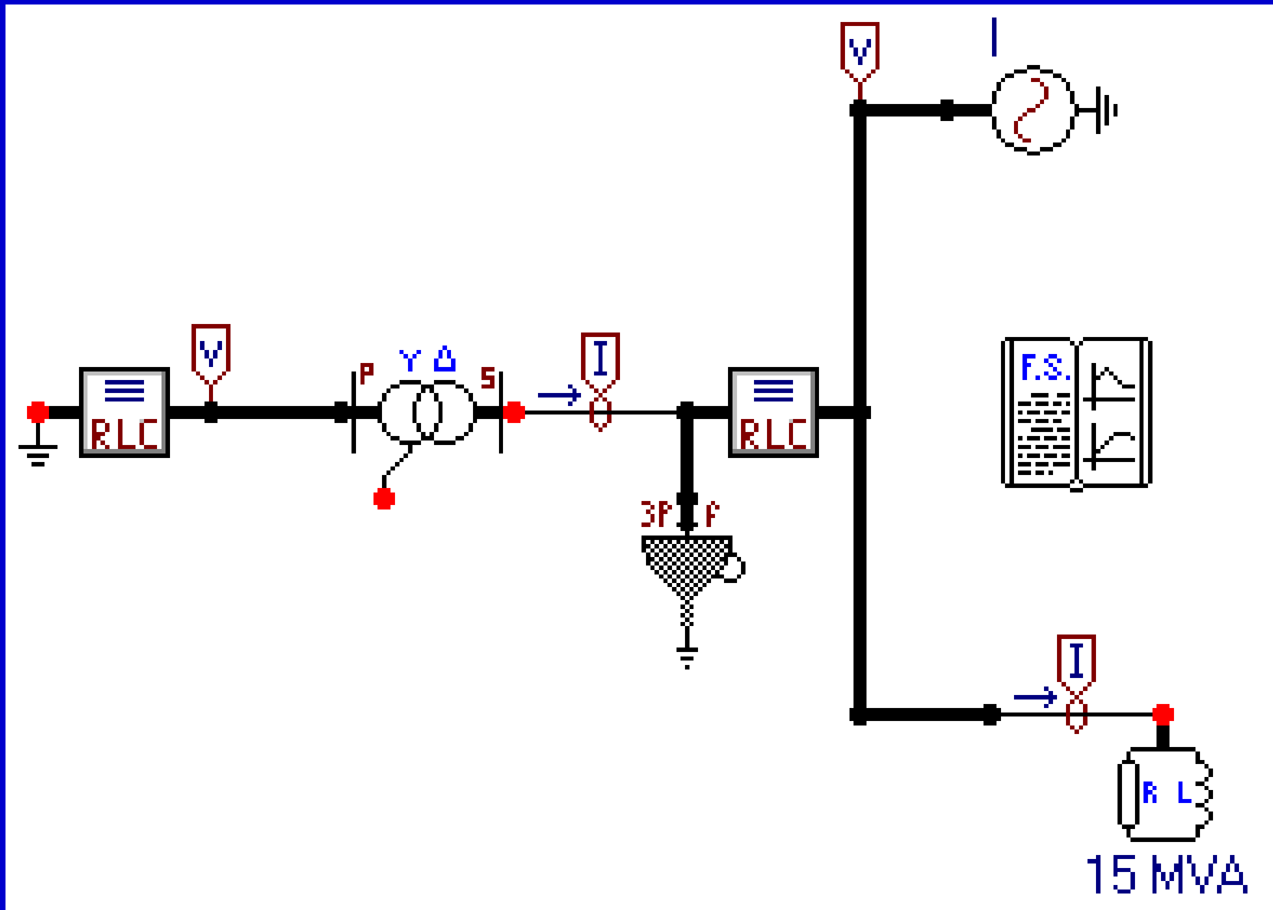
PCC voltage and current

Harmonic Resonance



Capacitor bank current

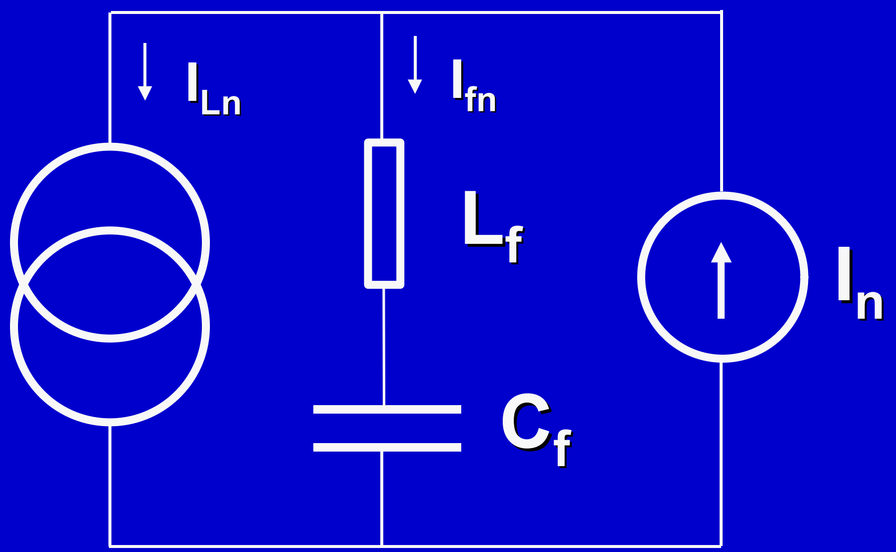
Harmonic Resonance



FREQUENCY SCAN after installing the passive filter

Harmonic Resonance

$$Z_n \to \infty$$

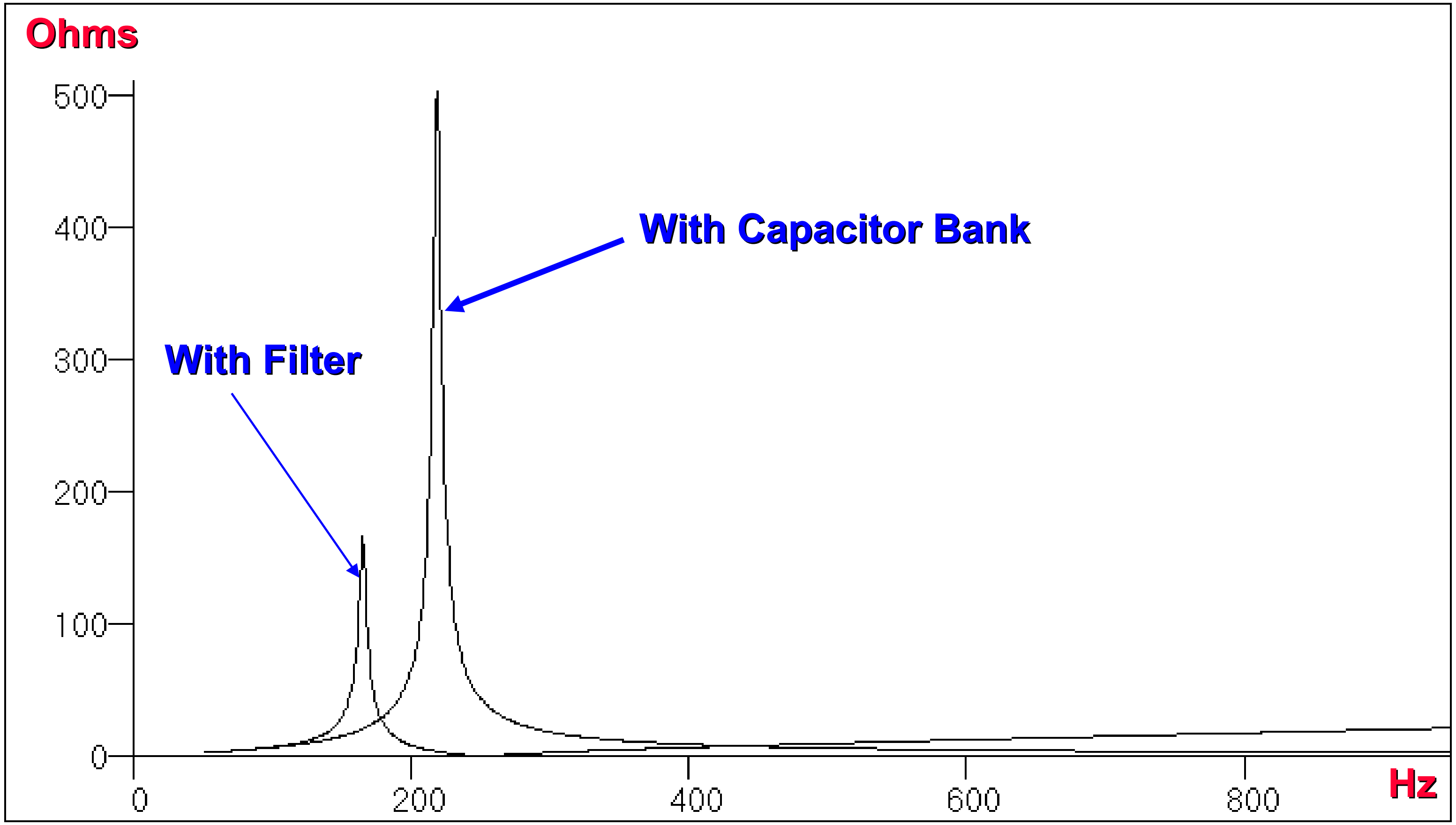


$$\omega_n L_f = \frac{1}{\omega_n C_f} \qquad \left(n^2 X_L = X_C\right)$$

$$L_f = \frac{1}{\omega_n^2 C_f}$$

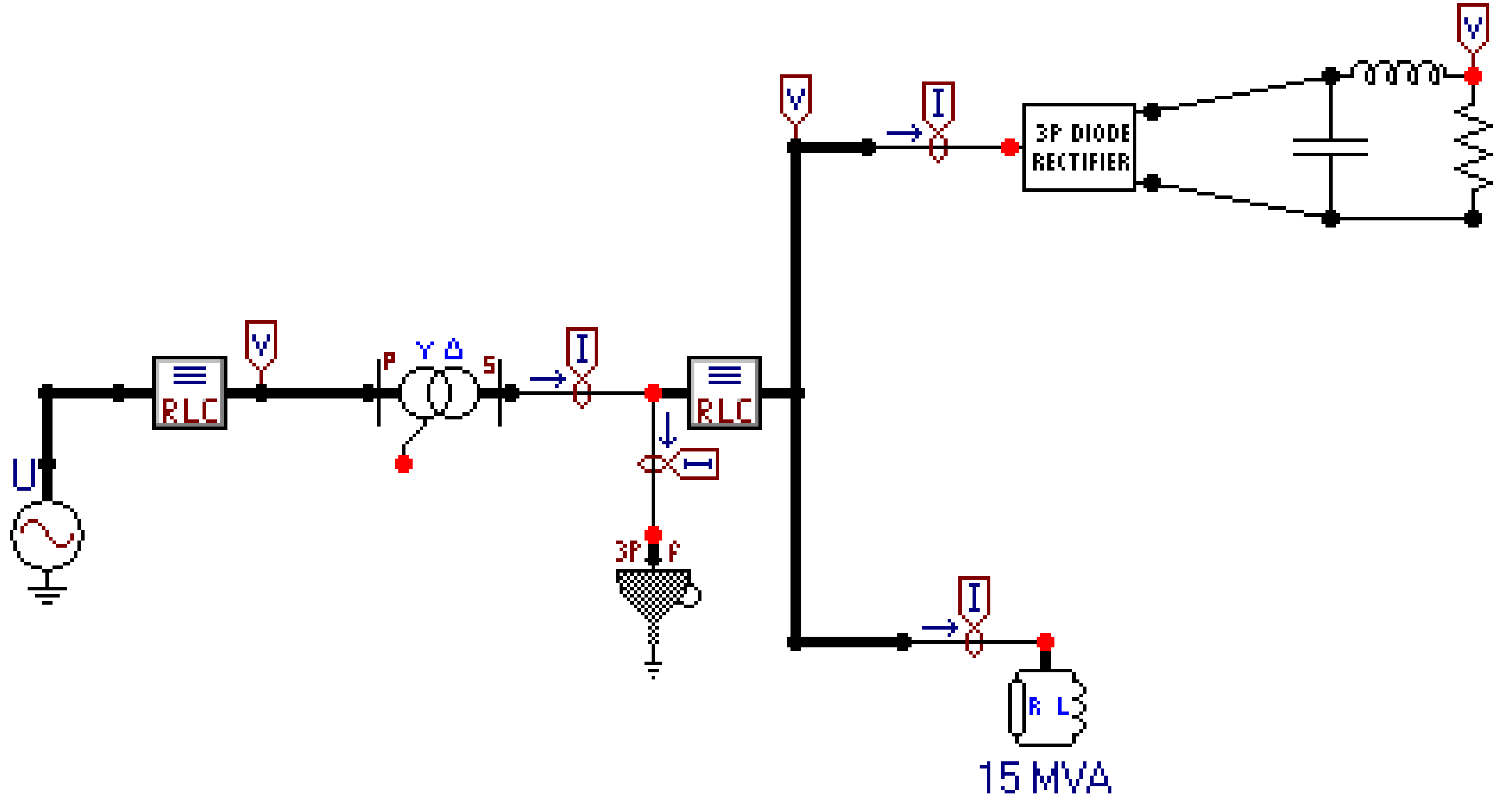
$$Q_f = \frac{V^2}{X_C - X_L} = Q_C \frac{n^2}{n^2 - 1}$$

Harmonic Resonance



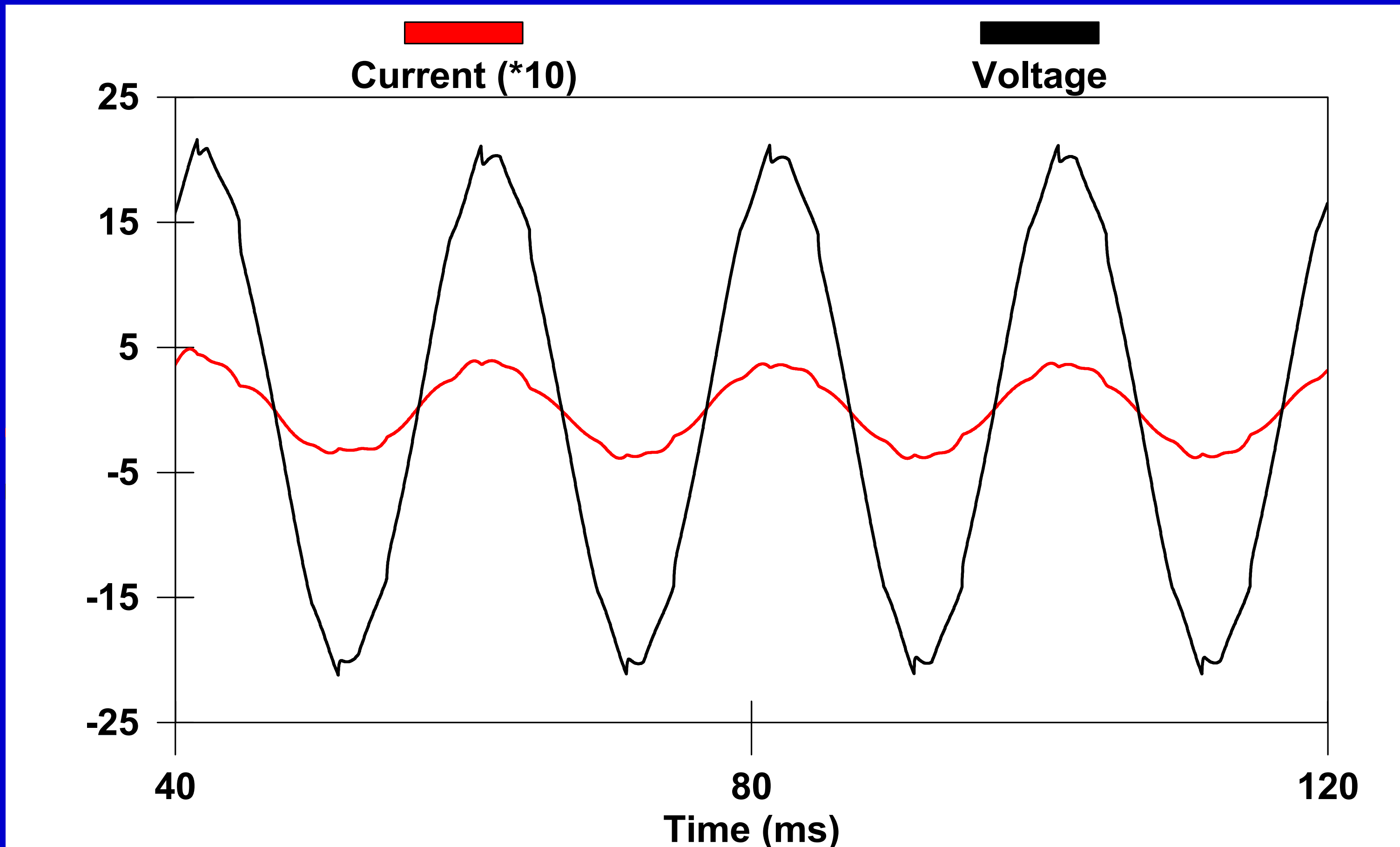
Frequency response after installing the filter

Harmonic Resonance



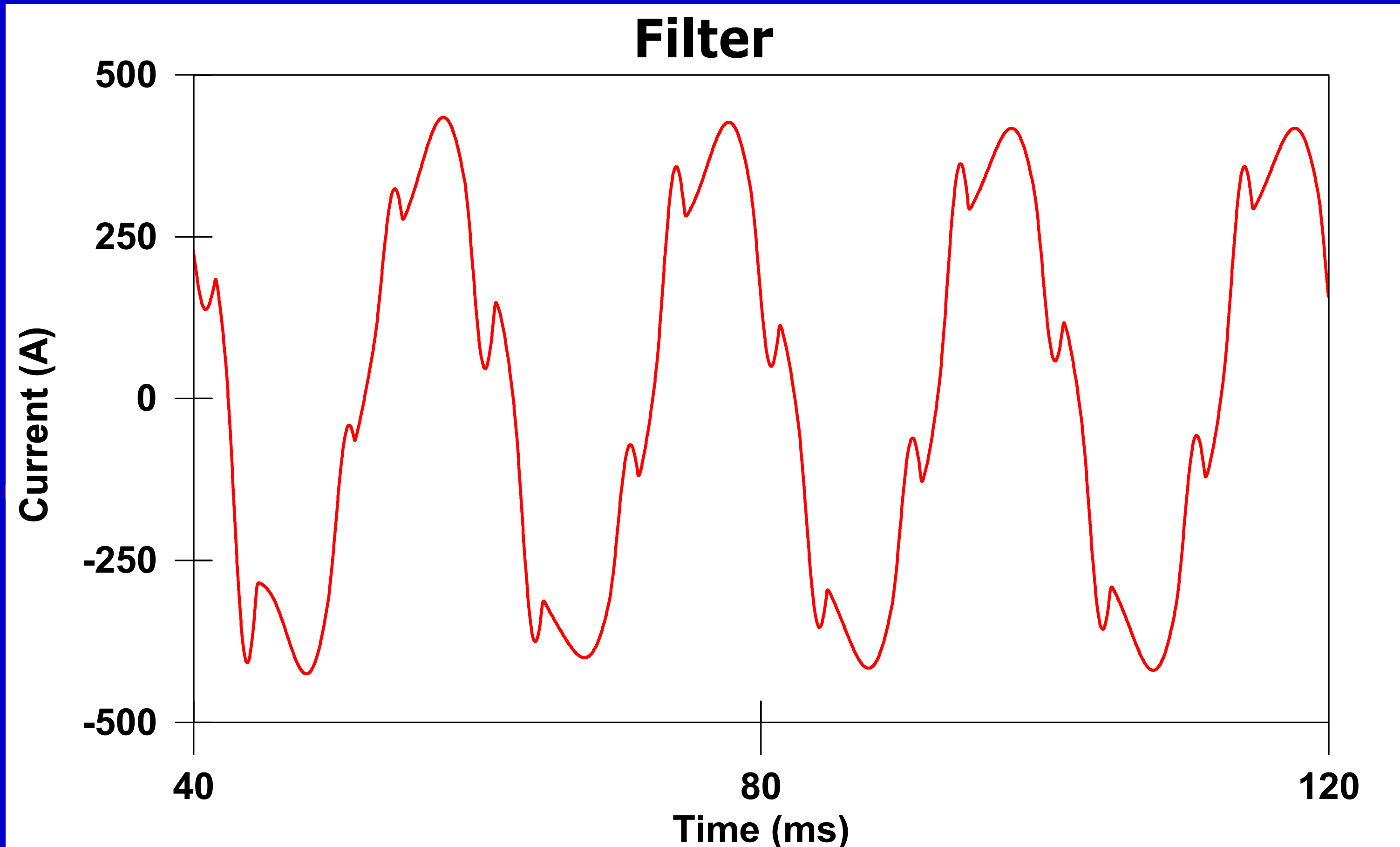
Transient simulation after installing the passive filter

Harmonic Resonance



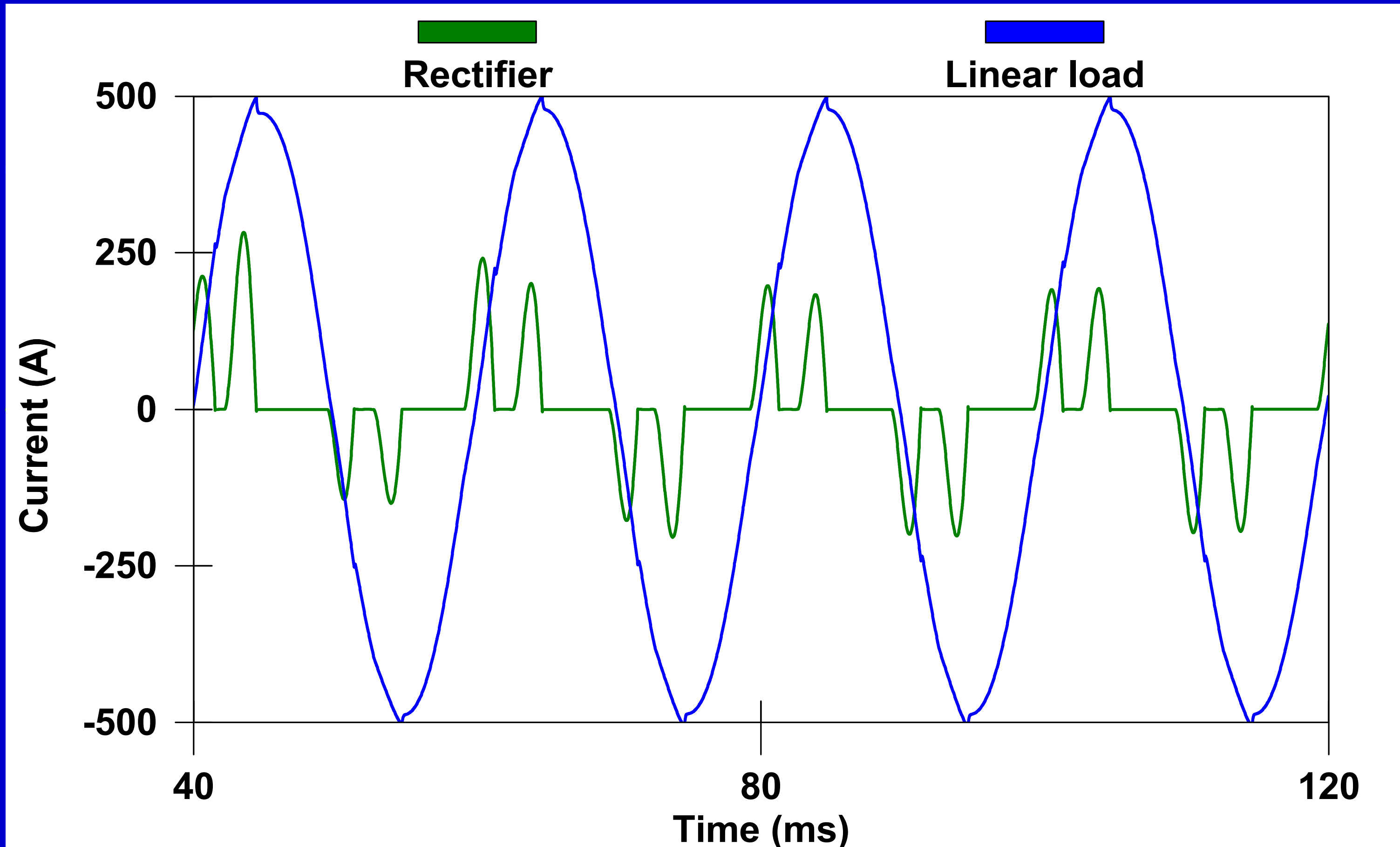
PCC voltage and current

Harmonic Resonance



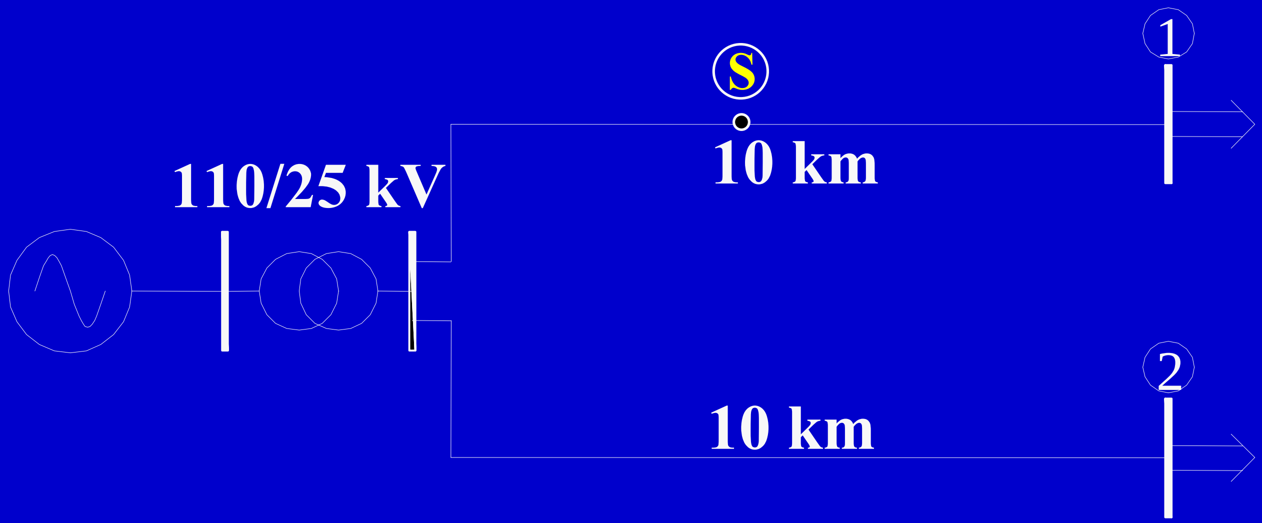
Filter current

Harmonic Resonance



Rectifier and linear load currents

Voltage Dip Calculations



HV Equivalent : 110 kV, 1500 MVA, X/R = 10

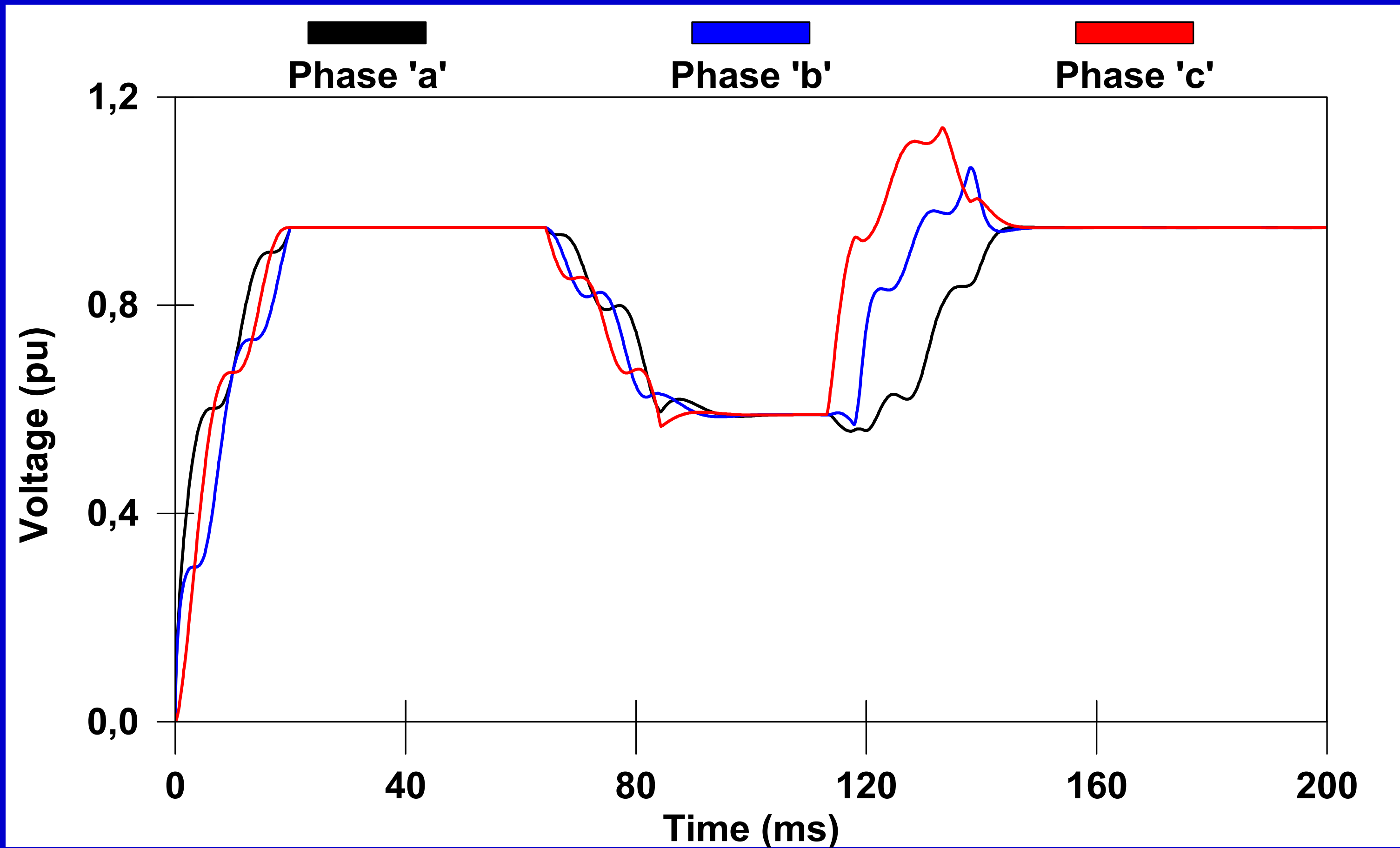
Substation Transformer: 110/25 kV, 10 MVA, 8%, Yd11

Lines : $Z_{1/2}$ = 0.61 + j0.39, Z_0 = 0.76 + j1.56 Ω/km

Voltage Dip Calculations

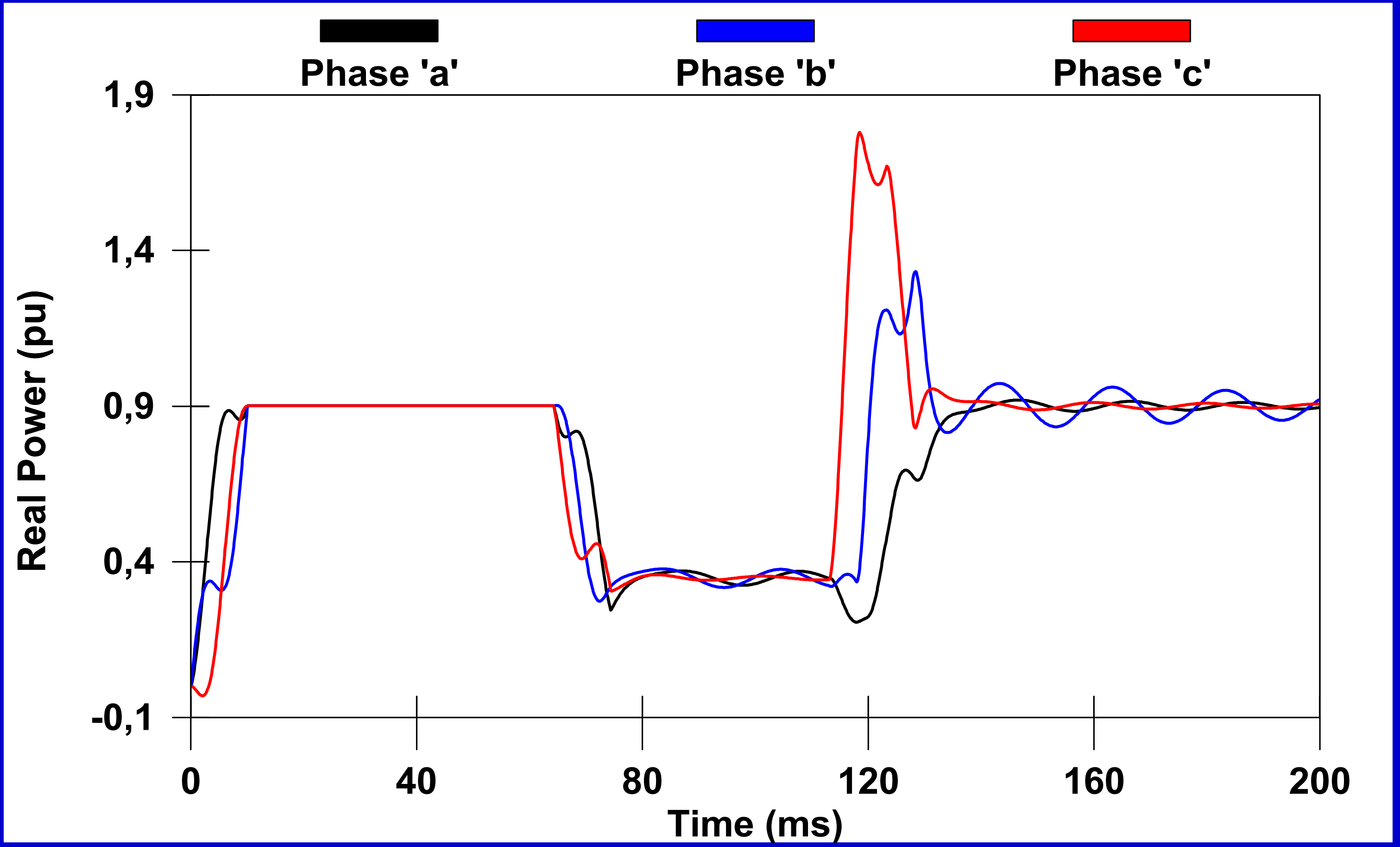
- Calculation of voltage and power demand at Node 2
- Type of faults
  - three-phase-to-ground
  - single-phase-to-ground
- Fault location : 4 km from the substation
- Parametric studies considering
  - the fault location
  - system parameters (SCC, Transformer SC ratio)

Three-phase fault - Node S



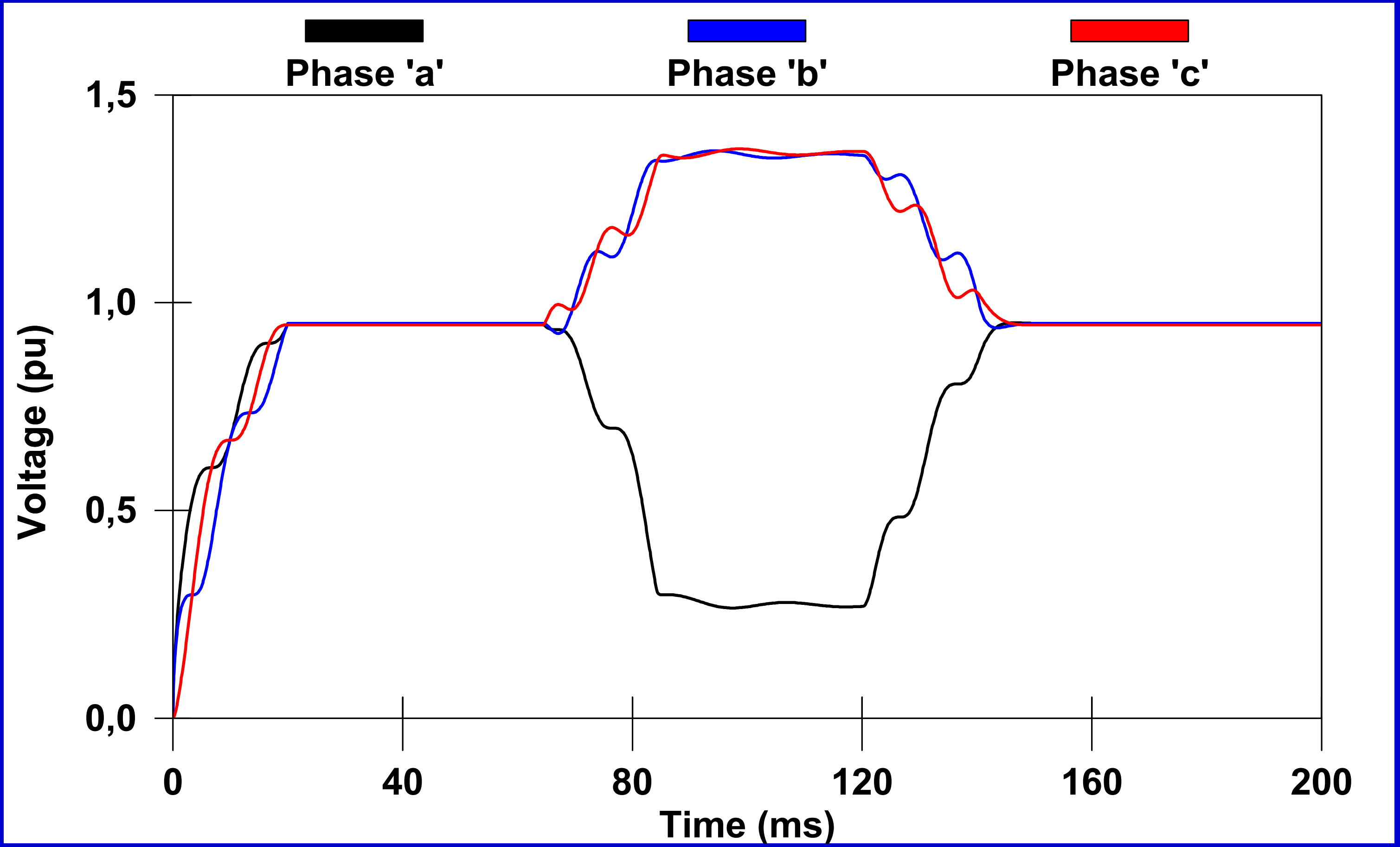
Line-to-ground voltages - Node 2

Three-phase fault - Node S



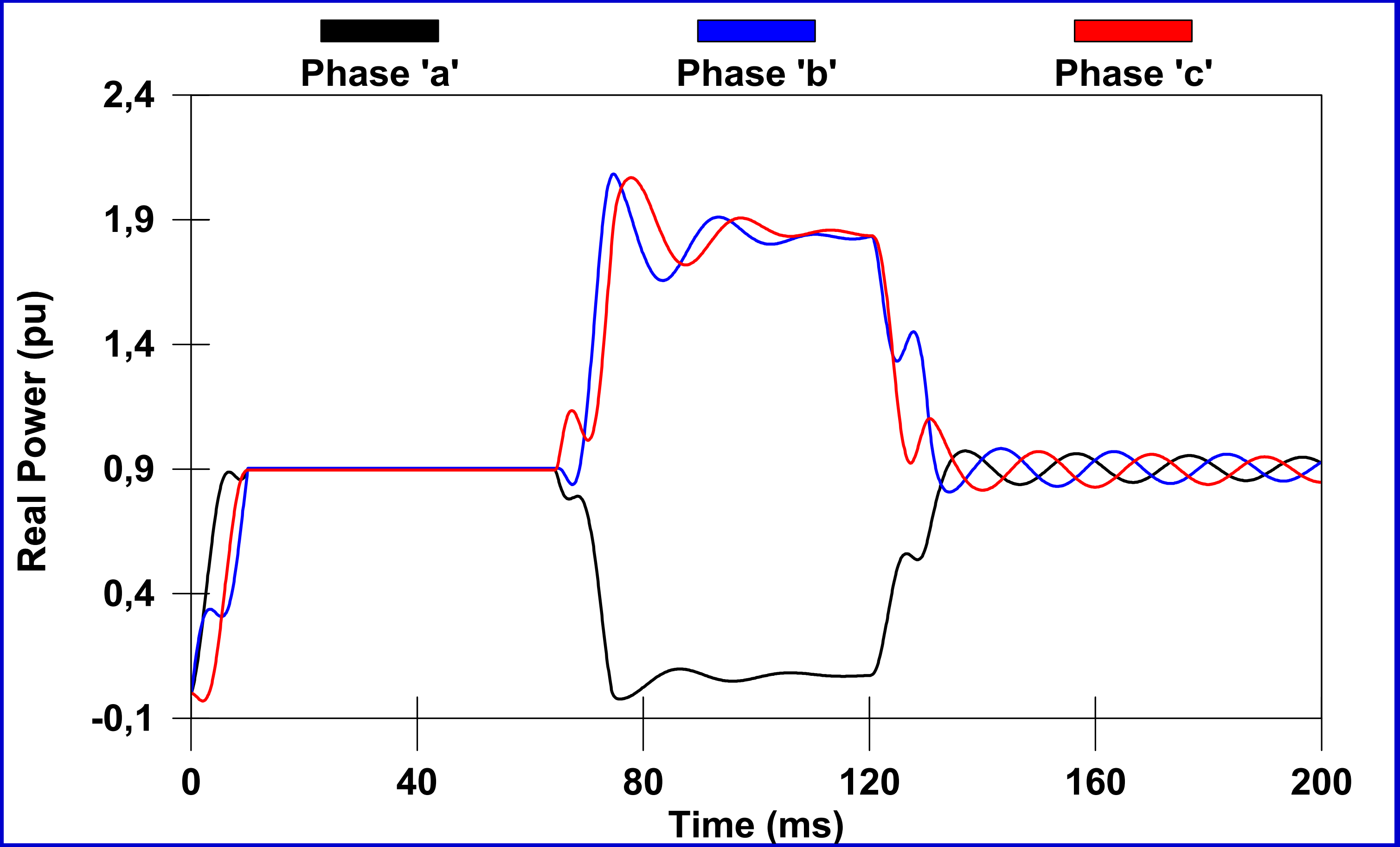
Power demand per phase - Node 2

Single-phase fault - Node S



Line-to-ground voltages - Node 2

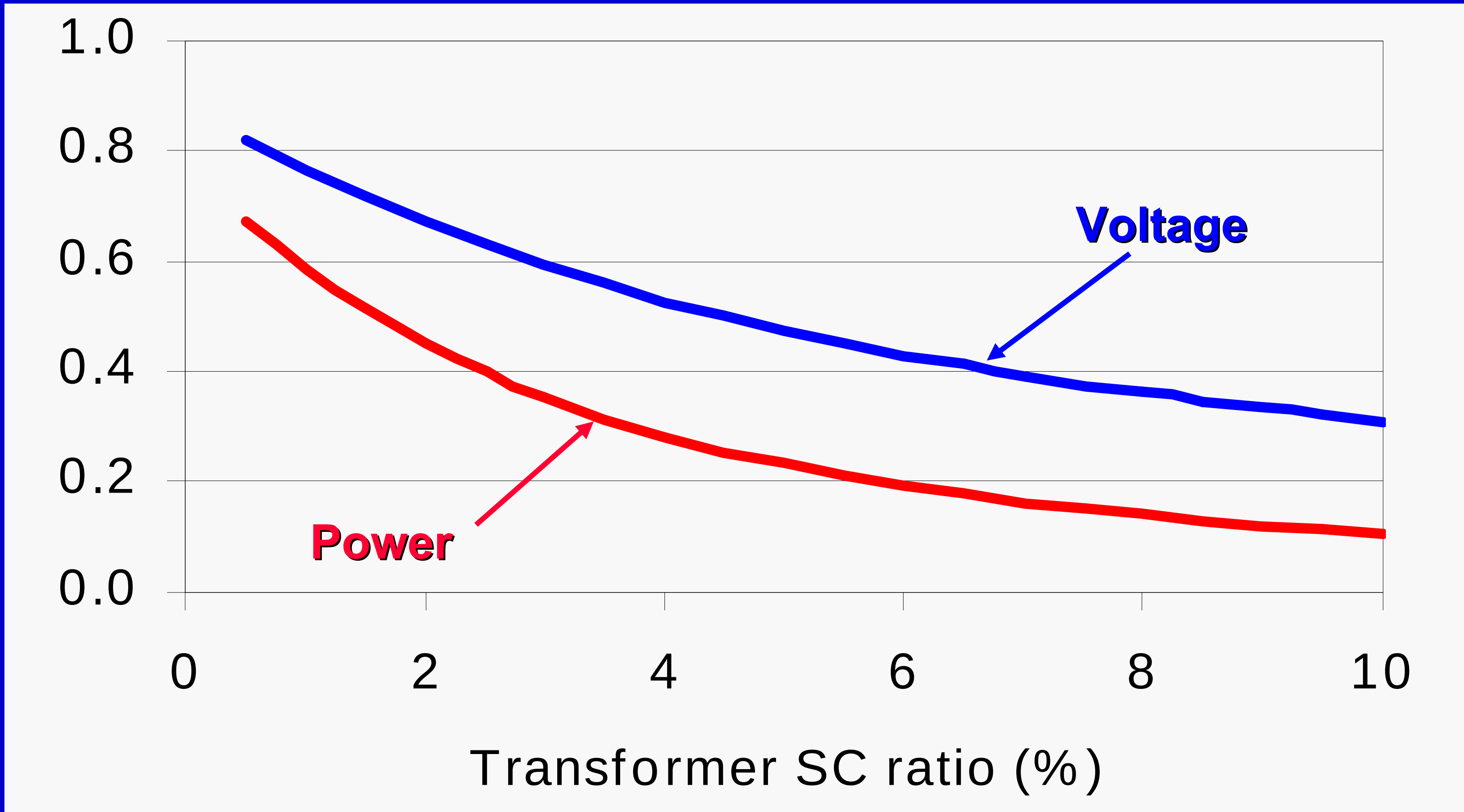
Single-phase fault - Node S



Power demand per phase - Node 2

Parametric analysis

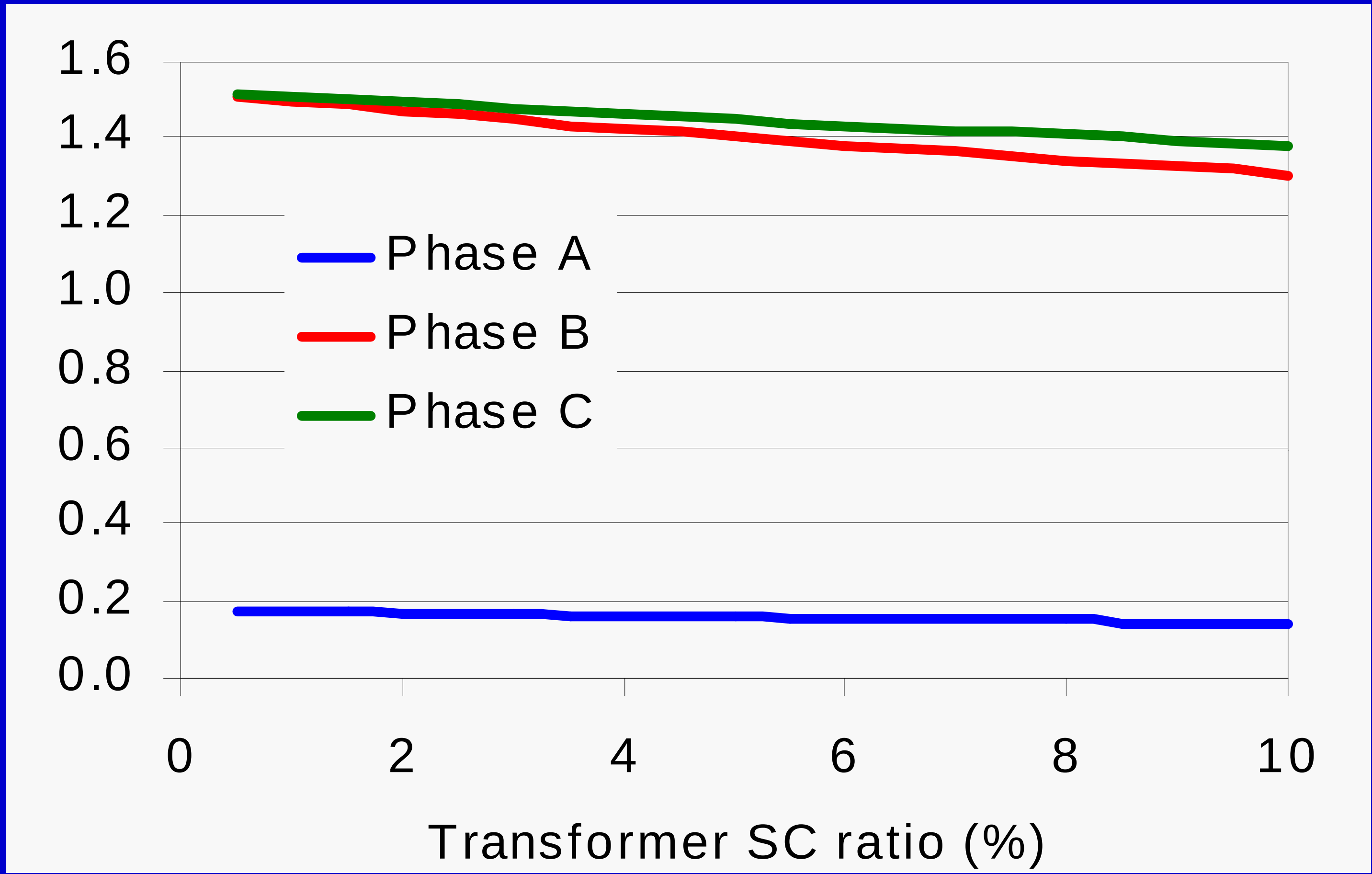
Three-phase-to-ground fault at 4 km from the substation



Voltage and power demand per phase - Node 2

Parametric analysis

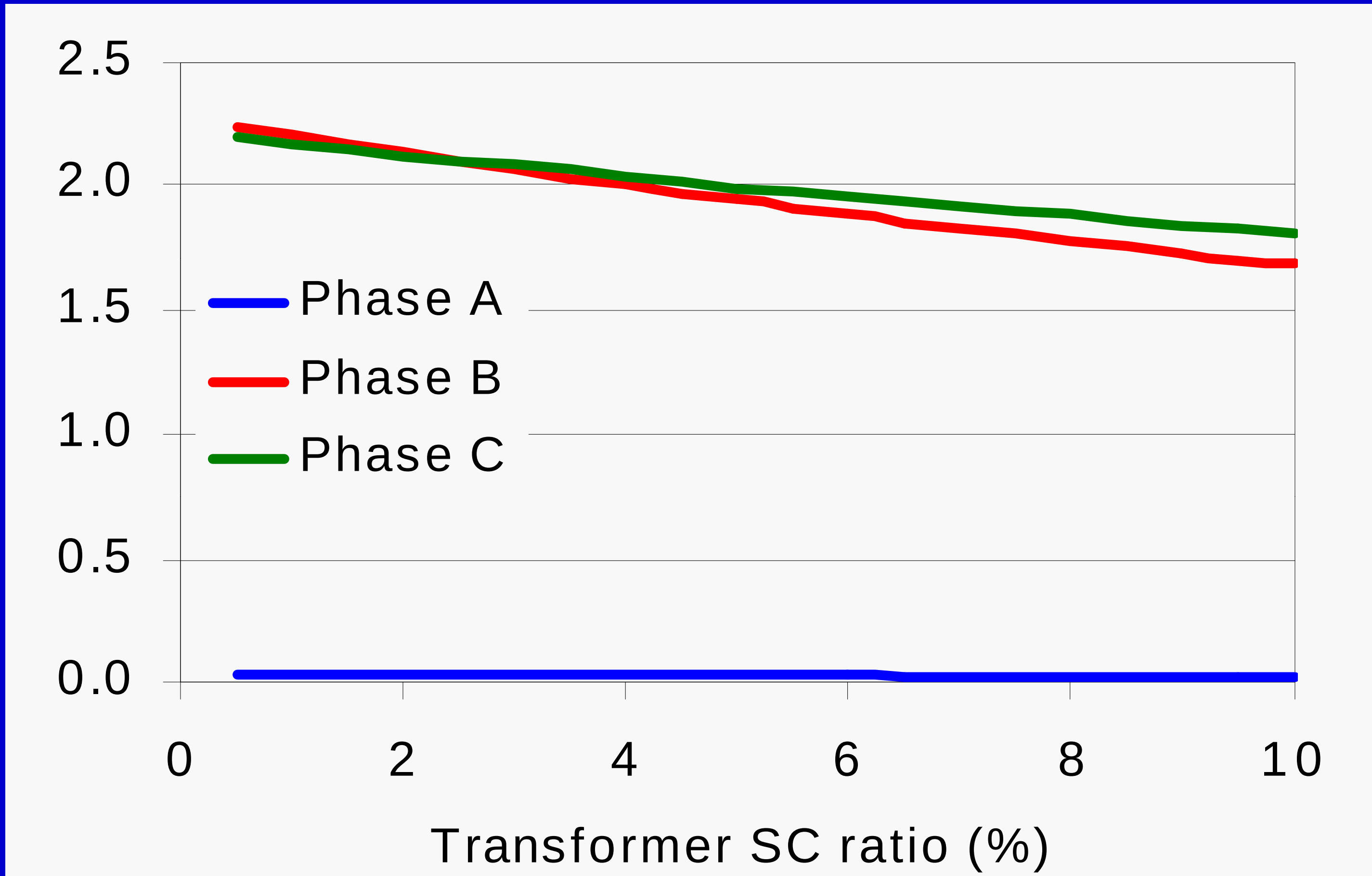
Single-phase-to-ground fault at 4 km from the substation



Line-to-ground voltages - Node 2

Parametric analysis

Single-phase-to-ground fault at 4 km from the substation



Power demand per phase - Node 2

Parametric analysis

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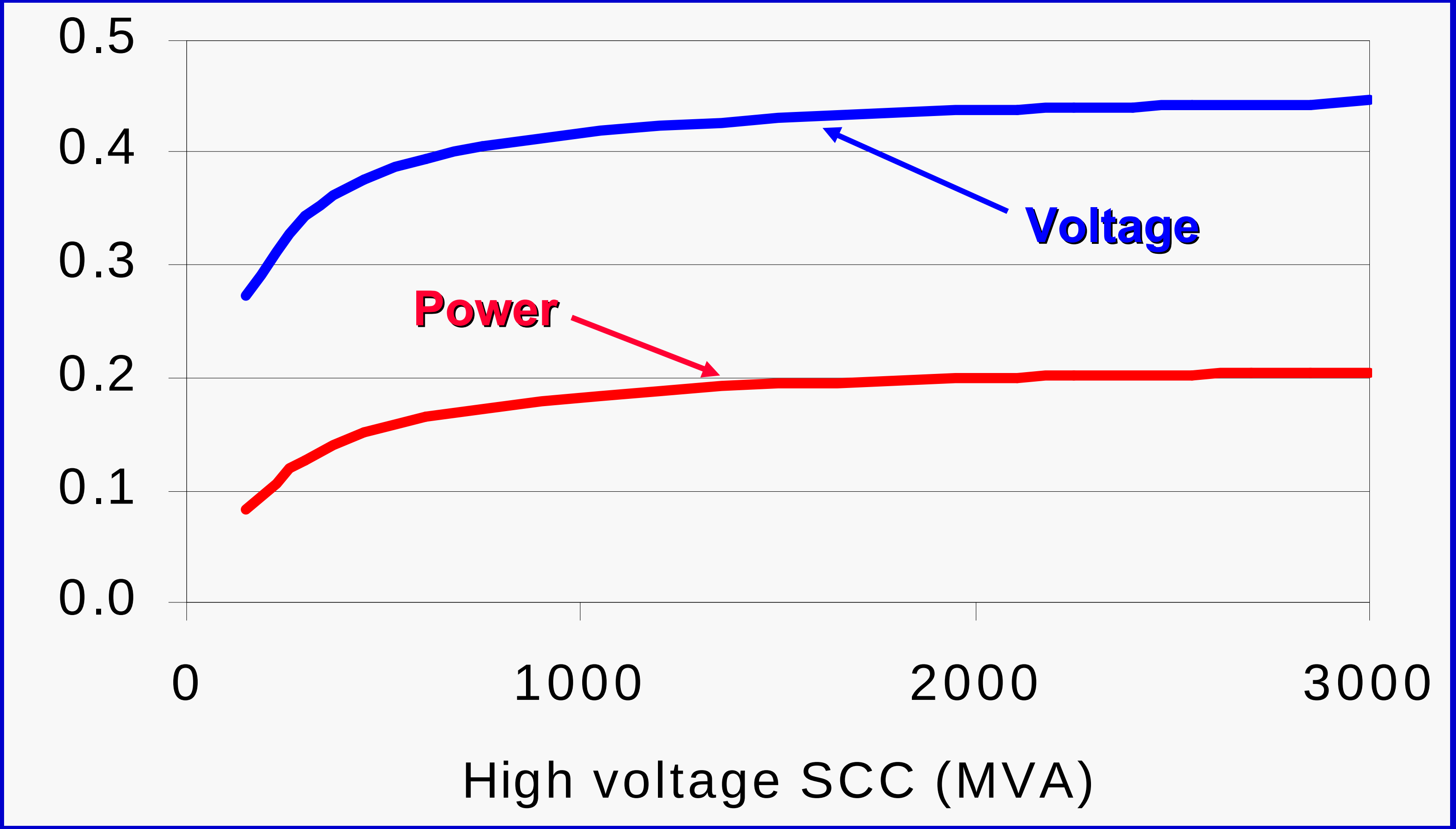
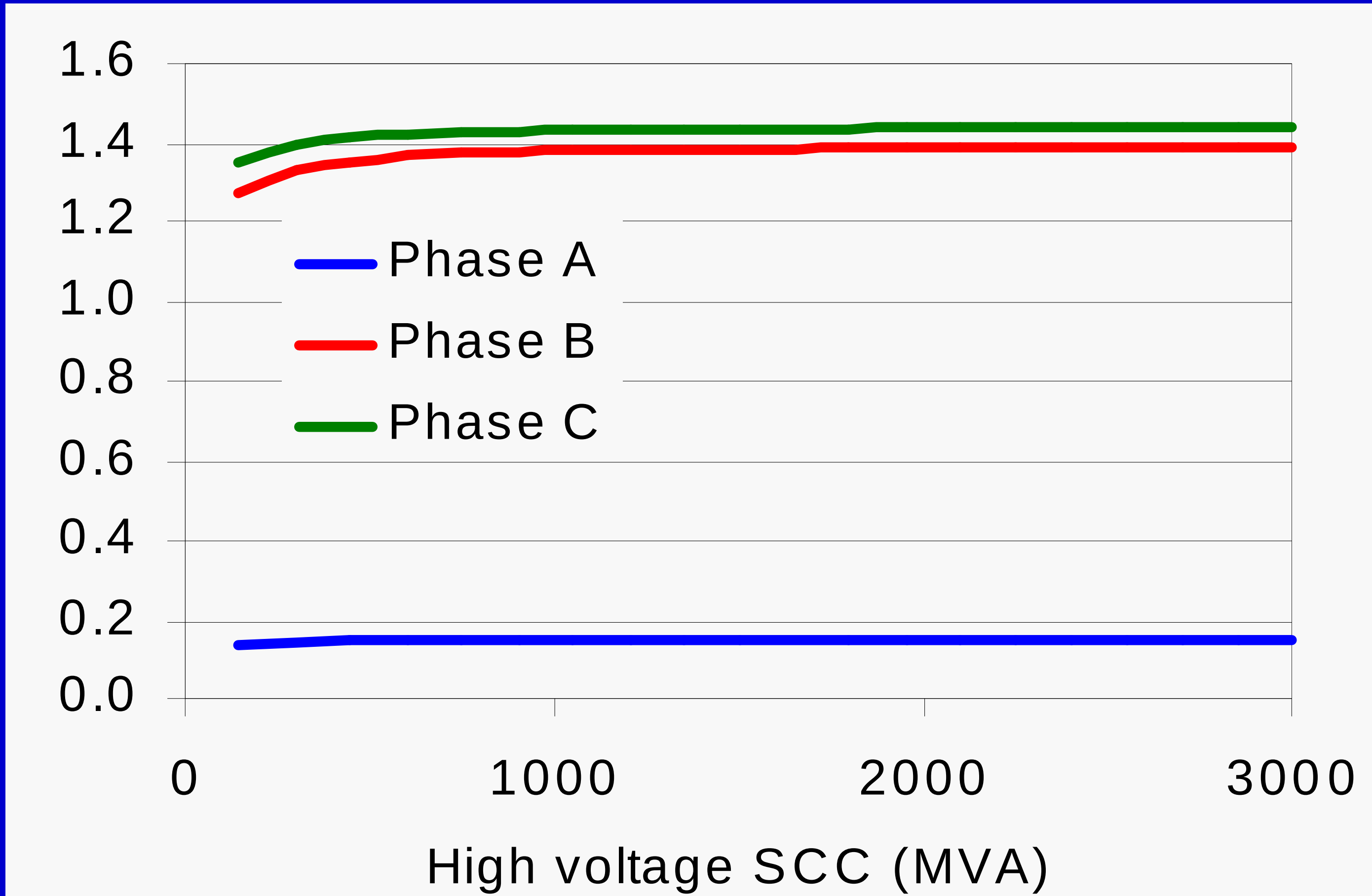


Voltage and power demand per phase - Node 2

Parametric analysis

Single-phase-to-ground fault at 4 km from the substation



Line-to-ground voltages - Node 2

Parametric analysis

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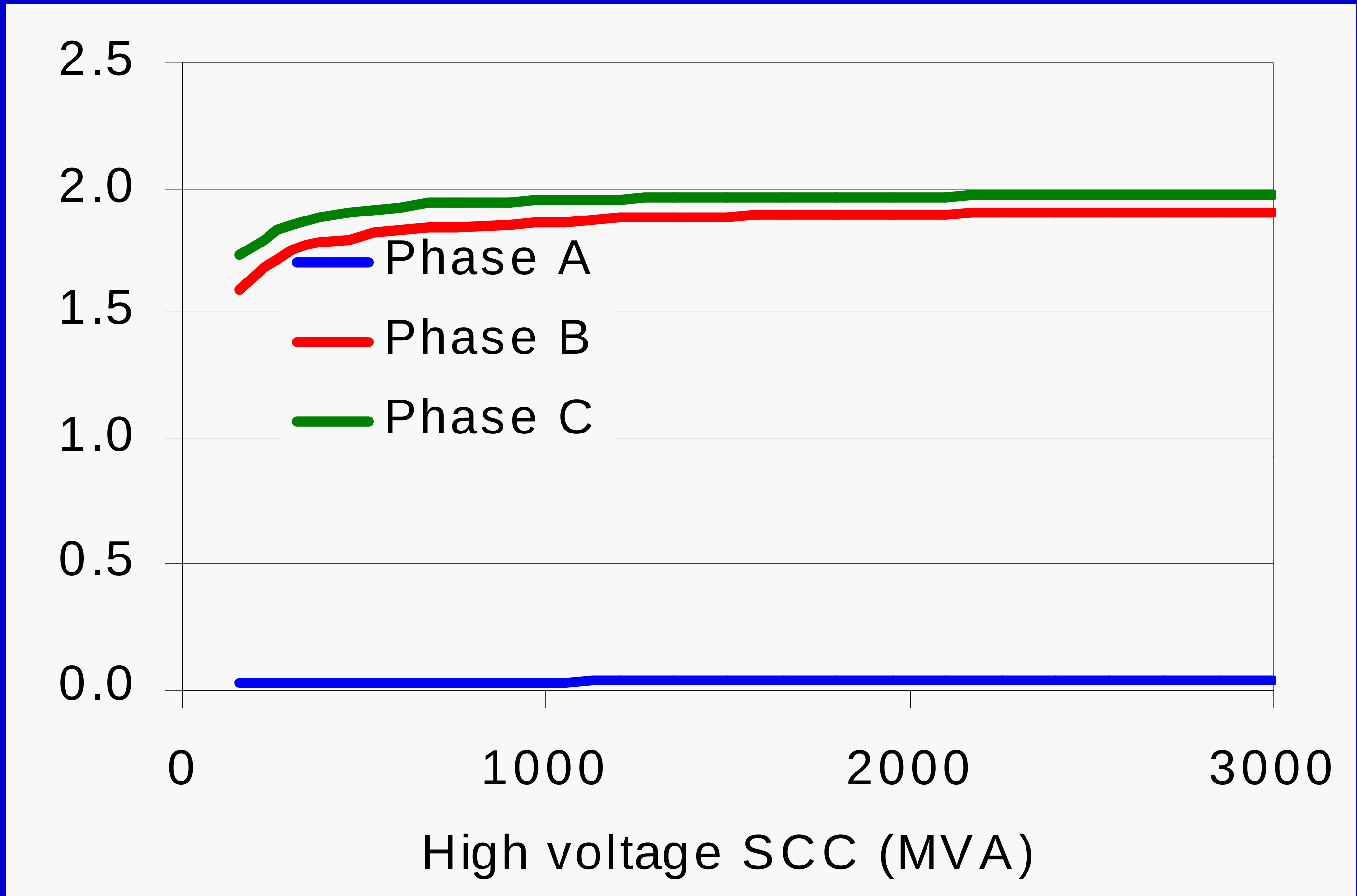
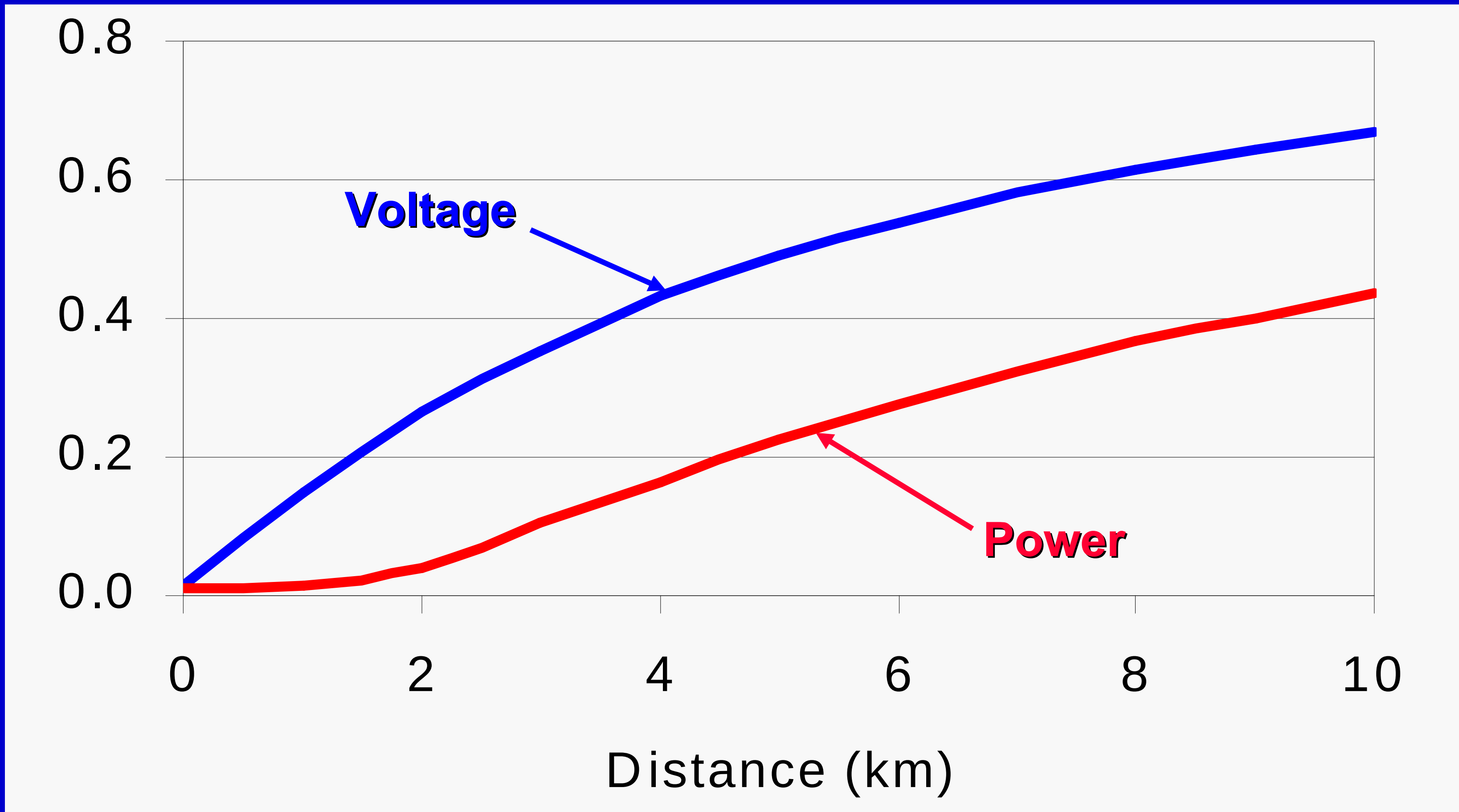


Power demand per phase - Node 2

Parametric analysis

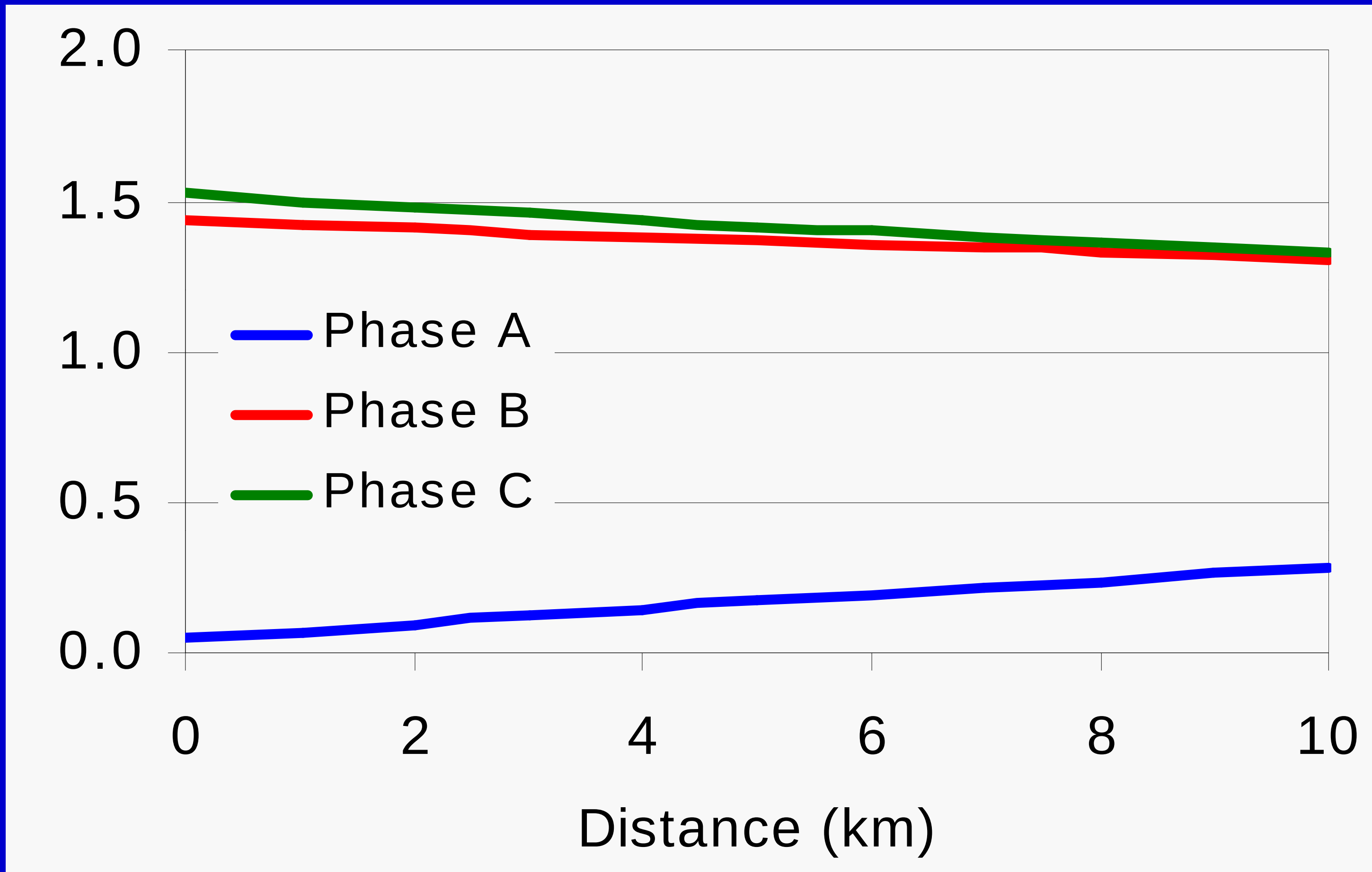
Three-phase-to-ground fault



Voltage and power demand per phase - Node 2

Parametric analysis

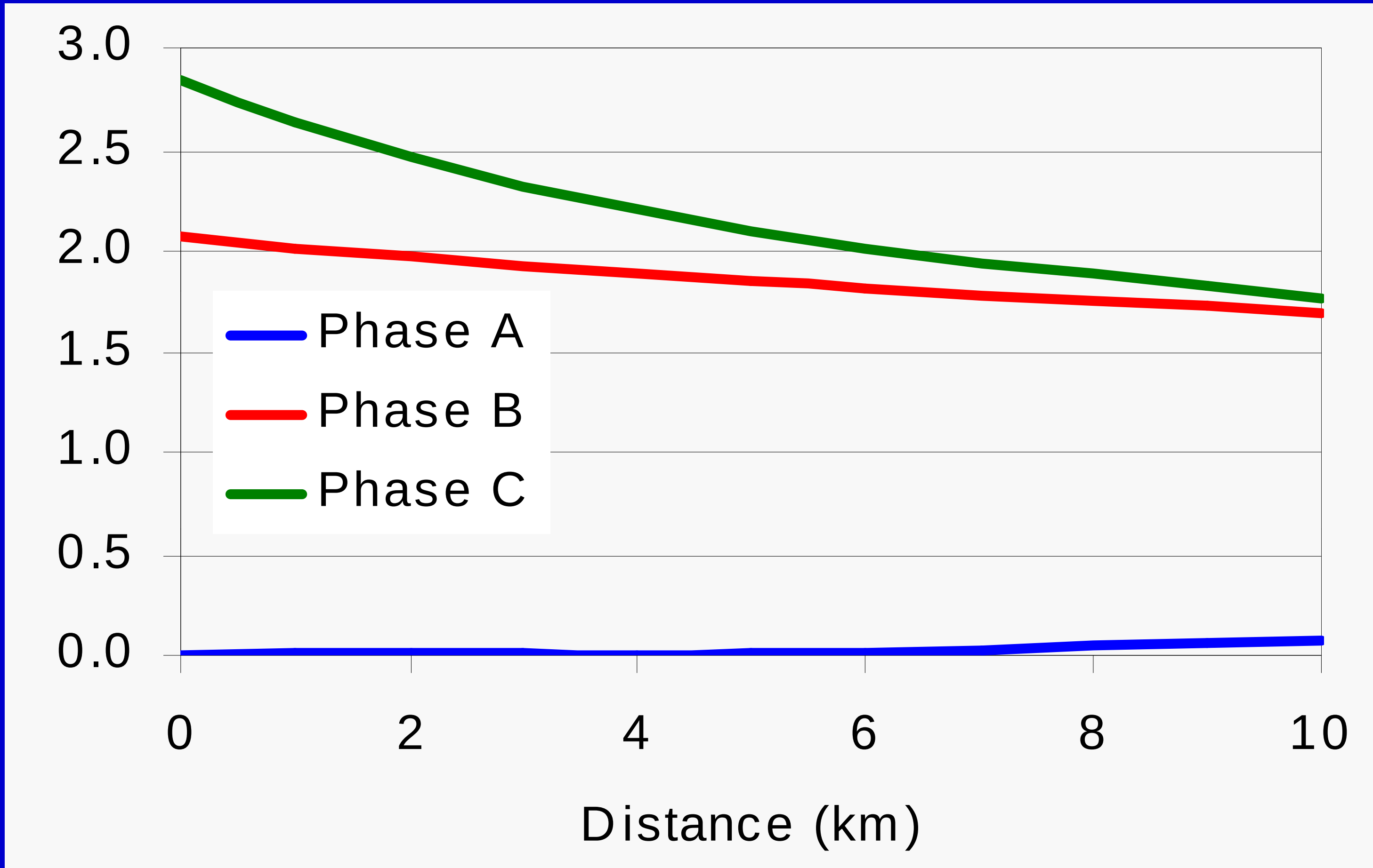
Single-phase-to-ground fault



Line-to-ground voltages - Node 2

Parametric analysis

Single-phase-to-ground fault



Power demand per phase - Node 2