Hector Latorre, ABB FACTS, 2016-11-24
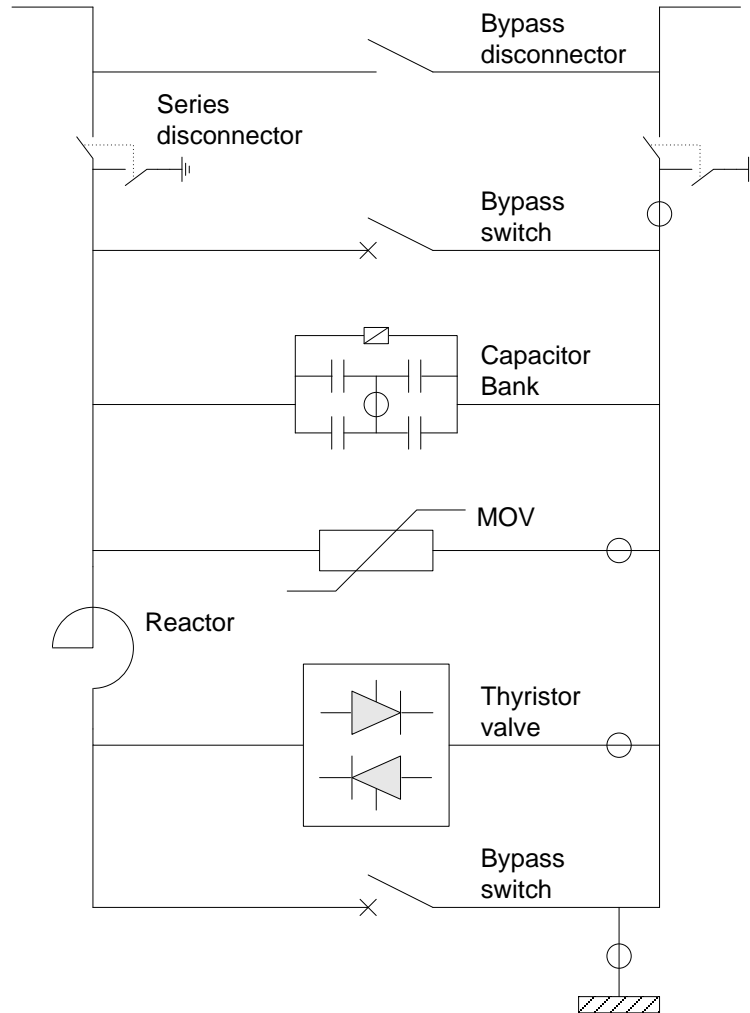
TCSC Introduction and its capability on SSR Mitigation

Power and productivity
for a better world™

ABB

500 kV TCSC

TCSC
Single Line Diagram

Bypass disconnector

Series disconnector

Bypass switch

Capacitor Bank

MOV

Reactor

Thyristor valve

Bypass switch

ABB
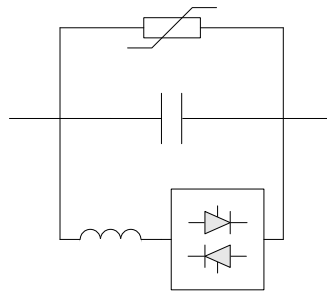
TCSC
Operational objectives

- Thyristor Controlled Series Compensations (TCSC)

- Subsynchronous resonance (SSR) mitigation,

- Power oscillation damping,

- Transient stability

- Current (power flow) control,

- Voltage control (reactance control),

- Phase balancing control

ABB

TCSC
Main components

- **Capacitor bank:**
  compensation degree given by the customer

- **MOV:**
  study performed as a FSC
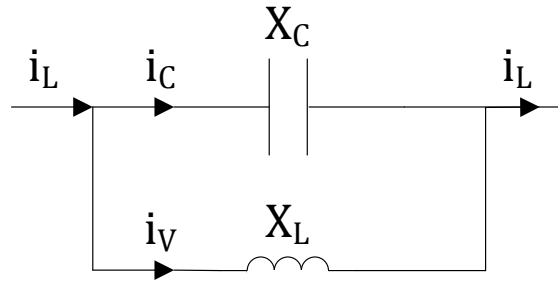
- **Reactor:**
  determined by the factor λ

$$\lambda = \frac{\omega_0}{\omega_N} \qquad\qquad \lambda = \sqrt{\frac{X_C}{X_L}}$$

- λ can be between 2 and 4. Typical values: 2.5 and 3.5

- **Thyristor valves:**
  Number of thyrstors is mainly a function of the capacitor voltage at triggering instant and protective level
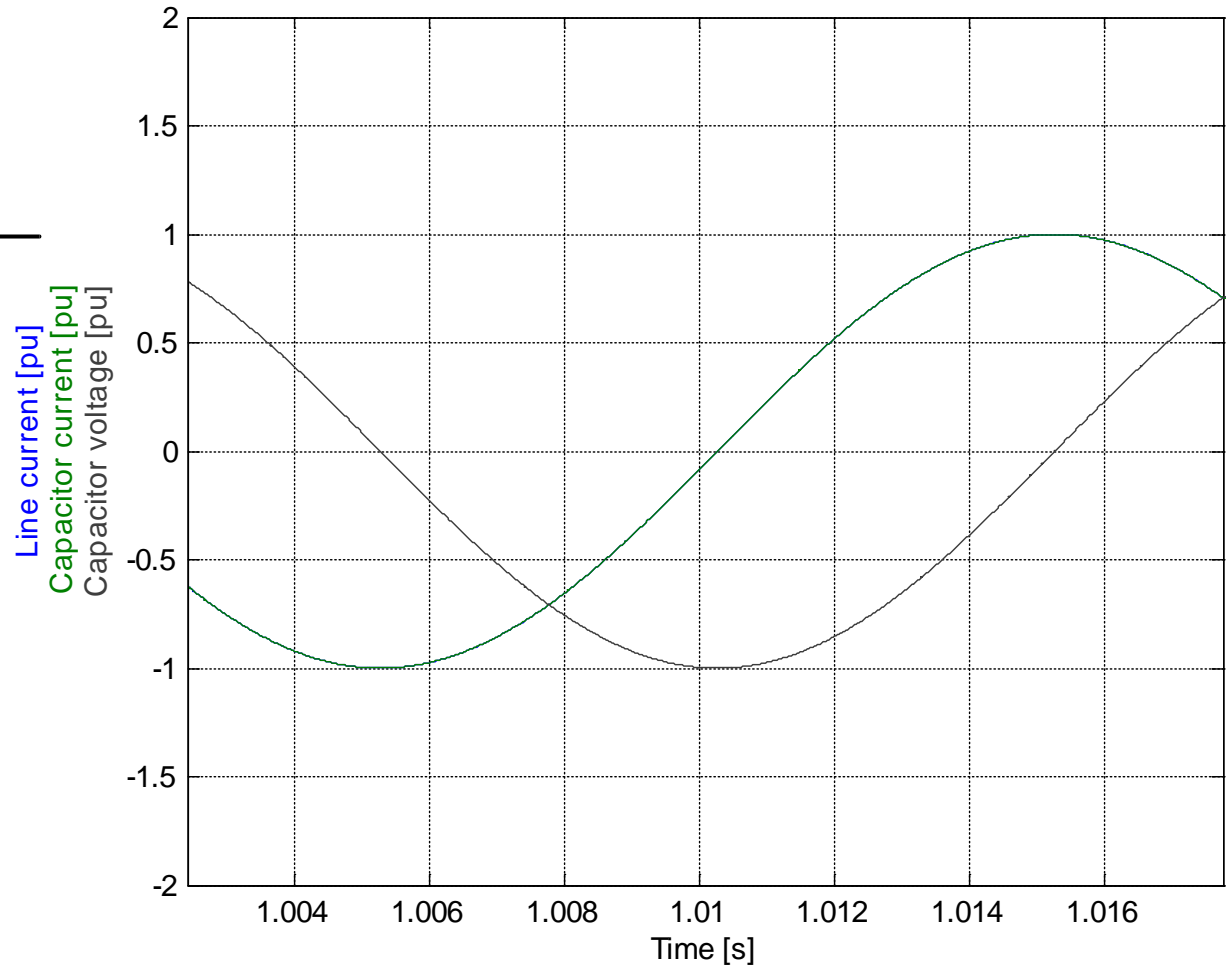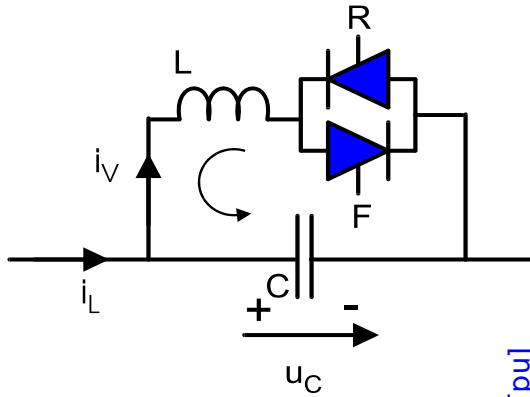
TCSC
Steady state operation
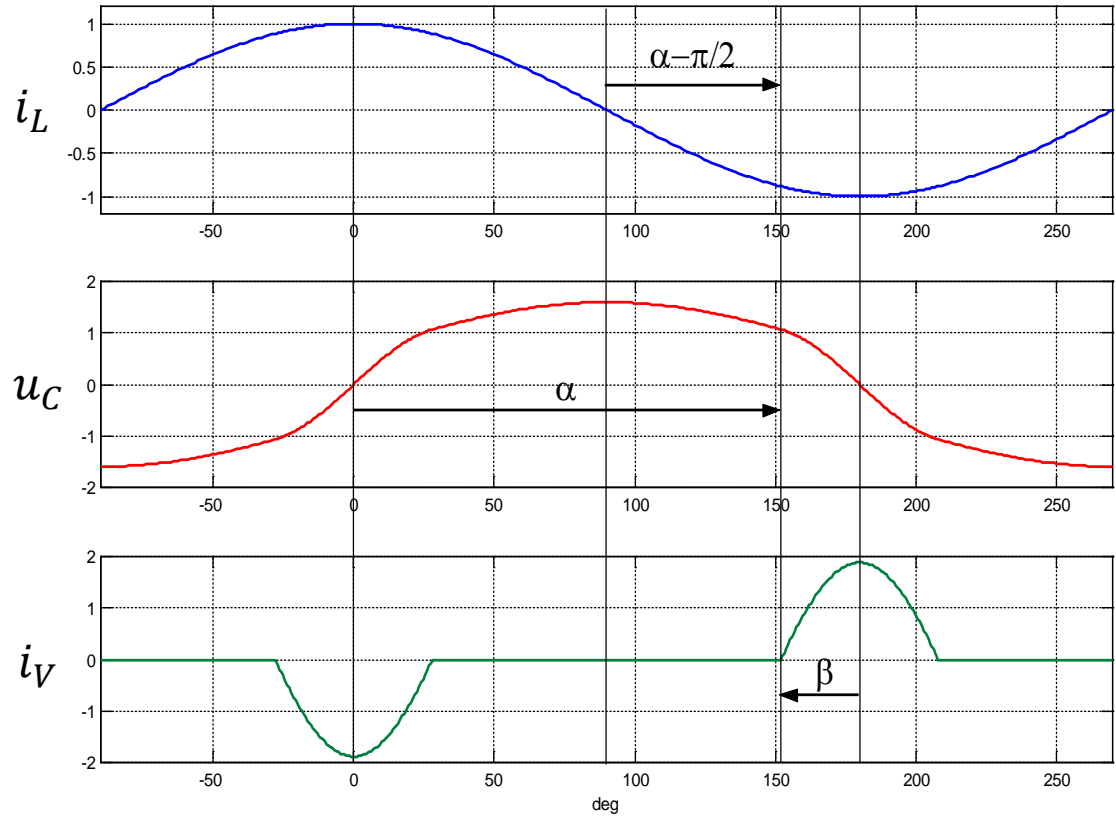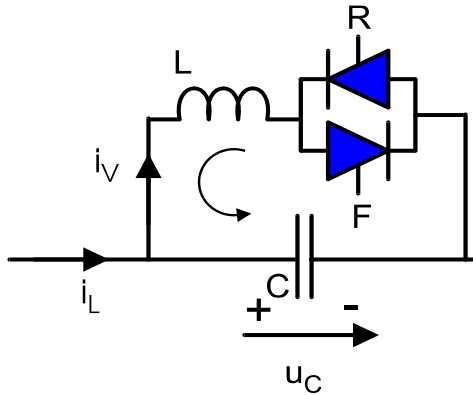
- Currents in TCSC circuit

$$i_V = i_L \frac{-jX_C}{j(X_L - X_C)}$$
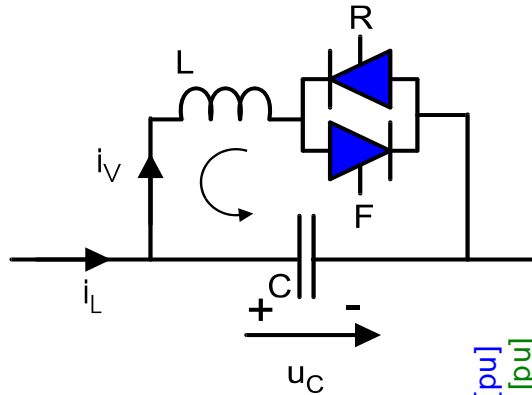
$$i_C = i_L \frac{-jX_L}{j(X_L - X_C)}$$

TCSC Operation
Blocked mode

TCSC Operation
Capacitive (boost or Vernier) mode
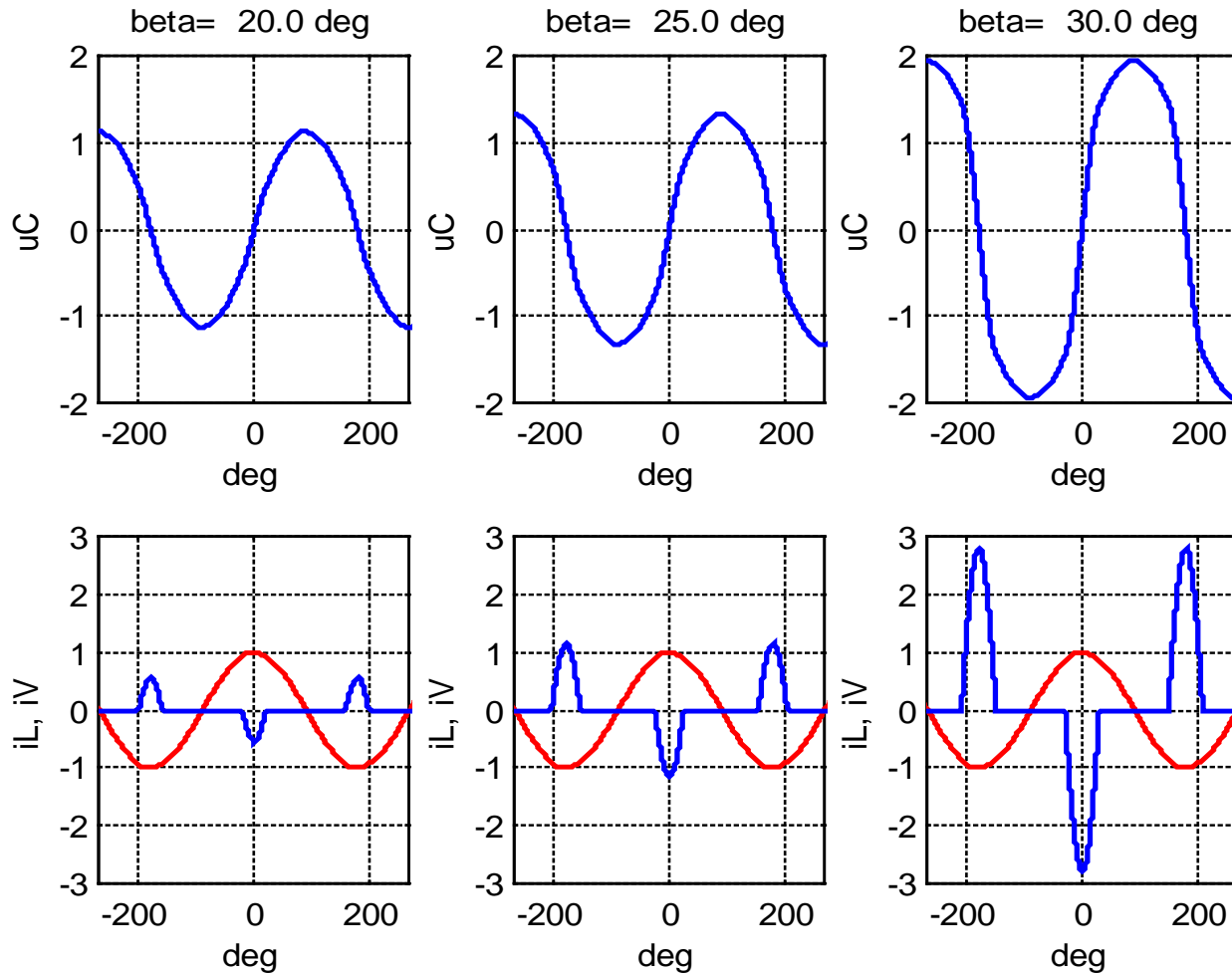
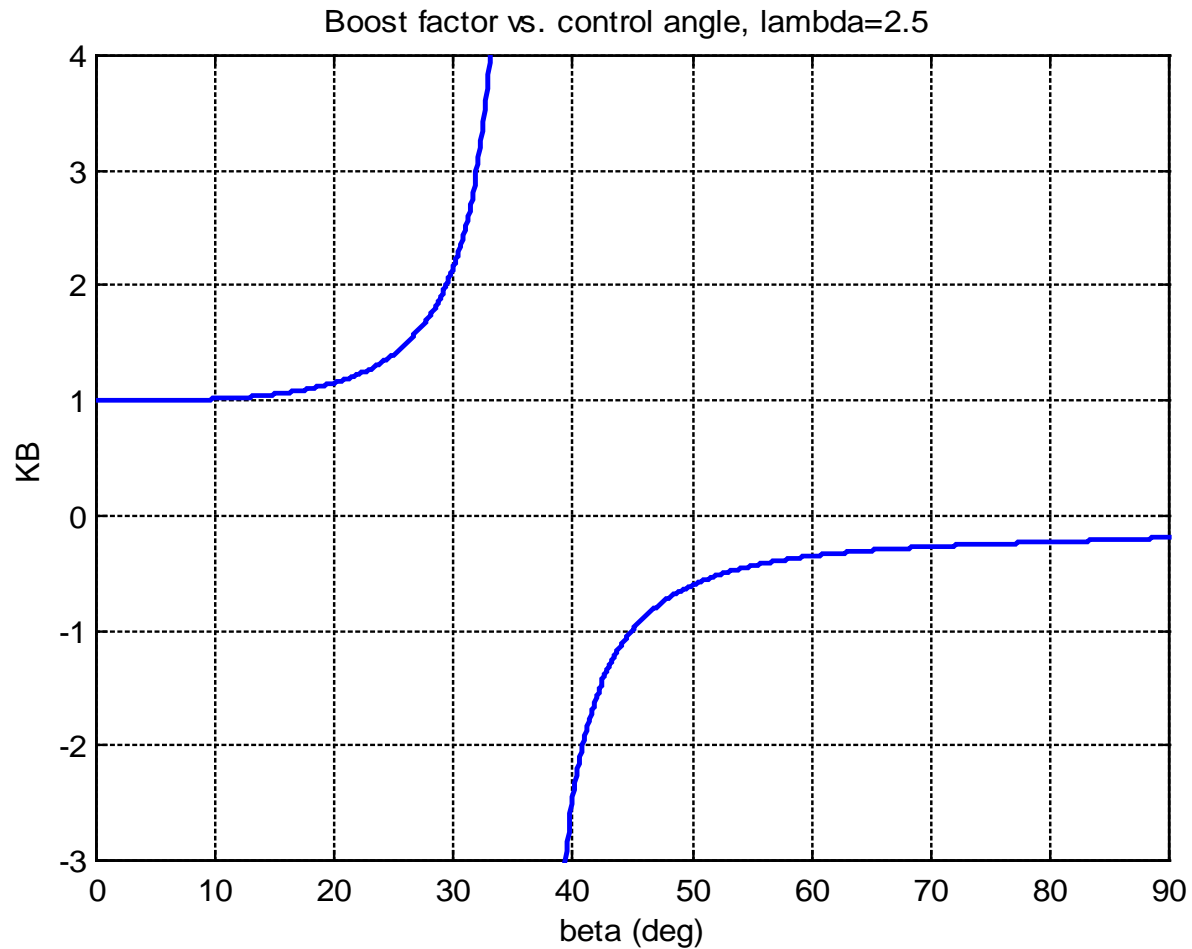# TCSC Operation
Capacitive (boost or Vernier) mode

Boost factor:

$$k_B = \frac{\widehat{U}_{app}}{\widehat{U}_{C0}}$$
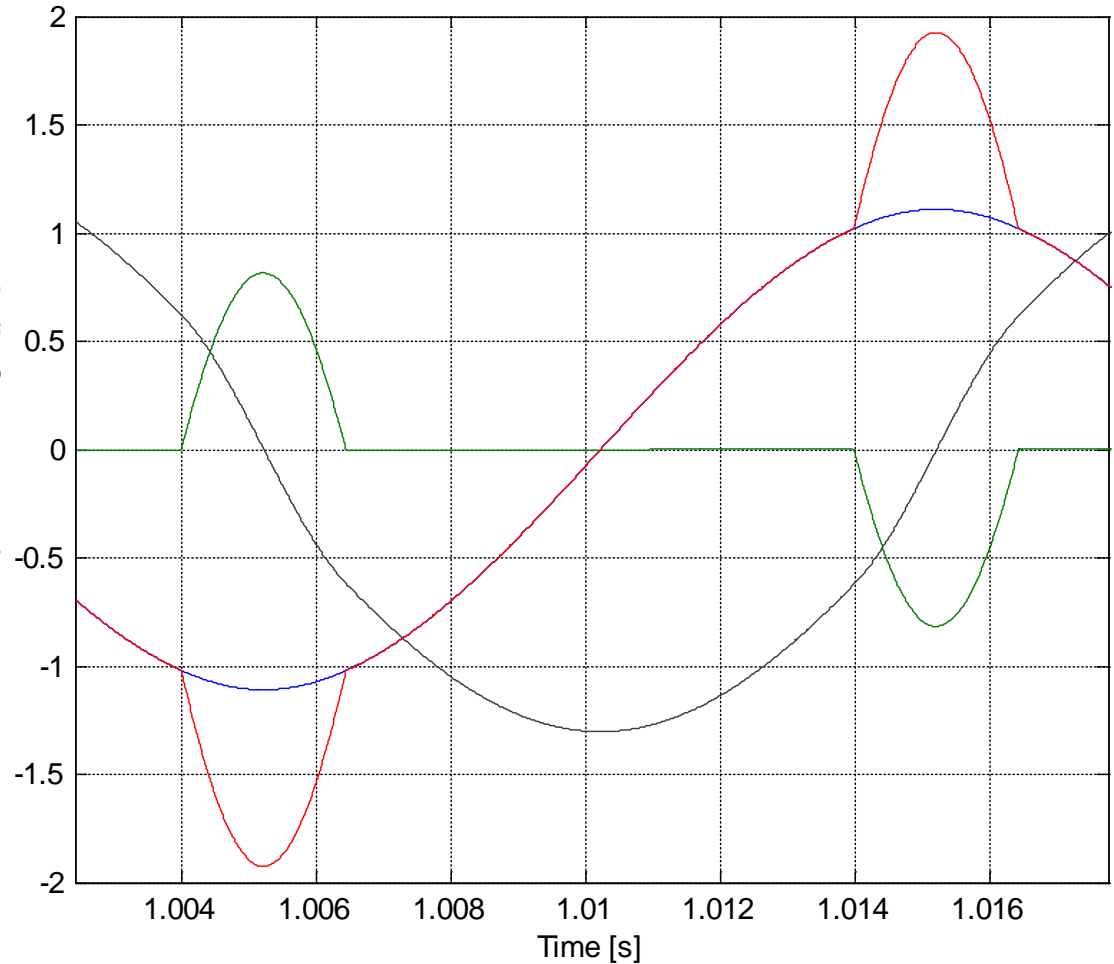
Operation in CAP mode

Steady state relation between firing angle and kB

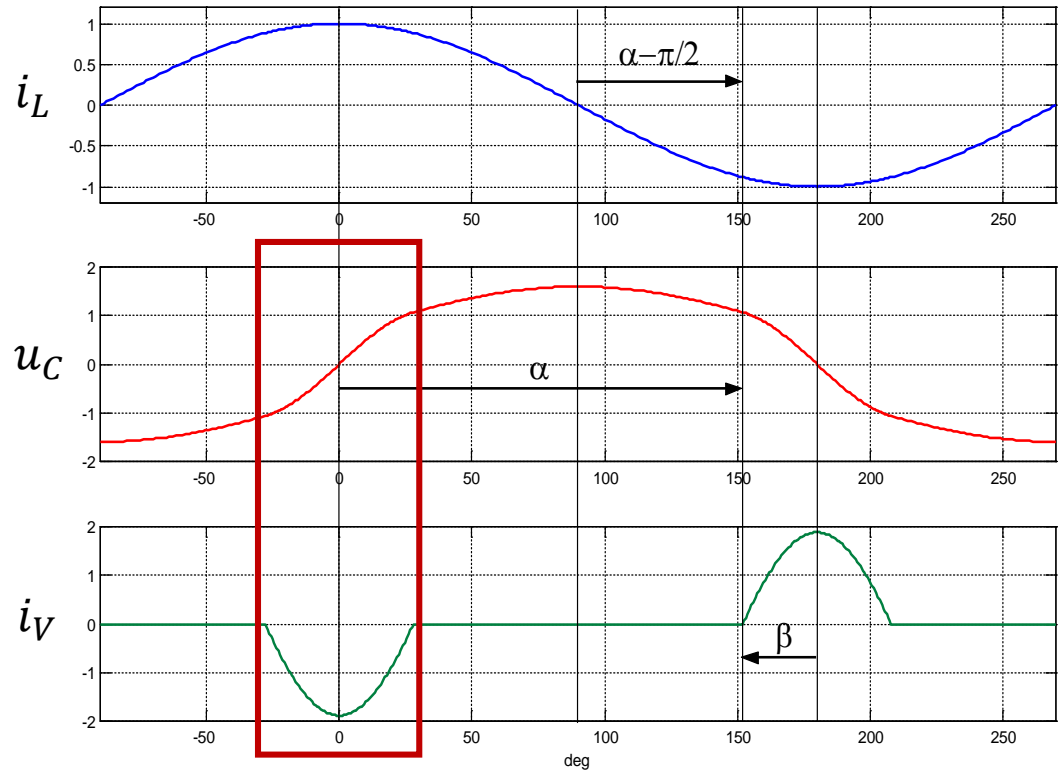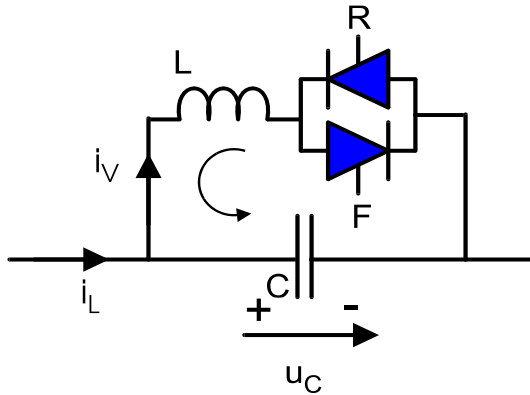Boost factor vs. control angle, lambda=2.5
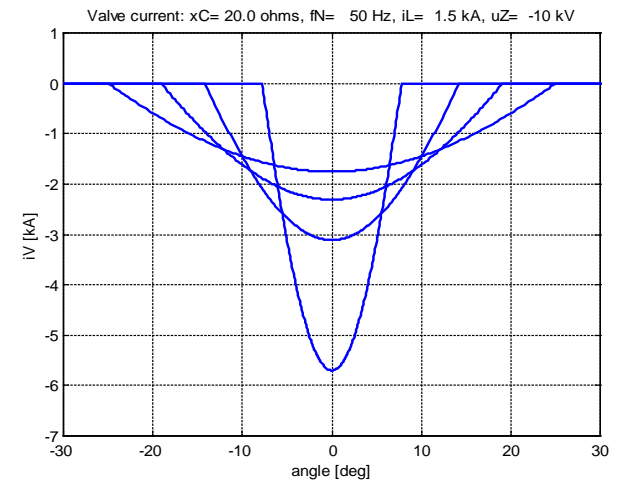
Typical operating range for POD
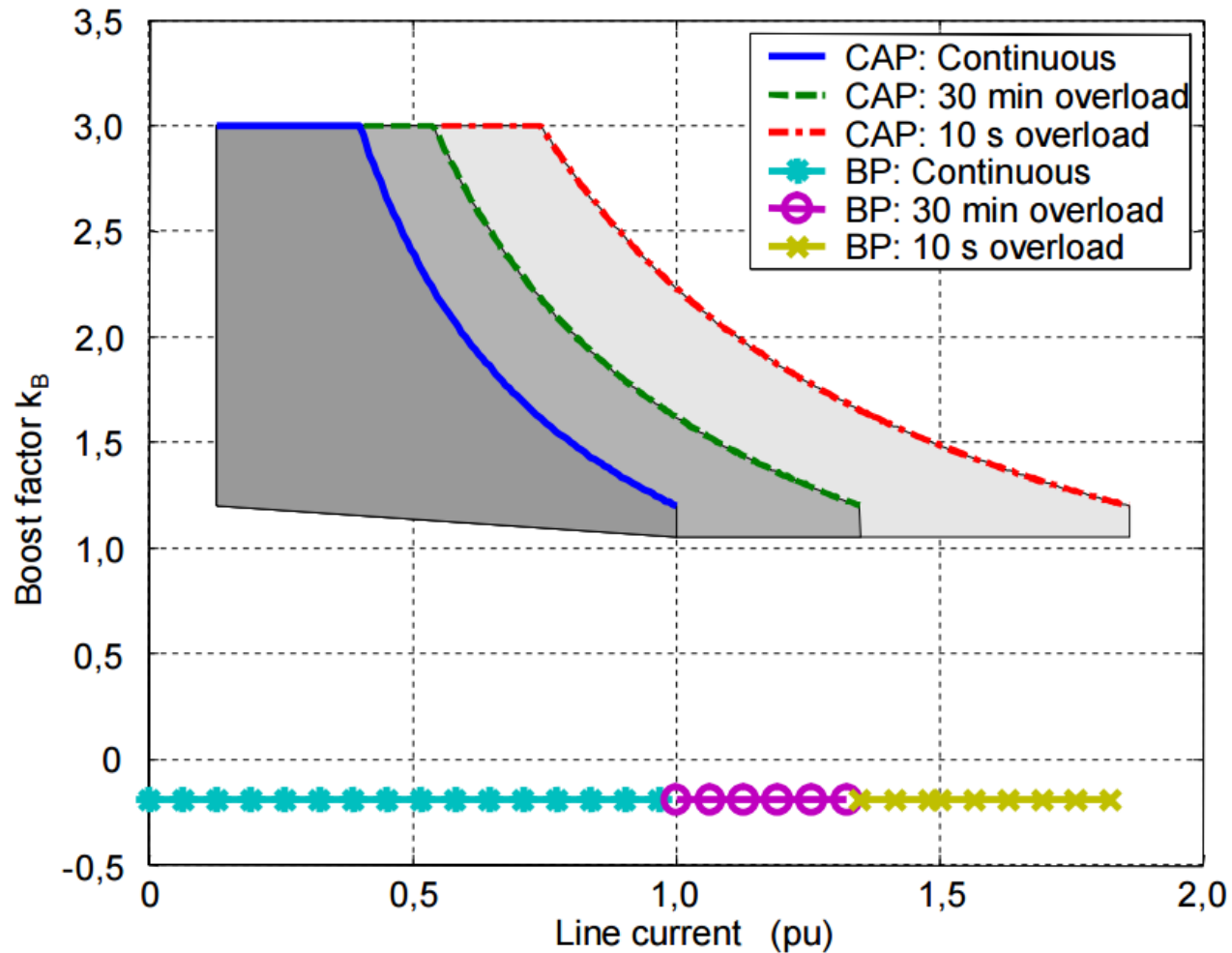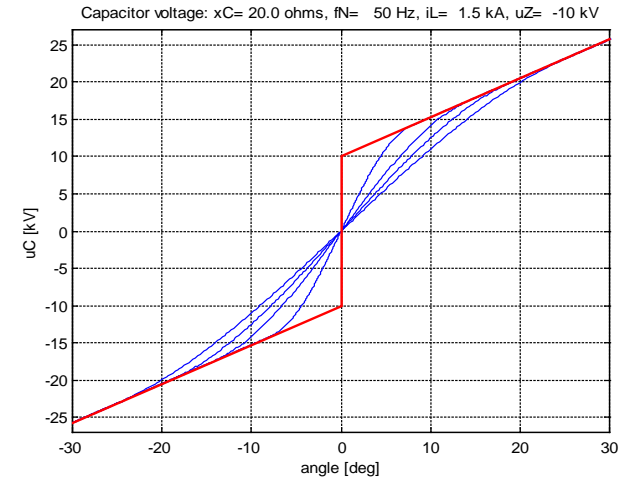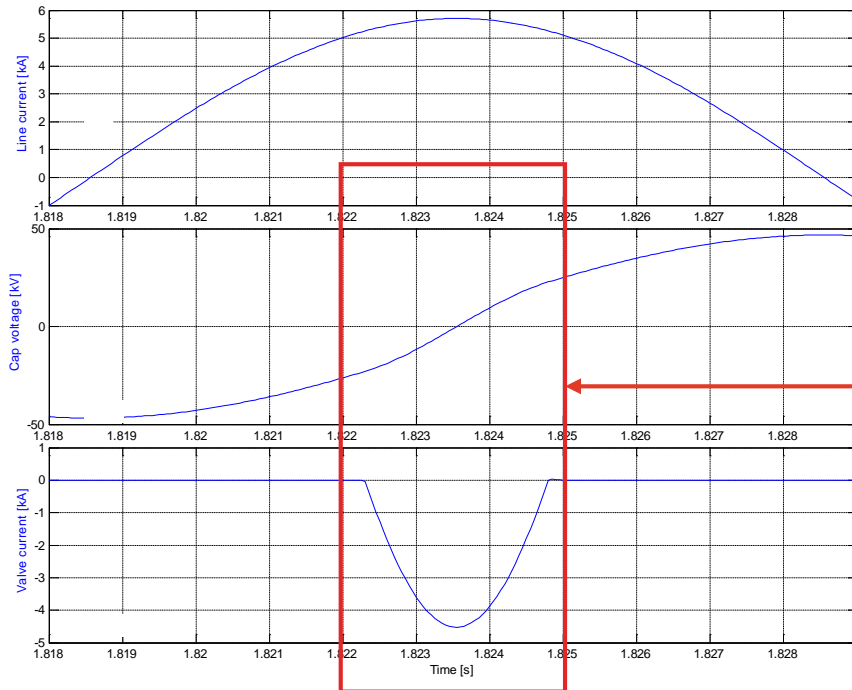
Typical operating range for SSR mitigation
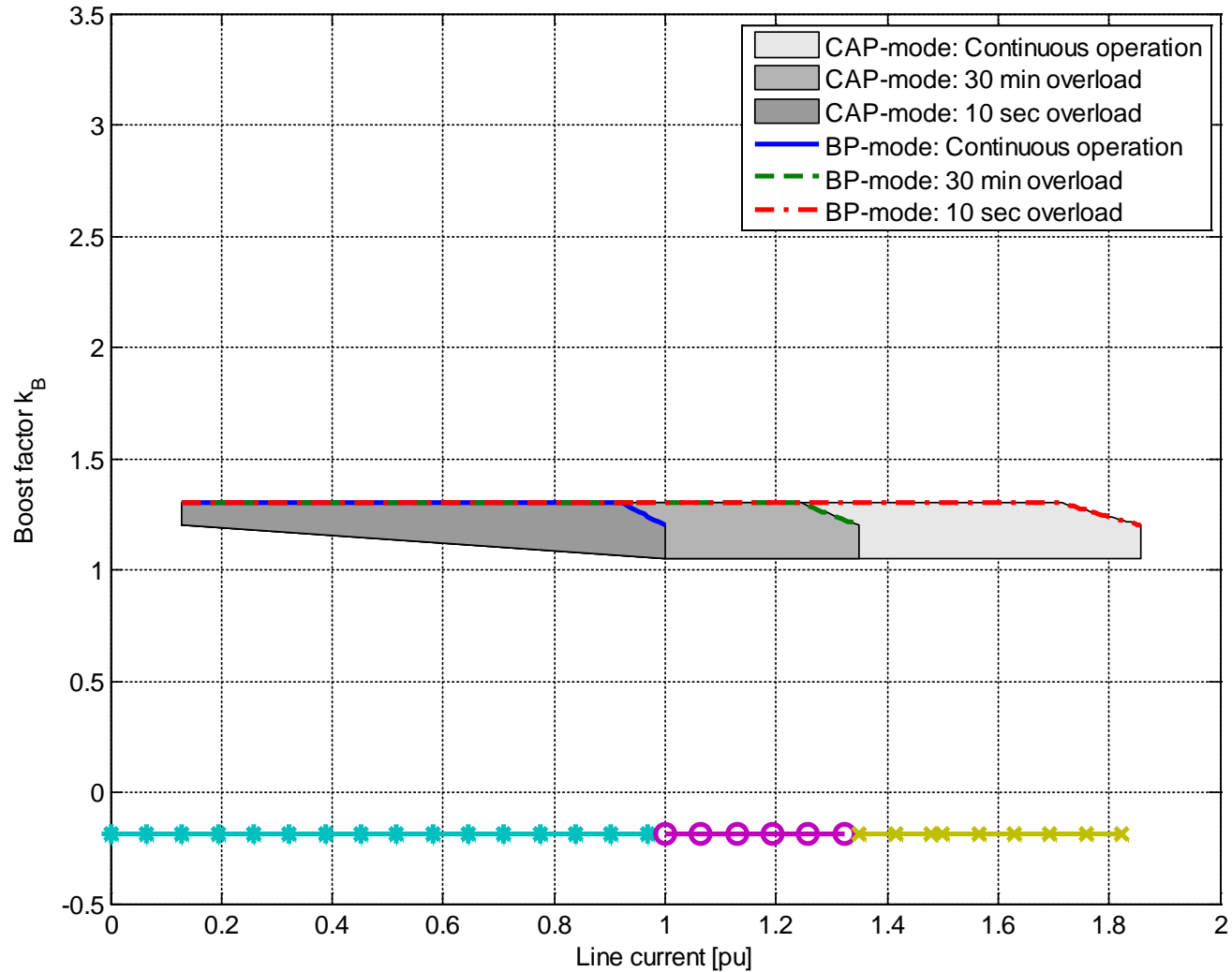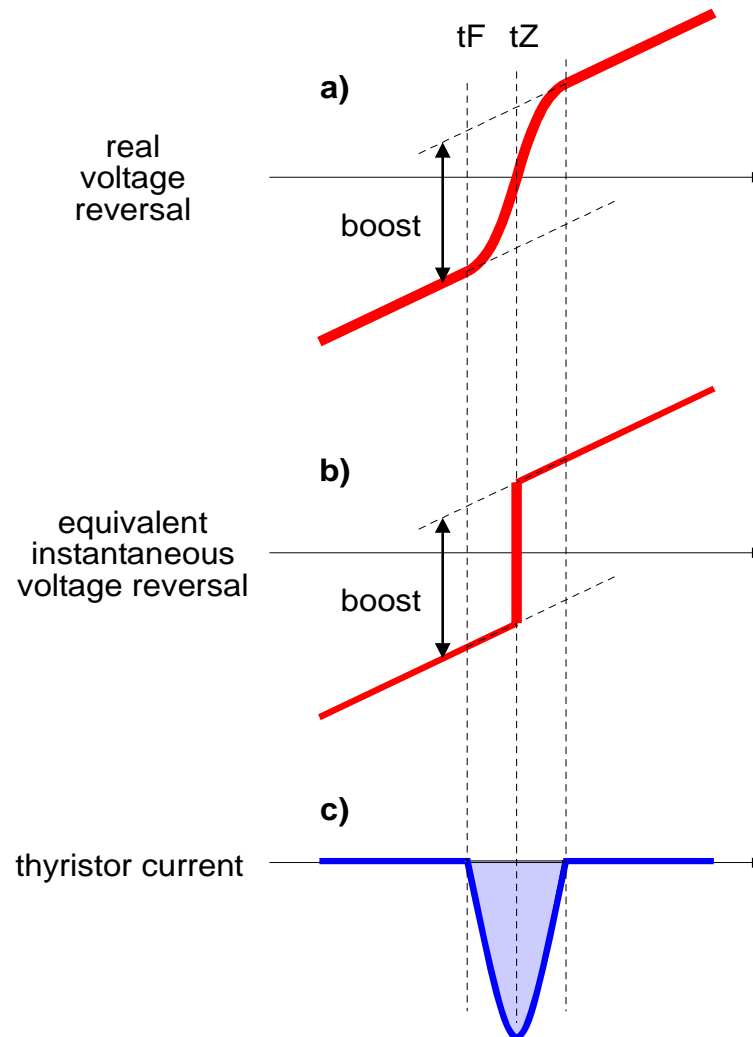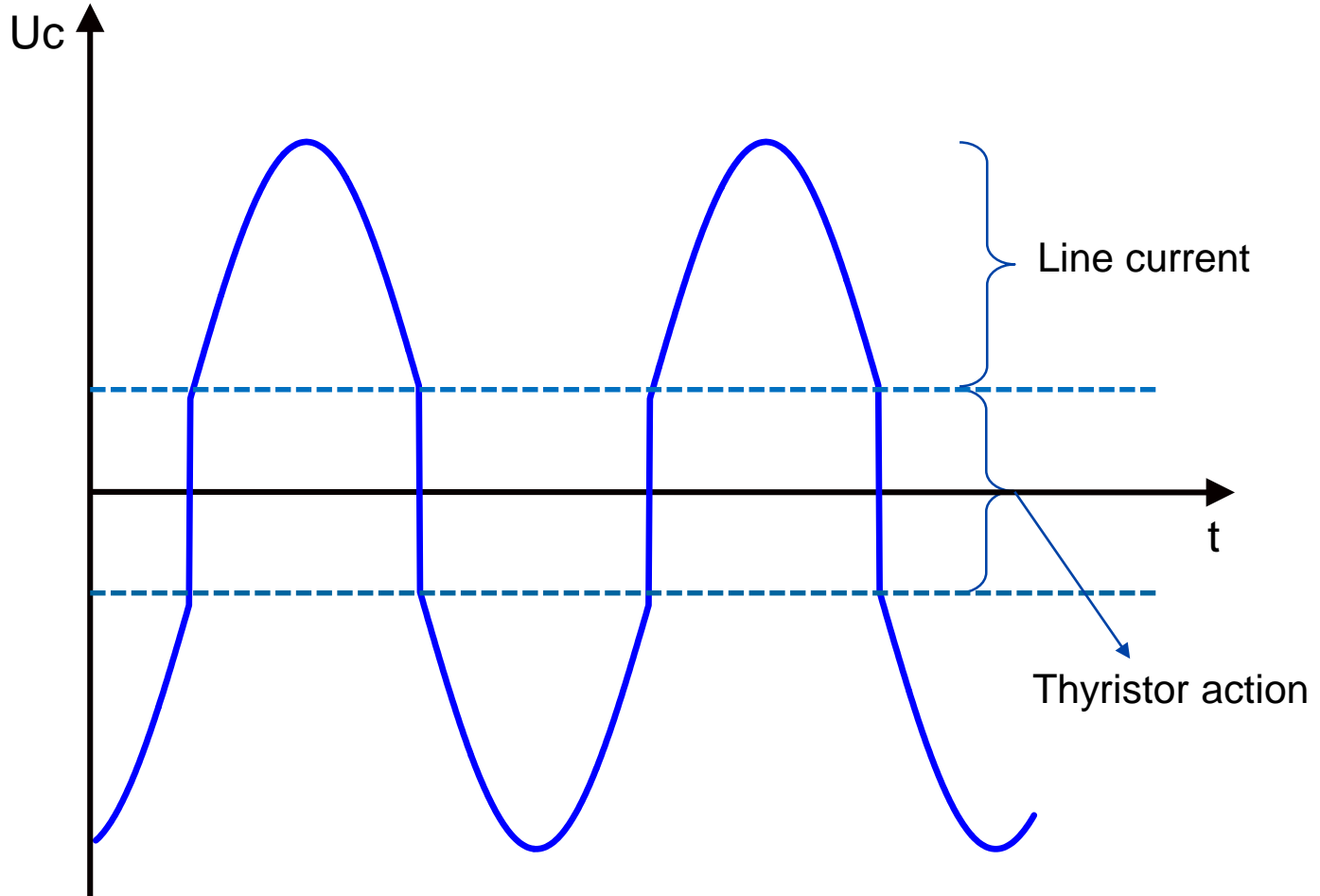
TCSC Control
Synchronous Voltage Reversal

Synchronous Voltage Reversal
Thyristor action

Equivalent instantaneous voltage reversal

Idealized steady-state voltage
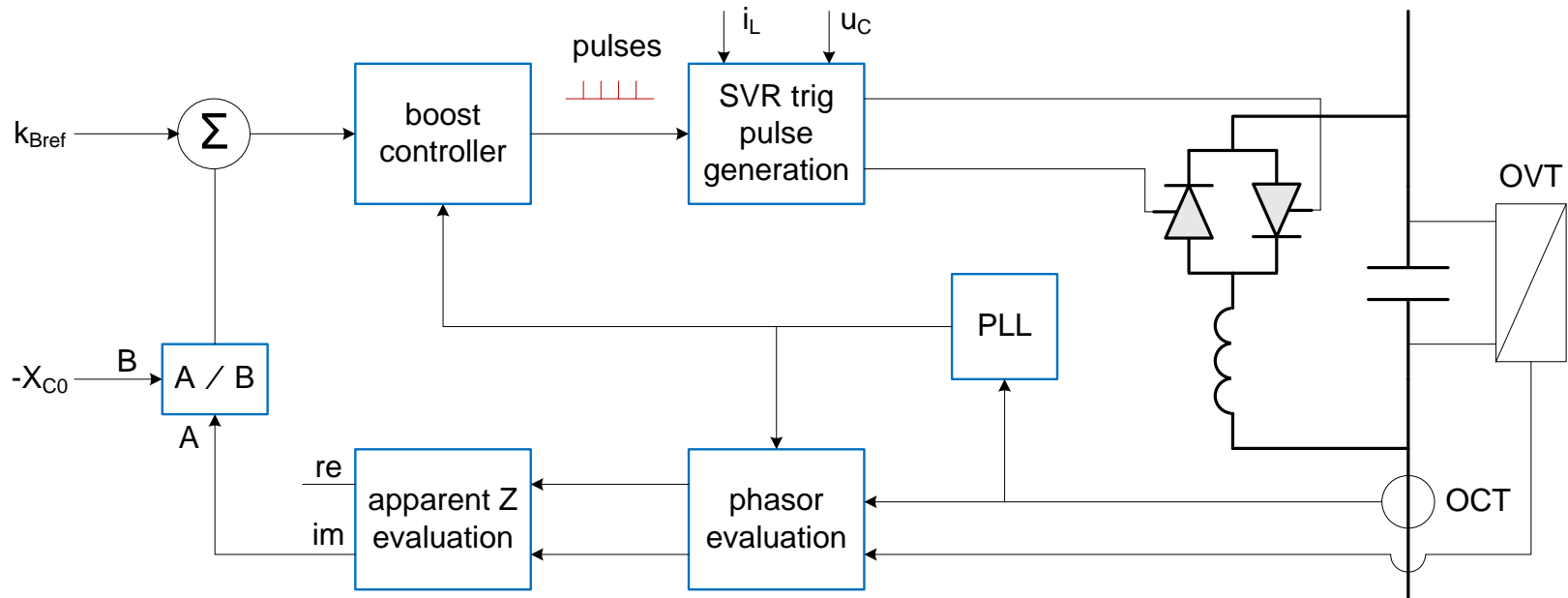

Uc

Line current

t

Thyristor action

ABB

Boost control

Line current

i_L

i_L

$\Delta\varphi_C > 0$

i_L

$\Delta\varphi_C < 0$

Capacitor voltage

u_C

$\Delta u_z = 0$

u_C

$\Delta u_z > 0$

u_C
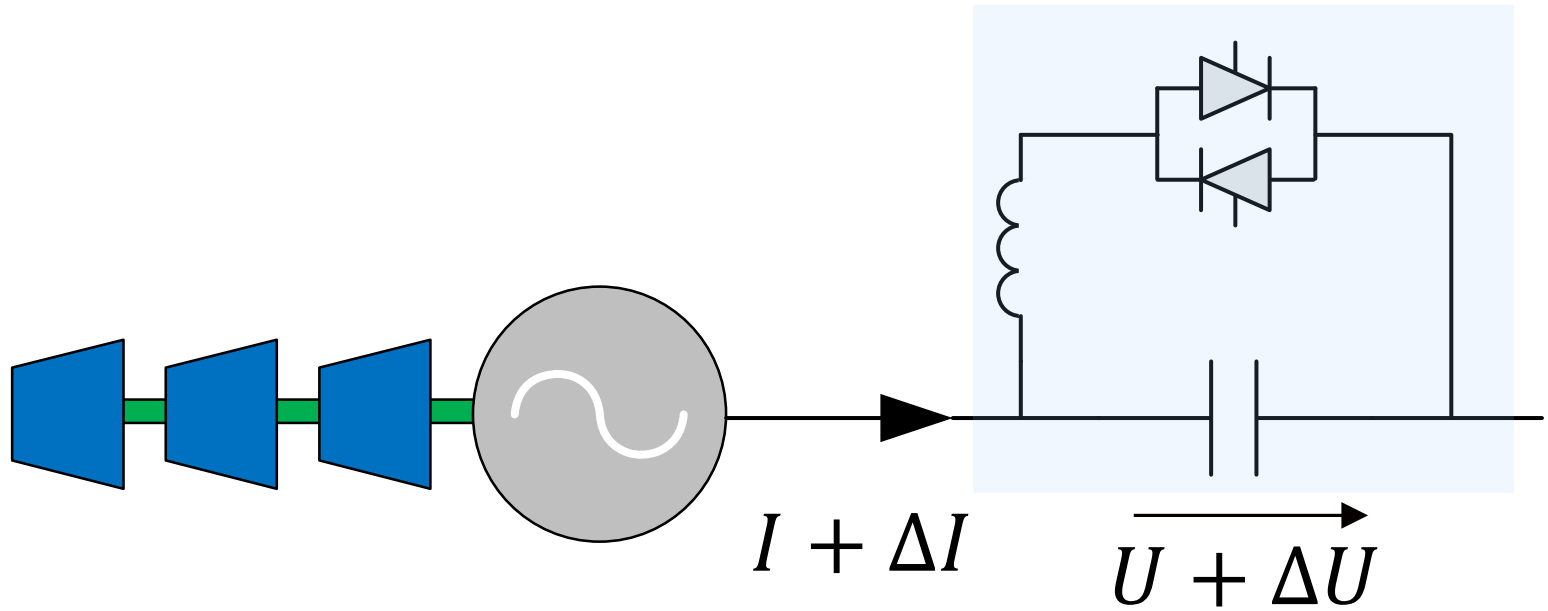
$\Delta u_z < 0$

constant
boost

increasing
boost

decreasing
boost

ABB
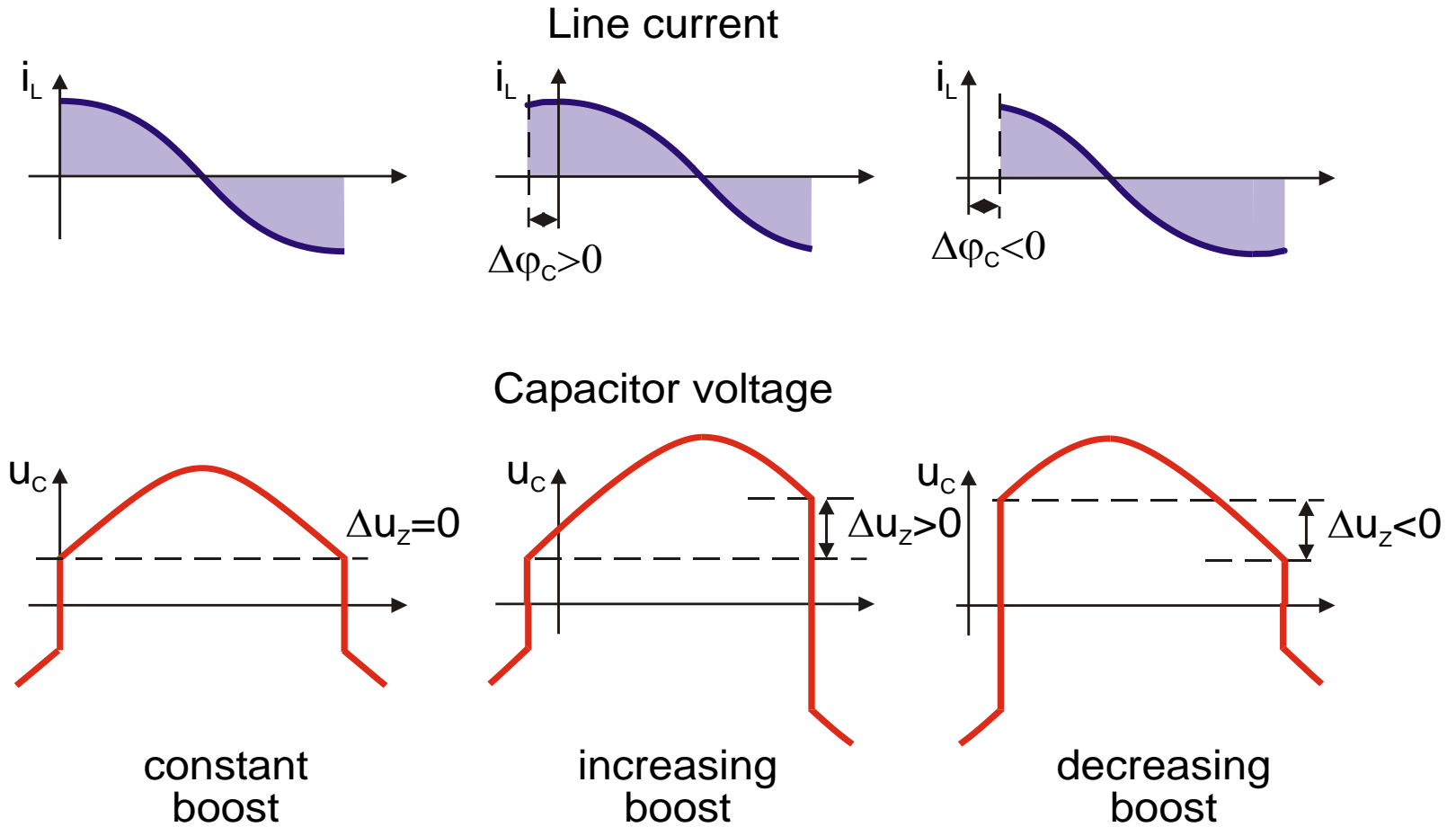
Outline TCSC control

OCT: Optical Current Transducer
OVT: Optical Voltage Transducer

Apparent impedance

$$I + \Delta I$$

$$\overrightarrow{U + \Delta U}$$
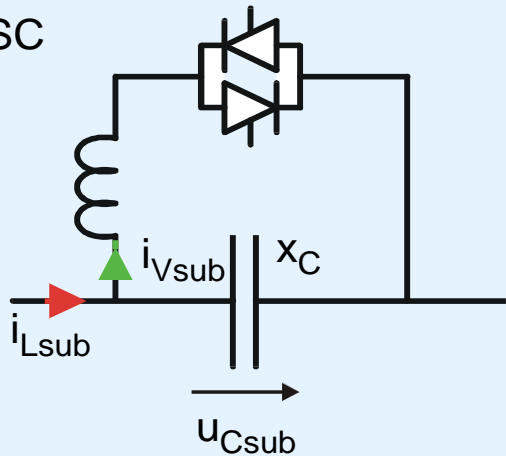
$$Z_{app} = \frac{\Delta U}{\Delta I}$$

Apparent impedance for FSC and TCSC

fixed series capacitor

x_C
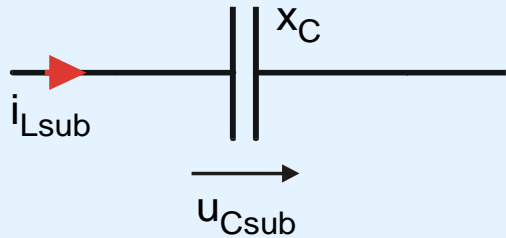
i_{Lsub}

u_{Csub}

$$z_{app} = \frac{u_{Csub}}{i_{Lsub}} = -j\,\frac{f_N}{f_{sub}}\,x_C$$

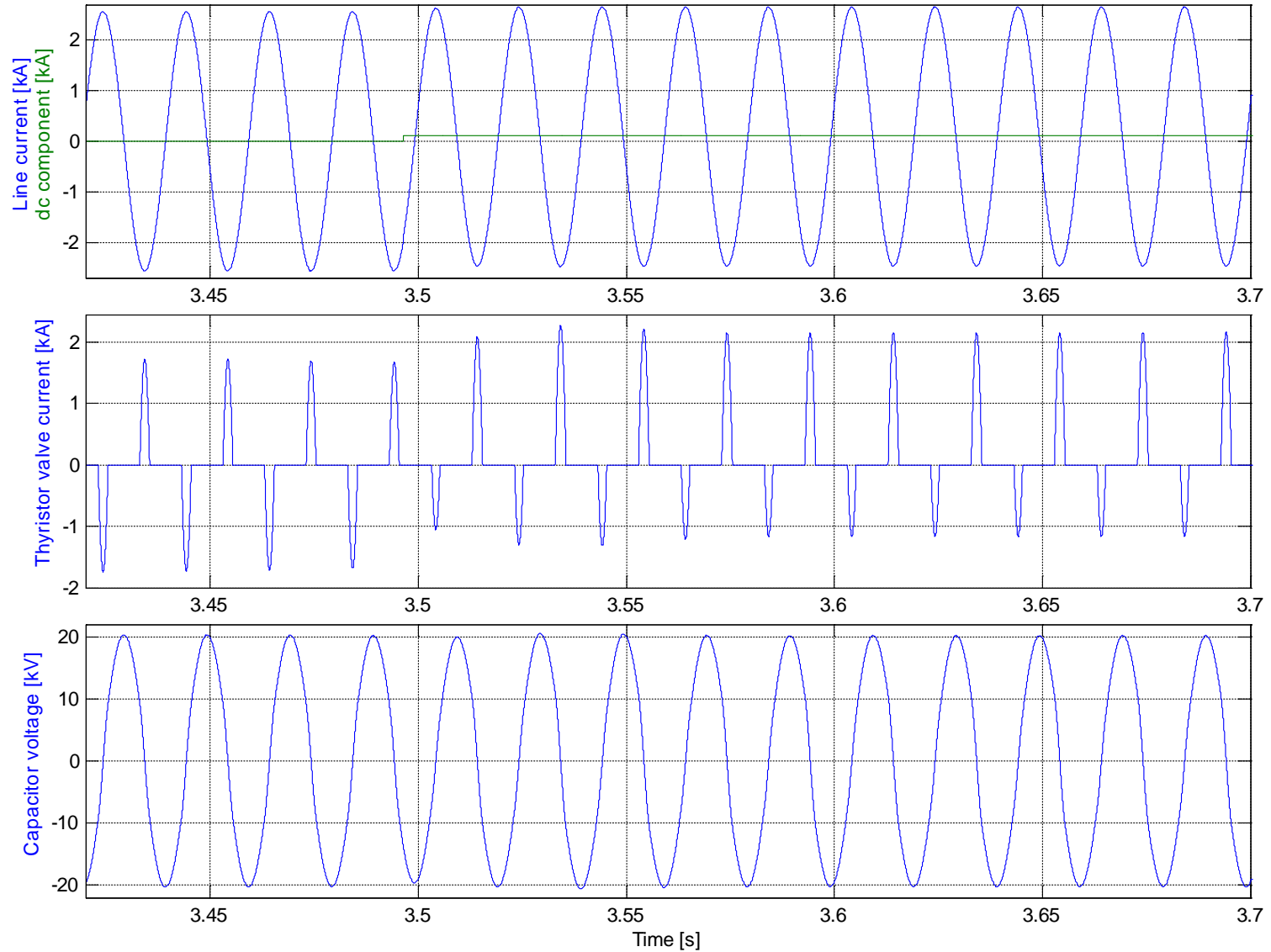**TCSC**

i_{Vsub} x_C

i_{Lsub}

u_{Csub}

$$z_{app} = \frac{u_{Csub}}{i_{Lsub}} = -j\,\frac{f_N}{f_{sub}}\,\frac{i_{Lsub}-i_{Vsub}}{i_{Lsub}}\,x_C = ?$$

ABB

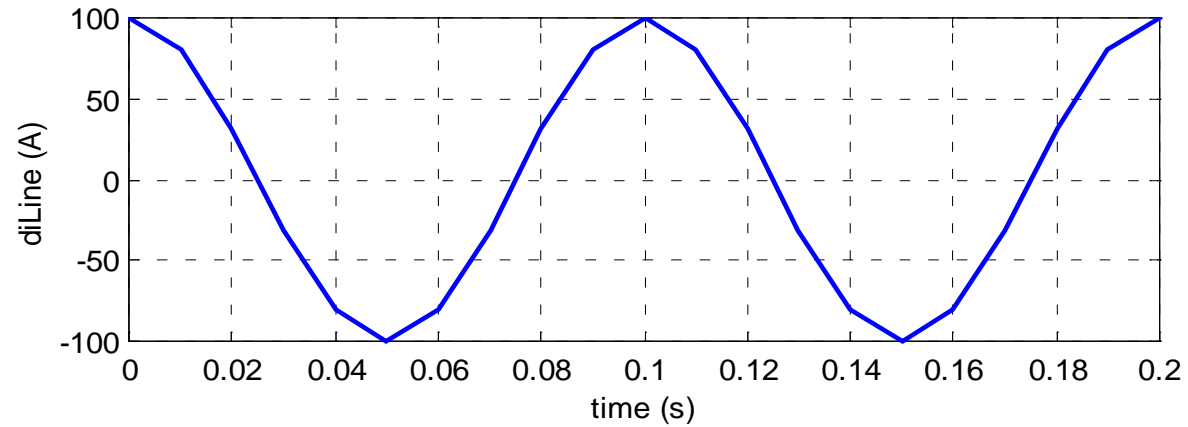# 10 Hz current in a fixed SC

Fixed series capacitor xC=20ohms, iL=1000A(50 Hz)+100A(10 Hz)
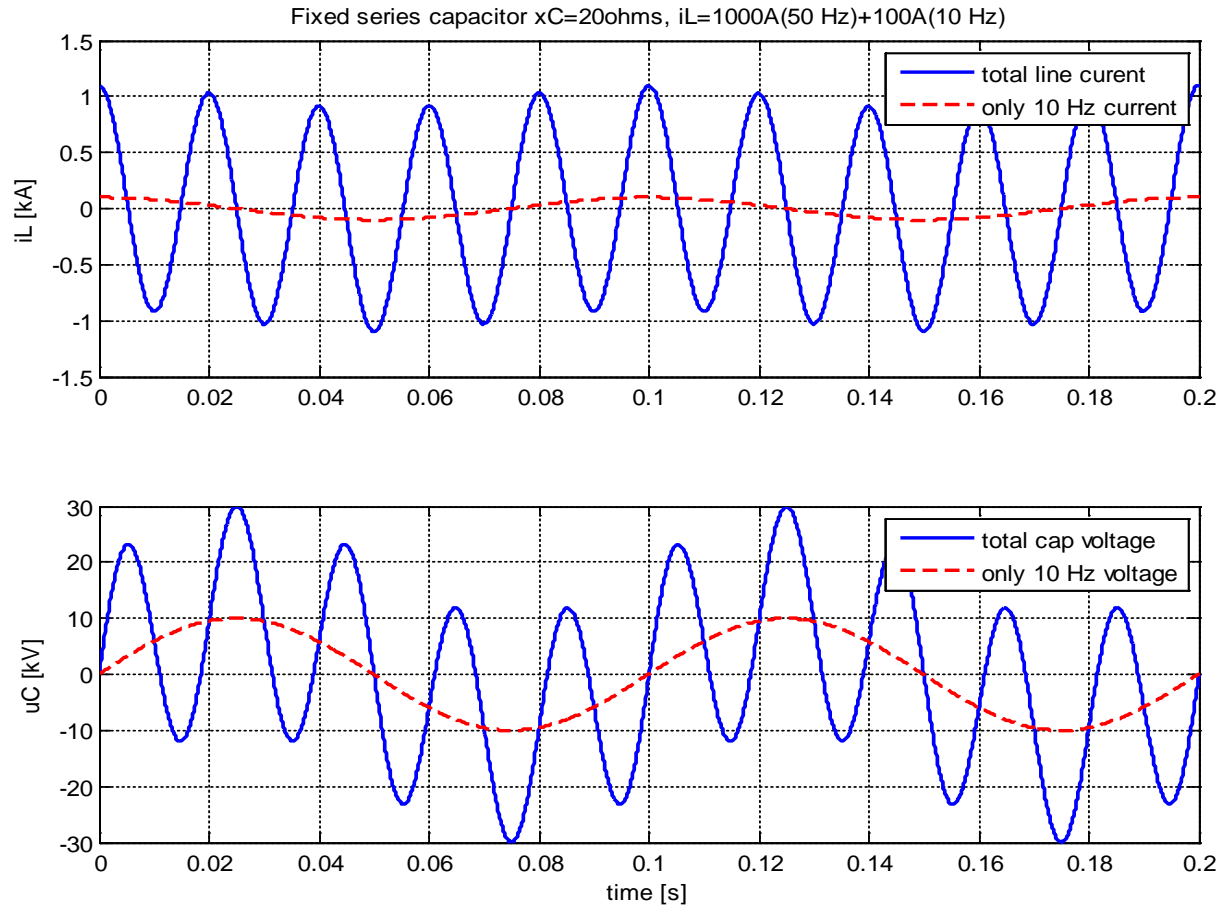
DC injection

10 Hz current in a TCSC

TCSC disturbed operation iL=1000A(50Hz)+100A(10Hz)
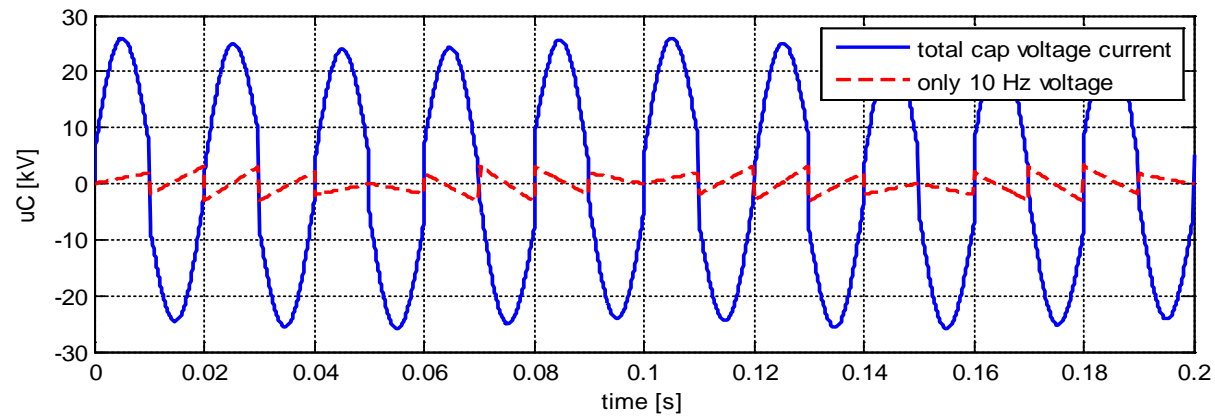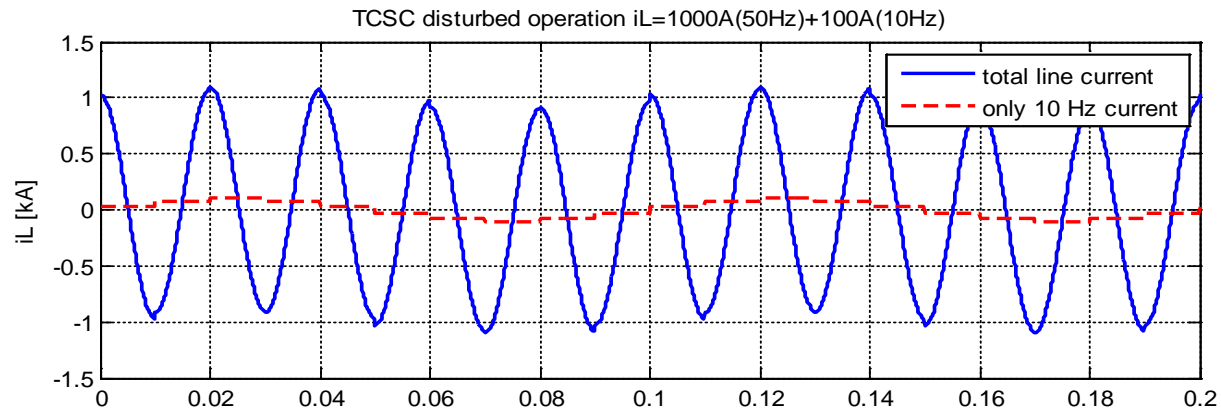
SVR apparent subsynchronous impedance

SVR apparent subsynchronous impedance
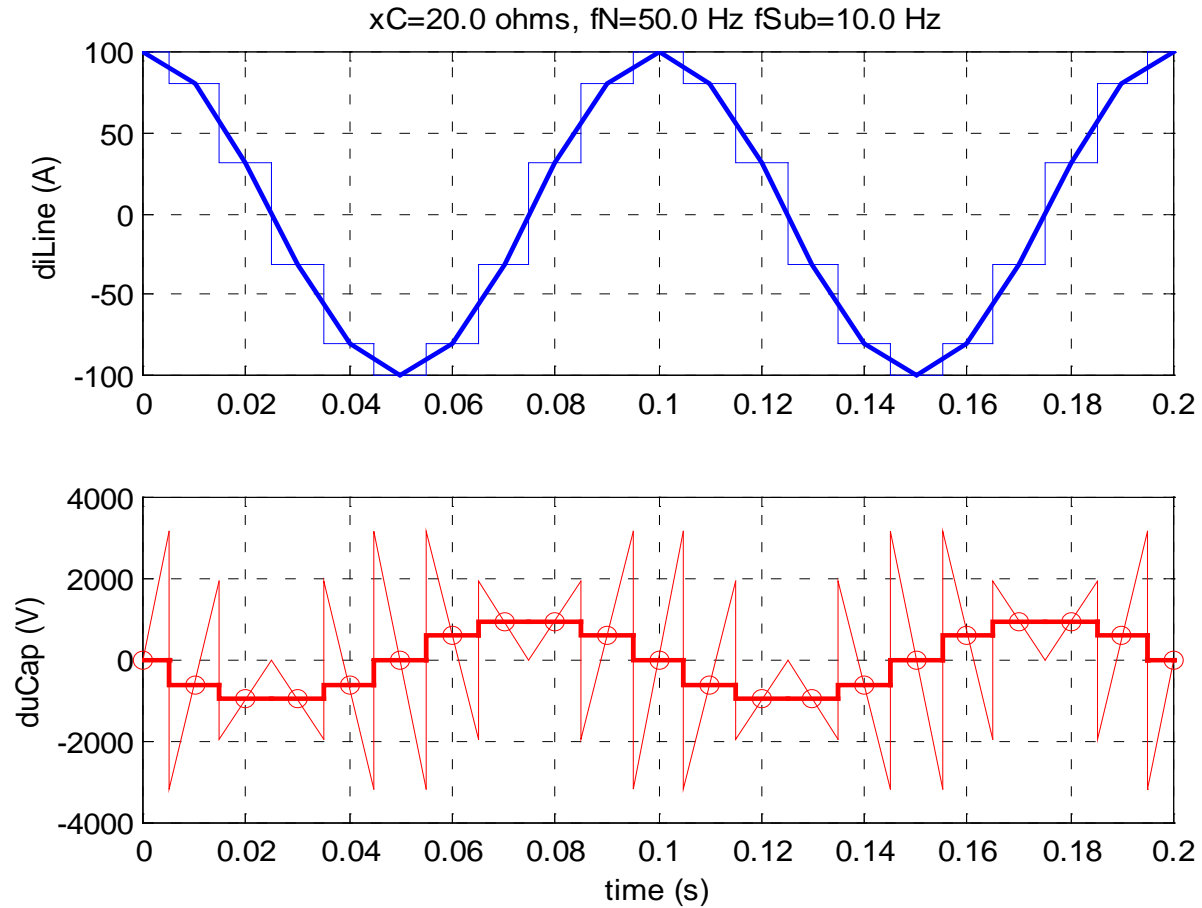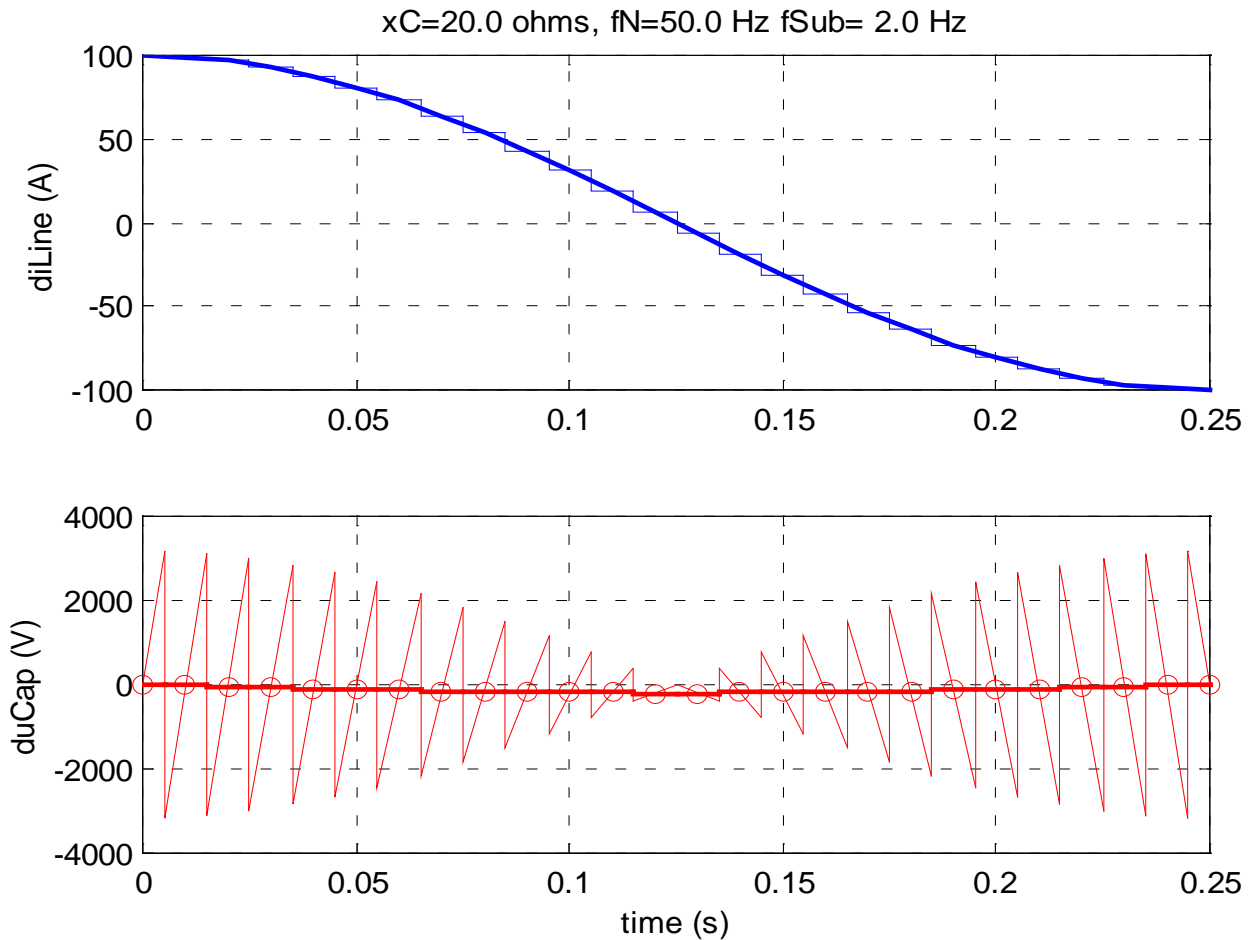
xC=20.0 ohms, fN=50.0 Hz fSub=10.0 Hz

SVR apparent subsynchronous impedance

xC=20.0 ohms, fN=50.0 Hz fSub=10.0 Hz

SVR apparent subsynchronous impedance

xC=20.0 ohms, fN=50.0 Hz fSub=10.0 Hz

SVR apparent subsynchronous impedance

2 Hz

xC=20.0 ohms, fN=50.0 Hz fSub= 2.0 Hz

SVR apparent subsynchronous impedance

5 Hz

xC=20.0 ohms, fN=50.0 Hz fSub= 5.0 Hz

SVR apparent subsynchronous impedance
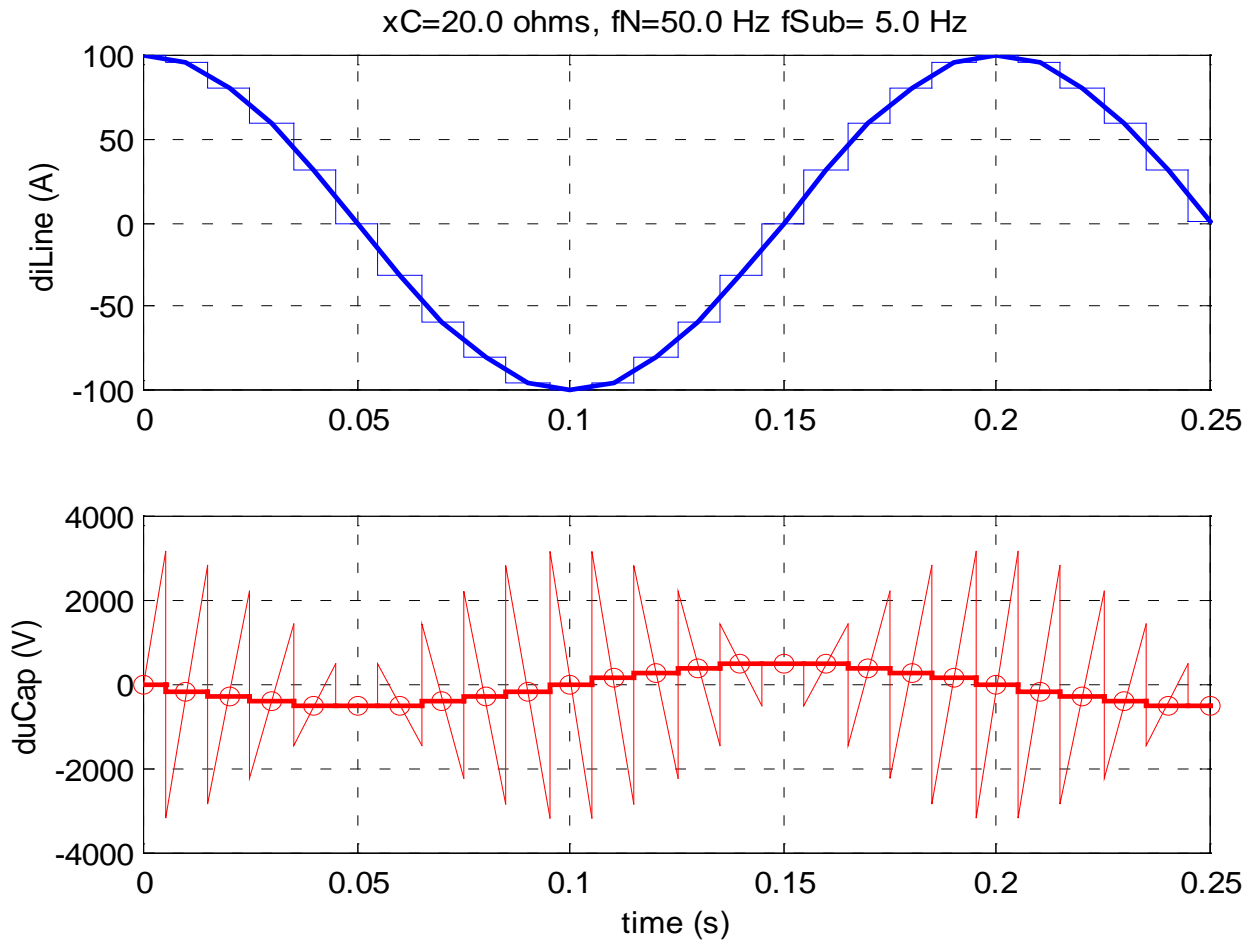
10 Hz

xC=20.0 ohms, fN=50.0 Hz fSub=10.0 Hz
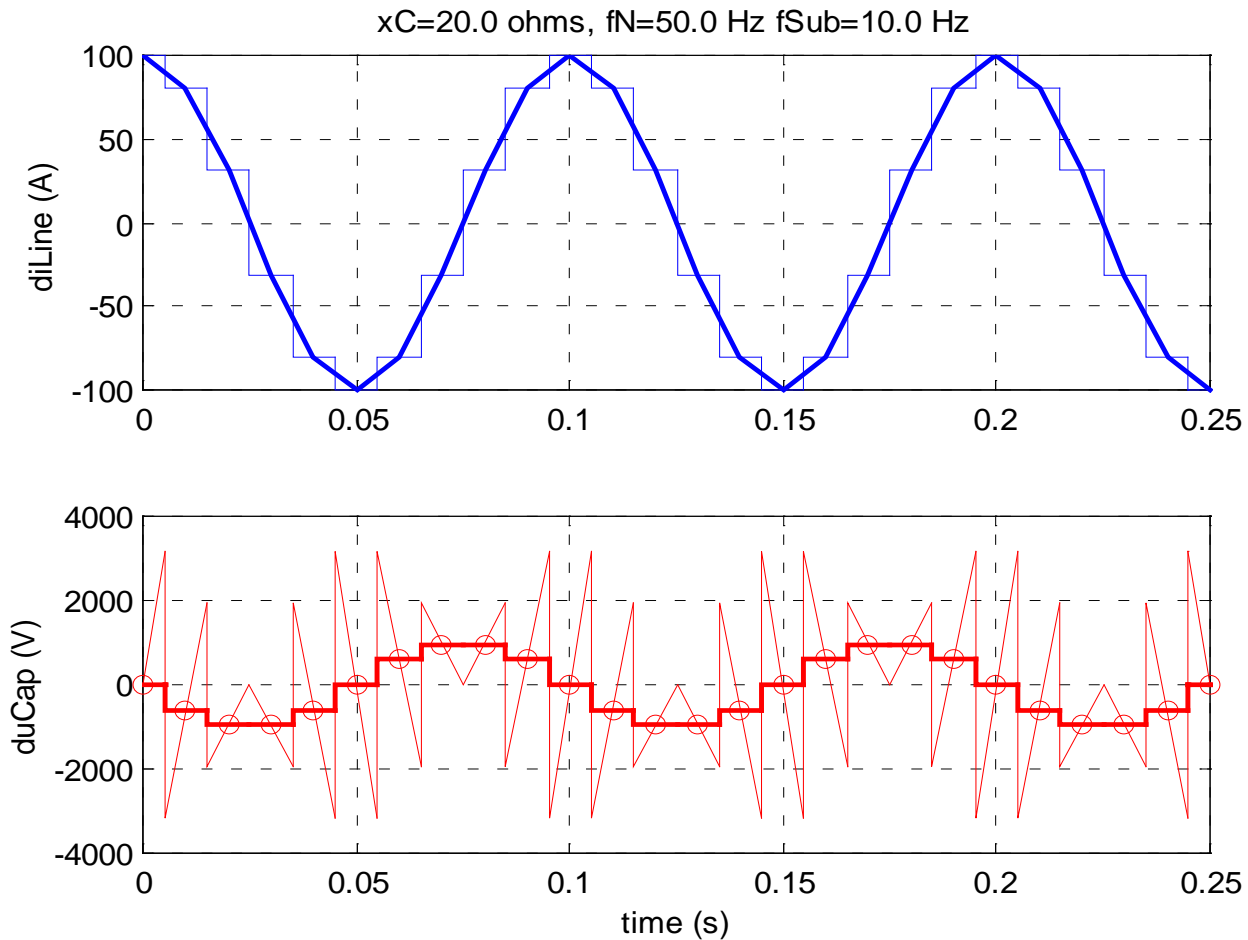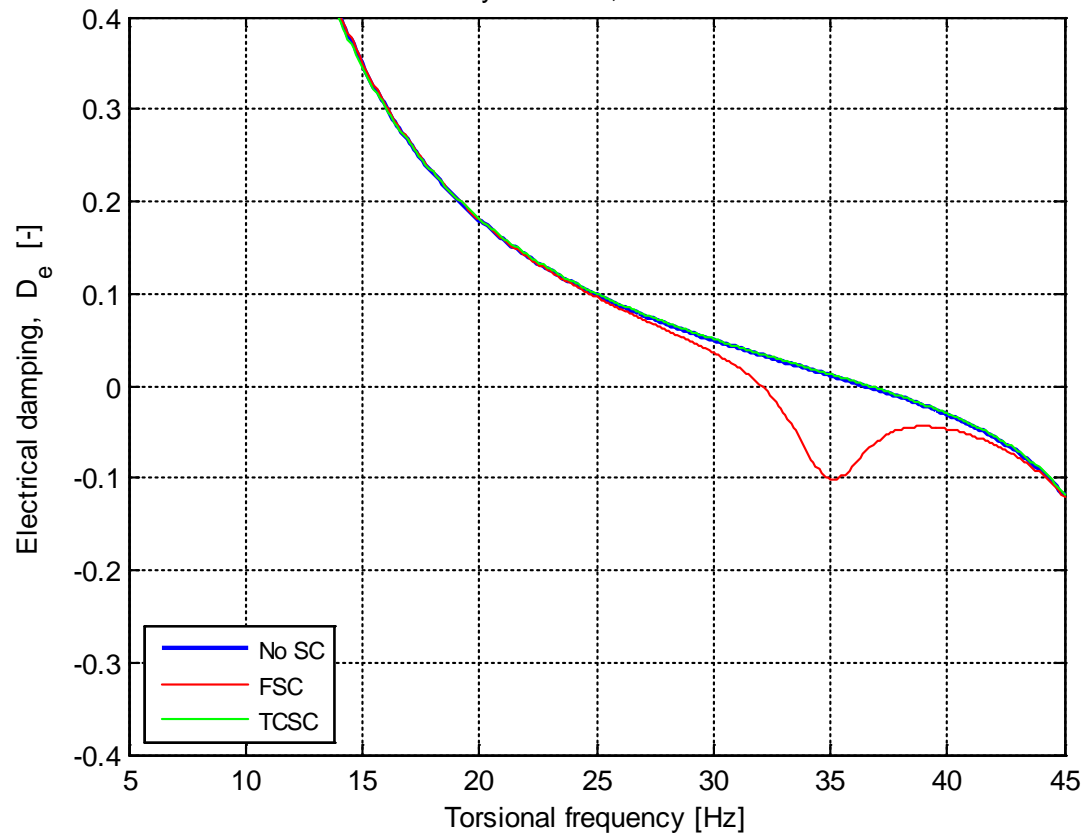
TCSC impedance characteristics
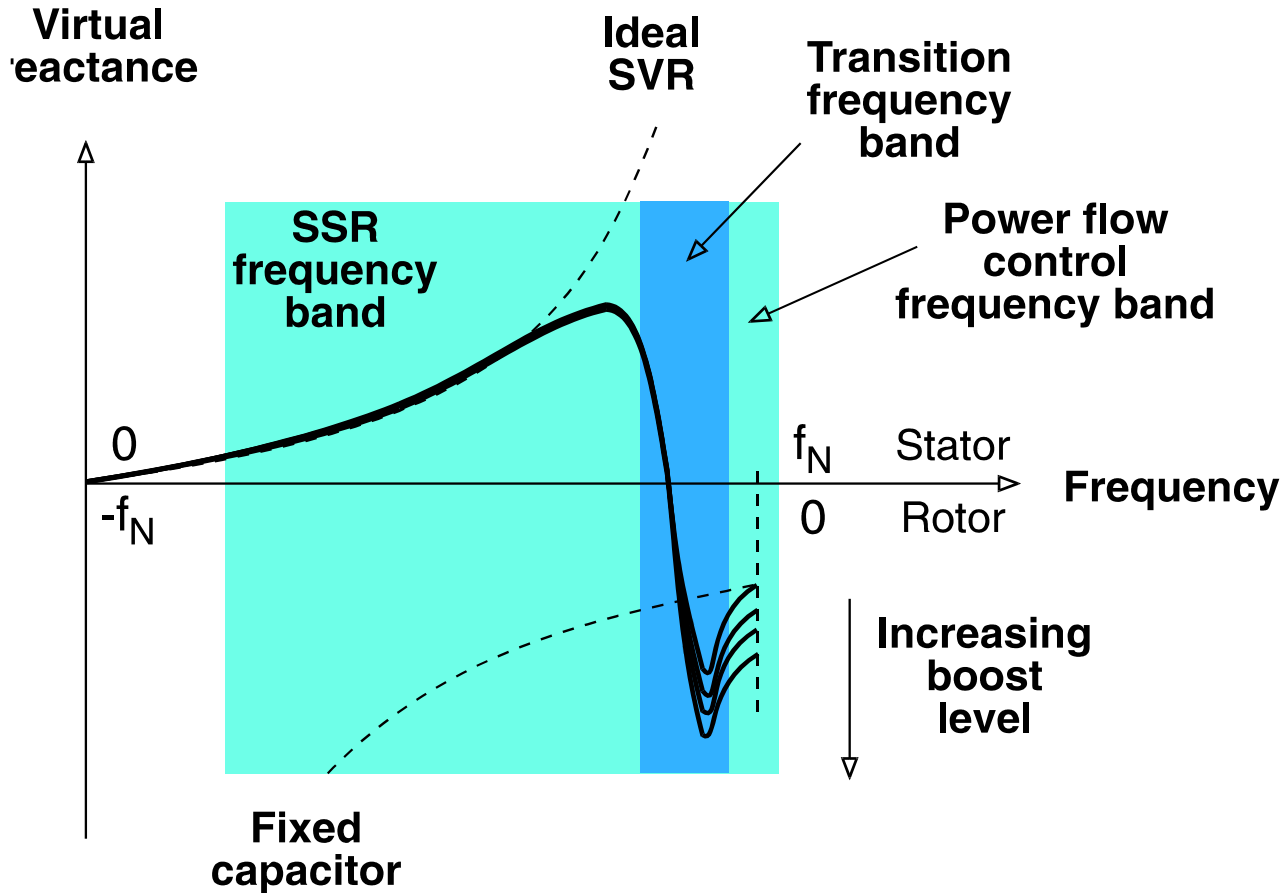
SSR Mitigation Example
TCSC

- Screening Studies

SSR Mitigation Example
TCSC

- RTDS Tests

ΔW

Te

Tm

Synchronous machine

Δ Y

Z_{Line}

TCSC

Voltage Source

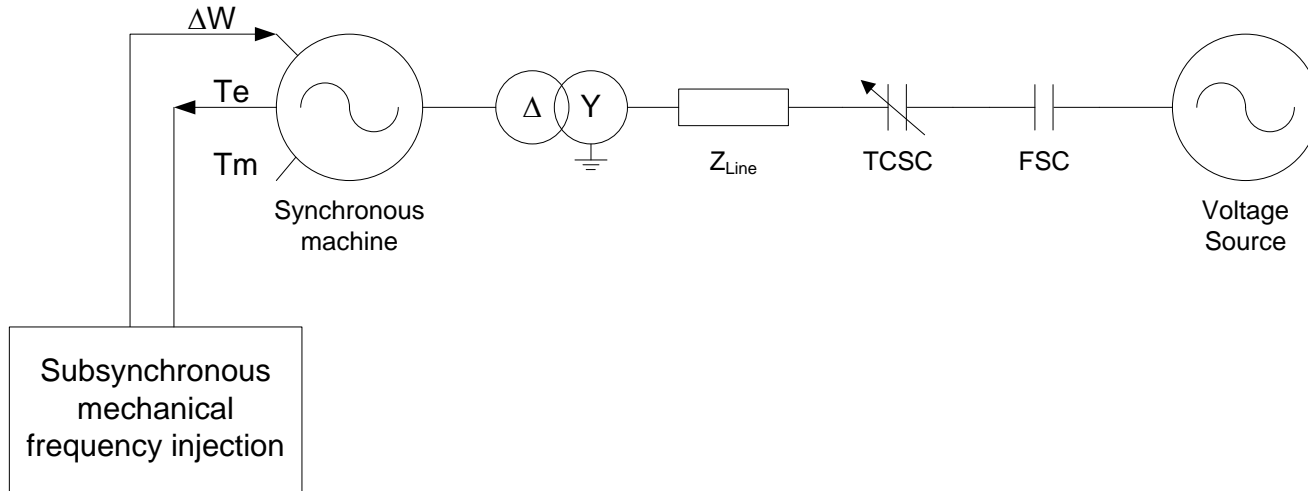Subsynchronous mechanical frequency injection

SSR Mitigation Example
TCSC

- RTDS Tests

S1:Mode 5 CAP FAT, S2:Mode 5 BLK FAT
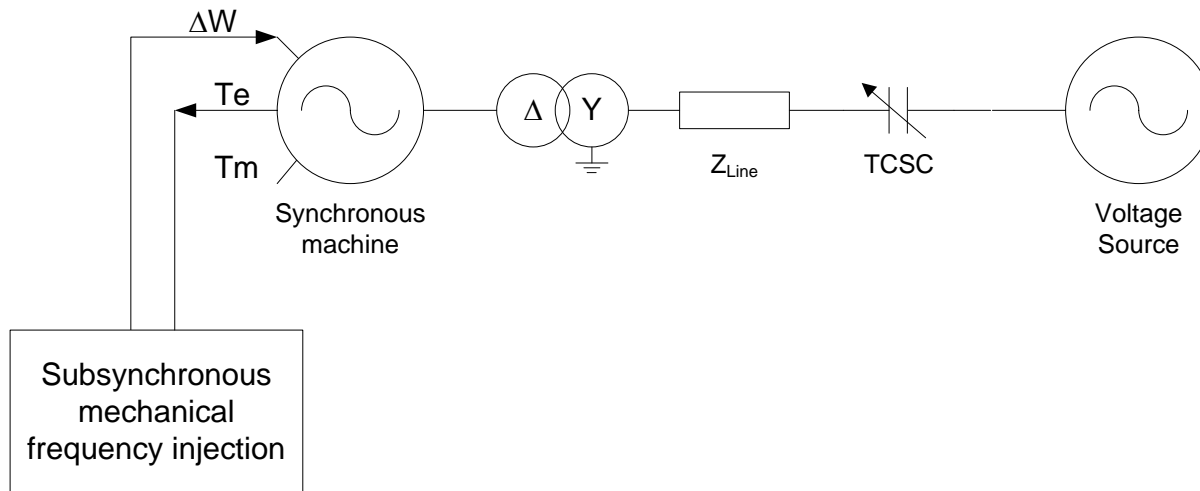
SSR Mitigation Example
TCSC and FSC

- RTDS Tests

SSR Mitigation Example
TCSC and FSC

- RTDS Tests

S1:Mode 4 CAP FAT, S2:Mode 4 BLK FAT

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