Active damping of oscillations in LC-filter for line connected, current controlled, PWM voltage source converters

Authors:
Olve Mo, Magnar Hernes, Kjell Ljøkelsøy
SINTEF ENERGY RESEARCH, Norway

Paper presented at EPE 2003, Toulouse
The challenge

- A low pass LC-filter is a commonly used method to reduce the switching ripple currents and voltages at the terminals of line connected PWM converters.

- The LC-filter introduces risk of oscillations in converter terminal voltage due to resonance between LC-filter capacitor and AC-grid reactance.

- Oscillations can be initiated by nearby load changes or by periodic disturbances in the grid (e.g. thyristor rectifiers).

- The challenge is to modify the control system in such a way that oscillations are damped without affecting the basic control tasks of the converter.
Applicability

- Filter oscillations is most likely to be a problem when the natural frequency of the oscillation is low (poorly damped).

- The worst cases will typically be those where the converter rating becomes comparable to the upstream transformer (or generator) rating.

- A typical example is emergency operation of isolated grids where converter ratings may become comparable to the emergency generator ratings.

- Other examples are ship and offshore power systems and distributed production units connected to a weak grid.
The power circuit

- Current controlled, line connected, PWM voltage source converter (For instance operated as active rectifier / inverter, STATCOM or active filter)
- The focused oscillation are illustrated by red arrows in the figure
Control system

- Closed loop control of filter inductor current and DC-link voltage, PWM
- Measures DC-link voltage, minimum two filter inductor currents and two line voltages.
- Synchronisation by phase locked loop
- Active damping is an "add-on feature" (red in the figure)
The active damping method

- The oscillating component of the capacitor voltage is extracted (the non-fundamental component)
- The error in the capacitor voltage is found by subtracting the oscillating component from its reference (=0)
- The error is amplified and added to the reference signal for the current controller.
Demonstration by simulation

- Application: PWM converter connected to the AC-grid at a point with low short circuit capacity compared to converter kVA rating

- Demonstration of damping of oscillations after a step reversal of the reference for reactive current

![Diagram of PWM converter, LC-filter, and Ideal AC Network](image)

- $V_{DC} = 450$ V
- $S_{conv} = 20$ kVA
- $f_{sw} = 5470$ Hz
- -40 dB at $f_{sw}$
- $L=0.82mH$
- $C=100\mu F$
- $R_C=1.0m\Omega$
- $R_L=6.4m\Omega$
- $S_{transf} = 30$ kVA
- $x_{transf} = 10\%$
- $L=0.6mH$
- $R=100m\Omega$
- $f_{grid} = 50$ Hz
- $v_{grid} = 230$ Vrms (l-l)
Active damping disabled

Filter capacitor voltages (phase a, b, c)

Active damping enabled

Phase a filter capacitor voltage (black)

Phase a current into AC-grid (red)
Laboratory demonstration

- Converter connected to a weak bus
- Three-phase diode rectifier connected to the same bus
- Measurements demonstrate that the active damping suppresses LC-filter filter oscillations trigged by the harmonics of the diode rectifier

![Diagram of the laboratory demonstration setup](image)

- $V_{dc} = 400$ V
- $f_{sw} = 5470$ Hz
- $C_{dc} = 3300 \mu$ F (no load or source connected to DC-link)
- $L = 0.82$ mH
- $C = 100 \mu$ F
- $R_c = 1.0$ mΩ
- $R_L = 6.4$ mΩ
- Transformer (ref. 230V)
  - $L_{transf} = 650 \mu$H
  - $R_{transf} = 130$ mΩ at 50Hz,
  - $300$ mΩ at 600Hz
- AC Network
  - $f_{grid} = 50$ Hz
  - $V_{grid} = 400$ Vrms (l-l)
- 3-phase diode rectifier
  - $R_{load,serial} = 28.5$ Ω
  - $L_{load,serial} = 1.2$ mH
  - (no commutation reactance)
Active damping disabled

Active damping enabled

Phase voltage at bus A (black)

Transformer current (red)
Conclusions

- Introduction of active damping is a possible measure for reduction of oscillations due to low pass LC-filters of line connected current controlled PWM converters.

- Simulations and measurements show that the method works as intended.

- The voltage quality at the point of connection can be maintained in cases were filter oscillations is to be expected when the low pass LC-filter is introduced.