PROJECT MEMO

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MEMO CONCERNS

Realisation of a 20kVA shunt active filter

DISTRIBUTION

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Abstract:
The presented memo discusses the development and the realisation of a shunt active filter. The presented active filter is realised by use of a PWM-converter with 10kHz switching frequency. This memo discusses simulation, laboratory development and realisation. The set-up is prepared and tested for the work on three-wire 230V line-line grid. The described filter works with current compensation so that the set-up is able to improve all kinds of currents. The filter can work in two modes:

- Compensation for harmonic current
- Compensation for reactive power and harmonic currents

However, the improvement for voltage distortion is not guaranteed because several problems are accrued which are improved and discussed but not completely solved.
These problems are:

- Delay between incoming current measurements and output of the converter current
- Oscillation of the inserted ripple filter (LC) with the grid inductance

The control of the active filter is realised by an Infineon C167 micro controller (μC). The principal working mechanism can be seen in Figure 1-1 (Page 5). An Illustration of the shunt active filter operation is shown in Figure 7-3 on Page 75.

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SIP-strategic institute programme

”Power electronics and energy storage technologies for cost- and energy efficient power systems”

AN 02.12.69 - Realisation of a 20kVA shunt active filter

(Andre Buettner)

Why filter?

- <u>Problem:</u>
- Insufficient power quality in low voltage AC-systems

- <u>Reasons:</u>
- External disturbances (power outages, sags a.s.o.)
- Combined use of linear and non-linear loads (consumer of non-sinusoidal currents) causes current harmonics

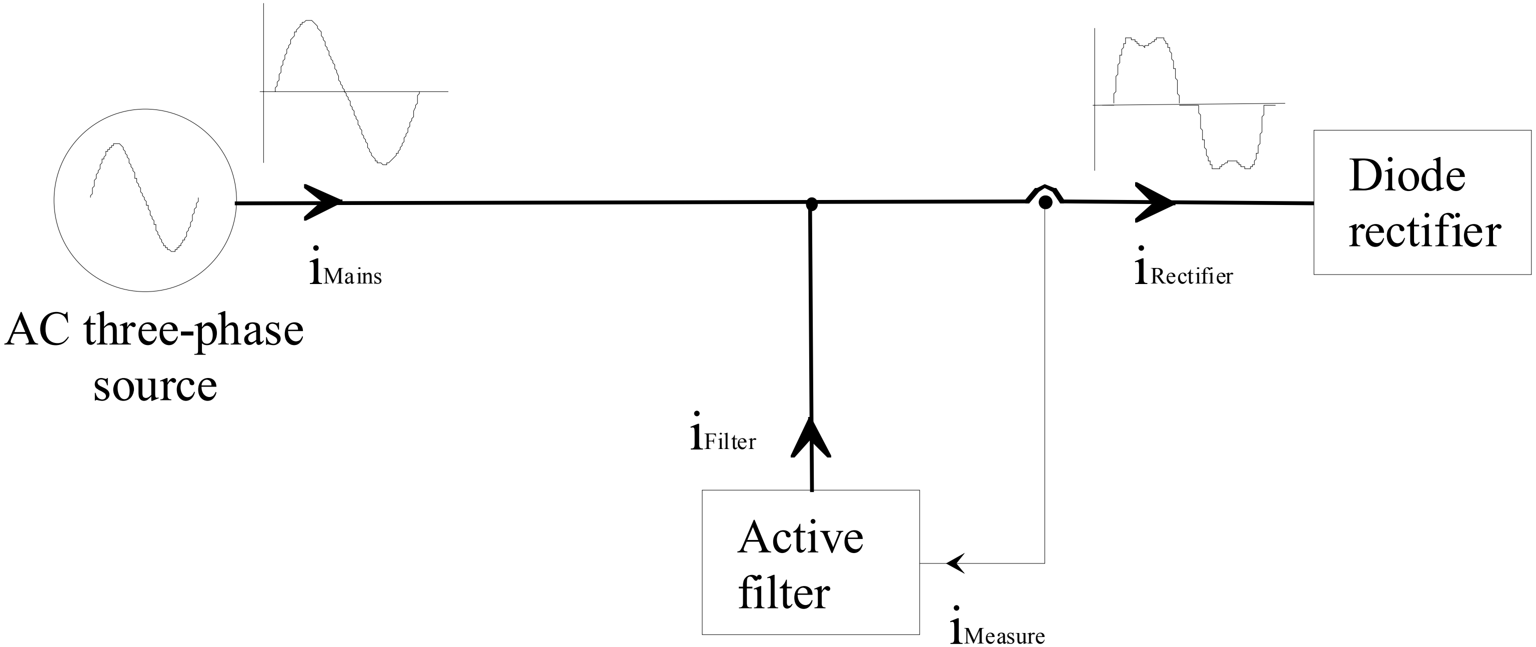
Compensation for harmonic currents

- Solution1:
- Passive harmonic filter
  - Compensation for a specific harmonic
  - Problem: causes oscillation with the grid inductance
- Solution2:
- Active filter
  - Compensation for a selected or all harmonics
  - Compensation for reactive power is possible

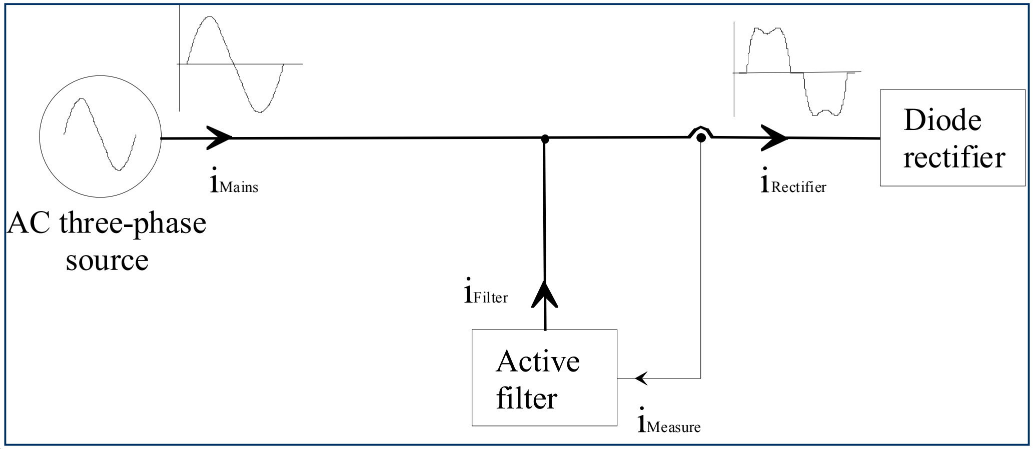
Types of active filters

- Series active filter
  - In series with the line
  - Need to conduct the complete line current
- Shunt active filter
  - Parallel with the load
  - Need to match the line voltage
- Hybrid filter
  - Combination of passive filter and active filter
  - Parallel and series
  - Cost effective solution in certain cases

Working mechanism for a shunt active filter



Derivation of the filter algorithm



$$i_{mains} = i_{rectifier} - i_{filter}$$

With the supposition of an ideal controller results

$$i_{filter} = i_{ref}$$

$$i_{ref} = i_{DC-link-controller} + i_{Compensation}$$

DC – link current negligible

$$i_{DC-link-controller} \approx 0$$

$$i_{ref} = i_{Compensation}$$

$$i_{rectifier} = i_{(1)rectifier} + i_{(2..n)rectifier}$$

$$i_{(1)rectifier} = i_{(1)active} + i_{(1)reactive}$$

$$i_{rectifier} = i_{(2..n)rectifier} + i_{(1)active} + i_{(1)reactive}$$

Shunt filter algorithms

- Compensation for harmonic currents

$$i_{Compensation} = i_{(2..n)rectifier}$$

so that

$$i_{Compensation} = i_{rectifier} - i_{(1)rectifier}$$

- Compensation for harmonic currents and reactive power

$$i_{Compensation} = i_{(2..n)rectifier} + i_{(1)reactive}$$

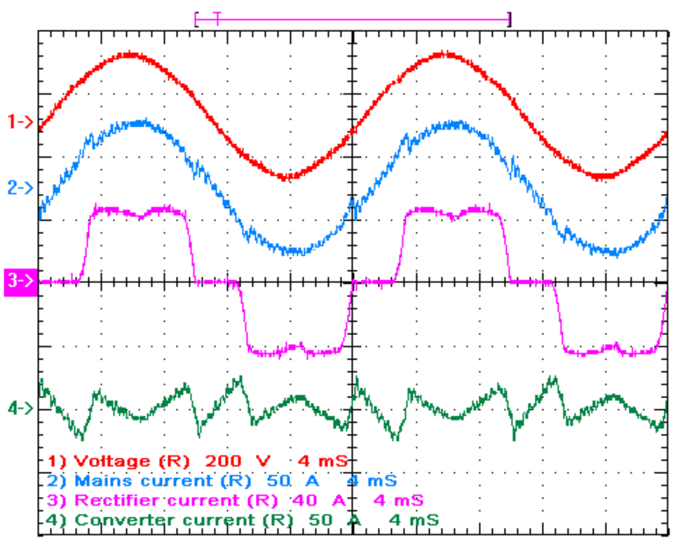
so that

$$i_{Compensation} = i_{rectifier} - i_{(1)active}$$

Main results

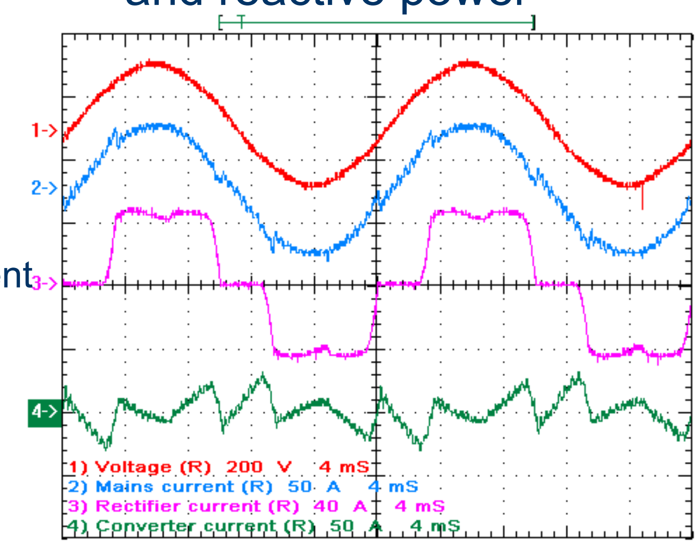
- Filter is able to improve all types of current shapes
- Possibility of compensation for harmonic currents and reactive power

Compensation for harmonic currents



- Annotations
  - 1 phase voltage
  - 2 mains current
  - 3 rectifier current
  - 4 converter current

Compensation for harmonic currents and reactive power



Current improvements

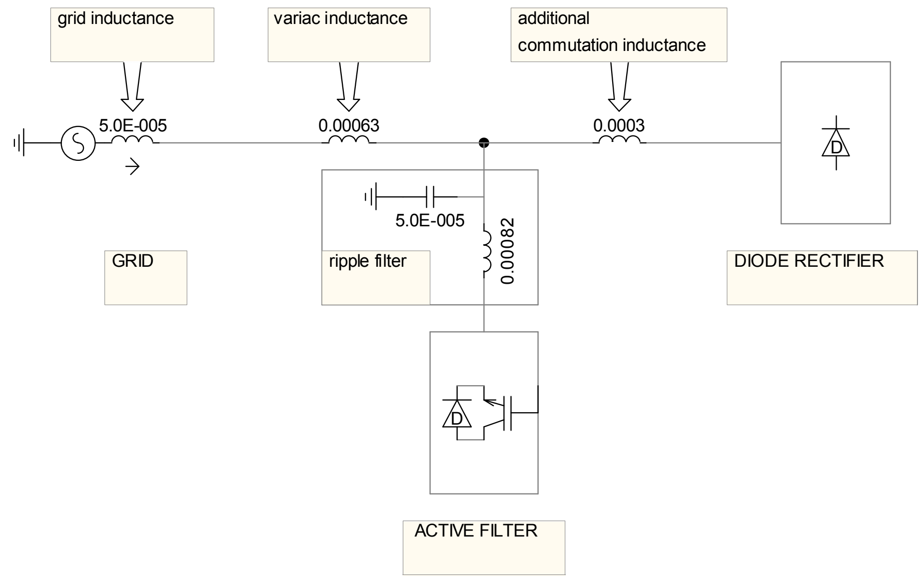
- 5th harmonic from 22% to 3.5%
- THD from 25% to 5%

Voltage improvement

- 5th harmonic from 2.6% to 1.9%
- THD from 2.8% to 2.2%

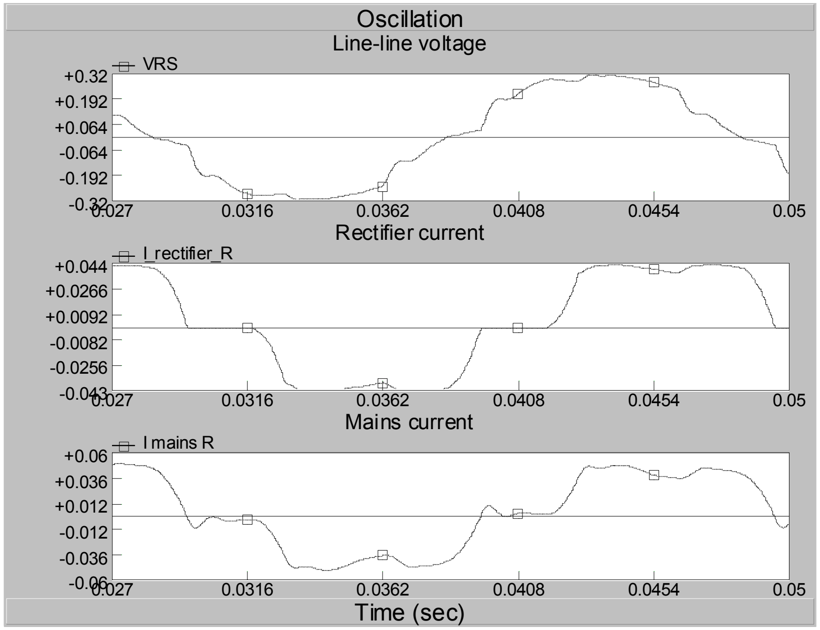
Accrued problems

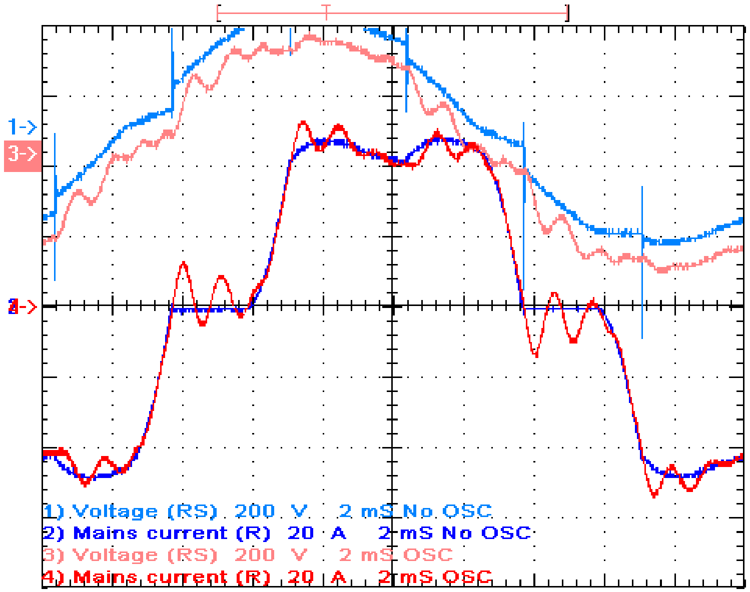
- Oscillation of the ripple filter capacitor with the grid inductance
- Delayed converter current



LC-oscillator ($C_{ripple\ filter}$ and L_{grid})

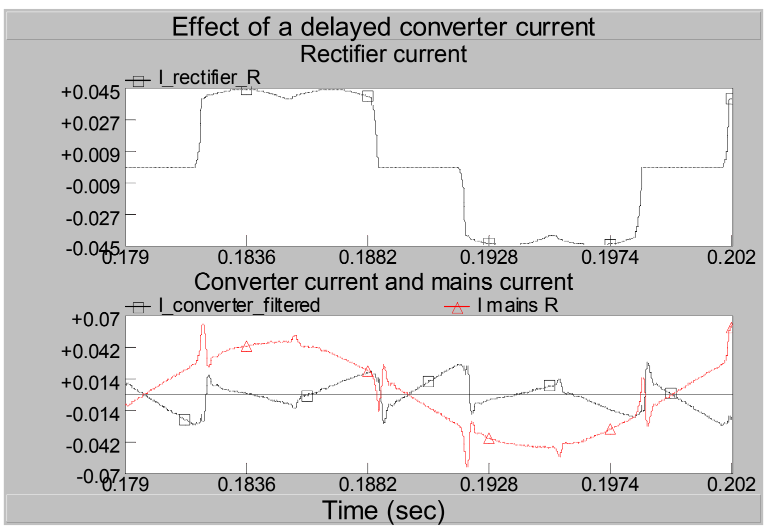
- Simulation
  - Graph1 – Line-line voltage
  - Graph2 – Rectifier current
  - Graph3 – Mains current
- Laboratory
  - Blue – non-oscillating signals
    - 1 line-line voltage
    - 2 mains current
  - Red – oscillating signals
    - 3 line-line voltage
    - 4 mains current

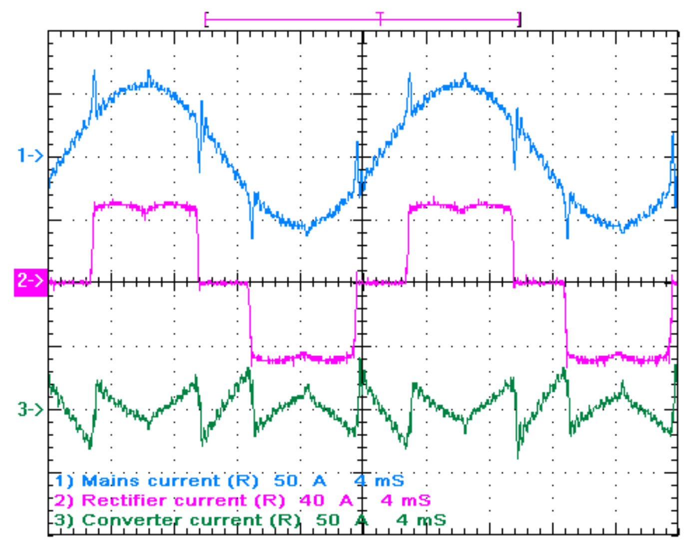




Delayed converter current

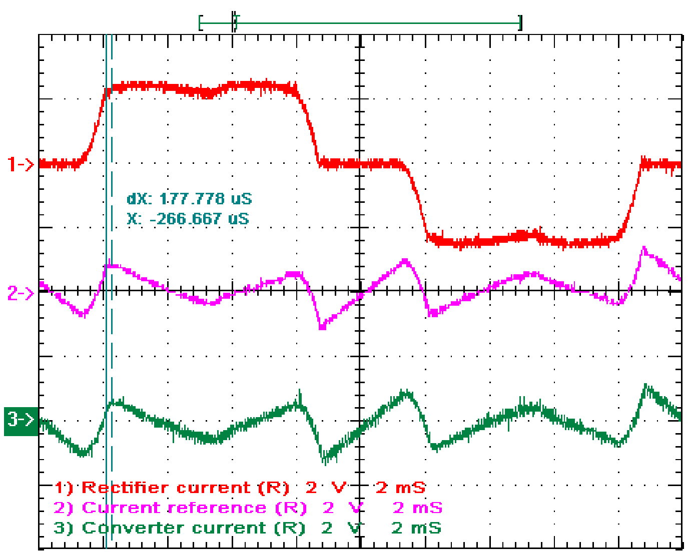
- Simulation
  - Graph1 – Rectifier current
  - Graph2
    - red mains current
    - black converter current
- Laboratory
  - Signal 1 – Mains current
  - Signal 2 – Rectifier current
  - Signal 3 – Converter current





Different delays

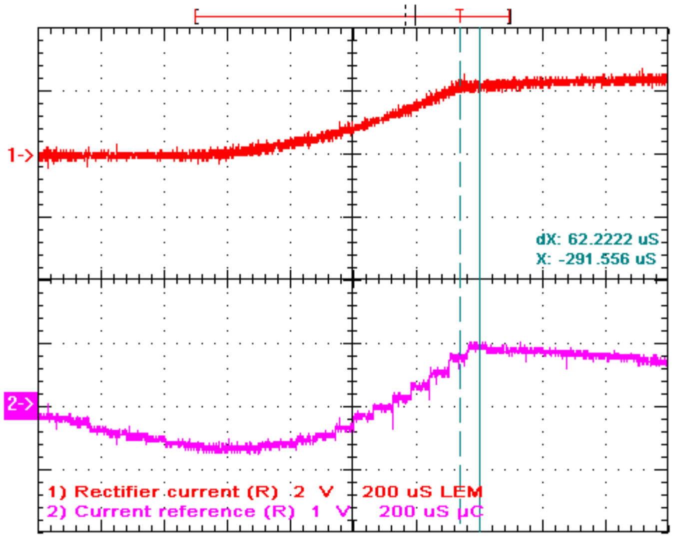
- Micro controller delay
  - delay between rectifier current measurement and output of the current reference
- Current controller delay
  - delay between reference and output of the fire pulses
- IGBT on delay
  - Turn on turn off of the gate drivers (negligible small)



- Annotations
  - Signal1 – Rectifier current
  - Signal2 – Current reference
  - Signal3 – Converter current

Micro controller delay

- between current measurement and current reference output
- 60µs - fastest interrupt repeating time

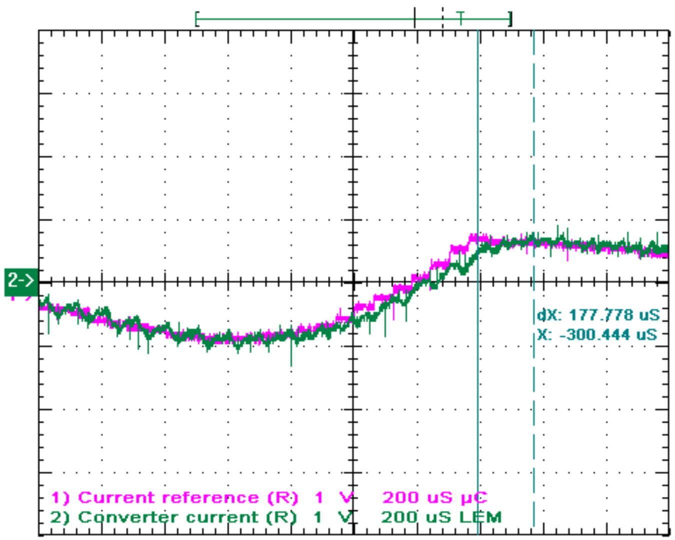


- Annotations
  - Signal1 – Rectifier current
  - Signal2 – Current reference

- Improvements
  - faster AD-converter
  - Decrease number of channels in use

Current controller delay

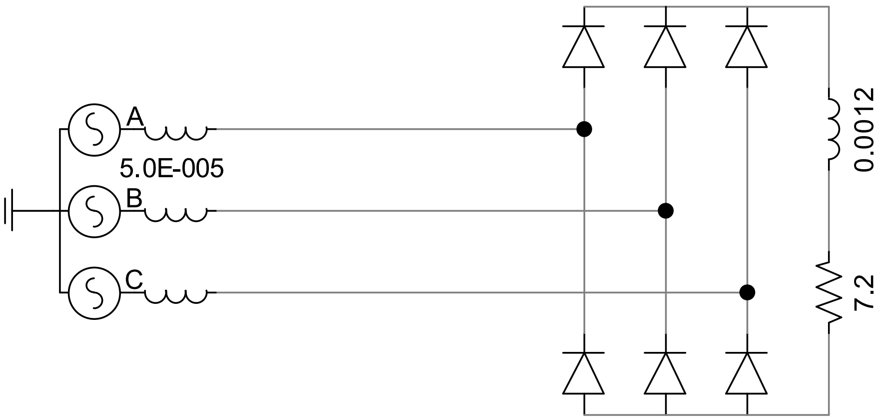
- between current reference and output of the converter current
- 0 to 150µs – depending on the reference frequency
- bandwidth problem

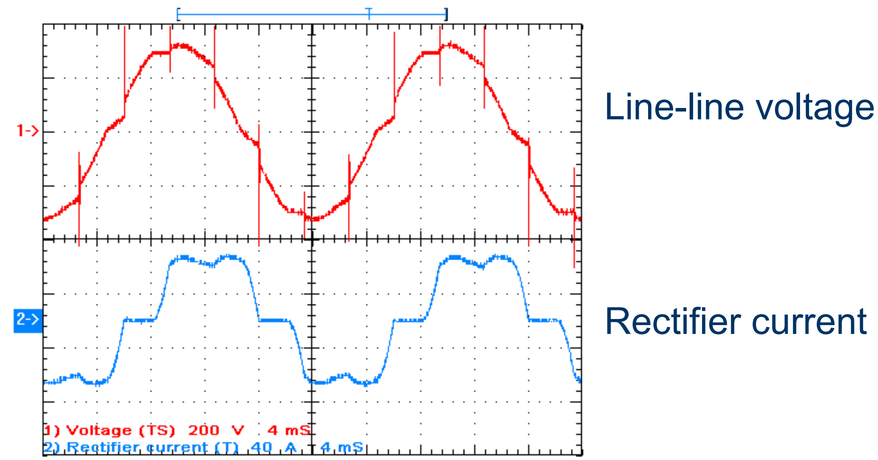


- Annotations
  - Signal1 – Current reference
  - Signal2 – Converter current

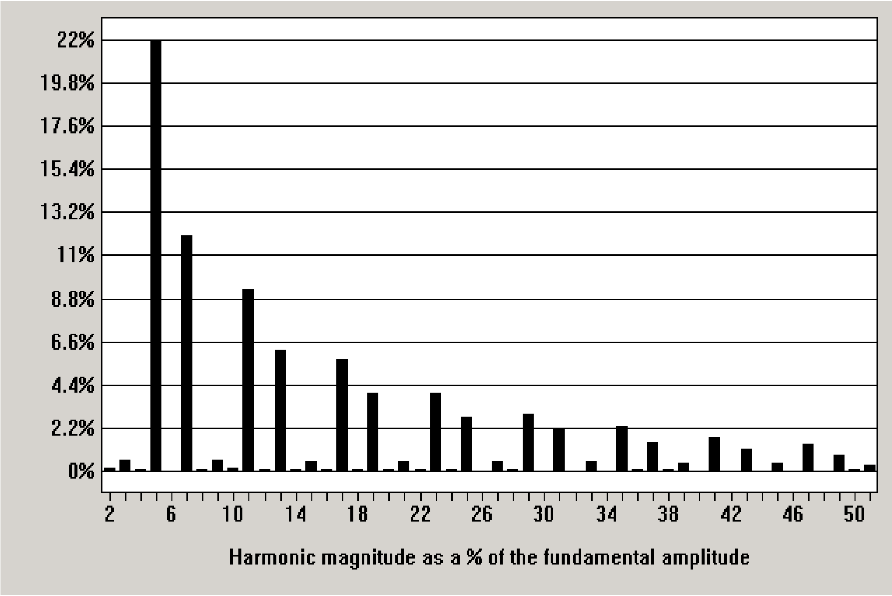
- Improvements
  - Faster current controller
  - Different typ of current controller

Diode rectifier with inductive DC-load

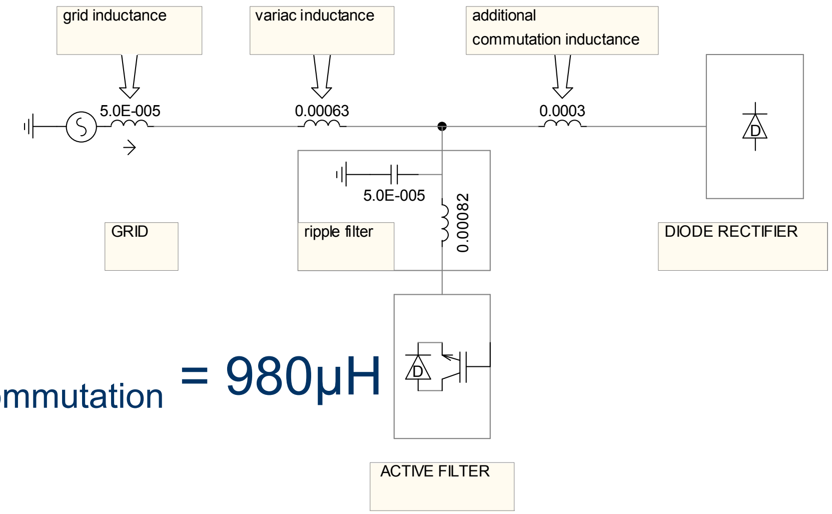




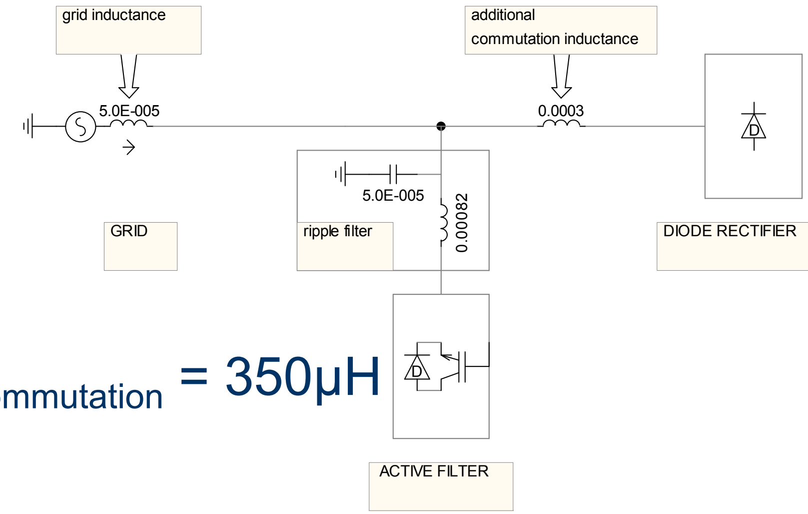
- 5th current harmonic 22%
- Current THD 25%-29%
  (Depending on the commutation)



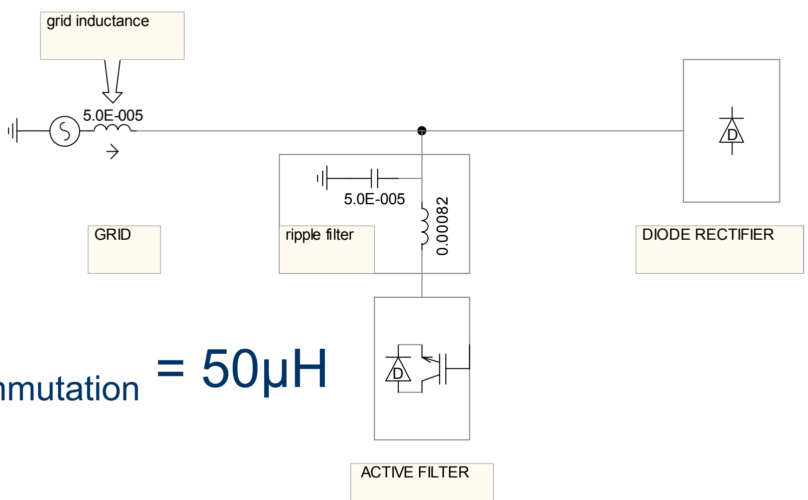
Different constellations for the rectifier



- $L_{Commutation} = 980\mu H$

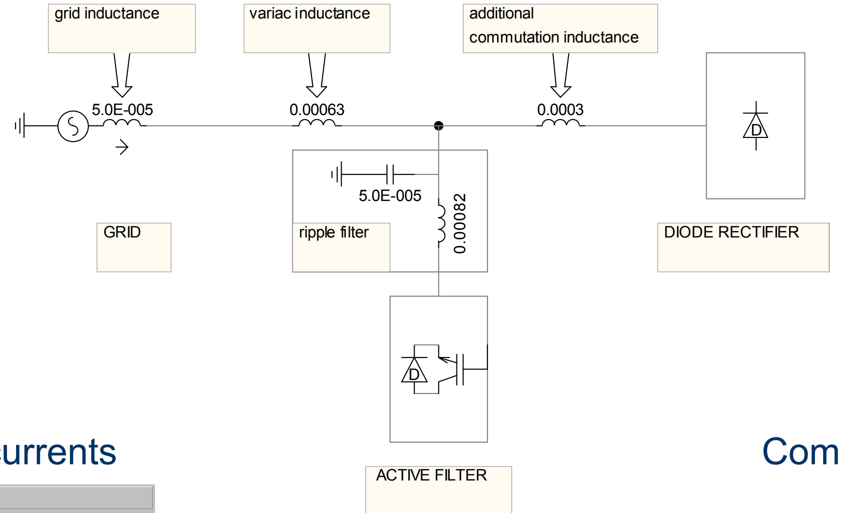


- $L_{Commutation} = 350\mu H$



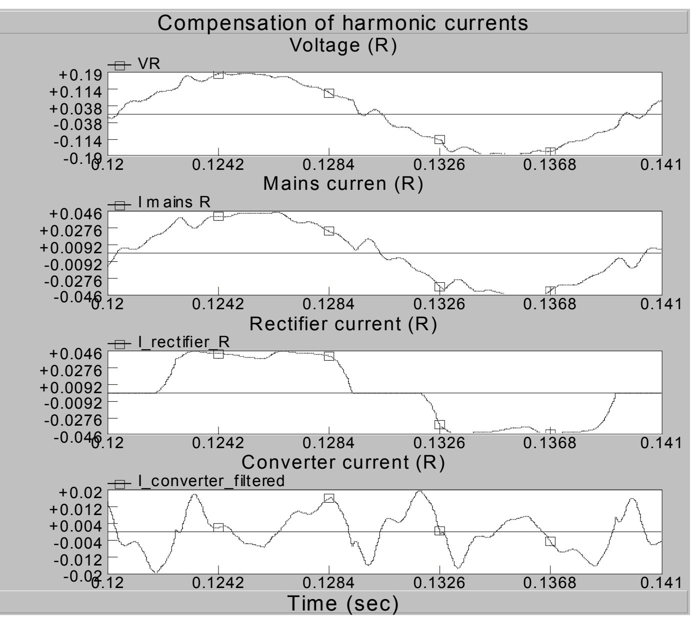
- $L_{Commutation} = 50\mu H$

Waveforms ($L_{Commutation}$ = 980µH)



■ Simulation

Compensation for harmonic currents



■ Annotations

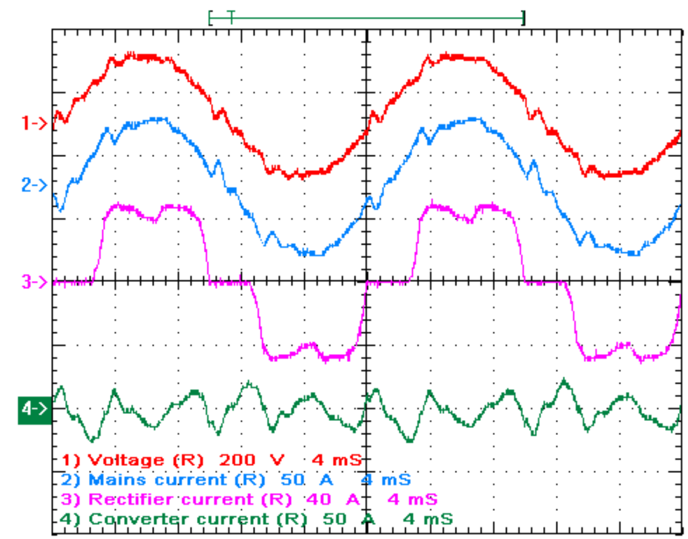
- ■ 1 phase voltage
- ■ 2 mains current
- ■ 3 rectifier current
- ■ 4 converter current

■ Oscillation

- ■ 883Hz=17th harmonic

■ Laboratory

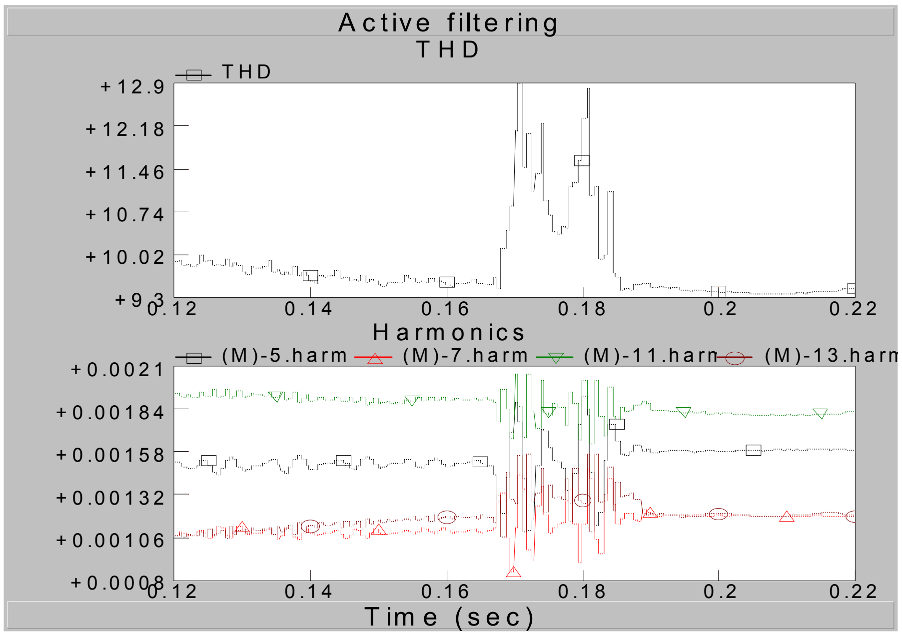
Compensation for harmonic currents



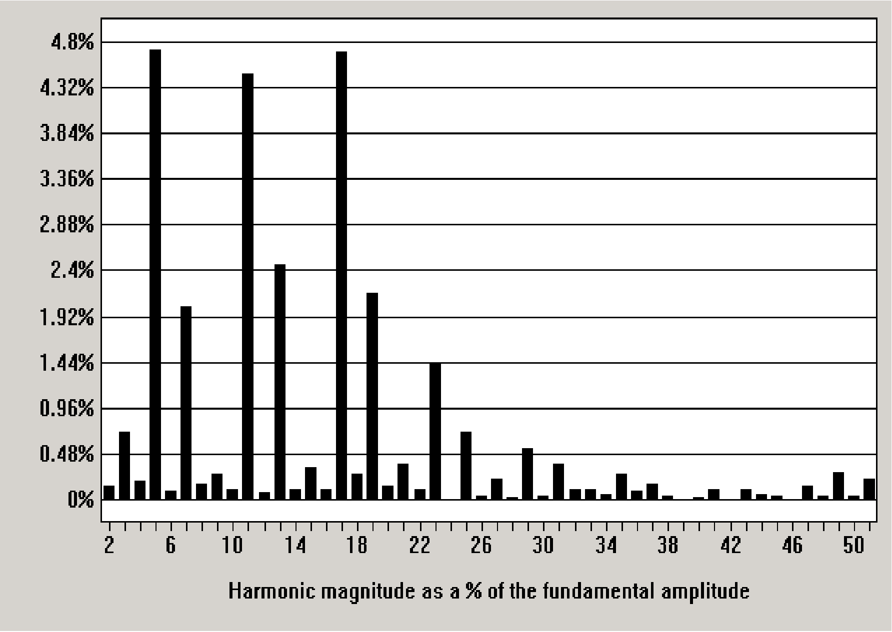
Results current ($L_{Commutation}$ = 980μH)

- Oscillation frequency 883Hz=17th harmonic

- Simulation



- Laboratory

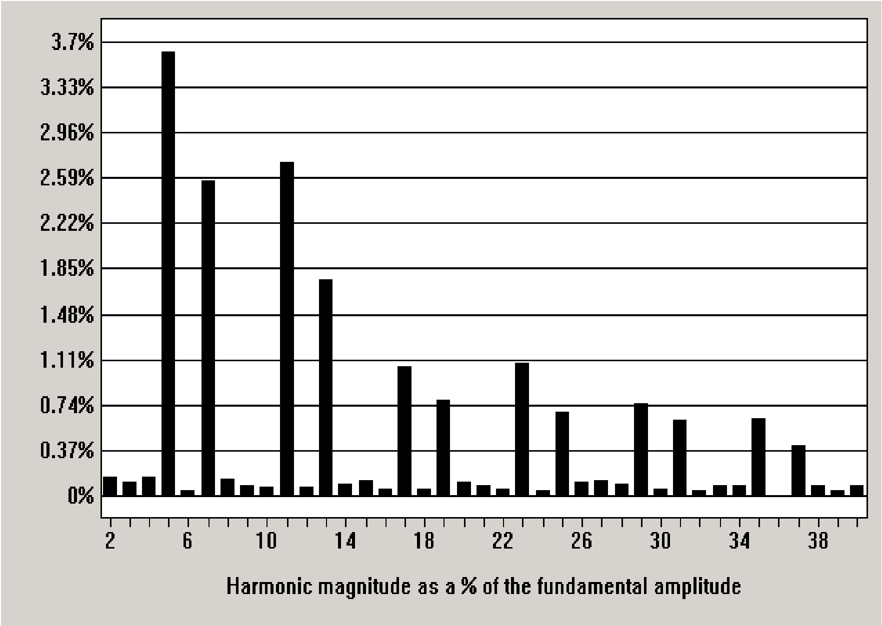


- Current THD about 9.5%
- Current THD about 9.3%

Results voltage ($L_{Commutation}$ = 980µH)

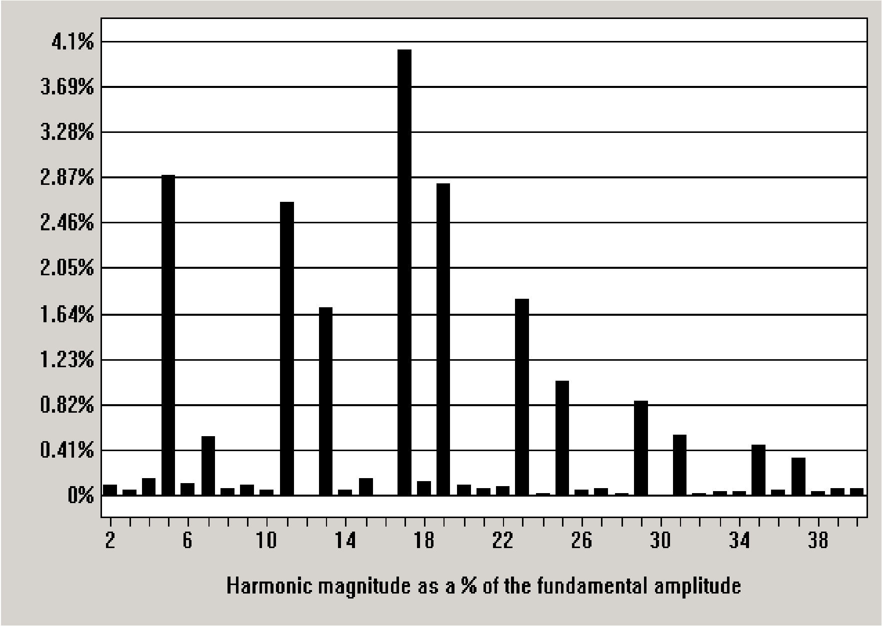
- Oscillation frequency 883Hz=17th harmonic

- without active filtering



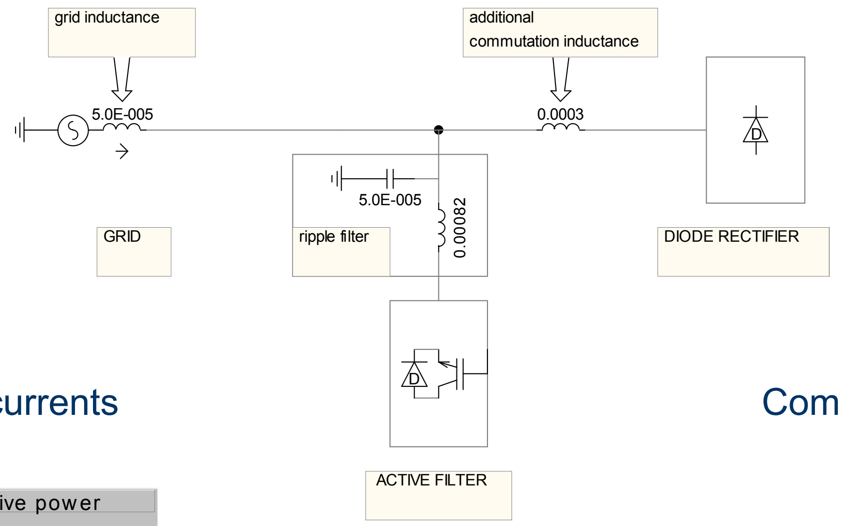
- Voltage THD 5.97%

- with active filter



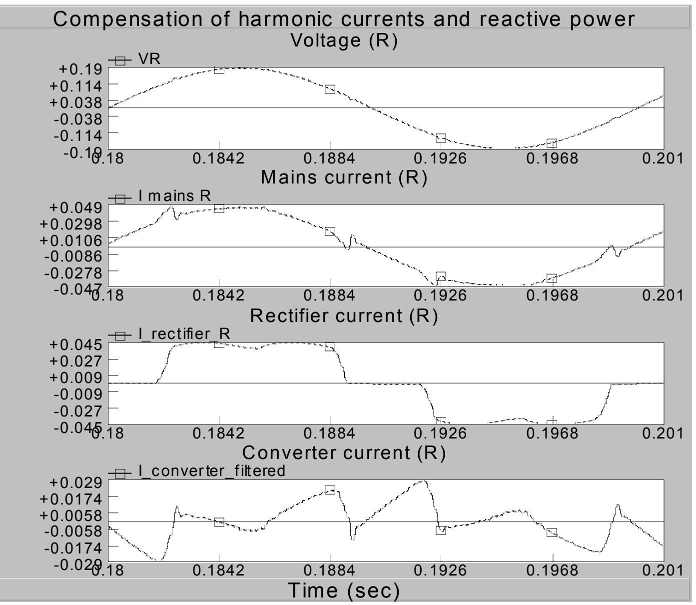
- Voltage THD 6.94%

Waveforms ($L_{Commutation}$ = 350µH)



Simulation

Compensation for harmonic currents and reactive power



Annotations

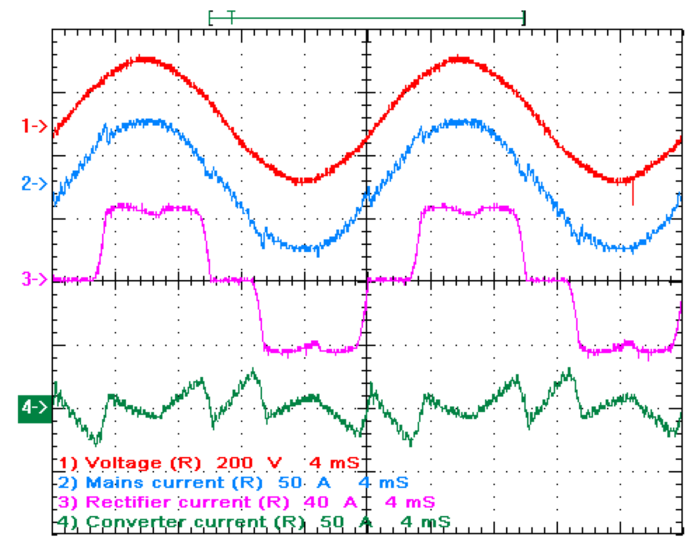
- 1 phase voltage
- 2 mains current
- 3 rectifier current
- 4 converter current

Oscillation

- 3183Hz=63[rd] harmonic

Laboratory

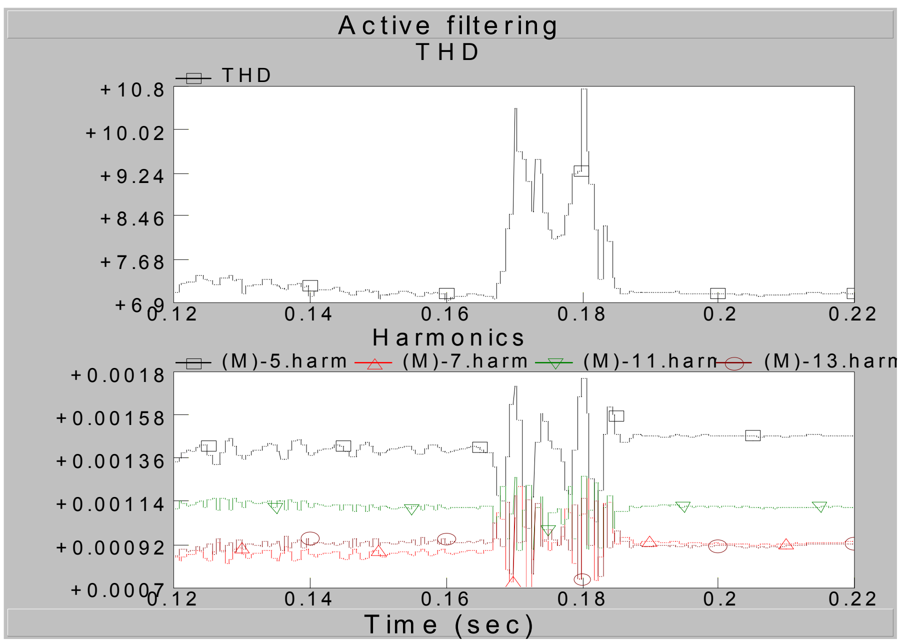
Compensation for harmonic currents and reactive power



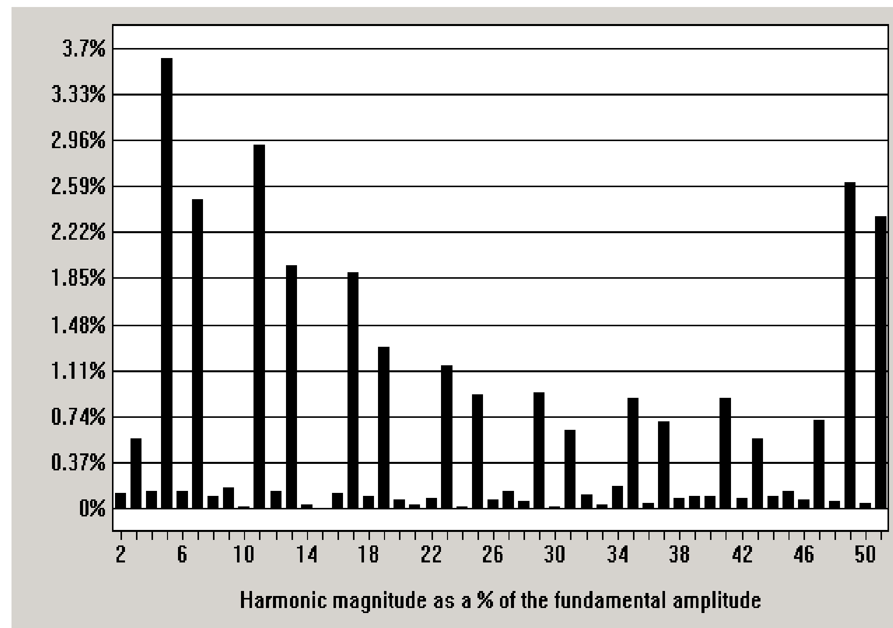
Results current ($L_{Commutation}$ = 350μH)

- Oscillation frequency 3183Hz=63rd harmonic

- Simulation



- Laboratory

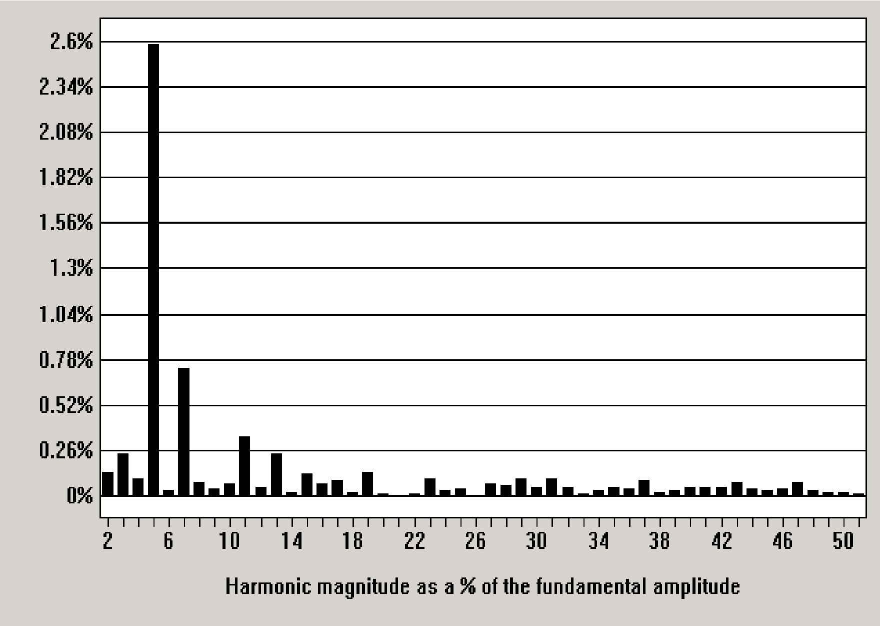


- Current THD about 7.2%
- Current THD about 6.68%

Results voltage ($L_{Commutation}$ = 350µH)

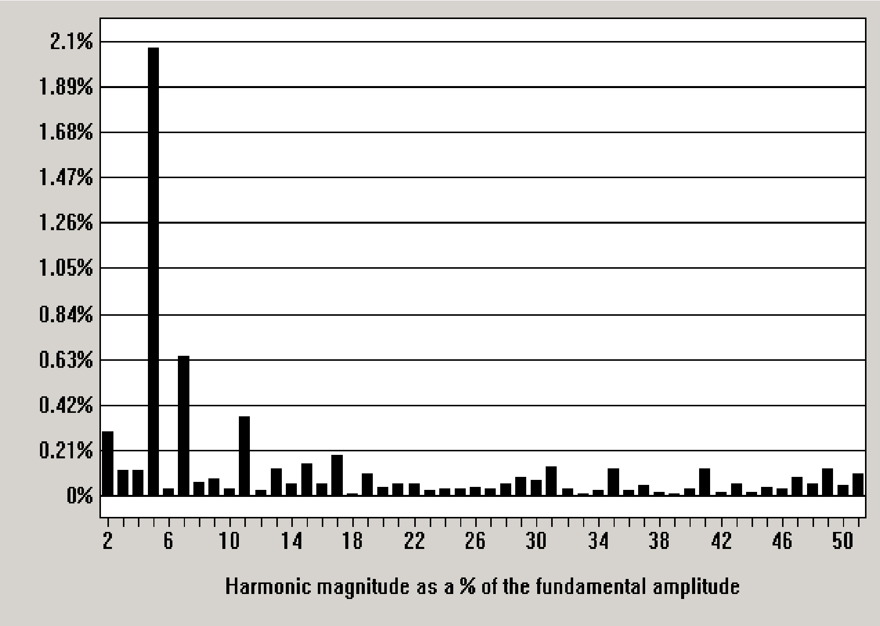
- Oscillation frequency 3183Hz=63rd harmonic

- without active filtering



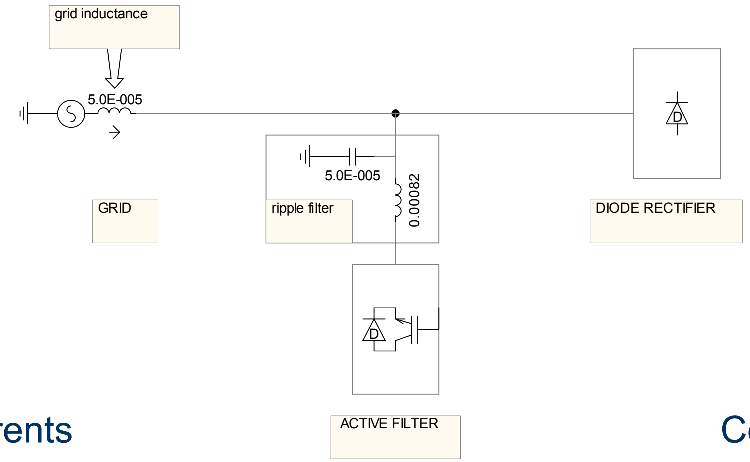
- Voltage THD 2.83%

- with active filtering



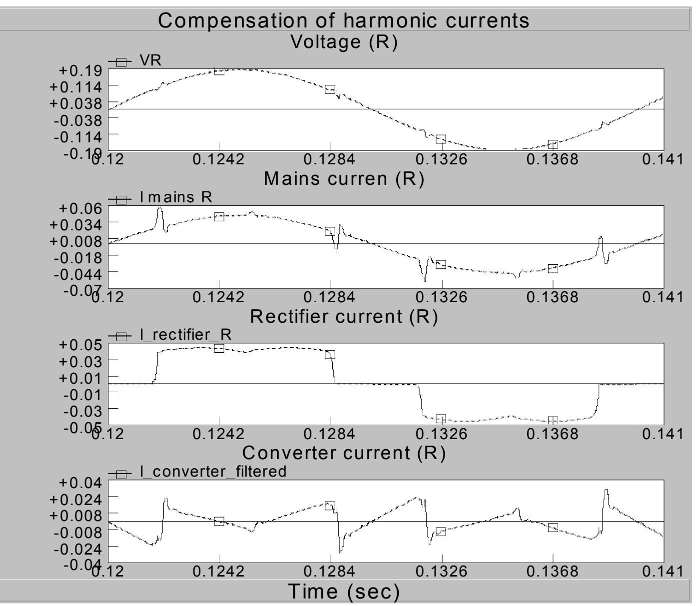
- Voltage THD 2.21%

Waveforms ($L_{Commutation}$ = 50µH)



Simulation

Compensation for harmonic currents



Annotations

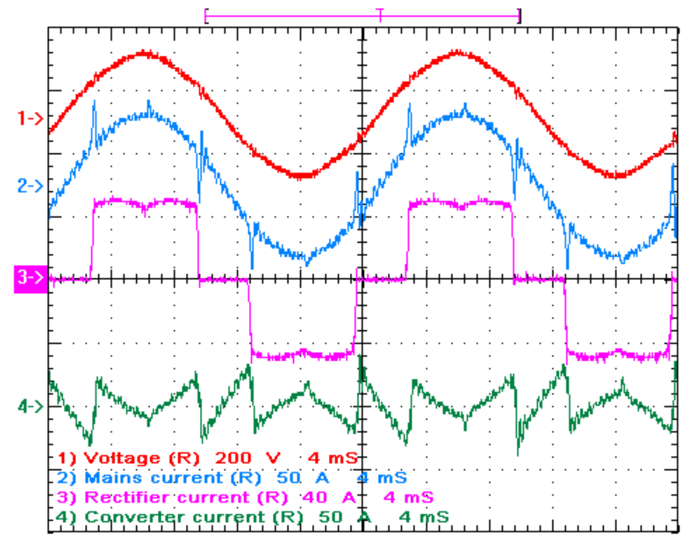
- 1 phase voltage
- 2 mains current
- 3 rectifier current
- 4 converter current

Oscillation

- 3183Hz=63[rd] harmonic

Laboratory

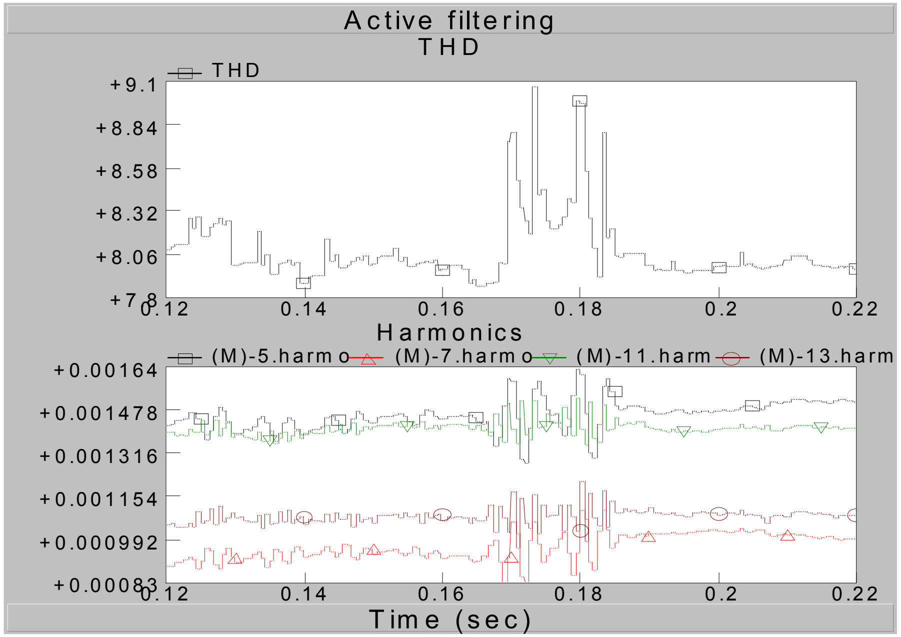
Compensation for harmonic currents



Results current ($L_{Commutation}$ = 50μH)

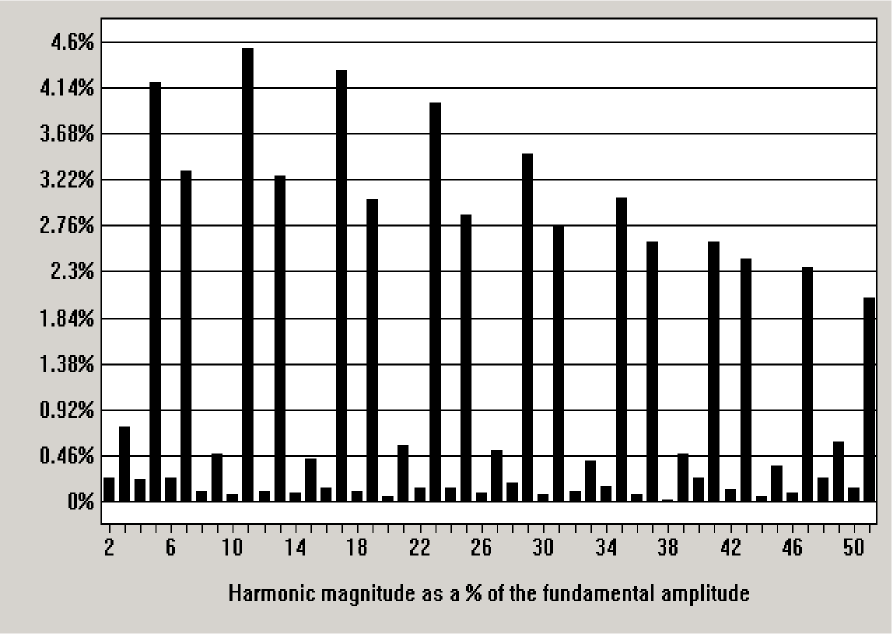
- Oscillation frequency 3183Hz=63rd harmonic

- Simulation



- Current THD about 8.2%

- Laboratory

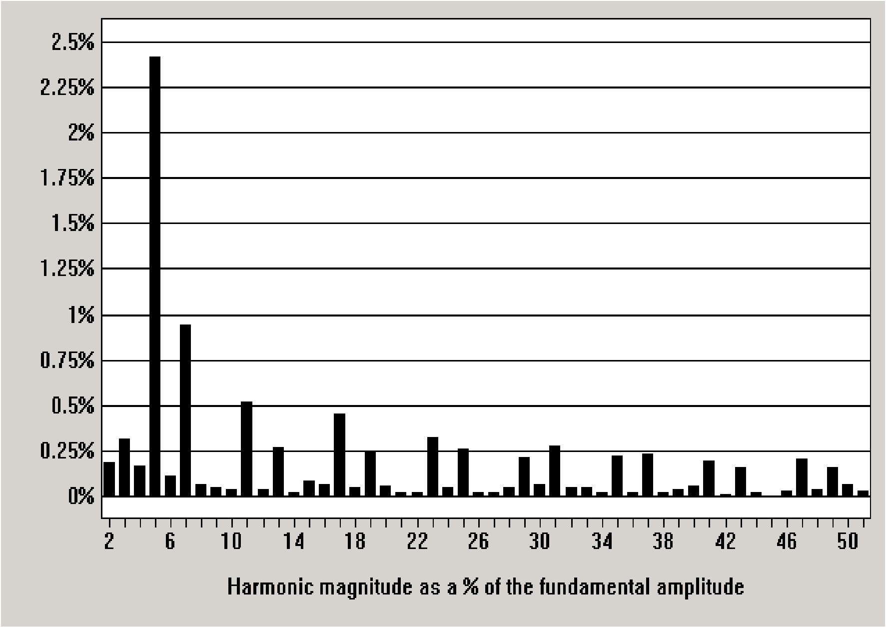


- Current THD about 12.5%

Results voltage ($L_{Commutation}$ = 50µH)

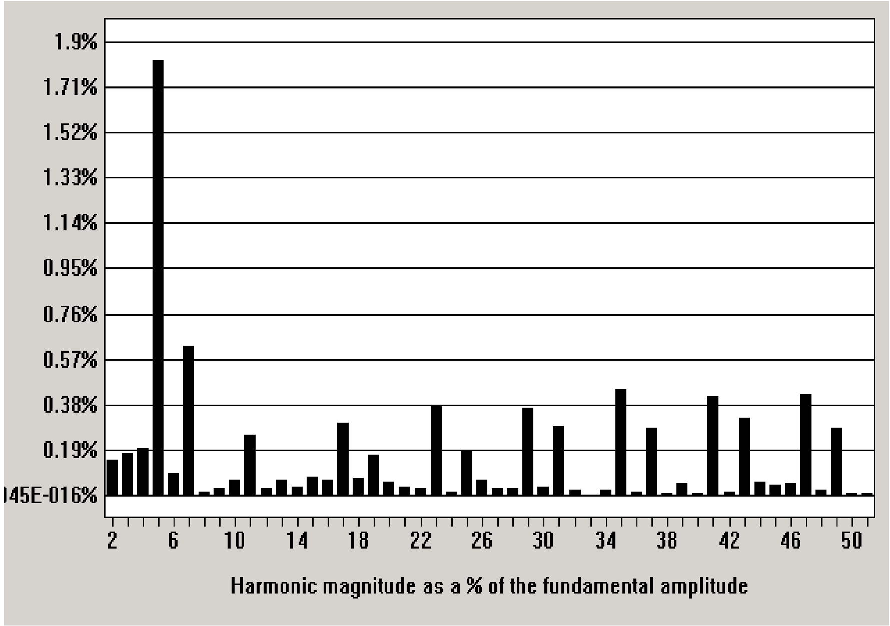
- Oscillation frequency 3183Hz=63[rd] harmonic

- without active filtering



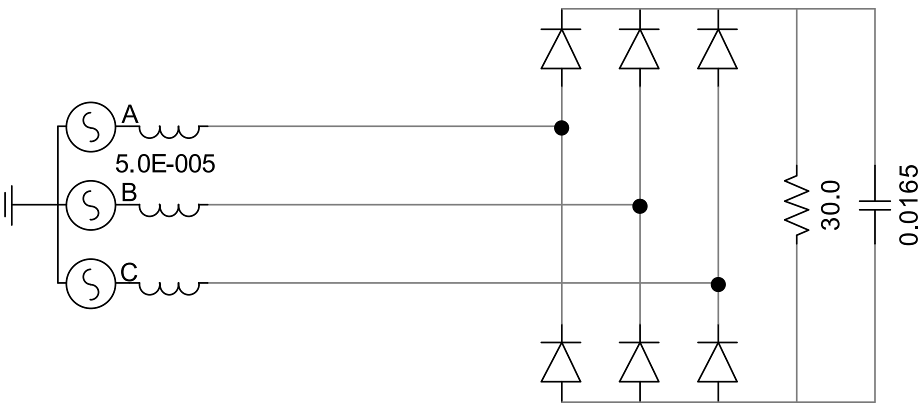
- Voltage THD 2.83%

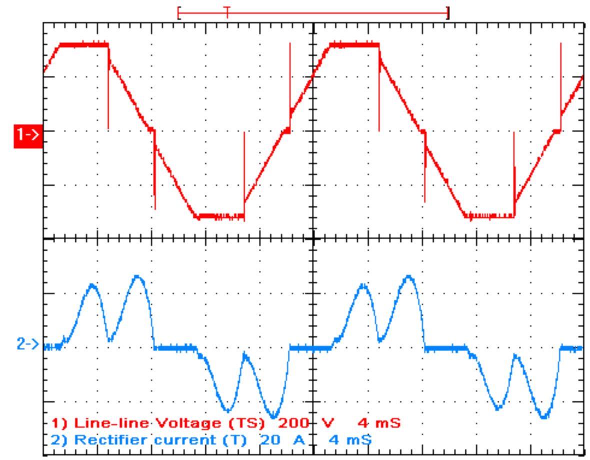
- with active filtering



- Voltage THD 2.21%

Diode rectifier with capacitive DC-load

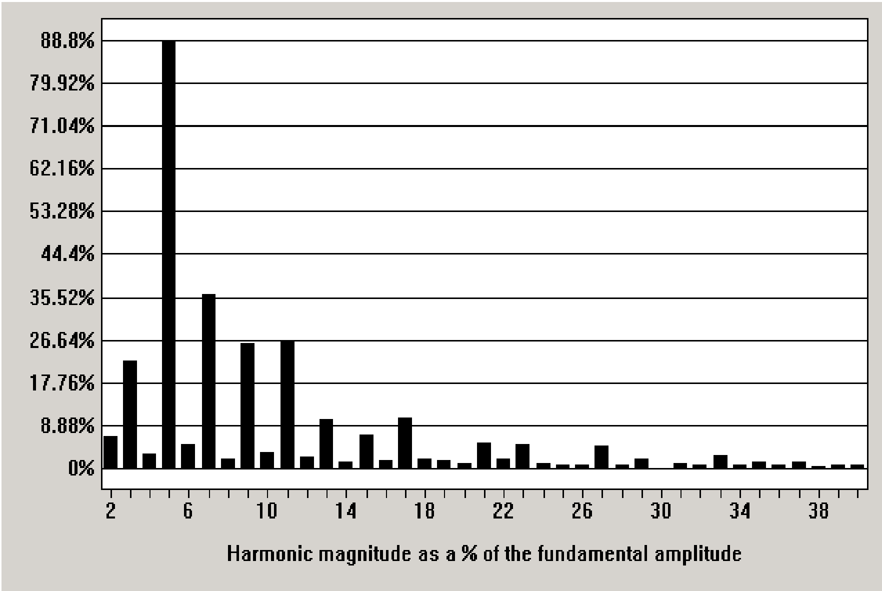




Line-line voltage

Rectifier current (discontinuous)

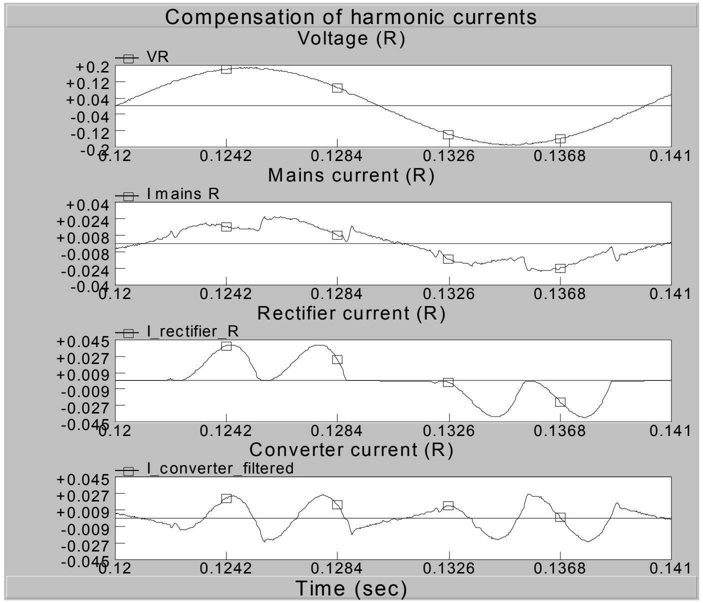
- 5^{th} current harmonic 89%
- Current THD 105% (discontinuous current flow)



Waveforms (RC-DC-load)

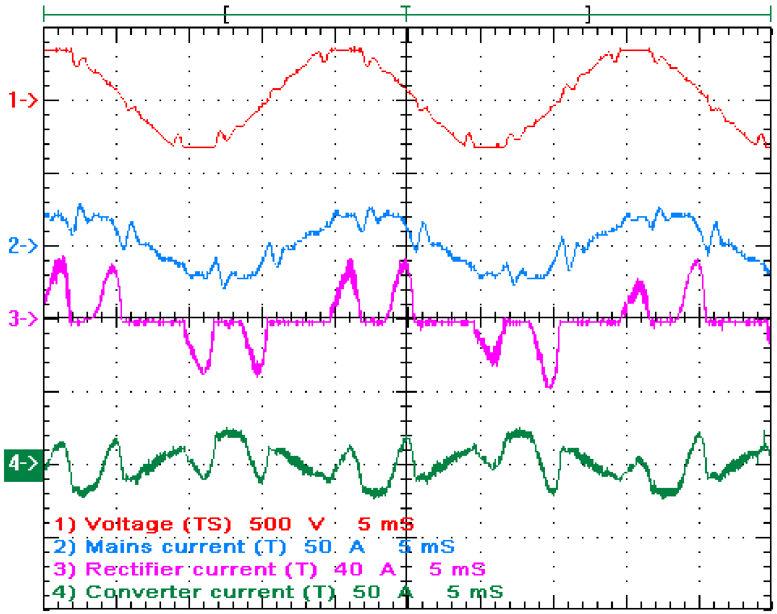
Simulation

Compensation for harmonic currents



Laboratory

Compensation for harmonic currents



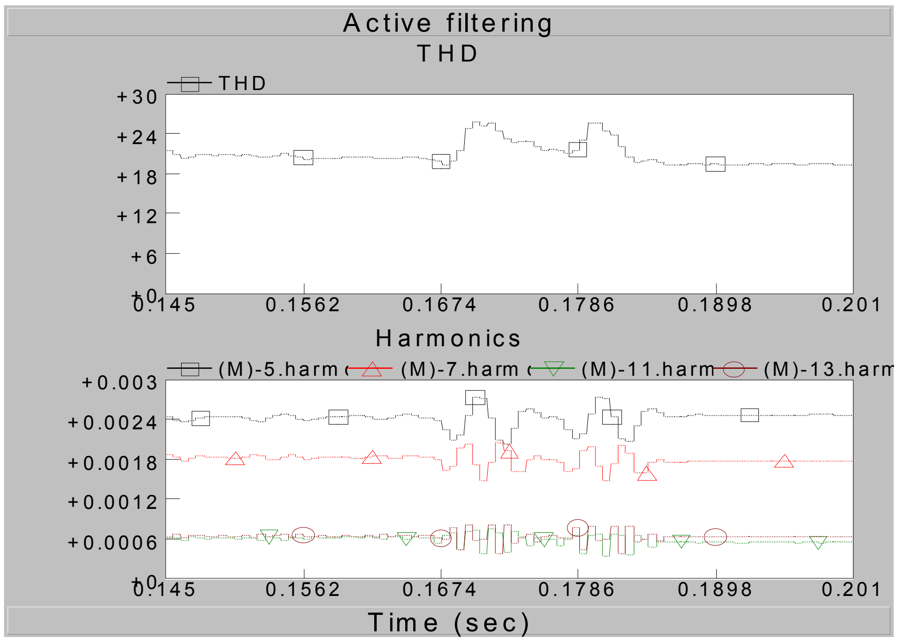
- Annotations
  - 1 phase voltage (R)
  - 2 mains current (R)
  - 3 rectifier current (R)
  - 4 converter current (R)

- Annotations
  - 1 line-line voltage (TS)
  - 2 mains current (T)
  - 3 rectifier current (T)
  - 4 converter current (T)

Results current (RC-DC-load)

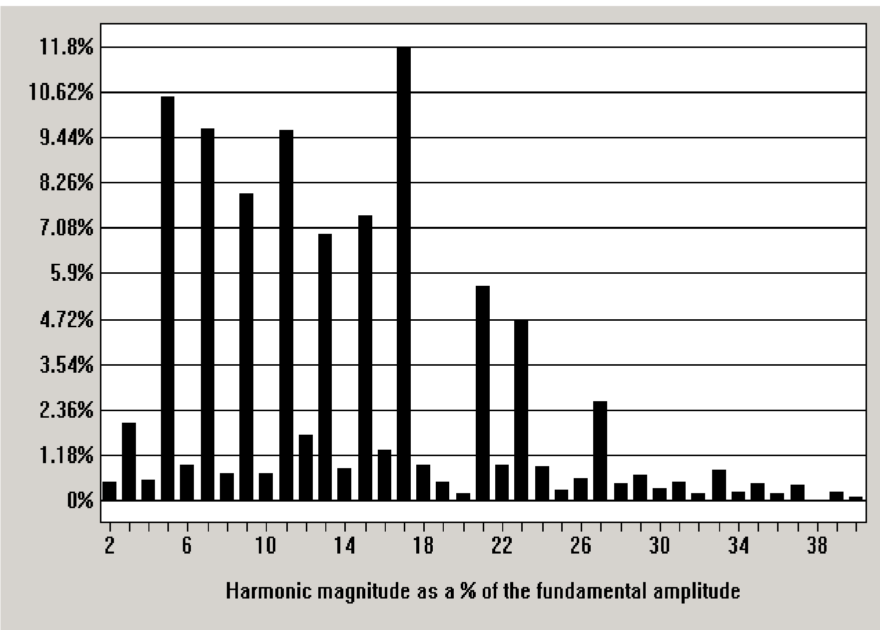
- Oscillation frequency 883Hz=17th harmonic

- Simulation



- Current THD about 22%

- Laboratory

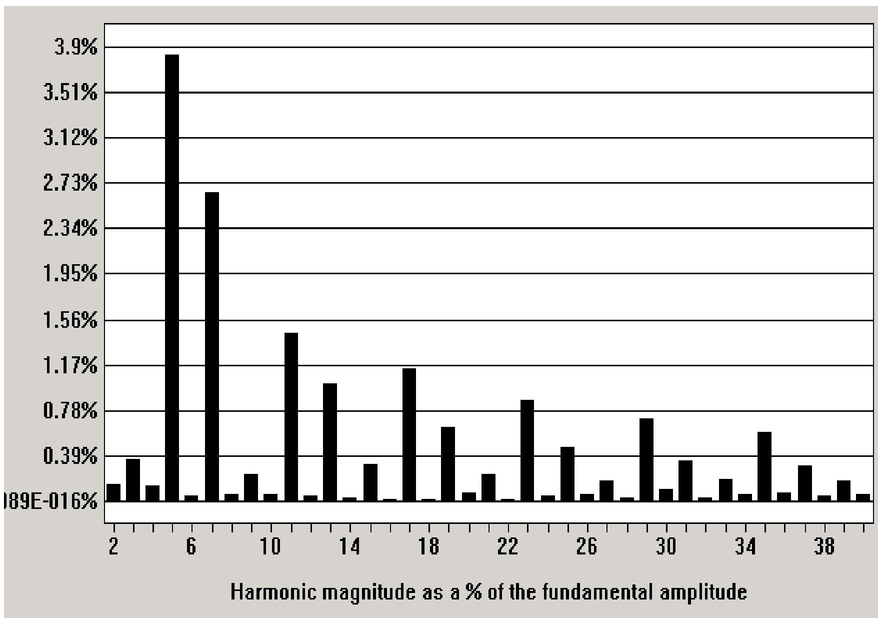


- Current THD about 25%

Results voltage (RC-DC-load)

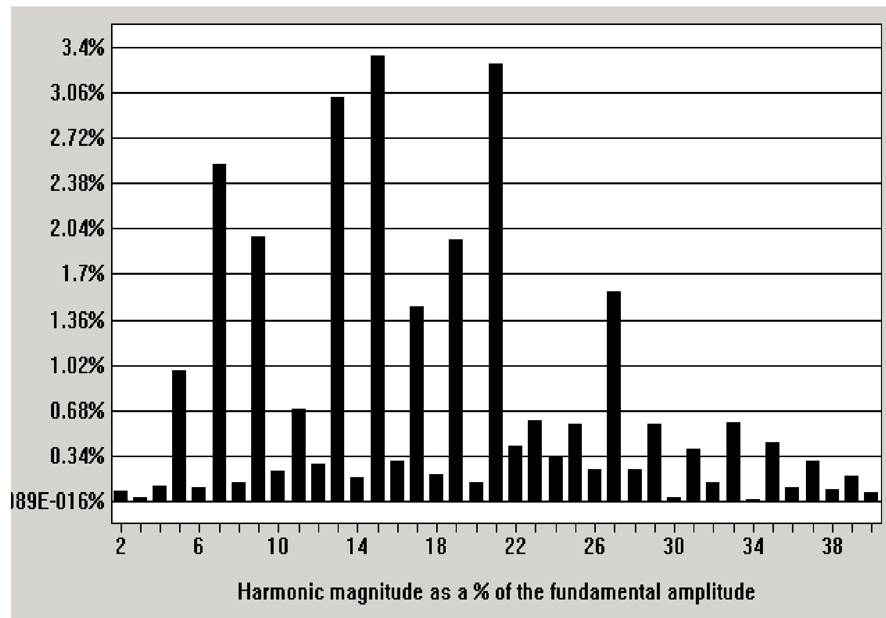
- Oscillation frequency 883Hz=17th harmonic

- without active filtering



- Voltage THD 5.4%

- with active filtering



- Voltage THD 7.3%

Summary

- Current improvements
  - Possibility of compensation for harmonic currents and reactive power
  - Filter is able to improve all types of distorted current shapes
- Voltage improvements
  - depending on the current flow trough the rectifier
  - continuous current flow: able to improve
  - discontinuous current flow: no guaranty for an improvement

Conclusions

- The major problems must be improved or solved

- Delayed current
  - Faster AD-converter
  - Replacement of the micro controller
    - by DSP
    - by Tricore
  - Current controller with a higher bandwidth
- Reducing the oscillation
  - Passive damping of the oscillating circuit (added resistor)
  - Active damping by modified control algorithm