Hybrid Active Filter for Power Factor Correction and Harmonics Elimination in Industrial Networks

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Winnipeg, MB, September 2011
Compensation devices

- **Definition:** providing the appropriate parameters of the power quality
  - reactive power compensation,
  - harmonics filtering.

- **EN 50160** – maximal values of voltage distortion at the utility-customer PCC.

- **Reactive power compensation and harmonics filtering**

  ![Diagram of passive and active compensators]

  **Passive compensators**
  + well-established technology,
  + robust,
  - may cause resonance,
  - size.

  **Active compensators**
  + operation does not depend on the impedance characteristic of the network,
  - high investment and operating costs,
  - switching losses.
Filter topology

- **Hybrid active power filters**
  - combination of passive (elements RLC) and active part (VSC),
  - passive part – reactive power compensation,
  - active part – improving operational characteristics of the PP

- **Most common topological structures**
  - Series hybrid filter
  - Parallel hybrid filter
Simulated network description

Stiff network 3750 MVA
Tr I 110/35 kV, 20 MVA, 10,82 %
Tr II 35/0,676 kV, 3,25 MVA, 7,41 %
Tr III 35/0,675 kV, 3,5 MVA, 6,62 %
DCM I 2,5 MW, 690 V, 350/450 min⁻¹
DCM II 2,15 MW, 690 V, 750 min⁻¹
Other load 6,1 MW, 0,96 MVAr

Fig. Industrial Network Parameters

Passive LC compensator
$Q_{PF}$ 5,4 MVAr
$L_{PF}$ 11,8 mH
$C_{PF}$ 13,81 µF
$f_{r-p}$ 395 Hz, 1,6 %

Fig. Passive Compensator Parameters
Resonance problem

Fig. Calculated impedance-frequency characteristics of the network with and without passive filter; a) series impedance, b) parallel impedance

<table>
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<tr>
<th>Passive filter</th>
<th>5\textsuperscript{th}</th>
<th>7\textsuperscript{th}</th>
<th>11\textsuperscript{th}</th>
<th>13\textsuperscript{th}</th>
<th>THD</th>
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<tbody>
<tr>
<td>$V_F$</td>
<td>8.77</td>
<td>0.21</td>
<td>0.09</td>
<td>0.1</td>
<td>8.78</td>
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<td>$I_S$</td>
<td>31.01</td>
<td>0.51</td>
<td>0.14</td>
<td>0.16</td>
<td>31.03</td>
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<tr>
<td>$I_F$</td>
<td>72.20</td>
<td>6.63</td>
<td>1.01</td>
<td>0.83</td>
<td>72.51</td>
</tr>
</tbody>
</table>

Tab. Harmonic content

Fig. Simulated waveforms
Hybrid filter – topology and control algorithm

**Used topology**

- three-phase, two-level, voltage-source converter (VSC) connected in series with the passive filter capacitance and inductance
- the voltage drop on the capacitor reduces the VSC voltage ratings
- no coupling transformer

**Control algorithm**

Control law: \( V_{AF}^* = K \cdot I_{Sh} \)

- current controlled voltage source

- Used topology
- Control algorithm

- Fig. Control block diagram of the active filter.
Passive part dimensioned for reactive power compensation.

Active part dimensions:
- The harmonic voltage consists of two components:
  \[ V_{AF,ref,h} = V_{S,h} + I_{L,h} \left( X_{C,h} - X_{L,h} \right) \]
  \[ = V_{S,h} + I_{L,h} X_{C,1} \frac{f_1}{f_h} \left( 1 - \frac{f_h^2}{f_R^2} \right) \]
- Harmonic current
  \[ I_{AF,h} = \frac{V_{S,1}}{Z_{PF,1}} + I_{L,h} = \frac{V_{S,1}}{X_{C,1}} \left( \frac{f_R^2}{f_R^2 - f_1^2} \right) + I_{L,h} \]
- Active part rating
  \[ S_{AF} = V_{AF} I_{AF} \]
Hybrid filter → ratings

Example

Active filter (no reactive power compensation)

\[ U_s = 1 \angle 0^\circ \]
\[ I_L = 1 \angle 45^\circ \]

\[ U_{s,h} = 0 \]
\[ I_{B,5} = \frac{1}{5} I_{B,1} \]
\[ \varphi_{I,5} = 5 \varphi_{I,1} \]
\[ I_{B,7} = \frac{1}{7} I_{B,1} \]
\[ \varphi_{I,7} = 7 \cdot \varphi_{I,1} \]
\[ f_R = 240 \text{ Hz} \]

\[ S_{AF} = U_{RMS} I_{RMS} = \sqrt{(1)^2 \cdot 0,2^2 + 0,14^2} = 0,244 \text{ p.u.} \]

Series hybrid filter

\[ S_{AF} = 0,025 \text{ p.u.} \]
Frequency response characteristics

Equivalent impedance at the series resonance point $f_{r-s}$

$$Z_{NpS} = \frac{K_\Phi}{N_\Phi}$$

Equivalent impedance at the parallel resonance point $f_{r-p}$

$$Z_{NpS}^f = \frac{X_{LSS}^f}{K_\Phi R_{SS}^f}$$

Fig. Impedance-frequency characteristics of the network with HAPF; a) series impedance, b) parallel impedance.
Simulation results

**Fig. Simulated waveforms**

- **PCC Voltage (%):**
  - Only passive filter
  - Hybrid filter

- **System current (%):**

- **Load current (kA):**

- **Active current (kA):**

- **Filter current (kA):**

- **DC voltage (kV):**

- **System current (kA):**
Conclusion

- The presented HAPF is composed of a small-rating VSC connected in series with a shunt single-tuned passive filter.

- For the connection to the network no transformer is needed.

- Since the rated power of the active filter is relatively low, the HAPF represents a viable solution to reactive-power compensation and harmonic filtering.

- The cost comparison between the hybrid, pure passive and stand-alone active filter is excluded from this paper, although it is mandatory as a proof of cost efficiency for the proposed solution.
Thank you for your attention!

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