Detuned Filters for Power Factor Correction of Adjustable Speed Drives

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Abstract: - This paper presents some significant investigations on detuned filters used in conjunction with adjustable speed drives as power factor correctors in a plant power system. Simulation and experimental results are presented and discussed in order to point out the benefits of the solution.

Key-Words: - Adjustable speed drive, Detuned filter, Harmonic distortion, Power factor correction

1 Introduction
The industrial AC Adjustable Speed Drives (ASD), incorporating power electronics have known lately a very dynamic increase due to the positive effects, like: energy savings, process optimization, smooth machine operation, maintenance facilities, etc. Because of its performance, ASD represents today a standard element in all automated process plants, where AC induction motors are used. At the same time, ASD became a significant non-linear load component for power distribution system, responsible for a serious harmonic pollution of the supply system, [1]. The main problems created by harmonics are: overloading and excessive heating and failure of various electrical equipment, undesired tripping of circuit protections, erroneous operation of control system components, damage of sensitive electronic equipment, EMI in communication systems, [2]-[5].
In the last years, major efforts have been focussed on harmonic assessment and reduction techniques, as an important aspect of power quality management, [2] – [5].
Power factor compensation in a network affected by harmonic distortion produced by non-linear loads, such ASD’s, have to be done with care, because the resonances can occur in the supply network. Resonances can lead to some undesirable effects, such as, [6]: overloading of various equipment (capacitors, transformers), amplification of harmonics and voltage distortion, interference with measuring and control systems. The tuned frequency in the resonant circuit formed by the capacitance of the compensation capacitor and the network inductance may match and amplify an existing harmonic current. Due to the amplified harmonics caused by the resonance, the voltage and current waveforms are distorted and this leads to further current and voltage distortions. To avoid these resonances, a reactor must be connected in series with the capacitor, in such a manner that the fundamental reactive power is compensate, but the harmonics are not amplified. This filter is known as a detuned filter. The capacitance of the capacitor is selected in order to compensate the reactive power at the desired level, and the inductance of the reactor is calculated so that the tuned frequency of the series resonant circuit formed with the capacitor is lower than the lowest harmonic frequency possible in the network (normally the 5th harmonic, at the frequency of 250Hz). The detuned filter behaves like a capacitor below its resonant frequency, that is, at the fundamental frequency it produces reactive power for the compensation purpose. Above the resonant frequency, the behavior of the detuned filter is inductive, so it cannot amplify the typical harmonic frequencies such as the 5th, 7th, 11th harmonics, [6], [7].
Usually, the resonant frequencies of the detuned filter are 204Hz or 189Hz. A detuned filter at a resonant frequency of 189Hz allows the connection to the network of more distorting consumers than a detuned filter having a resonant frequency of 204Hz, [5].
As is already mentioned in [6], depending of the detuning ratio, the impedance above the filter frequency is set to withdraw the harmonics from the installation to a certain extent (e.g. 5.7% or 7%). In case of extreme harmonic contents (e.g. $THD_V$>10%), this method of withdrawing the harmonics through the PFC system is no longer possible, as the capacitors would be overloaded. A
convenient solution in this case is a 14% detuning, in order to set the impedance such as to avoid resonance and thus allow PFC because all harmonic currents are blocked by the PFC setup.
The detuned filter is usually connected in parallel with the equipment to be compensated.
In [7] is presented an analysis of detuned filters based on simulation and measured results in an industrial power system. The main conclusion of the paper is that the harmonic distortion is not remove completely, but the detuned filters can contribute in a certain measure to the harmonic reduction.
The aim of this paper is to present some results related to application of detuned filters in an industrial power system having connected some adjustable speed drives. There are also used simulations to show the effects of power factor compensation without and with detuned filters.

2 Simulation results
The investigated power system is a municipal water treatment plant, whose single line diagram is shown in Fig 1. The system contains linear and nonlinear loads. The most common nonlinear loads in industry are the adjustable speed drives. In this case, three adjustable speed drives (one unit of 90kW and two units of 37kW) are used to drive the pumps for treated water. In the case when by means of the ASD-fed motors the system does not reach the preset pressure value, additional pumps are started, being supplied from the grid via softstarters, and then being by-passed on the grid. These line-fed motors are considered as linear loads. Other linear loads consist of different AC three-phase induction motors used in various auxiliary water treatment process.

![Simulation results](image)

In Fig. 1 Single line diagram of the water treatment plant power system

In Fig. 2 is presented the simulation scheme which was used to dimension the detuned filter and to show the negative effect of harmonics when single capacitors are used to compensate the power factor in the presence of harmonic distortion.
Simulation results are presented in Fig.3-Fig.5.
In Fig.3 there are represented the current waveforms and harmonic spectra respectively before compensation.

In Fig. 4, are represented the current waveform and harmonic spectra respectively, during power factor compensation with a single capacitor bank, without a series inductor.
The current waveforms and harmonic spectra are represented in Fig. 5, in the case of using a detuned filter in the simulation scheme.
Although the voltage waveforms are not figured here, they have been also recorded and measured.
Fig. 2 Simulation scheme of the power system

Fig. 3 Current waveform and harmonic spectra before compensation
Fig. 4 Current waveform and harmonic spectra during compensation with simple capacitor bank

Fig. 5 Current waveform and harmonic spectra during compensation with detuned filter
3 Experimental results

In order to ensure an effective power factor compensation at the electric supply busbars of the water treatment plant, a 90kVAR six steps detuned filter was used. Each step of the detuned filter consists of a capacitor and an inductor connected in series, Fig. 6. The steps are arranged such as the rating reactive powers of each pair of step are progressively: 7.5kVAR, 12.5kVAR, and 25kVAR. The series inductors are dimensioned in order to achieve a resonance frequency of 189Hz. The filter steps are switched ON and OFF by mean of a digital controller. The controller acquires the current (by mean of a current transducer CT) and the voltage in the Point of Common Coupling (PCC) and calculate the displacement power factor in order to compensate only the fundamental reactive power and not the harmonic distorted power.

![Fig. 6 Schematic diagram of the detuned filter](image)

The experimentally recorded results are presented in Fig. 7 - Fig. 9. In Fig. 7 there are recorded the current waveforms and harmonic spectra before compensation.

![Fig. 7 Current waveform and harmonic spectrum before compensation.](image)

In Fig. 8 there are recorded the current waveforms and harmonic spectra during compensation with capacitors only.

![Fig. 8 Current waveform and harmonic spectra during compensation with simple capacitor bank](image)
In Fig. 9 there are recorded the current waveforms and harmonic spectra during compensation with the detuned filter.

![Fig. 9 Current waveform and harmonic spectra during compensation with detuned filter](image)

The simulation and measured results concerning harmonic distortion, are summarized in Table 1.

<table>
<thead>
<tr>
<th>Case</th>
<th>THD$_V$ [%]</th>
<th>THD$_I$ [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Simulated</td>
<td>Measured</td>
</tr>
<tr>
<td>Without compensation</td>
<td>3.00</td>
<td>3.08</td>
</tr>
<tr>
<td>Capsitors only</td>
<td>4.36</td>
<td>4.40</td>
</tr>
<tr>
<td>Detuned filter</td>
<td>3.08</td>
<td>3.17</td>
</tr>
</tbody>
</table>

From Table 1, it can be observed a good agreement between the simulation and the measured results. The power factors experimentally determined for the three cases are presented in Table 2.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Without compensation</th>
<th>Capsitors only</th>
<th>Detuned filter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power factor</td>
<td>0.808</td>
<td>0.901</td>
<td>0.924</td>
</tr>
<tr>
<td>Displacement</td>
<td>0.919</td>
<td>0.932</td>
<td>0.944</td>
</tr>
</tbody>
</table>

From Table 2, it can be observed that the power factor is determined by the use of the capacitors and in a greater measure, by the use of the detuned filter. The presence of the detuned filter does not affect in a great measure the displacement factor.

4 Conclusion

In order to prevents any harmful resonance in networks affected by harmonics, the detuned filters represent the most affordable solution to compensate the reactive power and thus to improve the power factor. In this paper there was described the main features related to industrial implementation of detuned filters, by means of simulations and experimental investigation. The overall conclusion is that detuned filter ensures a real reactive power compensation, but the effect in harmonic reduction is not so significant.

References:


