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An Active Solution

Energy savings & harmonic mitigation in the water and wastewater industry

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Variable frequency drives (VFDs) provide several advantages to the water and wastewater industries, including energy savings, increased equipment life and efficiency, automation and process optimization. The most commonly implemented front-end topology is the six-pulse diode rectifier, due to its high efficiency, low cost, robustness and reliability.

The major concern associated with the diode rectifier is that it generates nonsinusoidal currents, referred to as harmonic currents, into the power supply. Harmonic currents cause harmonic voltage distortion and additional losses and heating in the electrical equipment, lowering efficiency and often creating the need for oversized AC supply transformers. These effects increase significantly as the VFDâ€™s power rating increases.

Over the years, many different harmonic mitigation solutions have been utilized. The simplest solutions consisted of passive filtersâ€”either series inductors or parallel capacitorsâ€”connected so that their impedance would block or sink the harmonic currents. Several other solutions emerged, such as pulse multiplication, magnetic waveshaping, reconfiguration of the power system and mixed nonlinear loads.

Lately, active solutions involving power converters and dedicated control algorithms have been explored in an attempt to improve the efficiency of harmonic mitigation. An active harmonic filter injects harmonic current with opposite phase to the nonlinear load current, canceling all harmonic currents and leaving only the fundamental current. Although several manufacturers exist, the active filter is still considered an emerging technology; however, recent technological progress in the semiconductor industry has allowed a steady increase of the power rating and switching frequency of the static power switch, a key element that has begun to change the perception of active filters. Furthermore, the evolution of digital signal processors and new control theories enabled superior harmonic compensation characteristics and stable operation of active filters compared to traditional passive filters.

Active Filters

Active filters detect the harmonic spectrum of the load current (IL) and generate an output current (IF), which ideally is of the same harmonic spectrum as the load current but in opposite phase. In this way, the active filter current cancels out the harmonic currents, leaving only the fundamental current (IS) (Figure 2).

Possible connections of active filters on the power network are either close to the nonlinear load (e.g., a high-power VFD) or at the point of the common coupling (PCC) as a central harmonic solution serving multiple VFDs (Figure 3).

The efficiency is higher than that of a passive filter because the active filter provides harmonic current mitigation but does not load the network at the fundamental frequency. Unlike passive filters, there is no need for connecting multiple branches for mitigation of several harmonic orders at once. One active filter is capable of mitigating up to a practical harmonic order of 30 to 50, meeting the actual harmonic standards and regulations.

Unlike passive filters, there is no parallel resonance when connecting the active filter to the network. If fitted with proper sensors and dedicated control, the active filter may dampen existing network resonances created by capacitive loads. Furthermore, the active filter can regulate the power factor, and the amount of generated reactive power is completely programmable and depends on the user-imposed reference.

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Unlike many other harmonic solutions, active filters can protect themselves against voltage imbalance and predistortion and maintain the quality of the compensated current. The active filter can prioritize the compensation of either harmonic or reactive power depending on momentary demands. This allows the active filter to fulfill the harmonic standards while simultaneously optimizing power factor compensation.

Performance Evaluation

The performance obtained with the selected harmonic mitigation solutions is evaluated based on the total harmonic current distortion (THDi) factor, which indicates the quality of the supply current after harmonic compensation. A lower THDi means a better harmonic compensation.

When comparing the performance between different harmonic solutions, the achieved THDi is not the only decisive factor. As with any electrical equipment installed on the power system, all harmonic solutions have power losses and, to some extent, generate reactive power (all passive solutions contain capacitors, inductors or transformers). The total apparent power has three dimensions: active, reactive and harmonic distortion power.

Figure 5 compares harmonic solutions based on three criteria: the ability to compensate the harmonic distorted power (DN), system power losses (PLoss) and generated reactive power (Q1 is positive if lagging power and negative if leading). The best performance is obtained by the solution that stays as close as possible to the origin, as this indicates minimum losses, complete compensation of harmonic currents and unity power factor.

Regarding the power losses, the active filter has the lowest among the presented solutions. Based on power electronics, the efficiency of active filters is significantly higher (estimated at 97%) than that of any passive solution. Furthermore, the active filter is a parallel solution, meaning that the VFD current does not pass through the active filter. The passive filter is also a parallel solution, but since it generates capacitive current, it has additional power losses. The other passive solutions (AC coil and multipulse rectifier) are based on series inductors or transformers supporting the full VFD current, and therefore, the losses are higher.

Regarding the compensation of reactive power, the active filter achieves unity power factor adjusted to the plant needs. The passive filter may also provide reactive power compensation, but the amount of reactive power can practically be controlled in two or three steps or not at all, depending on how many capacitor banks can be switched on and off. However, adjusting the reactive power dictates a simultaneous direct adjustment of the harmonic compensation that cannot be independently controlled. The other passive solutions (AC coils and multipulse rectifiers) can only provide lagging reactive power, not leading, dependent on the VFD loading.

A Better Solution

Although the harmonic currents may be reduced by different means, the latest developments in the semiconductor industry allow active filters to take over the performance of traditional harmonic solutions. Compared to the passive solutions currently used, the installation of active filters offers superior harmonic mitigation, wider compensated harmonic spectrum and adaptive compensation of reactive power according to the installation needs, resulting in higher energy efficiency and improved stability of the power system due to the lack of parallel resonance. Being fit with sensors, the active filter has major advantages over the previous harmonic solutions: safe operation, stability, self-testing and protection.

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