**A Comparative Analysis of Passive and Active Harmonic Filtering for Variable Speed Drive Loads**

**Introduction**

Harmonic distortion in electrical systems, particularly in environments utilising Variable Speed Drives (VSDs), presents significant challenges. VSDs, widely used to control motor speeds in industrial applications, generate substantial harmonic currents due to their non-linear operation; this means that the current they draw is not sinusoidal. **See Figure 1 for a representation of the voltage and current input of VSD**, which is often higher than needed for the power of the VSD and the connected motor. These harmonic currents can cause overheating, inefficiencies, and damage to electrical equipment. To help solve these issues, various methods of harmonic filtering are often employed, the two primary types being passive harmonic filters (PHFs) and active harmonic filters (AHFs). This paper examines the relative benefits and disadvantages of PHFs and AHFs, focusing on their application in systems with VSD loads.

**Variable Speed Drives and Harmonics**

VSDs adjust motor speed by varying the frequency and voltage supplied. However, they also introduce significant harmonic currents into the electrical network, typically in the 5th, 7th, 11th, and 13th harmonics. **See Figure 2 for the Typical Input Harmonics for a VSD and Purely Resistive Load**. These harmonics can lead to several unwanted effects, including increased losses in motors and transformers, interference with other electronic equipment, and increased power usage.

**Passive Harmonic Filtering**

Passive harmonic filters (PHFs), like REO's REOWAVE Passive, **see Figure 3**, use passive components—inductors, capacitors, and often resistors—designed to target specific harmonic frequencies generated by VSDs. These filters are typically installed at the point of common coupling (PCC) or near the VSDs to reduce the propagation of harmonics through the system.

**Benefits**

1. **Simplicity and Reliability**:
	* PHFs are simple in design, making them easy to install and maintain. Their operation is independent of complex control systems, enhancing their reliability, especially in industrial environments with VSDs.
2. **Cost-Effectiveness**:
	* PHFs are significantly less expensive than AHFs regarding initial investment and ongoing maintenance costs. This cost advantage is particularly beneficial in industrial settings where multiple VSDs are employed.
3. **Energy Savings**:
	* In systems with VSD loads, PHFs tailored for the application can reduce energy consumption by mitigating harmonic-induced losses, which can occur when the harmonics cause significant inefficiencies, such as excessive heat in motors, transformers, and other switchgear. This reduces cooling requirements and improves overall system efficiency. Energy savings could be as high as 10-20%.
4. **No External Power Requirement**:
	* PHFs do not require external power to operate, simplifying their integration into existing systems and avoiding the additional operational costs associated with power consumption. The operating losses for a typical PHF are around 1% of the rated power.

**Disadvantages**

1. **Limited Flexibility**:
	* PHFs are designed to target specific harmonic frequencies. Any changes in the harmonic spectrum, such as those caused by varying load conditions in VSDs, will reduce the filter's effectiveness.
2. **Risk of Resonance**:
	* PHFs can introduce resonance conditions within the electrical network, which may amplify specific harmonics instead of attenuating them. This risk requires careful filter design and tuning to match the characteristics of the VSD system.
3. **Size and Weight**:
	* The physical size and weight of PHFs can be considerable, particularly in systems with high-power VSDs, making installation more challenging in space-constrained or difficult to access environments
4. **Selective Harmonic Mitigation**:
	* PHFs are more effective at mitigating lower-order harmonics, like the 5th and 7th, which contribute most to system inefficiencies but may be less effective for higher-order harmonics, which can also be present in VSD-driven systems.

**Active Harmonic Filtering**

Active harmonic filters (AHFs) use advanced power electronics and digital signal processing to monitor and counteract harmonics dynamically. AHFs inject currents equal in magnitude and opposite in phase to the unwanted harmonics generated by VSDs, effectively cancelling them; this principle is known as destructive interference.

**Benefits**

1. **High Flexibility**:
	* AHFs are highly adaptable and can adjust to real-time load conditions and harmonic spectrums, making them particularly useful in systems with multiple VSDs where load conditions fluctuate frequently.
2. **Comprehensive Harmonic Mitigation**:
	* AHFs can target various harmonics, including lower- and higher-order harmonics, which is particularly advantageous in VSD applications where the harmonic profile can be complex.
3. **Compact and Lightweight**:
	* AHFs are typically more compact than PHFs, making them easier to install in environments with limited space.
4. **Elimination of Resonance**:
	* Since AHFs do not rely on passive components, they do not introduce resonance risks, making them safer and more reliable in dynamic systems.
5. **Energy Savings**:
	* After accounting for their power consumption, AHFs can achieve 2-7% net energy savings. These savings come from the improved efficiency of the entire electrical system due to the comprehensive elimination of harmonics.

**Disadvantages**

1. **Higher Cost**:
	* AHFs are much more expensive than PHFs regarding initial purchase and ongoing maintenance. The cost may be justified in complex systems with high harmonic content, but it can be a significant factor in more straightforward applications.
2. **Energy Consumption**:
	* AHFs require an external power source and typically consume 1-3% of the total load. While they reduce harmonic-induced losses, this additional energy consumption should be factored into the overall energy savings analysis.
3. **Complexity and Maintenance**:
	* The advanced technology in AHFs requires specialised knowledge for installation and maintenance, leading to potentially higher operational costs.
4. **Potential High-Frequency Noise**:
	* As with any device operating at high frequency, AHFs can introduce high-frequency noise into the system, which might interfere with sensitive equipment. Additional filtering or noise mitigation measures might be necessary.

**Net Energy Savings with Passive Harmonic Filters (PHFs) and VSDs**

**Typical Energy Savings:**

* **10-20% Energy Savings:** In most VSD applications, PHFs can reduce energy consumption by approximately 10-20%. **Figure 4 shows test results from a typical 30 kW VSD.** Eliminating harmonics improves the electrical system's overall efficiency by reducing overheating and unnecessary energy dissipation, reducing the need for additional cooling or oversized switchgear, supply infrastructure and cabling.

**Net Energy Savings with Active Harmonic Filters (AHFs) and VSDs**

**Typical Energy Savings:**

* **2-7% Energy Savings:** AHFs can reduce energy consumption by addressing a broader spectrum of harmonic frequencies and dynamically adapting to varying load conditions. In most VSD applications, AHFs typically provide 5-10% energy savings. However, because AHFs require power to operate and usually consume 1-3% of the system's total load, this power consumption slightly offsets the total energy saving.

**Summary of Net Energy Savings**

**Passive Harmonic Filters (PHFs): Net Energy Savings: 10-20%**

Most VSD applications will see savings in the 10-20% range, especially if the VSD runs continuously at the rated power - See figures 2 and 3 for test data from testing from two different VSDs

**Active Harmonic Filters (AHFs): Net Energy Savings: 2-7%**

AHFs typically offer 2-7% net energy savings after considering their power consumption, with the potential for higher savings in dynamic or highly variable load environments.

**Conclusion**

Passive and active harmonic filters offer distinct advantages and energy-saving potential when used with Variable Speed Drive (VSD) loads. Passive harmonic filters are generally more cost-effective and straightforward to implement, with energy savings that can be as high as 10-20%. However, they are less flexible and may introduce resonance issues.

While more expensive and complex, active harmonic filters offer superior flexibility and the ability to address a broader range of harmonic frequencies, making them particularly suitable for dynamic systems with fluctuating VSD loads. After accounting for their power consumption, AHFs can still provide net energy savings of 2-7%, along with improved overall power quality.

The choice between passive and active harmonic filtering in VSD-driven systems should consider the specific harmonic levels, load dynamics, space constraints, and budgetary factors, aiming to achieve the best balance between cost and energy efficiency.

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