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VFD options to meet IEEE 519 standards

To limit impacts of non-linear loads and harmonics

Summary

Originally published in 1981 and most recently updated in 2014, IEEE 519 is a recommended standard to help reduce the negative impacts of non-linear loads on electronics and control systems on the same grid as the source of harmonic distortion. Water and wastewater operations employ many large non-linear loads using variable frequency drives (VFDs) that are often the sources of harmonic distortion. IEEE recommends limits of 5-8% total harmonic distortion (THD) to the protect assets on the grid.

This paper considers many of the advantages and disadvantages of five VFD technologies and how each addresses the negative impacts of non-linear loads and harmonics. These technologies mitigate harmonics to comply with IEEE 519 and are often referred to as clean power drives. The options covered below are a six-pulse diode front end with no filter, six-pulse diode front end with passive filter, six-pulse diode front end with active filter, active front end (AFE) and 18-pulse diode front end.

Each option should be considered based on its own merits to address specific applications, including power level needs, cost, efficiency, reliability and space considerations.

1. **Six-Pulse Diode Front End with No Filter**

   Although readily available off the shelf, a six-pulse diode front end with no filter requires other system components to lower harmonics to meet the IEEE 519 standard. And while this no-filter option is low-cost and takes up little space, this drive choice may result in 30-50% THD. A six-pulse diode front end with no filter is only recommended when meeting the limits set by IEEE 519 is not required or when the power rating of the drive is very small in comparison to the overall load at the point of common coupling (PCC).

2. **Six-Pulse Diode Front End with Passive Filter**

   The second option is a six-pulse front end with a passive filter. The passive filter operates in series with standard six-pulse VFDs. This passive filter solution should meet the IEEE 519 THD recommendation. It has the smallest footprint of all the options. Additionally, the passive filter option is second on the list for efficiency, but only when operating at full load.

   However, the other technologies are much more robust and reliable. Harmonics from sources other than the drive can overload the filter, resulting in failure. These harmonic sources may come from other drives or pieces of equipment. Several passive filters on a grid can interact with each other causing resonance problems as well. The filters can also increase the VFD DC bus voltage, resulting in bus faults. Siemens does not recommend this as a viable option in larger horsepower applications.

3. **Six-Pulse Diode Front End with Active Filter**

   The third option is a standard, six-pulse drive or multiple drives operating in parallel with an active filter that can mitigate harmonics to within the IEEE 519 accepted THD range. The active filter option is an effective alternative where multiple small horsepower drives are installed in motor control center lineups. The active filter only needs to be sized for the running load. As a result, the active filter option offers a significant sizing advantage when some drives are redundant or the system has multiple drives that will never be loaded at the same time.

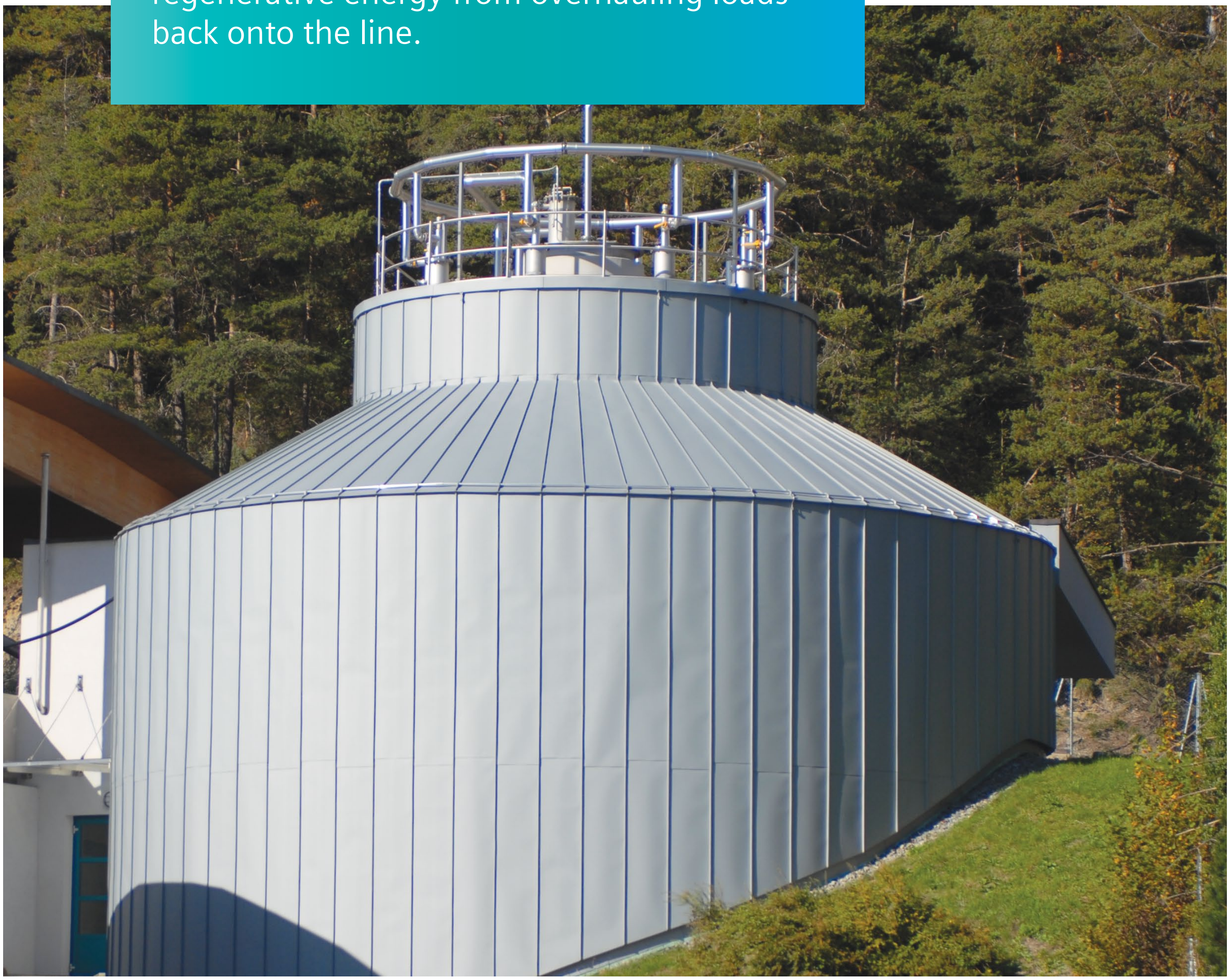
   The active filter uses current transformers (CTs) to measure distortion and injects the opposite distortion to offset it, much like noise cancelling headphones. This filter needs only to be sized according the harmonics to be mitigated and not to the total current load. For example, if a 100-HP drive is putting out 30% THD, the filter needs to be sized to 30 HP. By way of contrast, the passive filter discussed above would be sized to the load at 100 HP.

   Perhaps the greatest benefit of an active filter is that it does not operate in series with the drive. Instead, the filter is connected in parallel with the drive. In the event of a filter failure, it may not reduce harmonics, but the drive and the application keep running. In the case of a remote residential pumping station, this reliability advantage is very attractive.

   On the downside, active filters have numerous components that are controlled by a processor. As a result, if an active filter fails, it is complicated to repair. Also, the components, such as the filter and the CTs, are not built into the drive and require special installations and connections. This becomes especially complex and costly at higher power ratings and takes up extra space. Also, some active filters are system dependent and must be re-tuned when the system significantly changes. The entire system must be considered instead of just one VFD in a harmonic study as well.

Each application is unique. The best harmonics mitigation solution balances first cost, uptime requirements, efficiency and more.

Active front end (AFE) drives place regenerative energy from overhauling loads back onto the line.



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4. Active Front End

The active front end (AFE) drive option has the lowest distortion of all five technologies (~3% THD) and is capable of regeneration of energy from overhauling loads; not typical with pump applications. The AFE is two drives, back to back. The front end, or what is the rectifier section in a standard drive, is replaced by what is, essentially, another drive operating in reverse where the grid is the load.

An AFE drive has adjustable power factor (usually set to 1.0) and can be used to correct poor power factor in the system. It can also boost the output voltage to achieve significantly more than input voltage. This could be important when using custom motor designs.

The AFE has the longest power dip ride through of the options listed above (about 2x the ride through of a 6-pulse drive). Additionally the AFE can be generator-friendly due to its power factor capabilities, but careful and proper system configuration is necessary.

When compared to the other five technologies, the AFE represents the highest cost and largest size. An AFE is also complicated, making it more susceptible to nuisance trips than the other options. Additionally, since it has more active components, the efficiency is lower than other viable options discussed above. Similar to the active filter, the AFE option relies on substantial processor control as well as insulated-gate bipolar transistor (IGBT) control of the DC bus. In sum, if the filter or front end fail, the entire drive is down.

5. 18-Pulse Diode Front End

An 18-pulse drive combines an integrated three-phase transformer with three, phase shifted, three-phase secondaries feeding 18 diodes to form the rectifier section of the drive. By doing so, each secondary is out of phase with each other and, therefore, the harmonic distortion cancels each other out before passing back to the grid. In the Robicon W series, for example, this reduces the THD that passes back to the line to ~3%. Also, its transformer and 18-diode rectifier are packaged with the drive and delivered pre-wired all in one cabinet as a single, UL-listed unit.

Since all functionality takes place inside the drive, compliance with IEEE 519 at the PCC is certain. The 18-pulse drive can switch to backup generator without issues or further study. Because it has fewer components, it requires less space, is simpler to install and is more efficient than other options.

The 18-pulse option operates with no processor-controlled functions in the rectifier; the front end consists of hardware electronics (a transformer and diodes), virtually eliminating nuisance trips. Of all five options, the 18-pulse drive solution is the most robust and has the longest meantime between failure (MTBF). The 18-pulse is designed for medium to very large power ratings and is not susceptible to other system harmonics. Its successful reliability track record spans many years and is recommended for applications where it is critical that VFD nuisance trips or failures are greatly minimized.

While effective in large horsepower applications (50 HP and above), the 18-pulse option is not typically available for low power ratings.

Conclusion

Each of the possible options for mitigating harmonics offers advantages and disadvantages. There are cases where the newest technology has disastrous disadvantages and cases where older technology does not have a feature that could solve an installation problem. The most expensive solution may have features that have little to no benefit for a given situation. The least expensive solution may have hidden long term efficiency or maintenance costs.

By carefully considering the advantages and disadvantages of the different harmonic mitigation options, a selection will be made that results in the lowest total cost of ownership, the fewest service interruptions and the features that offer genuine benefits.

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