SIEMENS

Multi-pulse VFD inputs: When is more too much?

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When variable frequency drives (VFDs) were first introduced, they represented a significant step forward in precision motor control. But this advancement came with a drawback: The input circuits distorted the current, creating dangerous harmonics. For VFDs to be practical, the risk of harmonic damage would have to be mitigated.

Line reactors were the initial solution, soon followed by more powerful transformers with phase-shifted secondary windings. As the pulse count of the rectifiers increased, the total harmonic distortion (THD) decreased, until finally an 18-pulse arrangement was able to achieve a THD well below the 5% industry standard. Today these 18-pulse systems are the most common solution for low and medium voltage VFDs.

Recently, however, there has been a push for 24-pulse VFD inputs from some manufacturers—despite a lack of any apparent advantage over existing VFDs. In fact, the total cost of ownership for these circuits is remarkably higher. In this paper, we examine whether the improvement in THD offered by a 24-pulse circuit is worth the cost.

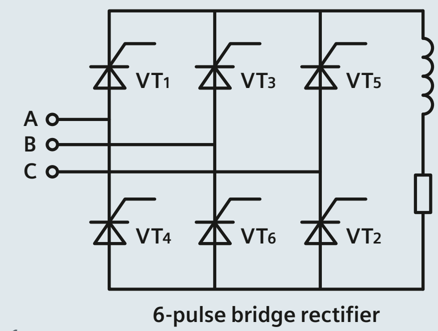

Figure 1

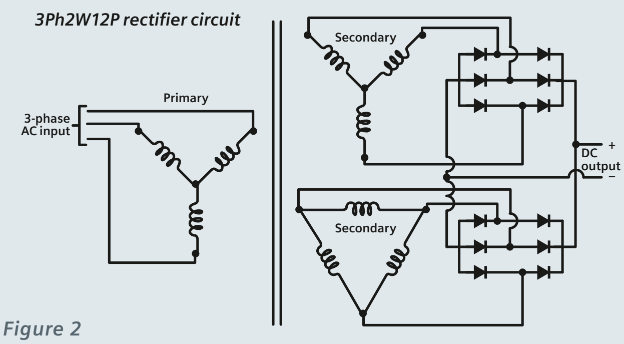

Figure 2

Early multi-pulse systems

The first drives utilized a three-phase rectifier, also known as six-pulse input (figure 1) or diode front end. Although these early VFDs converted power effectively, their non-linear loads would draw non-sinusoidal current from the power source, creating problematic harmonic distortion within the system.

The fundamental frequency and its integral multiples are combined in the waveforms that give rise to this non-sinusoidal current. Electrical systems that support a substantial proportion of non-sinusoidal loads can become dangerously unstable. Consequences range from elevated RMS current, nuisance fuse blowing, and overheated transformer and distribution equipment to random breaker tripping, equipment malfunctions, and shortened lifespans of motors and other expensive components.

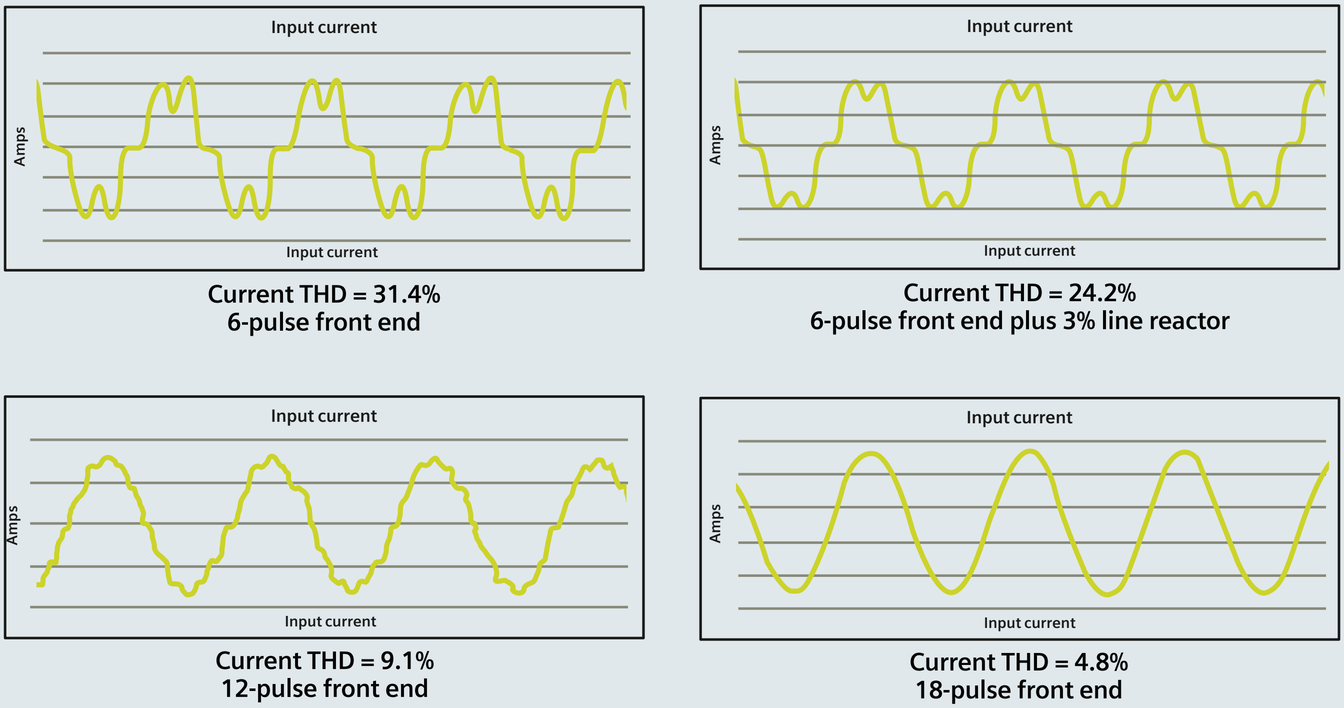

Figure 3 — Relative THD for various circuits

Steps were quickly developed to mitigate the non-sinusoidal loads, which could reach as high as 35% THD. At first, line reactors were used to help reduce harmonics in low-voltage applications. But eventually transformers with phase-shifted secondary windings became the preferred solution at higher voltage and power levels.

In the 1950s, the number of six-pulse rectifiers was doubled to improve harmonic cancellation in mining and electrochemical applications. These became known as 12-pulse systems (figure 2, page 1).

The harmonics were greatly attenuated in the 12-pulse rectifier circuits, but because even 10% distortion could still cause power issues within the plant, harmonic filtering was sometimes added to further reduce line harmonics. By themselves, the 12-pulse systems couldn't meet the industry standards established by IEEE-519, which limits the current distortion to less than 5%.

18-pulse performance

As seen in figure 3, as the pulse count increases, the THD decreases and the fidelity of the input power line is improved. Given the dramatic improvement in line harmonics offered by a 12-pulse system, the next logical step toward meeting IEEE standards was to increase the input to 18 pulses. This was achieved, as before, by adding another six-pulse rectifier circuit to the system.

The 18-pulse circuit for a medium voltage VFD is shown in figure 4. Though the addition of these diode circuits and the associated transformer winding incurs additional costs and losses, these are quickly offset by the elimination of supplemental harmonic filters and plant analysis.

Using IEEE-519 limits as the accepted industry standard, a typical harmonic analysis for an 18-pulse system is shown in figure 5. In this case, the THD is significantly lower due to the specifics of this plant (e.g., line stiffness, available short-circuit current). As indicated, the THD resulting from this scenario's 18-pulse system is 1.98%, which is well below the IEEE-518 requirement of 5%.

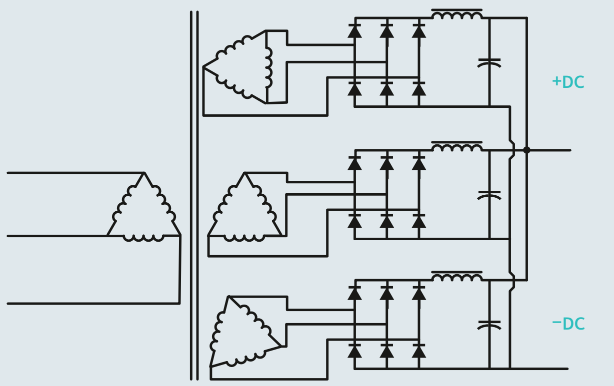

Figure 4 — 18-pulse rectifiers

Diminishing returns

Using the same plant characteristics found in figure 5, an analysis was performed to show the relative improvement when a fourth rectifier circuit is added. As (figure 6 page 4) shows, the resulting 24-pulse circuit further improves the THD associated with the VFD input.

Compared to the 18-pulse solution's 1.98% THD, the 24-pulse input achieves a 1.14% THD (figure 7, page 4) — an improvement of 0.84%.This additional performance would be acceptable if it did not come at a steep price. Not only does a 24-pulse circuit increase upfront costs; it also reduces efficiency, which you will pay for every year the equipment is in operation.

So, if both 18- and 24-pulse inputs are already well below the IEEE standards, what do you get for the 0.84% improvement in THD?

Less floor space, for starters. The larger footprint is usually due to an additional 24-inch cabinet for the fourth rectifier. If the rectifier can be accommodated within the existing cabinet, the associated transformer must include a secondary winding, making it bigger and more expensive.

Additional components also come with additional initial costs. In fact, raising the pulse count from 18 to 24 can increase the cost of a VFD and transformer by almost 16%. (Note that 12% of the cost increase is generally in the transformer.) This sizable increase in capital expenditure improves THD performance by less than 1% — not much of a bargain when the smaller, less expensive 18-pulse solution is already 3% below specified industry limits.

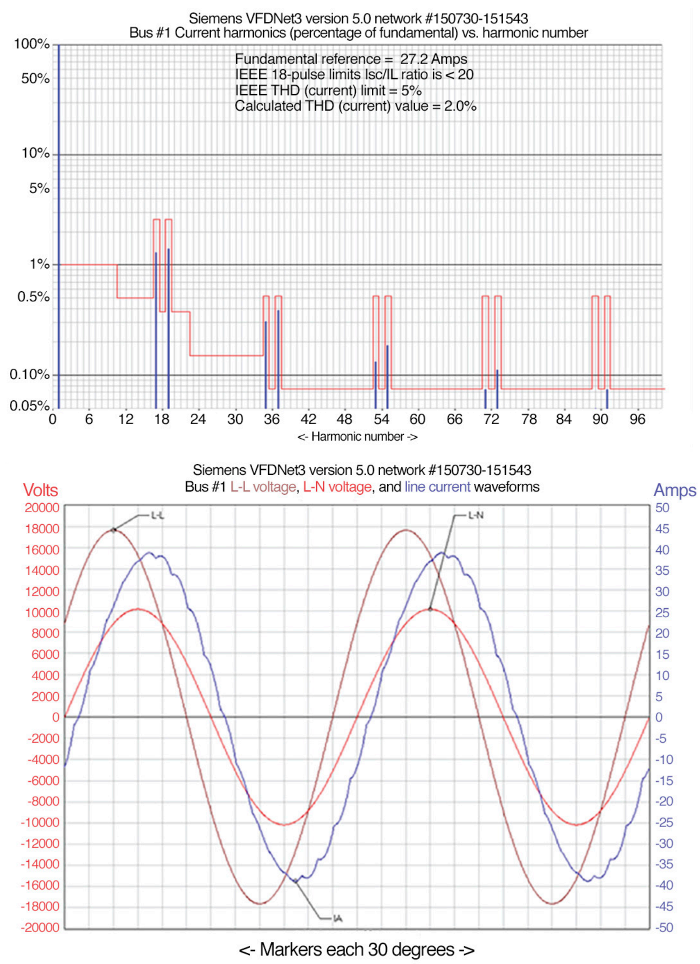

Figure 5 — 18-pulse THD

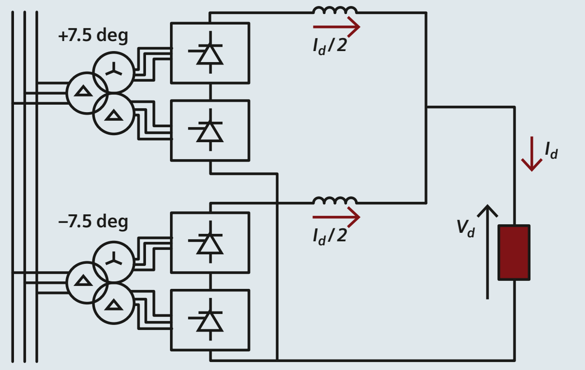

Figure 6 *— Typical 24-pulse circuit and transformer*

The addition of rectifier circuits and transformer windings also results in a 0.2% loss of efficiency, which can seem insignificant at first. However, on a 5,000 Hp VFD, these numbers add up quickly:

Assume you have a 5,000 Hp (3,730 kW) drive that operates 12 hours a day for between 260 and 365 days ($0.10 per kW-hr). Over 10 years, the 0.2% losses associated with your 24-pulse circuits and their additional power requirements add up to between $23,400 and $32,000 in operating costs, all without improving the plant in any significant way.

Conclusion

Although there are VFD manufacturers out there who emphasize the virtues of 24-pulse systems, these campaigns are largely self-serving. Perhaps they have standardized on this approach, or feel it gives them a better way to compete with lower-power Siemens SINAMICS PERFECT HARMONY GH180 air-cooled VFDs. Regardless, 24-pulse VFDs cost more — both upfront and in the long run — and fail to offer any distinct advantage to most customers.

The 18-pulse and 24-pulse systems are both significantly below the industry standard of 5% THD in most applications. Therefore, a 24-pulse VFD is not generally in the best interest of the customer and is not consistent with the Siemens approach of developing the best technical and commercial solution for the customer.

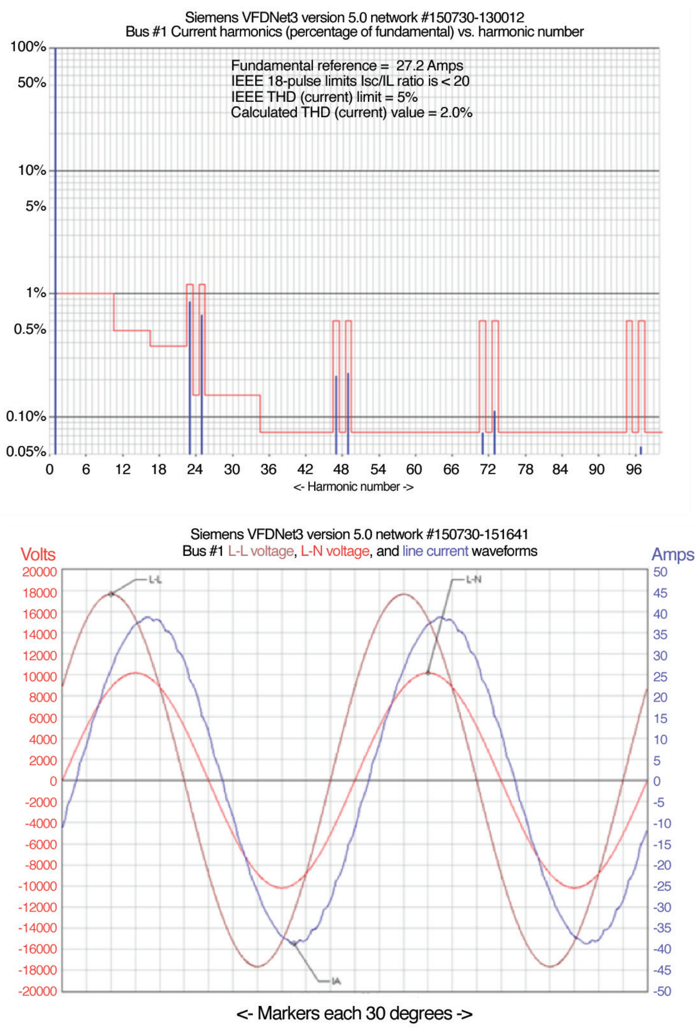

Figure 7 *— 24-pulse THD*

The increased pulse count associated with the SINAMICS PERFECT HARMONY GH180 VFD is a byproduct of the topology in that the number of power cells is determined by the motor voltage. Consequently, the pulse count is determined by the number of power cells (six times the number of power cells per phase). Other topologies, such as those examined in this paper, utilize separate rectifier modules that are assembled in six-pulse units (24-pulse operation requires four rectifier units).

Note that there are times when a 24-pulse system is the preferred solution, but for general purposes and most plants, the 18-pulse provides the highest performance and cost value to the customer.

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