

Benchmarking Three-Level Power Factor Correction Topologies

Power factor correction has long been a staple of UPS, SMPS and embedded drive devices. In recent years, a number of newly designed PFC topologies have hit the market. Now engineers are spoiled for choice: With so many more options, it is getting harder to pick the right topologies and components. This paper benchmarks three topologies—the Vienna rectifier, the symmetrical boost PFC and the neutral boost PFC—for the purpose of comparison. To this end, it factors two of the industry's key concerns, efficiency and cost, into the equation. **Baran Özbakir, Vincotech, Munich/Unterhaching, Germany**

The power factor (PF) is the ratio of the active power to the apparent power drawn by an electrical load. In other words, it is a measure of how efficiently the current is being converted into useful work. The PFC shapes the input current to synch it up with the input voltage, the aim being to maximize the real power drawn from the input. In the perfect PFC circuit, the input current is in phase with the input voltage without any harmonics.

Research on power factor correction circuits has been stepped up in recent years, especially for high-power applications [1]. There are recommendations and regulations for power electronics to limit harmonics on the power mains, and an important part of this is reducing harmonics from the converter side. Generally engineers try to

achieve low circuit complexity and low component stress, high power density, high efficiency, high robustness/reliability, and controllability of the output voltage [2].

Three-level, boost type PFC is an enticing solution for high power density and high efficiency. The three-level topology's great advantage is that it reduces voltage stress on the power semiconductor, which cut the losses and costs of power semiconductors and move toward higher switching frequencies. It is common practice to combine three single-phase modules in an AC system, thereby achieving the required output power level with three-phase PFC.

PFC topologies

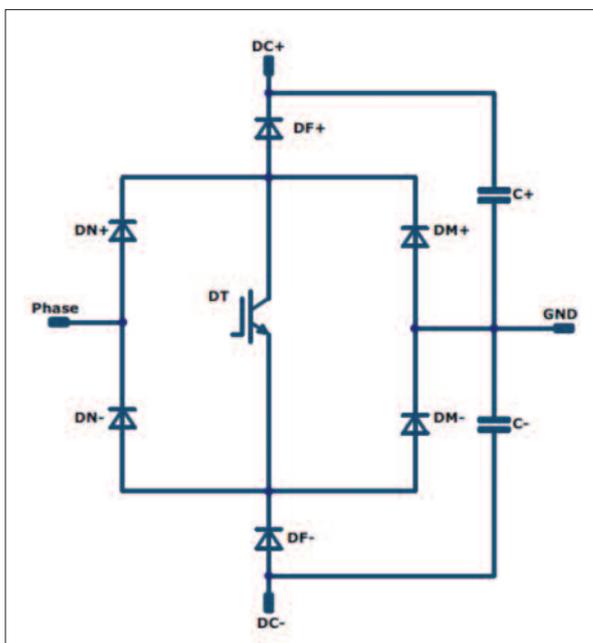
The Vienna rectifier is a unidirectional pulse-width modulation (PWM) rectifier as

shown in Figure 1. It was first proposed by J.W. Kolar and developed with F.C Zach at the Technical University Vienna [3]. The Vienna rectifier is used mainly in telecom power supplies, UPS and input stages of AC drive converter systems.

Its specifications and working properties at a glance are 1 switch (DT), 4 rectifier diodes (DN+, DN-, DM+, DM-), and 2 fast diodes (DF+, DF-). DT works at both half waves and DF+ and DF- are the pairs of DT. Voltage drop at excitation - 1x IGBT + 2x rectifier diode; voltage drop at boost (freewheeling) - 1x rectifier diode + 1x fast diode.

The Vienna rectifier's biggest advantage is that it is equipped with just one switch, which cuts costs and simplifies control. On the down side, static loss is relatively high during the excitation period. On top of that, the switch works at both half waves of the mains input current, and engineers need to carefully consider the thermal behavior.

Figure 1. The Vienna rectifier schematic

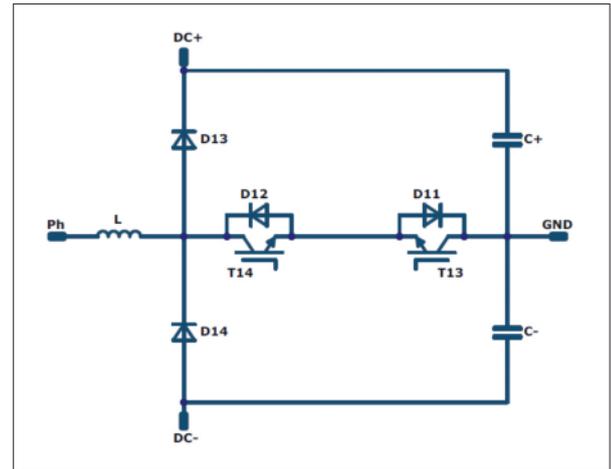
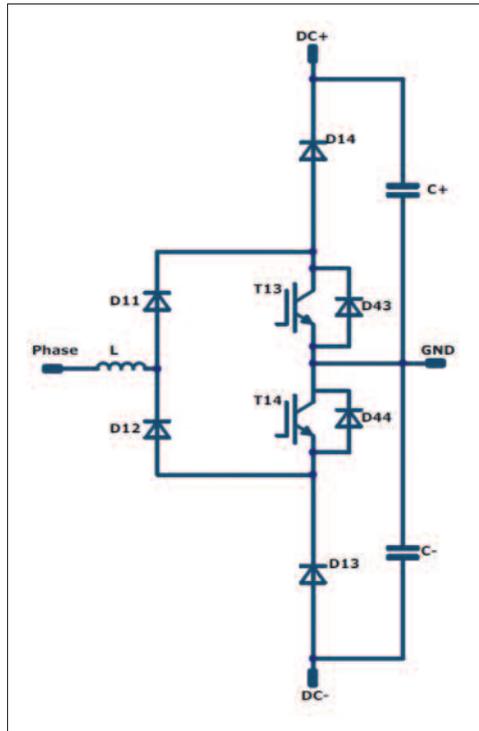


The symmetric boost PFC (SPFC, Figure 2) is a mainstay topology widely used in several applications such as UPS, welding, and power supplies. Its specifications and working properties at a glance are 2 fast switches (T13-T14), 2 rectifier diodes (D11, D12), 2 fast diodes (D14, D13), and 2 protection diodes (D43, D44). D11 and D12 work during one full half-wave - T13/D14 and T14/D13 are the pairs. Voltage drop at excitation - 1x IGBT + 1x rectifier diode - voltage drop at boost (freewheeling) - 1x rectifier diode + 1x fast diode.

Although the SPFC topology is equipped with two switches—that is, one more than the Vienna rectifier—its static losses are still low during the excitation period.

The Neutral Boost PFC (NPFC, Figure 3) is another commonplace topology used mainly for UPS applications. Its

RIGHT
Figure 2.
Symmetric
boost PFC
schematic



ABOVE Figure 3. Neutral boost PFC schematic

specifications and working properties at a glance are 2 fast switches (T13-T14), 2 rectifier diodes (D11, D12), and 2 fast diodes (D14, D13). T13/D14 and T14/D13 are the pairs. Voltage drop at excitation 1x IGBT + 1x rectifier diode - voltage drop at boost (freewheeling) 1x fast diode.

The NPFC topology also has one more switch than the Vienna rectifier, but the D13 and D14 diodes switch between DC+ and DC-, which increases switching and static losses.

Benchmarking the topologies

Six different power module designs were created, characterized and simulated to enable comparisons of the various

topologies' costs and efficiency. The simulation parameters are $V_{in} = 240 V_{RMS}$, $I_{in} = 14 A_{RMS}$, $V_{OUT} = 700 V_{DC}$ - these are representative of typical three-phase applications.

Figure 4 graphs the topologies' efficiency from 4 kHz to 50 kHz for comparison. To this end, the semiconductors' efficiency was calculated to benchmark the various types of power modules and see how the different designs measure up. Figure 5 charts the normalized cost of power module designs.

As the efficiency chart would indicate, the NPFC topology with MOSFETs and SiC diodes appears to be most efficient solution throughout the frequency range. The NPFC topology with fast IGBTs and Si

diodes performs well up to around 12 kHz, at which point it drops off and soon after intersects with the Vienna rectifier's curve. The SPFC topology with fast IGBTs and SiC diodes comes in second in the performance stakes. The SPFC topology with fast IGBTs and Si diodes keeps pace with the Vienna rectifier (a fast IGBT and SiC diodes) up to around 36 kHz.

The SPFC topology with fast IGBTs and fast Si diodes serves as the reference for cost comparisons. The Vienna rectifier, with a price tag just under the reference price, has the cost advantage. The NPFC topology with MOSFETs and SiC diodes is the most expensive solution, costing 3.4 times as much as the reference design. The SPFC topology offers the best compromise between cost and efficiency, which makes it the overall winner.

Conclusions

Although the NPFC topology with MOSFETs and SiC diodes achieves the highest efficiency, it is also the most

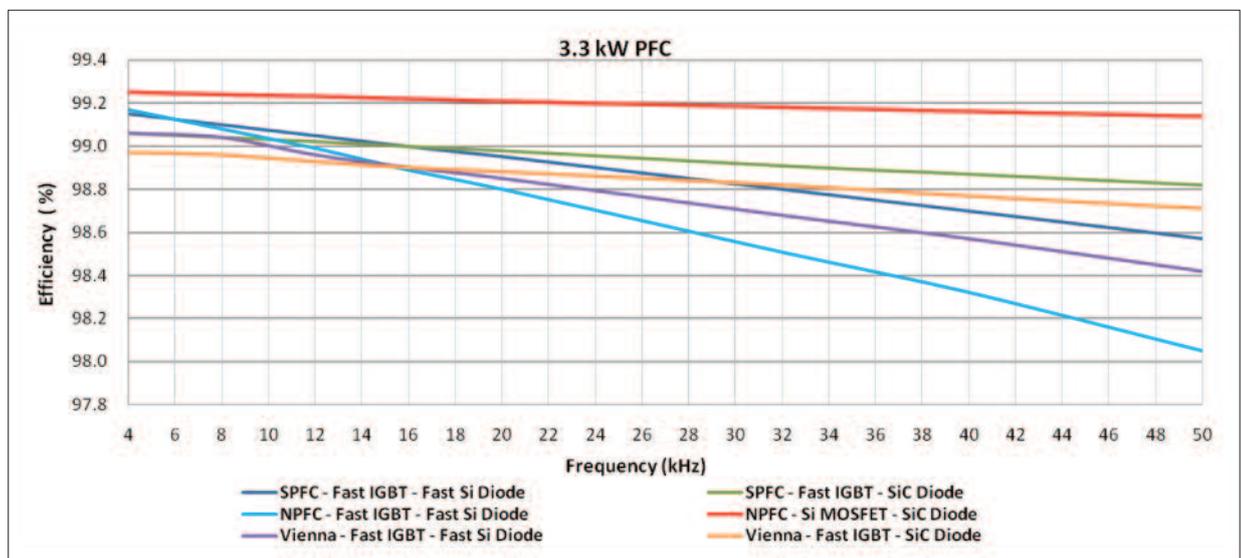


Figure 4. Efficiency comparison

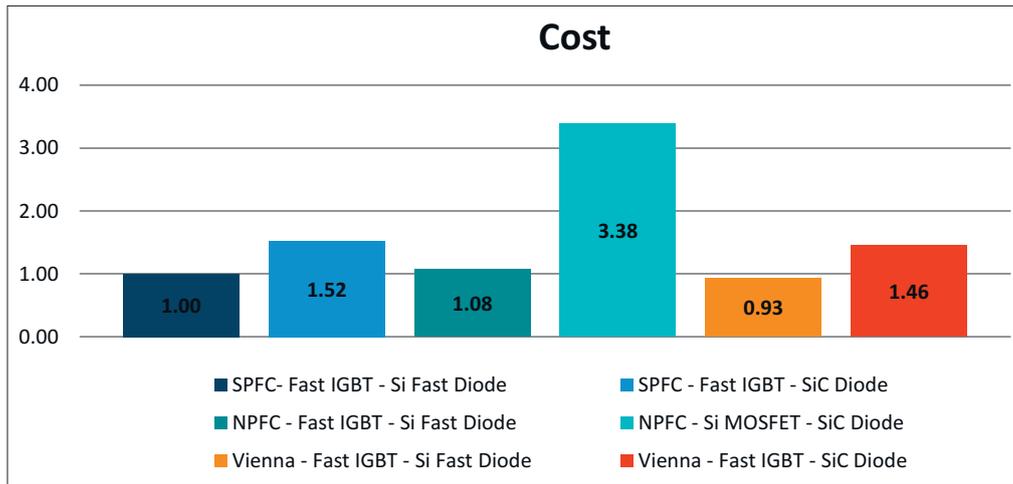


Figure 5. Cost comparison

expensive solution. The NPFC solution is more efficient than the Vienna rectifier up to around 12 kHz when IGBTs and Silicon diodes are used. The Vienna rectifier with a fast IGBT and fast Si diodes and the SPFC solution with fast IGBTs and fast Si diodes are cost-efficient solutions. If we consider the conditions for real-world applications, the frequency range from 12 to 36 kHz is where the best trade-off between efficiency and cost can be made. This is precisely where the SPFC topology comes out on top. This conclusion is confirmed by

an emerging trend in the UPS and ESS (energy storage system) markets, where power modules featuring this promising SPFC topology are on the rise. Vincotech anticipated this development and now offers the flowSPFC 0 family of power modules for up to 100 A, with higher power modules to soon follow.

Literature

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