

High Power UPS Achieves Significant Size and Weight Reductions While Enhancing Performance

History of transformer-free UPS technology

First appearing at lower power levels, transformer-free UPS designs have been around two decades or so. A vast majority of designs below 30 kVA are now transformer-free, meaning that the UPS does not contain power line frequency magnetics (transformers or inductors). This transformer-free design trend is moving up in power levels because power line magnetics are both material and labor intensive. On the other hand, the high frequency power processing needed is technology intensive. In general, advances in technology mature sufficiently to support improved value to the customer without sacrificing needed reliability. Once that point is reached, the technology-intensive design becomes the preferred value leader. Technological advances in technology have had a similar impact upon switch mode power supplies as well as personal computers.

Transformer-free UPS: A growing trend

At higher power levels reaching above 30 kVA and now as high as 1100 kVA, the challenge is to switch high currents rapidly at high voltages without high losses or excessive peak voltages. Over the last decade, high power insulated gate bipolar transistors (IGBT) have matured enough to allow conversion frequencies of 10 kHz and above without large sacrifices in efficiency at these higher power levels. In addition, some creative control strategies permit further reduction of switching losses to the point where the new transformer-free technology UPS is competitive with the old technology UPS—even when measured in terms of system efficiency.

Transformer-free vs. legacy UPS designs

Figure 1 illustrates the basic topology of the legacy and new transformer-free technology UPS powertrain. A phase-controlled rectifier, while efficient and cost effective, produces large harmonic input currents and reduced input power factor which is unacceptable at many sites and incompatible with some generators. Large input inductors and harmonic filters are needed to bring the harmonics down to 5 to 10% total harmonic distortion (THD) and power factor (PF) up to >0.99 PF. These components add cost and weight and increase footprint. In addition, they do not hold THD down and PF up over a wide load range. They are typically effective only above 60% of full load. At light loads below approximately 40%, the input PF can actually become leading and will cause incompatibility with generators. The PF also varies with line voltage but is only specified at nominal line.

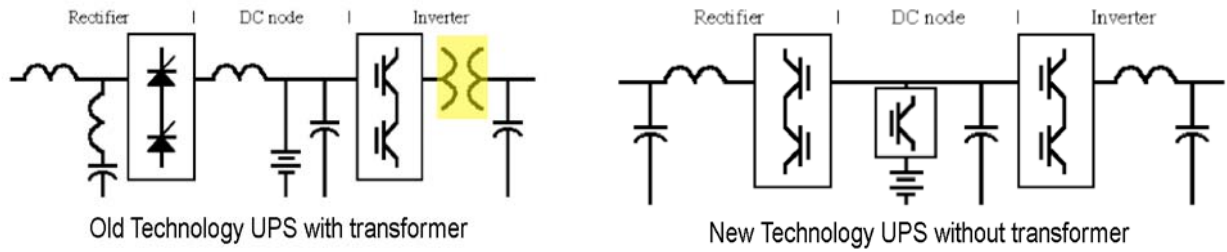


Figure 1. Simplified schematics of legacy and new transformer-free technologies

As shown in Figure 2, the transformer-free design with an IGBT rectifier inherently holds PF up and THD down from 10 to 100% load. It is highly compatible with generators and avoids the additional generator over-sizing commonly required with a silicon-controlled rectifier (SCR). These superior input characteristics are maintained over the input voltage operating range.

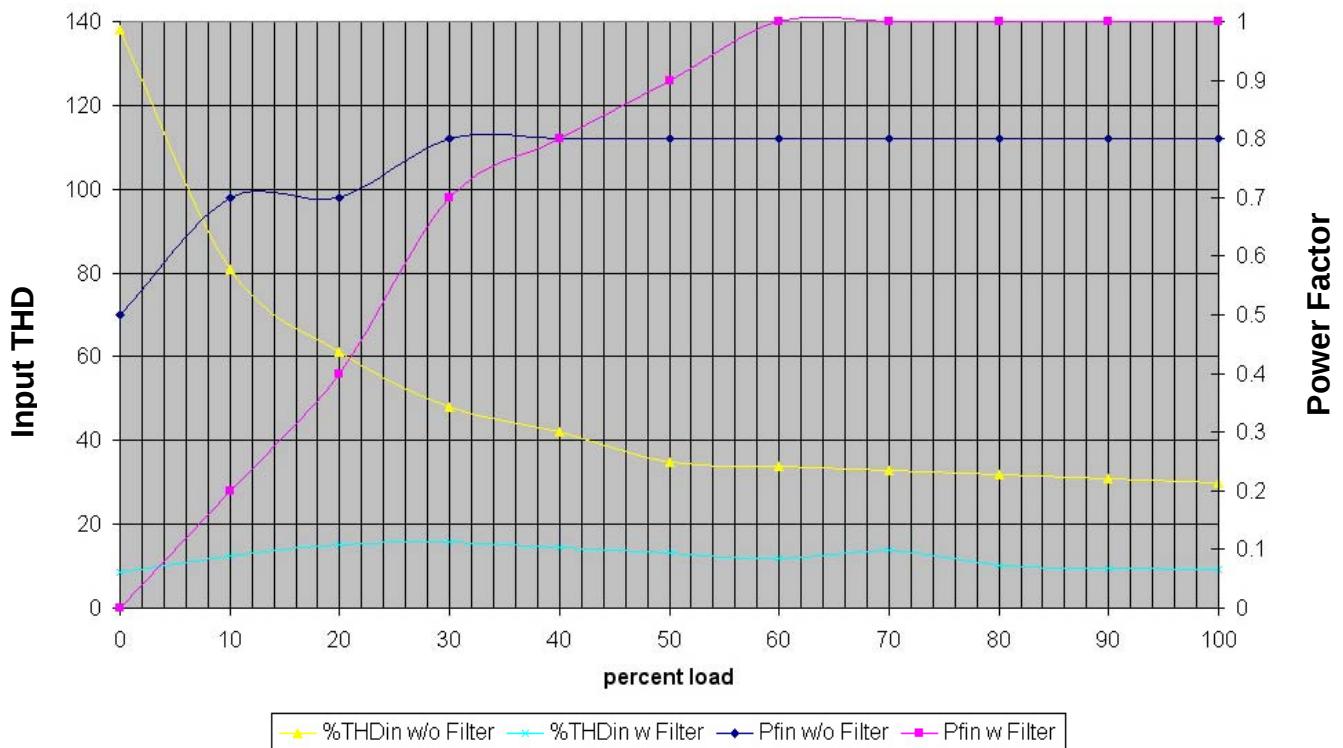


Figure 2. Typical input characteristics of legacy UPS designs

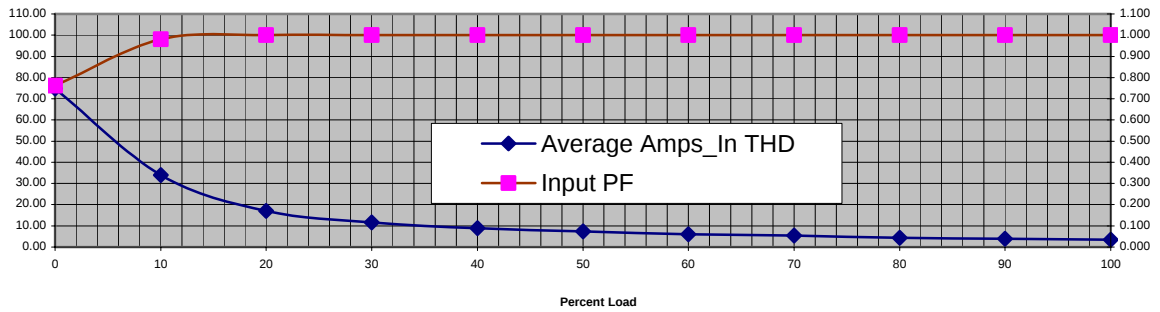


Figure 3. Typical input characteristics of transformer-free UPS designs

THD and transformer-free UPS designs

In regards to harmonic distortion, the severity level depends upon the particular application and location. For example, a 10% distortion component at a low frequency causes far less voltage distortion than one at a high frequency. Without adequate input filtering, a rapid di/dt (current spike) resulting from SCR firing can cause severe line voltage notching and interfere with adjacent equipment. In fact, it takes more than 14% THD before the input PF is reduced below 0.990 by the THD alone. (See Figure 4 below.)

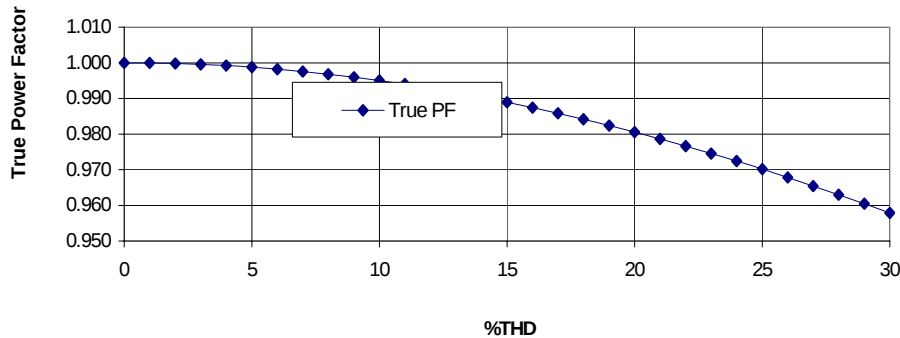
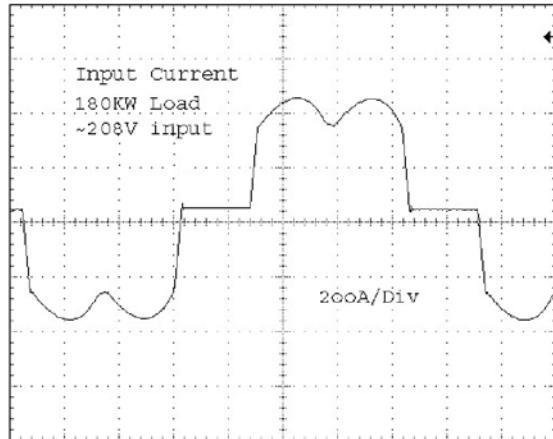


Figure 4. True power factor versus THD



Typical 6 SCR input current with 30% or more THD with di/dt limited by input inductors.

The higher switching frequencies used in the transformer-free designs allow the use of smaller filter inductors and faster response times with improved waveform integrity:

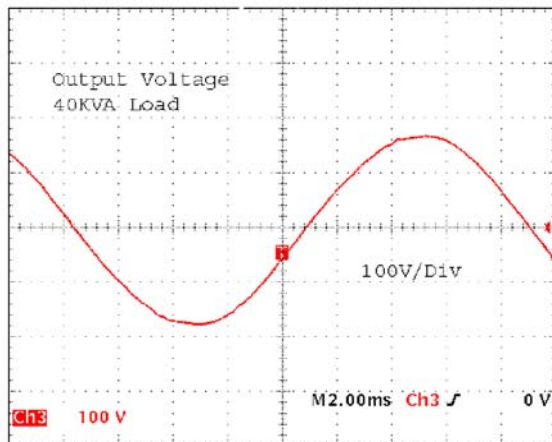
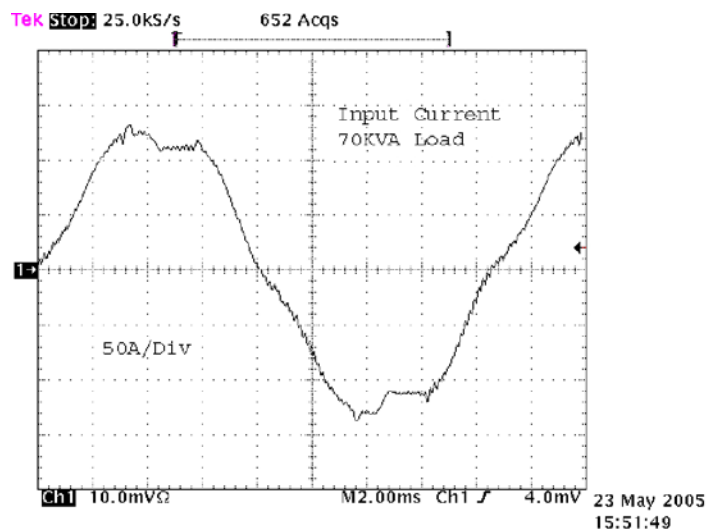


Figure 5. Typical input and output waveforms of a transformer-free topology UPS

The powertrain in Figure 6 shows that an output neutral can be generated along with phase voltages without a transformer. While only three-wire input is needed for online operation, a neutral connection is needed to support bypass operation. In the legacy topology, a Delta to Wye transformer is typically used to generate the output neutral.

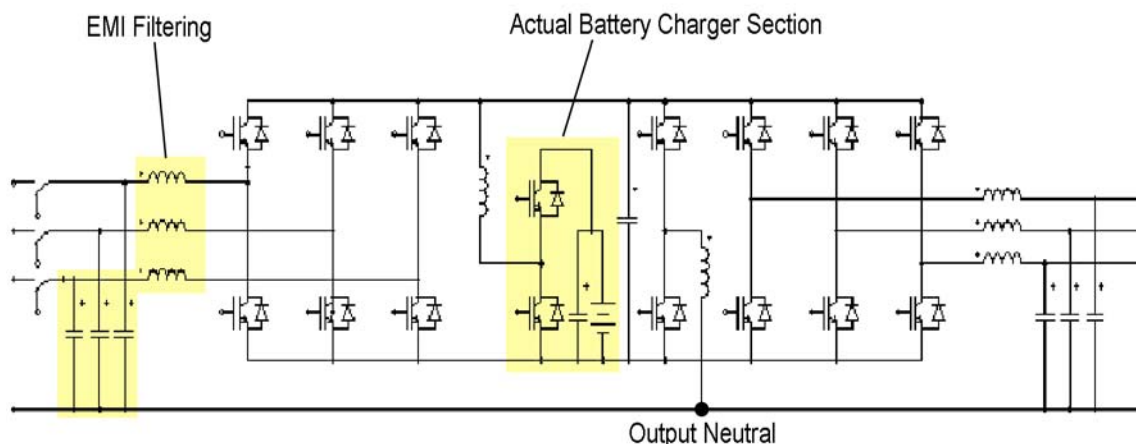


Figure 6. Powertrain that does not require transformers

Battery management advantages of a transformer-free UPS

Note that a half bridge converter can control battery voltage independent of bus voltage and also allows a range of battery voltages (e.g. 192 through 240 cells) to be accommodated. This converter also enables the battery to rest in an open circuit state to avoid continuous ripple current and the accelerated aging (especially at elevated temperatures) resulting from floating at a voltage significantly higher than open circuit voltage. With these additional capabilities, ABM[®] technology and other charging techniques can be more effective in extending battery service life. ABM technology is a feature of most Powerware[®] battery charger designs.

The IGBT rectifier stage supports the power drawn from the line while the Inverter stage supports the output current. With an input PF of >0.99, a load power up to 90% of rated kVA can be supported while maintaining ample reserve to recharge the battery. During periods of reduced line voltage, some recharge power is given up to ensure continued to support of output load. When the line level returns full/fast recharge capability will be restored.

With a SMALL Inductor/Capacitor (LC) low pass filter at the input, even the moderate di/dt changes in the input inductors are prevented from disturbing the line voltage – just as they are filtered at the output voltage by the same LC filter.

Legacy UPS components vs. transformer-free UPS components

An example of what is eliminated by using a transformer-free design is shown in Picture 1 which displays the “Magnetics Package” (Mag Pak) for a conventional topology UPS. The output transformer, input line inductors, DC bus choke, output filter inductors, and input harmonic filter inductors are included. Not only is it very heavy, but it is also a significant contributor to the size of the overall unit. The size and obvious weight difference in legacy components versus new transformer-free technology is visually apparent when the units are compared side by side.



Transformer-free mag pak

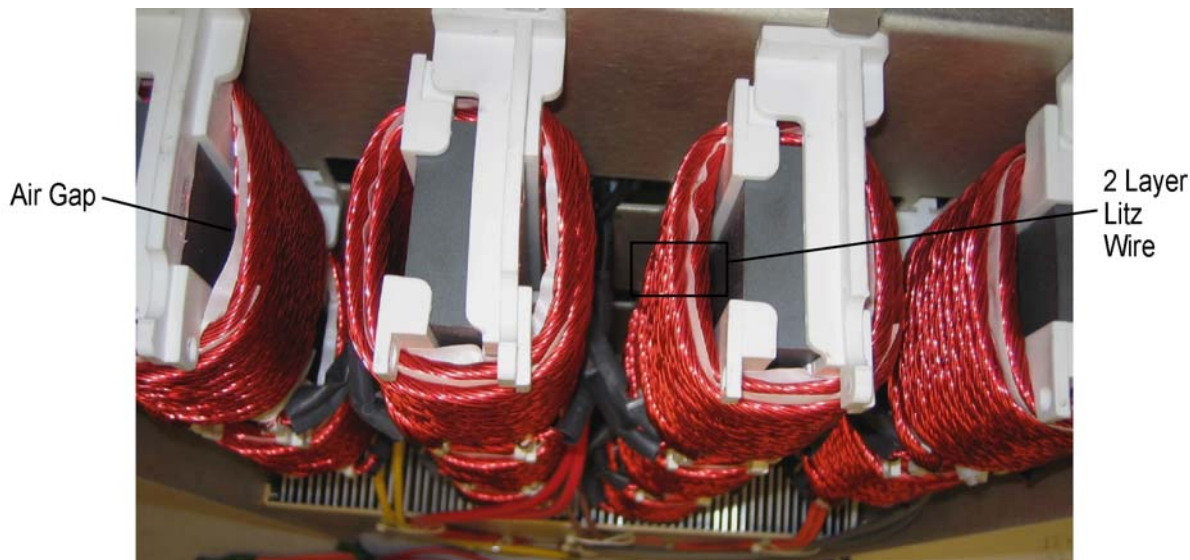
Transformer-based mag pak

Picture 1. Illustration of comparative size of magnetics package (mag pak) for a 275 kVA UPS



Picture 2. Inductors for half of a complete powertrain of the transformer-free topology

These inductors are soldered into a power printed circuit board (PCB) and mounted to an aluminum u-channel chassis at a fraction of the size, weight, and cost. An end view is shown in Picture 3.



Picture 3. End view of inductors in a transformer-free UPS

In a transformer-free UPS, closed-core designs are often used. With high current and low inductance, a large air gap often results. Eliminating all but the center leg of the core also results in a low net permeability with less core material to purchase. Limiting the winding to only two layers and incorporating a space between core and winding allows direct forced cooling to all of the windings. At ~10 KHz and up, solid wire would suffer from excessive skin and proximity effect losses. With such excellent cooling, only a simple litz wire is needed at a fraction of the cost of traditional multi-layered litz. A ferrite core generates very low losses and avoids being heated by the winding. Used in pairs, the far field can be reduced while gaining ~15% useful inductance by orienting in anti-parallel configurations. (See Figure 7 below.)

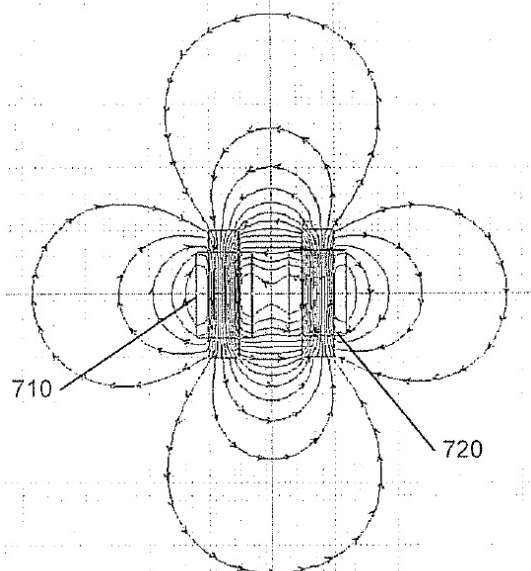


Figure 7. Anti-parallel field

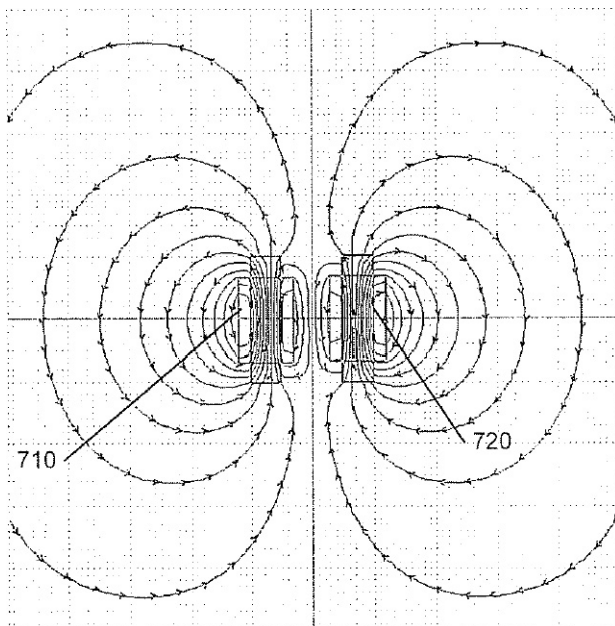


Figure 8. Parallel field

With the far field reduced and an aluminum chassis containing the flux, the oft-anticipated interference problems with stray magnetic fields are avoided.

Conclusion

The new transformer-free topology with small and lightweight filter inductors, high performance IGBTs in both inverter and rectifier, and advanced control strategies can bring improved performance and value. Compared to legacy UPS topology designs, a transformer-free UPS is typically only 25% the weight and occupies 60% the footprint*. Low input THD (<4.5% at full load) and high input power factor (>0.99) are supported down to nearly 10% load without the need for an additional input filter. In addition, full load efficiency can reach 94% and above. The packaging can be designed so that cooling and wiring do not require side or rear access or clearance. With these new benefits, this technology-intensive design will become the preferred topology.

*Powerware 9395 UPS used for comparison

Eaton - setting the standard for three-phase UPS power protection

From the first commercial UPS to the new, high-efficiency Powerware® 9395 UPS - named the Electrical Power Product of the Year for 2007 by *Plant Engineering* magazine - Powerware UPSs from Eaton® have set the standard for power protection and backup for more than 40 years. Innovative Powerware product designs and a commitment to excellence have helped Eaton to earn the designation of "Power Quality Company of the Year" by Frost & Sullivan for three years in a row. To find out more, visit us on the Web at www.powerware.com or call us at 800-356-5794.

References:

ACHIEVING HIGH EFFICIENCY IN A DOUBLE CONVERSION UPS WHILE USING AN IGBT PWM RECTIFIER

John Tracy, Eaton Corporation, Power Quality 2005 Conference Proceedings

ACHIEVING OPERATIONAL PERFORMANCE DURING SEVERE MAINS UTILITY TRANSIENTS AND DISTURBANCES USING AN IGBT PWM RECTIFIER

Hans Pfitzer / Eaton Corp., Power Quality 2005 Conference Proceedings

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