Transistorized UPS Rectifier Reduces Reflected Harmonics

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This concept has been successfully used in other parts of the globe for the past five years and has recently found its way to our shores.

Voltage and current harmonics on the power distribution network have long plagued the minds of power engineers and users of UPS systems. Many of them have used passive devices in an attempt to minimize the negative effects of these harmonics. Now, a next-generation IGBT (Insulated Gate Bipolar Transistor) UPS rectifier has been developed that mitigates the effects of reflected current harmonics without the use of input passive resonant LC filters. This new device cancels current harmonics electronically. This article discusses the development concept, the topology and the performance characteristics of this active UPS rectifier technology. The article also presents performance data from an actual field installation.

Traditional Technology

For decades, most three-phase static UPS systems have employed SCR based rectifiers as the basis for the AC to DC power conversion stage. Their use has met with such popularity that, while the static inverter stage has evolved several times over the last few decades (SCR®Bipolar®IGBT), the rectifier stage has been stagnant

Table 1. *IGBT/IPM Development Concept.*

System Needs	Required Device Performance
• Low Audible Noise	• High Speed Switching
• High Efficiency	• Low Loss (V_{cesat}, t_f, t_{rr})
• Stable Control	• Large Safe Operating Area (SOA)
• Ruggedness	• Appropriate Short Circuit and Overtemperature Protections
• Miniaturization	• Short t_{off}
• Flexible	• Small Package, High Level Integration

Note: *The dimensions of a 600V/600A module are about 1" H x 4" W x 3" D.*

in its development. In fact, SCR based static rectifiers are as popular today (if not more) as they were upon their inception. However, in spite of being ubiquitous, SCR based rectifiers do have specific negative aspects that can create severe problems to the UPS installation.

Perhaps the single most important drawback of the SCR technology is its inherently high level of reflected current harmonic distortion. This distortion can be as low as 12% for a fully loaded 12-pulse rectifier and as low as 34% for a fully loaded 6-pulse rectifier. Consequences to the input distribution system of such high current distortion are well understood. Consequences include high voltage distortion, overheating transformers, mysterious computer lock-ups, etc. UPS manufacturers and specialty firms have been quick to react to alleviate these problems.

These adverse consequences have led to the introduction of the now popular resonant input LC filter that is tuned to a specific frequency, typically the 11th harmonic in 12-pulse rectifiers and the 5th harmonic in 6-pulse rectifiers. Current Total Harmonic Distortion (THD) levels have been

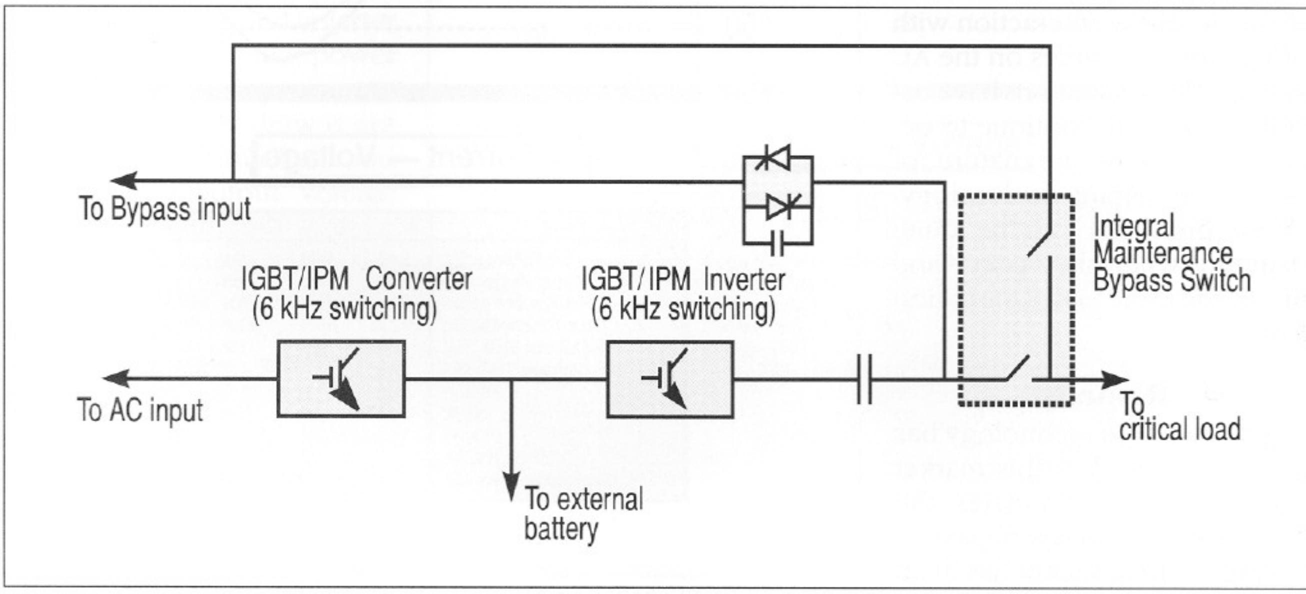


Figure 1. *IGBT/IPM UPS Single Line Diagram Including Transistorized Converter and Inverter. System Configuration Is On-Line Double Conversion.*

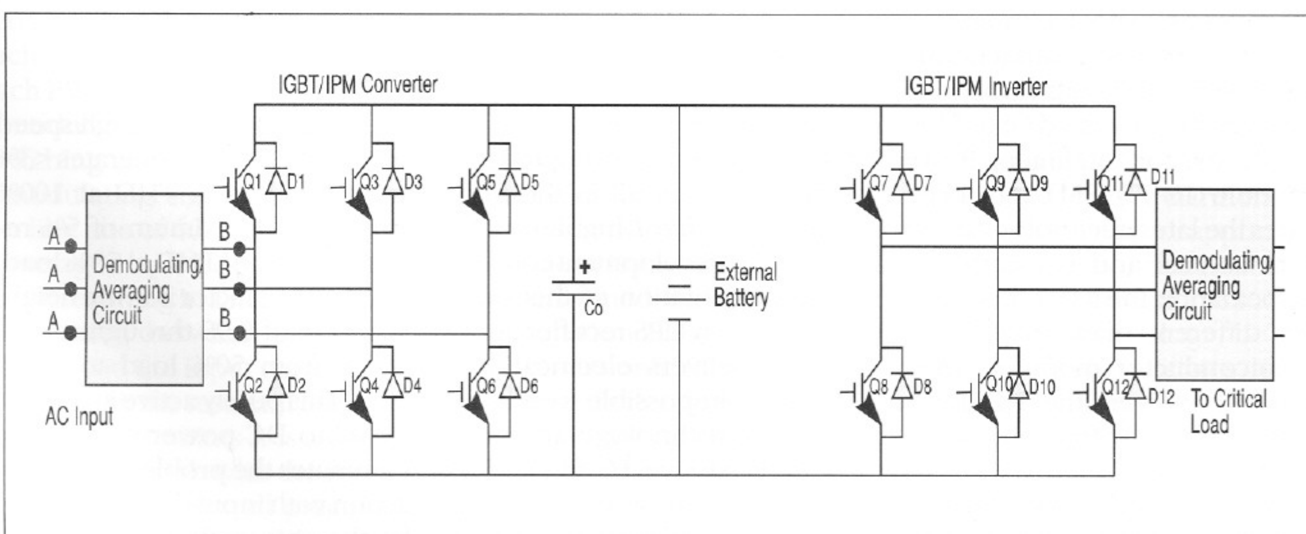


Figure 2. *IGBT/IPM Three-Phase Boost Converter Topology for Active Reduction of Reflected Input Current Harmonic Distortion Without the Use of a Passive Resonant LC Filter. Inverter Also Uses IGBT/IPM Technology.*

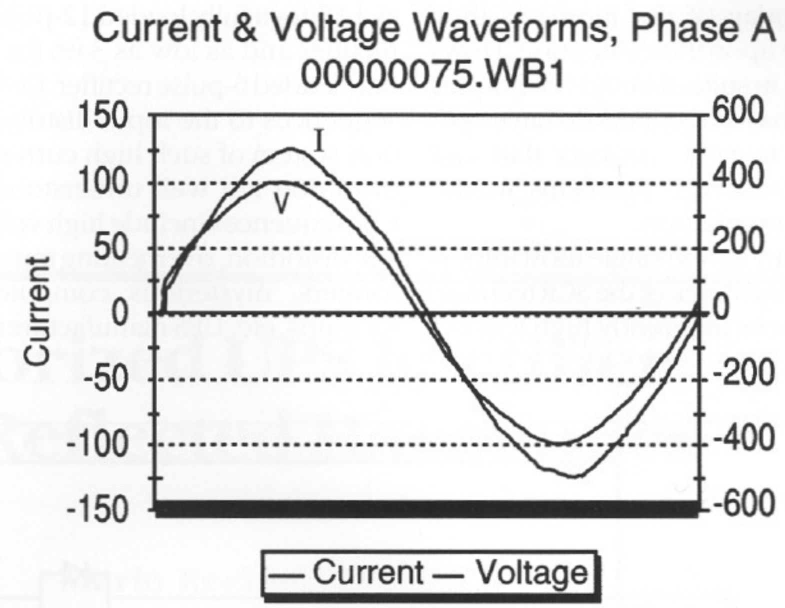
lowered to between 5% and 10% of the fundamental. These levels are true at full load only, and deteriorate at lower load levels. Thus, the filter may reduce the current THD to, say 7% at full load, but the THD at 50% load will be significantly higher. Other potential shortcomings of these tuned input LC filters include possible resonance with building power factor correction capacitors, possible incompatibility with generator systems and possible filter overload due to interaction with other current sources on the AC system. These situations have occurred, and will continue to occur, since it is the nature of passive resonant technology. These problems can be quite daunting when they occur and may result in the loss of the critical load.

Remedy

A three-phase technology has been introduced to this market that effectively eliminates the problems associated with passive LC filters. This concept has been successfully used in other parts of the globe for the past five years and has recently found its way to our shores. The technology is centered around a semiconductor, developed by Mitsubishi, identified as the Insulated Gate Bipolar Transistor/Intelligent Power Module (IGBT/IPM). It incorporates the latest technology in system control and packaging. In appearance, the IGBT/IPM looks no different than most power semiconductor modules. Internally, however, the IGBT/IPM differs radically from the simple IGBT module.

The IGBT/IPM is an integrated power module that incorporates an IGBT, gate drive circuitry, short circuit sensing and protection circuitry and finally, overtemperature sensing and protection circuitry all in the same package. *Table 1* highlights the IGBT/IPM development concept.

Implementation of this semiconductor in UPS rectifier applications delivers electrical performance impossible to achieve with SCR technology and rudimentary passive LC filters. The single most important benefit realized with this new technology is high input total power factor. The UPS rectifier (now termed "converter" because of its high speed switching action) generates <3% reflected current THD at 100% load and a maximum of 5% reflected current THD at 50% load. Total power factor is in the neighborhood of 0.99 throughout the range from 50% load to 100% load. This purely active approach to AC to DC power conversion eliminates the problematic interaction with input devices, as may be the case with passive LC filters. The device's active approach to harmonic mitigation also elimi-



Summary Data:	A	B	C	Total
Crest Factor (I):	1.45	1.43	1.44	
Crest Factor (V):	1.43	1.43	1.43	
Displacement Power Factor:	-99.4	-99.6	-99.5	-99.5
True Power Factor:	99.2	99.5	99.3	99.3
Current THD (%):	2.2	2.2	1.8	
Voltage THD (%)	1.8	1.4	1.7	
K Factor:	1.0	1.0	1.0	
KVA:	24	24	24	72
KW:	24	24	24	72
True KVAR:	3	2	3	8
Displacement KVAR:	-2	-2	-2	-8

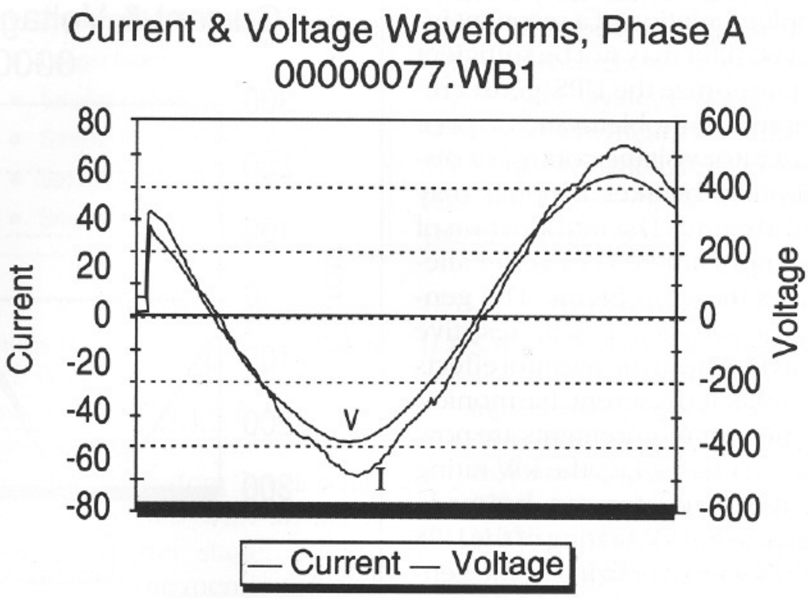
Figure 3. *Input Voltage/Current Relationship of 75kVA IGBT/IPM Converter. Data Taken at Primary Feeder Isolation of Dedicated 75kVA Feeder Isolation Transformer. UPS Operating at Full Load and Powered by Utility.*

nates potential problems with input resonance, generator incompatibility and filter over-loading.

Topology

Figure 1 shows a typical one-line diagram of the IGBT/IPM based converter/inverter sections of the UPS. The inverter is also based on an IGBT/IPM platform and is shown here for clarity and system continuity. Indeed, due to its near unity input power factor, the converter and inverter utilize identically rated power modules. Oversizing due to higher input current draw is not required since, at full load and identical input/output voltage ratings, the converter actually draws *less* current than the inverter full load nominal output rating!

Essentially, the converter operates along the same principles as a typical PWM controlled three-phase inverter. Operation of the converter involves the sequential PWM switching of the IGBT/IPM transistors to boost the input voltage to the desired DC bus level. Referring to *Figure 2*, three PWM voltage waveforms 120 electrical degrees apart from each other result at points B. Each PWM waveform consists of a modulated (or carrier) signal switching at a rate of 6kHz and a modulating signal alternating at a line rate of 60Hz. The carrier is averaged by the demodulating circuit resulting in a near resistive relationship between the input voltage and the input current. In other words, the resultant *current* waveforms at points A is a 60Hz sinusoid in phase with the input source voltage. For all practical purposes, the relationship is resistive since, aside from textbook academics, all AC powered loads,



Summary Data:	A	B	C	Total
Crest Factor (I):	1.50	1.42	1.45	
Crest Factor (V):	1.43	1.43	1.43	
Displacement Power Factor:	-99.7	-99.7	-99.6	-99.6
True Power Factor:	99.7	99.2	99.2	99.3
Current THD (%):	4.9	4.7	4	
Voltage THD (%)	1.7	1.3	1.5	
K Factor:	1.1	1.1	1.1	
KVA:	12	13	12	37
KW:	12	13	12	37
True KVAR:	-1	2	2	5
Displacement KVAR:		-1	-1	-3

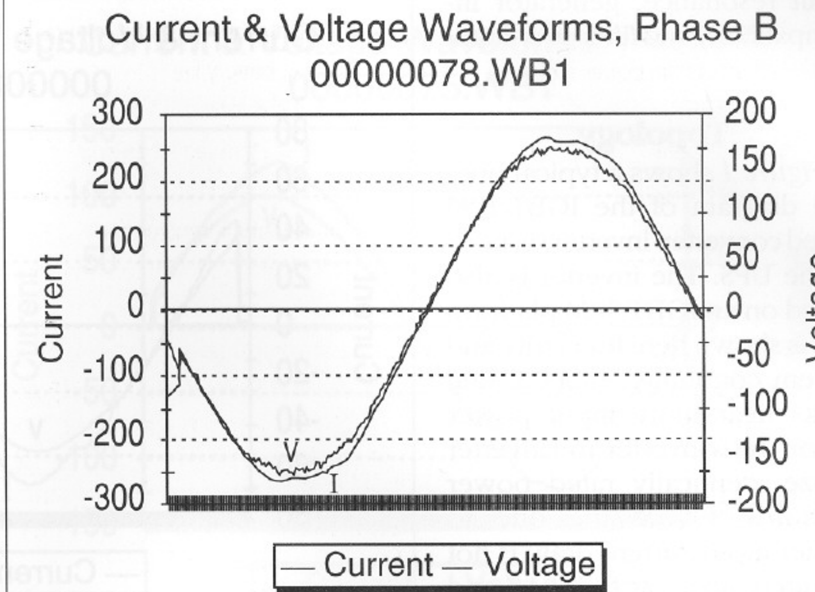
Figure 4. *Input Voltage/Current Relationship of 75kVA IGBT/IPM Converter. Data Taken at Primary Feeder Isolation Transformer With UPS Operating at Half Load, Powered by the Utility.*

including resistive load banks, exhibit a certain level of inductive properties. *Figures 3, 4* and *5* depict input current and voltage waveforms taken at different load levels on a 75kVA UPS equipped with this type of IGBT/IPM converter. These data came from a study performed on an actual field installation a few hours before commissioning. Note that total power factor and current distortion do not vary much with significant changes in applied load.

Benefits

In addition to its inherently high total power factor, the transistorized converter concept provides the user with benefits not previously realized with conventional technology. Perhaps the single most important benefit of this approach to input harmonic mitigation is in generator applications. UPS/generator compatibility when using conventional SCR-based rectifier technology, be it 6-pulse or 12-pulse, dictates that a certain amount of oversizing is required. This oversizing is implemented in an effort to reduce the effects of alternator heating and generator voltage control, both of which are caused by the high level of reflected current harmonics. In some cases, even doubling of the generator capacity or the implementation of a resonant input LC filter may not be sufficient to harmonize the UPS/genset relationship.[1] Problems such as poor generator voltage control or distribution breaker tripping may still abound. The introduction of the transistorized converter alleviates these problems. The generator set sees a near resistive load free from the harmful effects of reflected current harmonics. Generator requirements are now on a 1:1 basis, i.e., the kW rating of the generator can be made equal to the kVA rating of the UPS (moderate oversizing of the generator is recommended for future expansion). Traditional SCR based rectifiers require generator oversizing by a factor 'c', where c>1. Factory tests have shown that a 30kW generator was sufficient to power a fully loaded 30kVA UPS on a continuous basis. As such, ingenious, but costly, additional circuitry is not required to render the genset/UPS system compatible.

Other advantages of the IGBT/IPM technology in UPS converter applications may not be as obvious, but nonetheless provide inherent benefits not previously possible with traditional technology. As mentioned above, IGBT/IPM technology incorporates drive and sense circuitry directly inside the power module. Inherent benefits of this technology include higher MTBF (Mean Time Before Failure), smaller system footprint, reduced weight, reduced inductive and capacitive parasitic elements and improved thermal management system.[2] Although not as glamorous and apparent as the UPS/genset compatibility mentioned above, these few points merit consideration since the purchase and/or specifying of UPS systems is not limited to simply one or two parameters.



Summary Data:	A	B	C	Total
Crest Factor (I):	1.42	1.40	1.40	
Crest Factor (V):	1.42	1.43	1.43	
Displacement Power Factor:	-99.9	-99.9	-99.9	-99.9
True Power Factor:	-99.7	-100	-99.8	-99.8
Current THD (%):	2.1	2	2	
Voltage THD (%)	2.1	1.9	2	
K Factor:	1.0	1.0	1.0	
KVA:	23	22	23	68
KW:	23	22	23	68
True KVAR:	2	0	1	3
Displacement KVAR:	0	-1	0	-1

Figure 5. *Input Voltage/Current Relationship of 75kVA IGBT/IPM Converter. Data Taken at Converter Input Terminals. UPS Operating at Full Load and Powered by Generator.*

Another performance characteristic of the active converter topology is its ability to provide power to the inverter without drawing from the battery bank even at 100% step load changes. This ability stems from the field proven PWM control method utilized in the control of the converter functions. Large changes in DC load conditions are quickly sensed by the feedback loop, manipulated by the control circuit and corrected by the appropriate gating of the IGBT/IPM without discharging the battery bank. Traditional SCR control methods cycle the battery under 100% load step changes resulting in reduced battery life. This can be an important consideration if a battery is not available when one needs it most.

One last benefit that cannot be understated involves the distribution system feeding the UPS. Just as smaller gensets are required to power UPSs incorporating transistorized converters versus similarly rated UPSs using SCR based rectifiers, so too are smaller feeder cables, smaller feeder distribution breakers and

Table 2. *IGBT/IPM Converter Characteristics.*

• Low reflected current THD	• Improved thermal management
• High input total power factor	• Longer battery life
• High MTBF	• Smaller genset
• Small footprint	• Smaller input feeder cables
• Reduced weight	• Smaller input feeder breaker
• Reduced parasitic elements	• Smaller input transformer

smaller distribution input transformers required for the IGBT/IPM converters. Although this may seem strange at first sight, recall that power factor and load current have an inverse relationship (i.e., for the *same* kW rating, higher power factor = lower current draw while lower power factor = higher current draw). In mathematical terms, for a three-phase system:

$$P = \sqrt{3}VI \times pf$$

Where:

P = input power which is constant

V = rms input voltage which is constant

I = rms input current which is not constant

pf = total power factor which is not constant

Equation (1) reveals that, for constant power and constant voltage, increasing power factor reduces the rms input current and vice versa. Therefore significant cost savings for both labor and material may be achieved at the distribution system level when installing a UPS with an active input converter stage. *Table 2* summarizes the mentioned performance characteristics of the IGBT/IPM UPS converter technology.

Conclusion

Active power factor correction technology has been available to users of single-phase switch-mode power supplies for over a decade. Now, with the advent of high performance Intelligent Power Transistor, users of critical three-phase UPS systems can now enjoy the same benefits that were impossible just a few short years ago. In a way this is somewhat ironic – here were the power supply manufacturers trying to improve the quality of power while on the other hand three-phase UPSs powering these marvelous products were polluting the power system the power supplies were meant to clean up. The transistorized UPS converter has put things back into their proper perspective.

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[1.] S.W. McCluer (EPE Technologies) and M. Sieberg (Kato Engineering), *Generators and UPS - Good News, Bad News*, Power Quality Assurance Magazine, March/April 1994.

[2.] M. Miller (Publisher/Editor in Chief) and S. Davis (Associate Publisher/Senior Editor), *Integrated Power Modules Are in the Launching Stage*, PCIM Magazine (Publisher's Viewpoint), September 1996.

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