All Transistors Are Not Greated Equal: The Advantages of IGBT's in 3-Phase UPS Products

A White Paper by Liebert

SUMMARY

In recent years, manufacturers have been changing over to transistorized inverters in their low-to-medium power Uninterruptible Power Supply (UPS) products. This paper studies the types of power semiconductors presently in use, explaining the advantages and disadvantages of each.

Semiconductor Basics

Power semiconductors are the heart of any Uninterruptible Power Supply (UPS). Until recently, Silicon-Controlled Rectifiers (SCRs) were used in the rectifier, the static switch and the inverter sections of most larger UPS products. SCR devices are reliable and widely available in the power ranges necessary for UPS applications.

What is an SCR?

An SCR is a semiconductor with unique properties. It can serve as a rectifier and as a static latching switch. Furthermore, it can handle more power (both voltage and current) than typical transistors, under both continuous and surge conditions. It is the most rugged semiconductor available and, in most cases, it can handle more watts per dollar than other types of semiconductors.

The SCR serves as an ON-OFF switch. The SCR can be turned on by a momentary application of control current to the gate, while transistors require a continuous ON signal. The SCR can be turned ON in about 1 microsecond and OFF in 10 to 40 microseconds[1]. The SCR is ideal for the rectifier and static switch sections of UPS products, but has disadvantages when applied to the inverter sections, as we shall see.

How are Transistors Different?

A transistor permits current to flow through a circuit when the base drive of the transistor receives an electrical signal. Transistors are not latching devices, so they can be turned off by simply removing the base drive signal. To minimize *switching losses*, however, special drive circuits are required to turn the devices off quickly. Transistors also experience *saturation losses* during the conduction stage of the cycle.

A transistor is considered efficient if it has high “gain” -- when a relatively small amount of power applied to the base permits a comparatively large amount of current to flow in the collector/emitter.

Bipolar Transistors and Darlingtons

Conventional *bipolar transistors* produce gain by current conduction. A current applied to the base drive causes a proportional current to flow in the collector/emitter.

A special type of bipolar transistor is called a *Darlington*, and it consists of two transistors linked together. The collector/emitter of the first transistor is used to activate the gate drive of the second. Darlingtons have higher gain than single bipolars and are easier to control. The disadvantage is that they have higher saturation losses and require special drive circuits to minimize switching losses.

Field-Effect Transistors
Field-Effect Transistors (FETs) work differently than bipolars. They don't inject current into the base drive. Instead, they conduct when they sense a >*voltage* on the gate. This means that relatively little power is consumed in the base drive. However, the power-conducting portion has a relatively high resistance. This creates excessive losses and lower efficiency, making it unsuitable for use in large UPS products.

IGBTs
Insulated Gate Bipolar Transistors (IGBTs) combine the best of conventional bipolar transistors and FETs. Like FETs, they only require a voltage across the base in order to conduct. However, like conventional bipolars, they are efficient conductors of current through their collector/emitters.

IGBTs, then, are the preferred transistors for UPS applications. They are significantly more efficient and are easier to control than any other power semiconductors. As of this writing, IGBTs are commonly available with ratings up to 1200 amps and about 1700 volts, making them suitable for use in low-to-medium-size UPS systems.

Why the change to transistors?
If SCRs are so rugged, reliable and (relatively) cheap, why would anybody prefer transistors? The answer has several parts.

First the SCR is more difficult to control, requiring commutation circuits to force the device OFF during its conduction cycle. The SCR can be latched ON with a very short pulse of current. But the SCR can only be turned OFF (a) by the input current falling to zero (e.g. when rectifying alternating current) or (b) by applying a reverse current. Turnoff time for large SCRs is about 30-35 microseconds. For rectifier applications, the SCRs can be virtually self-commutating since the AC waveform performs the commutation at the zero crossing point. Likewise SCRs are ideal for static switches, as the AC waveform provides commutation, and the control circuitry to turn ON the SCR is very simple and reliable. By contrast, inverter applications of SCRs do require commutation circuits.

Second, commutation circuits add bulk to the inverter, using SCRs and heatsinks almost as large as those of the inverter itself. This means that transistorized inverters can be smaller for the same power output.

Third, the SCR commutation circuits increase parts count. This alone boosts the cost and -- everything else being equal -- tends to lower the reliability of the device.

Fourth, the commutation circuits add perhaps 5-6 dBA of audible noise during UPS operation, even when the UPS is lightly loaded.

Fifth, the commutation circuits consume power, decreasing overall efficiency.

Sixth, the transistor is a faster switch than the SCR, so it can be more efficient if saturation losses are low. In addition, the faster switching permits better voltage regulation during transient or non-linear load conditions.

The bottom line is that transistors -- properly applied -- can make the UPS more efficient and provide better output voltage control. Despite their higher initial cost per device, transistors permit UPS designers to simplify UPS inverters, improve end-to-end efficiency and lower system cost.

Avoiding the Stampede
For many years, power transistors have been widely used in smaller UPSs (Under 150 kVA). The results were very rewarding, and encouraged manufacturers of larger UPS products to follow suit. However, IGBTs have not been widely available in the higher power ranges until fairly recently. And when available, the IGBTs were considerably more expensive than ordinary bipolar transistors. Therefore some UPS manufacturers plunged ahead with conventional bipolar

transistors and Darlingtons, seeking incremental improvements in efficiency and reduction in parts count. In most cases, our competitors chose to put the power transistors in *parallel.* This allowed them to use less-expensive devices, although at a comparatively higher risk.

By contrast, Liebert designers chose to pursue a course that would not compromise the Series 600's enviable reliability record. Since the first shipments in March of 1989, the Series 600 has proven to have a field MTBF in excess of one million hours[2]. Much of the Series 600 durability is attributable to the inverter topology and the ASIC logic chips. The Liebert Series 600 was originally designed to operate with either SCRs or IGBTs in the inverter. Therefore the Liebert design team waited until the IGBT manufacturers were able to furnish mature products in the required current ratings which could be used with our unique topology and control logic.

Liebert chose *not* to be hurried into using power semiconductors in parallel. For these applications, the most reliable configuration is the single device. Transistors in parallel can only approach the reliability of single devices if:

- They are N+1 redundant,
- They have matched operating characteristics,
- A fault can be cleared without shorting the leg (i.e. each device must be individually fused),
- A monitoring/detection circuit signals the loss of redundancy, and
- A method of current sharing can be provided that guarantees sharing during conduction *and* the ON/OFF transitions.

Liebert designers felt these were too many "ifs."

Using Transistors Intelligently
It takes more than good transistors to make an efficient inverter. The Liebert Series 600 has a unique inverter design that takes full advantage of the capabilities of the power semiconductors while minimizing the inherent losses.

Conventional UPS inverters are pulse-width modulated (PWM). To work properly, these inverters must operate at relatively high switching frequencies -- typically 2,000 to 20,000 cycles per second. Power semiconductors experience switching losses each time they are turned ON and OFF. The loss is a fixed amount per cycle, so a low-frequency inverter will inherently be more efficient than a high-frequency inverter. Furthermore, faster switching speeds require faster transistors -- which typically have higher saturation losses.

By contrast, the Liebert Series 600 has a hybrid inverter topology, using both PWM and stepwave inverter technology. This permits an exceptionally low switching frequency -- less than 1,000 cycles per second. As a result, switching losses are greatly reduced. This, in turn, permits our designers to specify transistors with the lowest saturation losses.

Lower switching frequencies in a conventional PWM design would lead to poor performance under non-linear load conditions. However the Series 600 -- with its hybrid PWM/stepwave technology in conjunction with the design of the output magnetics and filter -- can power a 100% non-linear load with a nearly pure sine wave.

Highest Reliability *and* Highest Efficiency
At Liebert, reliability is our primary design goal. All other factors are considered, but are secondary to the pursuit of uninterruptible system uptime. Since the Series 600 had already achieved the highest documented MTBF in the UPS industry, it was essential that the change to transistorized inverters be accomplished in a way that would only enhance that MTBF.

Liebert designers accomplished exactly that. The new Liebert Series 600T retains the inverter topology, ASIC-based control logic and big-screen operator interface of the original Series 600. Eliminated are the bulky commutation circuits with their associated efficiency losses. The result is a compact UPS with all the best features of the older product *plus* better efficiency and a lower parts count. Reliability should only improve.

The Liebert Series 600T is not the first UPS to use a transistorized inverter. But it remains the only UPS to realize the full potential of power transistors: highest efficiency, lowest parts count, lowest switching losses, lowest saturation losses and a topology that applies the IGBT in its most reliable configuration.

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[1]Reference General Electric Company training materials.
[2]Reference Liebert *TECHNICS* paper, "Field MTBF: What Do The Numbers Really Mean?"