

# APPLICATION NOTE

## Using IGBTs as Switches in Uninterruptable Power Supply Functional Blocks



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### INTRODUCTION

[Insulated Gate Bipolar Transistors \(IGBTs\)](#) are known as excellent solutions to perform various power conversion tasks. They are particularly well-suited to implement Uninterruptable Power Supplies (UPS) that provide power to AC line-connected equipment in the event that the AC mains voltage experiences a failure.

The purpose of a 5 kW UPS is to maintain the AC mains voltage between the time when a power failure occurs and the back-up diesel generator kicks in. The UPS will connect and supply the AC current needed for the few minutes required for the generator to supply the load current required.

Instead of using MOSFETs, IGBTs in Uninterruptable Power Supplies allow the designer to specify a simpler and smaller heatsink design because IGBTs have lower power loss and higher thermal conductivity. For this reason, [Bourns® IGBTs](#) are optimal solutions for many UPS functional blocks commonly found in data server installations, network and communication hub facilities, and at industrial manufacturing plants for powering industrial robotic operations and their communication networks. IGBTs are also beneficial in static UPS systems that are used in data centers to monitor the operations' supply power and maintain battery back-up autonomy for power continuity.

This white paper outlines why using IGBTs as the switching elements in the UPS functional blocks is advantageous. It will highlight the smaller, lighter weight, and higher efficiency benefits that IGBTs provide in UPS designs. The white paper will provide an overview of how simpler circuits and lower Bill of Material (BOM) costs can be achieved which also typically results in fewer components to fail, higher backup operational reliability, and a higher Mean Time Between Failure (MTBF) for the UPS.

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### UPS TYPES

The offline UPS is the most common type of UPS and is shown as a block diagram in Figure 1.

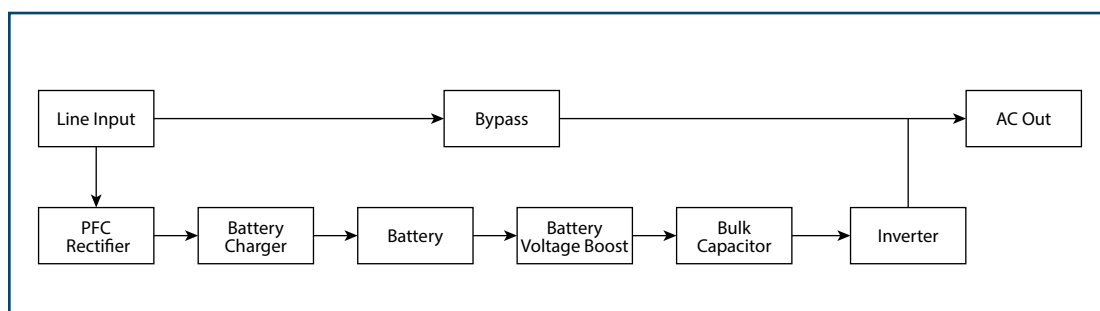


Figure 1. | Offline UPS power flow

The central idea with this type of UPS is that the battery is charged slowly at a low current and discharged quickly at a high current to provide the AC output power. The stages where IGBTs are used are:

- PFC rectifier - battery charger changes AC to DC and charges battery
- Battery voltage boost changes DC to AC at a higher voltage
- Inverter changes DC to AC at the same or a different line frequency

The second most common type of UPS is the online UPS as shown in Figure 2. This UPS is considered online since the AC output voltage is constantly available to the load. The load current continuously runs through the DC to AC inverter.

In the offline UPS, the PFC rectifier supplies power only to charge the battery at a lower current than it provides during UPS output operation. In the online UPS, the PFC rectifier stage supplies the full rated power of the UPS whenever demanded by the connected load demands – which could be continuously. This highlights the major online UPS benefit: there is no changeover time, which is the time required in the offline UPS to start the DC to AC inverter and change the bypass relay to provide output power from the inverter. This time could be as long as one power frequency cycle, which can be either 16.7 ms or 20 ms.

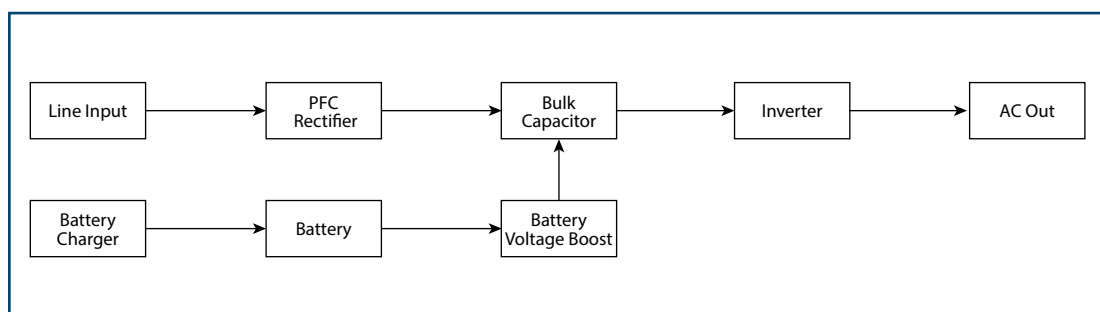


Figure 2. | Online UPS power flow

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### UPS POWER CONVERSION BLOCKS

The power switching functions needed to assemble these two types of UPS are:

- PFC rectifier - battery charger changes AC to DC and charges battery or bulk capacitor
- Battery voltage boost changes DC to AC at a higher voltage
- Inverter changes DC to AC at the line output frequency

The following describes the four UPS conversion blocks using IGBTs:

- PFC AC line 208 to 250 VAC to charge bulk capacitor to nominal 360 VDC, switching 7 kW (Online UPS)
- PFC AC line 208 to 250 VAC to charge batteries to maximum 1.2 kW (Offline UPS)
- 40 to 60 VDC input to voltage boost switcher to 360 VDC bulk capacitor
- Inverter 360 VDC bulk capacitor to 220 to 240 VAC out

### STORAGE BATTERY SELECTION

Every UPS application and product definition can and will be different. For this application note, a net 5 kW AC output example is used. An additional power converter is planned for in the beginning to overcome the loss of power due to the switching losses that occur in every stage. For a net 5 kW output and 90 % efficiency for all stages, the system power needs an additional 556 watts.

A UPS is usually designed for the nominal output power for the limited time that the storage battery will supply the required current until its voltage reaches the minimum discharge voltage. Using four 12 V batteries that have 100 A-h capacity will satisfy this requirement. Four deep cycle sealed lead-acid batteries will supply 154 A for 15 minutes to an end voltage of 40 V. This is 6160 W, which is greater than the requirement by 11 %. This margin allows for battery aging and still provides the 5 kW output. The four 12 V batteries need a maximum 20 A at 58 VDC for charging.

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### POWER FACTOR CORRECTION: POWER FROM THE AC LINE

Offline switching power converters normally have an input current that is not sinusoidal. The input current waveform has a high harmonic content because current is drawn in pulses at the peaks of the input voltage waveform. Taking power from the AC power line usually results in harmonics of the power line frequency to be impressed back on the AC line. This results in harmonic energy creating circulating currents and power loss (temperature rise) in line transmission transformers, which is undesirable. The rectifiers that charge the capacitors at each peak of the line voltage allow peaking spikes of current to flow for a few milliseconds. Figure 3 below shows the current spikes.

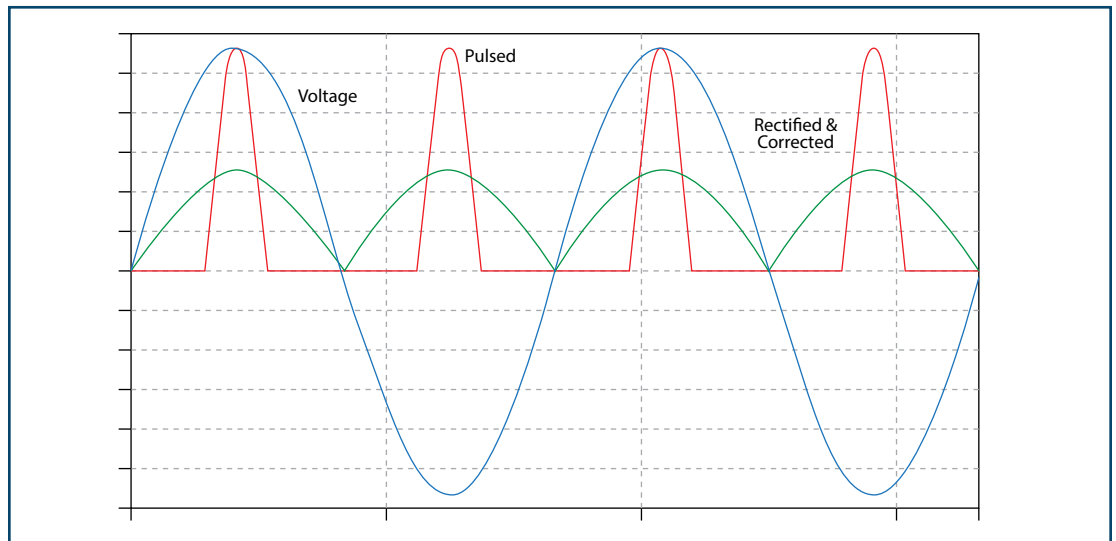


Figure 3. | Line Voltage With Pulsed And Rectified Currents

An active Power Factor Correction circuit controls the input current to follow the line voltage, forcing the converter to look like a resistive load to the line. A resistive load has  $0^\circ$  phase shift between the current and voltage waveforms. Power Factor (PF) is defined as the cosine of the phase angle between the sinusoidal waveforms of the current and voltage. Therefore, a purely resistive load would have a Power Factor of 1.

The technique of making the load current follow the line voltage so there is no phase difference is referred to as "Power Factor Correction." When the Power Factor is 1 (cosine of phase angle between voltage and current), power on the AC line flows only when the voltage is high, and the harmonic distortion is low. The PFC makes a full-wave diode rectifier appear as a resistive load to the line by taking current from the line only when the voltage is high.

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### PFC CHANGING AC LINE VOLTAGE 208 TO 250 VAC TO 360 VDC

The Power Factor Correction (PFC) section for the online UPS takes power from the AC line 208 to 250 VAC<sub>rms</sub> to charge the bulk capacitor to a nominal 360 VDC, switching 20 to 60 A. The controller achieves a near unity power factor by shaping the AC input line current waveform to correspond to that of the AC input line voltage. The controller for this PFC stage implements average current mode control. This control method maintains low distortion sinusoidal line current which reduces the input harmonic distortion to a minimum.

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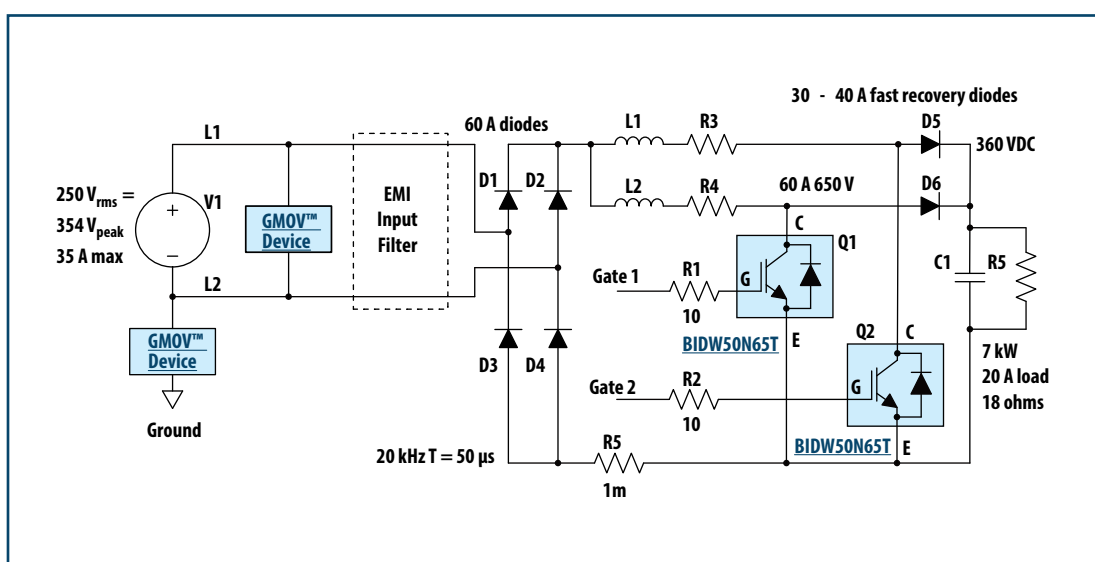


Figure 4. PFC Switching Section AC Line to 360 VDC 7 kW

Figure 4 illustrates the form of the PFC switching section for the 7 kW rectifier. It begins with protection from power line surges, has an EMI filter to comply with line harmonic energy requirements, and includes a full wave bridge rectifier. Two chokes (L1 and L2) operate with the IGBT switches U1 and U2 to allow current to pass. The load R5 represents the load for the PFC rectifier.

The Gate 1 and Gate 2 controls are timed so they pass current when the line voltage is available to supply it. The gates are enabled by calculating when the AC line is capable of delivering current to the load and to regulate the voltage on the storage capacitor C1. The basic IGBT active period is calculated from a constant frequency around 20 kHz.



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### PFC AC LINE BATTERY CHARGER 20 A AT 58 VDC

The PFC section takes power from the AC line at 208 to 250 VAC<sub>rms</sub> to charge the battery at a maximum 20 A at 58 VDC. Note that this forward converter is also appropriate for a high-power PoE (Power over Ethernet) supply.

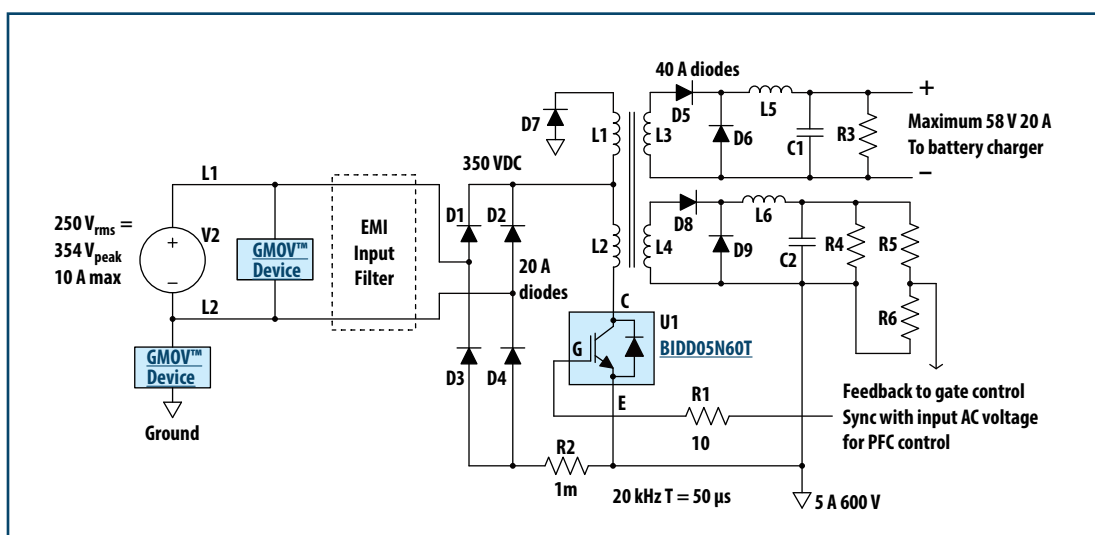


Figure 5. PFC switching section AC line to 58 VDC 1.2 kW

The charging current is sensed by measuring the voltage on R2.

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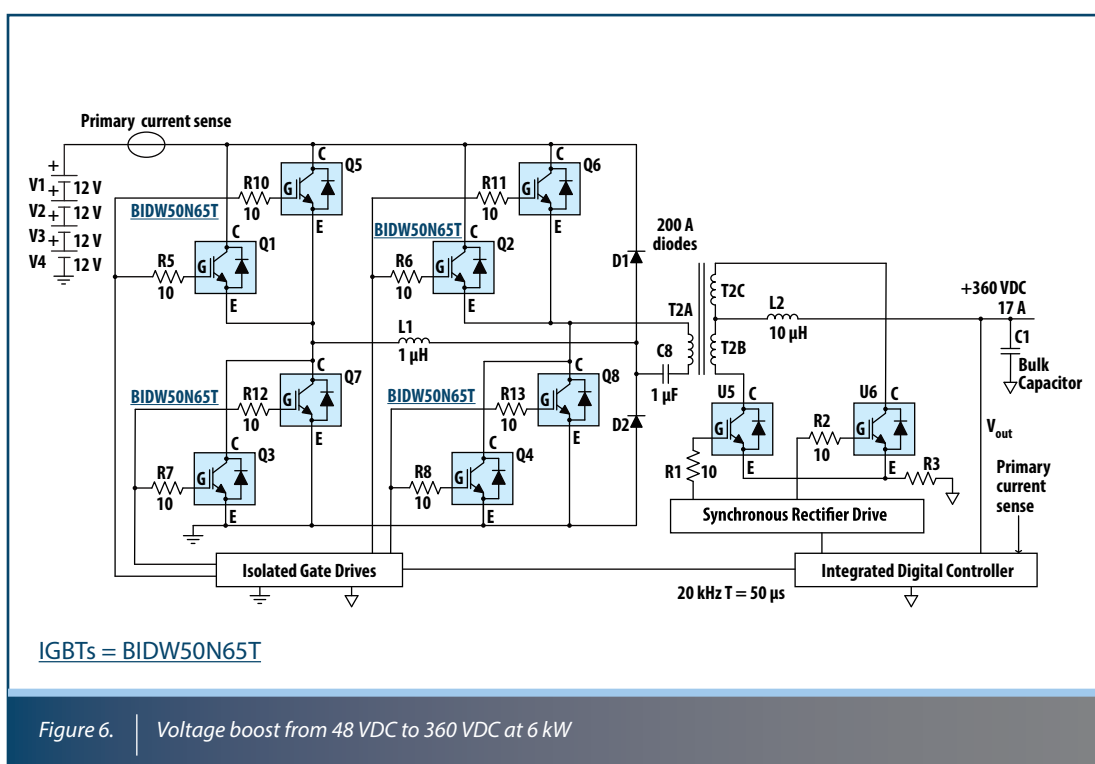
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### DC VOLTAGE BOOST CONVERTER

The low DC voltage is stepped up using a classic flyback output with an H-bridge primary switching circuit as shown in Figure 6. Current is taken from the four 12 volt batteries in series through the switches U1 to U4 to charge the flyback transformer T2. The transformer secondary is rectified by the full wave synchronous rectifier U5 and U6. The integrated digital controller creates the full H-bridge gate drive signals by sensing the output voltage, output current, and primary current.



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### DC TO AC INVERTER 5.5 KW

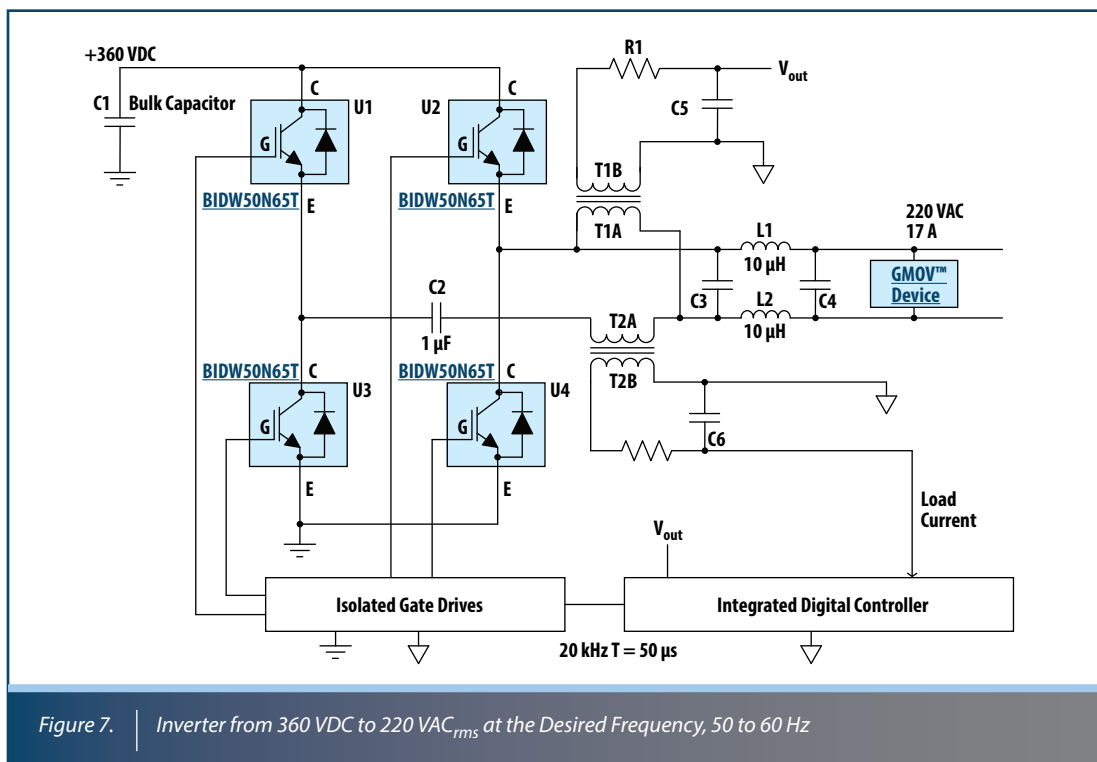


Figure 7. | Inverter from 360 VDC to 220 VAC<sub>rms</sub> at the Desired Frequency, 50 to 60 Hz

Figure 7 shows a full-bridge direct drive inverter from 360 VDC to 220 to 240 VAC output. The integrated digital controller uses the synthesized AC voltage and current waveforms to control the gate drives for the H-bridge switches. The switching phases are calculated from the internally calculated power frequency waveform and compared to an internal 20 kHz clock. Frequency stability and a narrow tolerance of the resultant AC waveform are provided by the stable frequency control.



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### CONCLUSION

Using appropriately rated IGBTs in many different circuit configurations yields useful and varied power conversion circuits. IGBTs perform as switches and rectifiers with combinations of diodes and magnetic components to make the various building blocks for several types of Uninterruptable Power Supplies. Modern digital control circuits streamline the control and tuning of the conversion circuits so that the desired function at the highest efficiency can be achieved.

Bourns offers a line of advanced IGBTs with high current and up to 30 % power dissipation features that allow circuits to function with the least amount of high frequency noise and reduce the number of components required to help lower total BOM costs. Combined with the ease of driving the gates in the same way as driving MOSFETs, employing Bourns® new IGBTs makes designing the complete UPS application circuit a relatively straightforward process.

See Bourns' web pages for complete specifications and other application information.

### ADDITIONAL RESOURCES

- [Product Page: Bourns Discrete IGBT](#)
- [Technical Library: Bourns Discrete IGBTs](#)
- [White Paper: Understanding IGBT Data Sheet Parameters](#)
- [White Paper: Achieving Fast IGBT Reverse Recovery Loss](#)
- [White Paper: Measuring IGBT Conduction Loss to Maximize Efficiency](#)
- [White Paper: Bourns® IGBT vs. MOSFET - Determining the Most Efficient Power Switching Solution](#)

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