Introduction to Three Level Inverter (TLI) Technology

This Application Note reviews three level inverter topology, often referred to as Neutral Point Clamped (NPC) inverter. The three level inverter offers several advantages over the more common two level inverter. As compared to two level inverters, three level inverters have smaller output voltage steps that mitigate motor issues due to long power cables between the inverter and the motor. These issues include surge voltages and rate of voltage rise at the motor terminals and motor shaft bearing currents. In addition, the cleaner output waveform provides an effective switching frequency twice that of the actual switching frequency. Should an output filter be required, the components will be smaller and less costly than for an equivalent rated two level inverter. Most often the NPC inverter is used for higher voltage inverters. Because the IGBTs are only subjected to half of the bus voltage, lower voltage IGBT modules can be used. Powerex's TLI series of IGBT modules provides a cost effective way to bring the advantages of this topology to 460V applications. For more detailed information please refer to the datasheets located on the Powerex web site.

Basic Circuit Configuration and Its Behavior

Figure 1 shows the circuit configuration of the NPC inverter. Each leg has four IGBTs connected in series. The applied voltage on the IGBT is one-half that of the conventional two level inverter. The bus voltage is split in two by the connection of equal series connected bus capacitors. Each leg is completed by the addition of two clamp diodes.

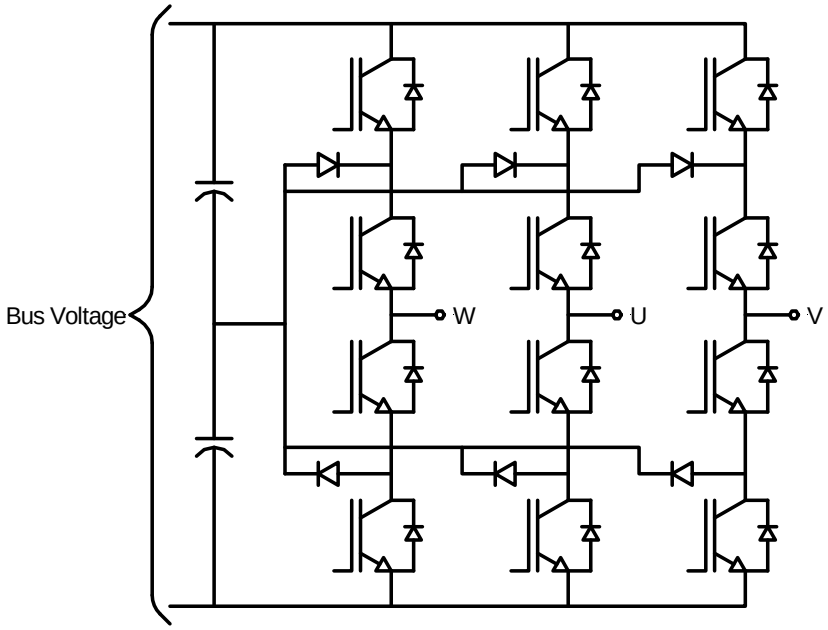

Figure 1. NPC Inverter

This topology traditionally has been used for medium voltage drives both in industrial and other applications. In addition to the capability of handling higher voltages, the NPC inverter has several favorable features including lower line-to-line and common-mode voltage steps and lower output current ripple for the same switching frequency as that used in a two level inverter.

Ouptut Voltage and Switching States

The NPC inverter can produce three voltage levels on the output: the DC bus plus voltage, zero voltage and DC bus negative voltage. The two level inverter can only connect the output to either the plus bus or the negative bus. (Refer to Figure 2 for the following example.) For a one phase operation, when IGBTs Q1 and Q2 are turned on, the output is connected to Vp; when Q2 and Q3 are on, the output is connected to V0; and when Q3 and Q4 are on, the output is connected to Vn.

Switching states for the four IGBTs are listed in Table 1. Clamp diodes D4 and D5 provide the connection to the neutral point. From the switching states, it can be deduced that IGBTs Q2 and Q3 are on for most of the cycle, resulting in greater conduction loss than Q1 and Q4 but far less switching loss. In addition, the free wheel diodes for Q2 and Q3 are for most cases, soft switched as the IGBT parallel to the diode is on, thus holding the recovery voltage across the diode to that of the IGBT Vce.

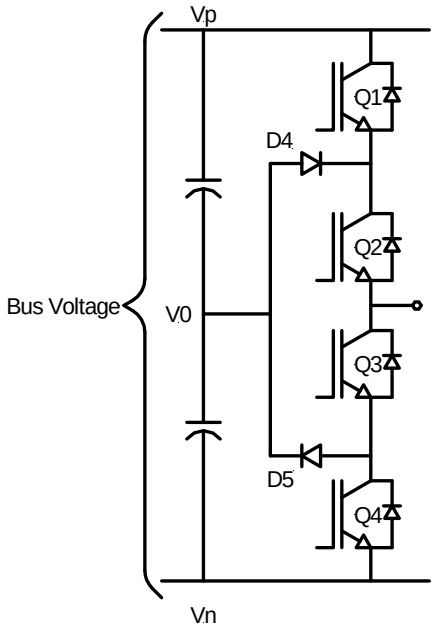

Figure 2. Single Leg

Table 1. Switching States

IGBT	Vout = Vp	Vout = V0	Vout = Vn
Q1	On	Off	Off
Q2	On	On	Off
Q3	Off	On	On
Q4	Off	Off	On

The DC bus capacitors are connected in series and establish V0, the mid-point voltage. Due to available capacitor voltage rating, series connected capacitors are generally required in inverters rated for 480V and 600V service. In NPC inverters, maintaining the voltage balance between the capacitors is important to the proper operation of the NPC topology.

Figure 3 is a graph of the leg output voltage and Figure 4 is a graph of the phase-to-phase output voltage. Careful observation shows that the effective switching frequency of the phase-to-phase voltage in Figure 4 is twice that of the phase voltage shown in Figure 3. A two level inverter is required to use two times the switching frequency of an NPC inverter in order to achieve the same ripple in the output current. This simple fact coupled with the intermediate voltage steps of the NPC inverter offers two advantages over the two level inverter. First, there are far less switching losses in the NPC inverter and second, if an output filter is required, the filter components will be smaller in both value and size than the filter components for a two level inverter.

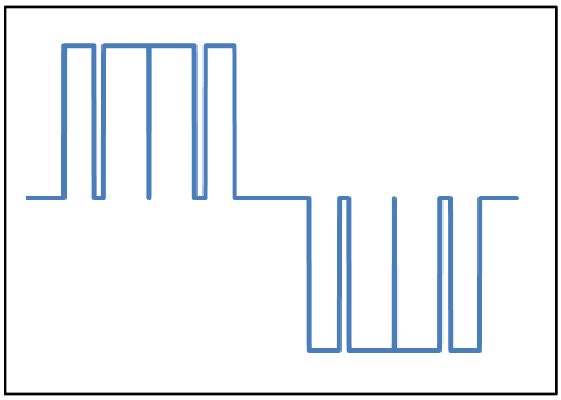

Figure 3. Leg Output Voltage

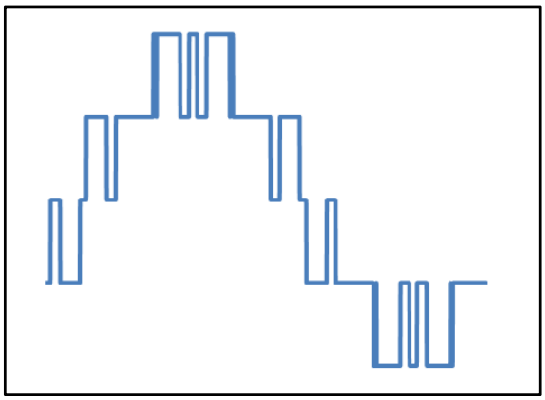

Figure 4. Phase-to-Phase Output Voltage

Summary

The Powerex TLI series IGBT modules, specifically designed for low voltage NPC or three level inverters, provide a cost effective approach for the design of an inverter with the following desirable characteristics:

- High quality output voltage and current waveforms result in less motor stress even for long power cables.
- High efficiency design due to decreased switching losses
- Reduced output filter component size and cost as compared to a two level inverter
- Proven Powerex IGBT module reliability