
Bulletin 1336 Plus Igbt Technology Application Note # 114

PURPOSE

The introduction of IGBT based variable frequency drives has raised concerns about this equipment's impact on motor life. There are several technical issues which may impact motor insulation. The purpose of this document is to provide information and guidelines for the Users of PWM drives with IGBT inverters.

WHAT THIS NOTE CONTAINS

This note will describe the phenomenon known as reflected wave, standing wave or transmission line effect that occurs at the motor terminals due to an impedance mismatch between the cable and the motor. Installation recommendations will be offered for those applications that may be most susceptible to this phenomenon.

INTENDED AUDIENCE

This application note is intended to be used by personnel familiar with the hardware components and programming procedures necessary to operate the Bulletin 1336 PLUS.

WHERE IT IS USED

The diagrams, parameter settings, auxiliary hardware and/or installation recommendations in this application note are designed to address specific issues in many different applications. Some changes by the Users may be necessary to apply the concepts of this document to a specific application.

TERMS AND DEFINITIONS

- IGBT - Insulated Gate Bipolar Transistor
- BJT - Bipolar Junction Transistor
- GTO - Gate Turn Off
- SCR - Silicon Controlled Rectifier
- Random - Motor windings that are wound without ensuring that the first turn and last turn are at opposite ends of the slot.
- Concentric - Motor windings that are wound with each successive winding wound "on top" of the next, ensuring that the last turn is on the opposite end of the first turn.
- Phase Paper- Insulating paper inserted between phases of the stator windings at the end turns.
- Slot Paper - Paper placed in the slots of the stator core to insulate between the core and the winding.

DESCRIPTION

Voltage Wave Phenomenon - Any two-wire cable (e.g., a coaxial cable, a parallel wire line, or a twisted pair) has some stray capacitance between the two wires of the cable. When current flows in the cable, it produces a magnetic field near the conductors, and when the current changes, the changing magnetic field produces a back electromotive force in the cable. Any cable has a certain capacitance and self-inductance. The capacitance and inductance are proportional to the length of the cable and so may be defined as a capacitance C per unit length and an inductance L per unit length. Calculating the actual C & L is quite difficult except with coaxial style cables where the shape and arrangement of the conductors are simple and known, but the relative impact of various installation methods should not be overlooked. (Single conductors loosely arranged in a cable tray will have a higher stray capacitance than the same conductors in a single conduit).

With Z being the characteristic impedance of the line $\chi \propto \sqrt{L/C}$ and R being the resistance of the load, unless R and Z are equal, there **must** be a reflected wave on the line and **some** of the power incident on R will be reflected back to the source. The resulting magnitude of the reflected wave **can be** twice the amplitude of the peak voltage. On a VFD, The magnitude of the peak is its DC bus voltage.

$$V_{\text{wave voltage}} = 2 \cdot 1.35 \cdot 460 = 1240V$$

While this doubling of the voltage at the motor can be **theoretically calculated**, in reality, most installations will not see more than a 20% or 30% increase in voltage at the motor windings. Many factors, including type and size of cable used, wire routing and type of cable tray or conduit used, can affect the actual reflected wave amplitude.

Figure 1 shows the reflected wave on a IGBT drive at 250ft. The two waveforms show drive terminal voltage (CH3) and motor terminal voltage (CH4). Scaling is at 200V/div and 500usec/div. The magnitude of increase caused by the reflected wave is less than 50%.

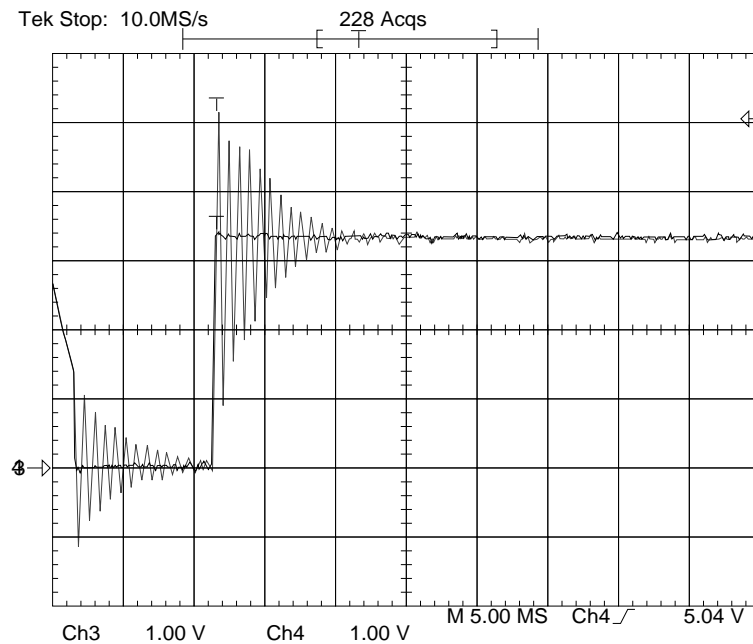


Figure 1

DESCRIPTION (Cont.)

The velocity of this reflected wave, is also dependent on the cable impedance and capacitance. The velocity, along with the dv/dt of the voltage source, is used to determine at which distance from the source the reflected wave will fully develop. The concerns that some have expressed regarding IGBT based inverters is twofold;

1. The IGBT switching device has a higher dv/dt (faster turn-on time) than standard bipolar devices, increasing the velocity of the reflected wave.
2. The faster switching time allows higher carrier frequencies which increases cable capacitance.

Both imply a shorter distance at which the reflected wave is at maximum amplitude and, thus, a shorter maximum motor cable length for IGBT based drives. The **assumed result** is that a voltage **twice the inverter DC bus voltage** can be applied across the motor windings, causing premature motor failures.

Assuming that, in a typical installation, motor characteristic impedance and cable impedance are **not equal**, voltage reflection will occur. This is true whether IGBT, BJT or GTO inverters are used. If the pulses take longer than the rise time to travel from the inverter to the motor, then a full reflection will occur at the motor.

DESCRIPTION (Cont.)

Figure 2 shows the reflected wave with an IGBT drive at 250 ft.

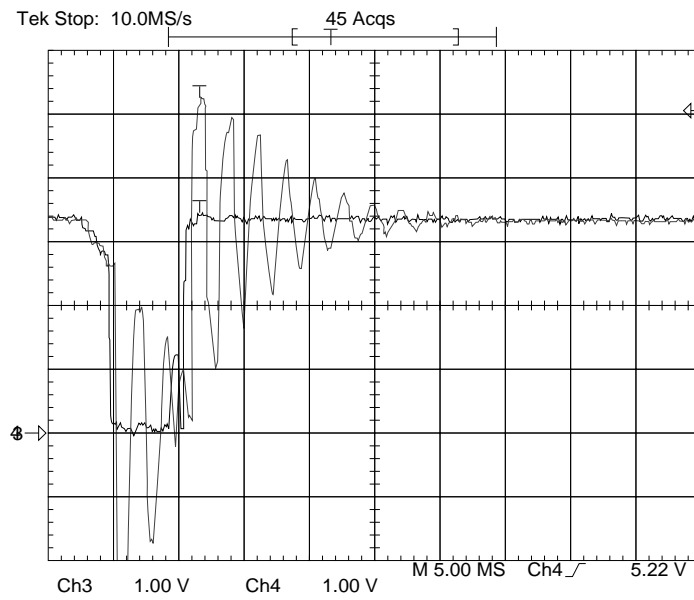


Figure 2

Figure 3 is the reflected wave with a BJT drive at 250 ft. Notice that, regardless of the device technology, there is **no significant difference** in the magnitude of the reflected wave.

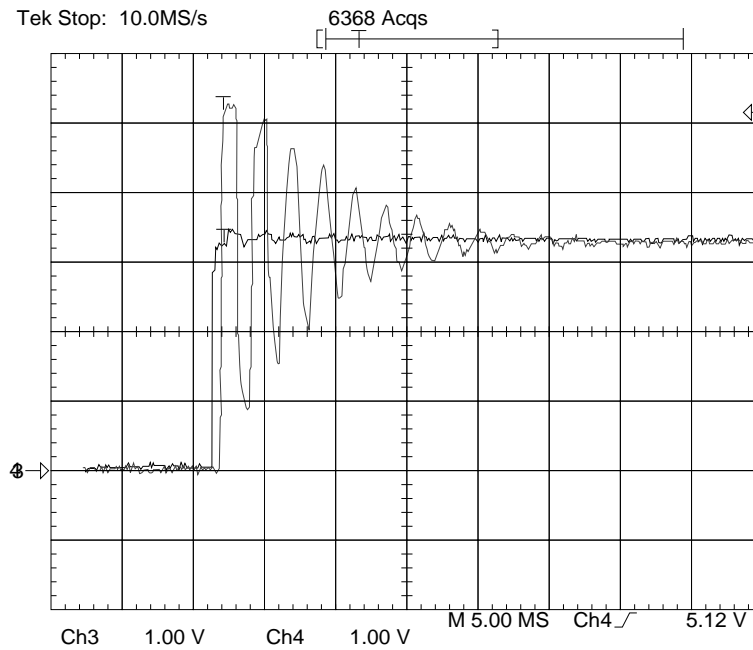


Figure 3

APPLICATION CONSIDERATIONS

The following table provides estimates of the distance at which the reflection reaches maximum peak amplitude. Variations in these estimates reflect differences in dv/dt of the devices, cable used and installation techniques.

Device	Distance:Meters	Distance:Feet
IGBT	30 - 60	100 - 200
Bipolar	75 - 150	250 - 500
GTO	180 - 300	600 - 1000
SCR	180 - 300	600 - 1000

It is important to understand that, while these distances can be calculated, they should not be misconstrued as limits on the length of cable between motor and drive. Consultation with major motor manufacturers and broad experience in the application of variable frequency inverters have produced the following **facts**:

1. Motor failures or decreases in motor life expectancy are very seldom associated with their use on inverters.
2. In the U.S. the ANSI BIL insulation requirement for motors is **two times the rated voltage plus 1000 Volts** (2000 Volts on 460 Volt motors). This is well over the expected amplitude of reflected waves.
3. Smaller, less expensive motors that have less of a design safety factor will be more susceptible to possible damage from any source. (IEC contactors can cause failures in lesser design motors)

The design criteria of any motor plays the major role in its life expectancy. The two design elements that most significantly affect motor life are:

- A. **Successive winding Vs random winding.** Some manufacturing techniques lay the stator windings randomly in the slot, allowing the start and finish windings to lay side by side. This increases the likelihood that excess voltage, regardless of the source, will damage the motor windings. Concentric or compound wound motors are assembled so that each successive winding is layered **on top** of the previous winding, assuring that the first and last turn are on **opposite** ends of the slot. This increases the motors integrity in the face of higher voltages. See Figure 4.

APPLICATION CONSIDERATIONS (Cont.)

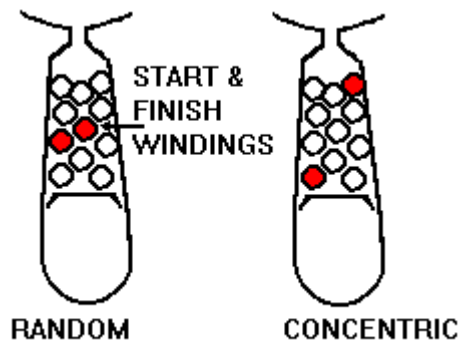


Figure 4

- B. **Phase and Slot Papers.** In an effort to control costs, motor manufacturers have, in recent years, eliminated phase and slot papers from many motors. Phase papers greatly increase the motor winding insulation integrity at the end turns, where most motors show greatest susceptibility to damage. The introduction of downsized energy efficient motors has increased this susceptibility by compacting the end turns. Slot papers and slot sticks increase the insulation and withstand ability to mechanical damage caused by windings moving in the slots by insuring that damage does not occur during assembly.

Japanese drive manufacturers have long recognized the problems caused by inferior quality in motor construction. In recent years they have begun working closely with Japanese motor manufacturers to return to construction and design that includes both Phase/slot paper and concentric windings. Allen-Bradley's inverter duty rated 1329 motors have both elements.

CONCLUSIONS

1. There is no indication that the introduction of IGBT inverters has caused or influenced an increase in motor failures.
2. Any anticipated failures could occur with any inverter design including Bipolar and GTO.
3. Allen-Bradley has over 200,000 installed inverters of many types without undue motor failure issues.
4. Customers should be encouraged to use quality motors in all applications and limit motor lead length wherever possible.
5. Whenever possible, all motor conductors, including a ground conductor, should be contained in a single metal conduit.