

Monthly Informative Application Guidelines, with respect to *Motors & Drives* to keep you better INFORMED.

APPLICATION GUIDELINE #15

(Reliability against Voltage and Current with VFD's)

Brought to you by your Motor & Drive Specialists.....

Transistor **current** and **voltage** ratings are factors that are key in the design and manufacture of high performance industrial drives. Robust drive platforms do not come at low cost but they translate into unsurpassed reliability. Many industrial plants have very high cost per hour downtime liabilities and money spent up front on the most robust equipment available pays off many-fold in the future years of reliable service.

Voltage ratings become an issue when utility power is high coming into the facility, when transformers are set to high voltage tap settings, when the motor experiences regeneration, when reflected wave phenomenon occurs, and/or when fast decelerations are required. **Current ratings become an issue** when momentary overloads are experienced (high torque requirements at start up or during running), when motor faults occur, when longer transistor switching times are required, and when fast acceleration times are required.

1700V PIV (Peak Inverse Voltage) IGBTs

In order to understand the significance of utilizing more expensive, 1700V rated IGBTs in 600V drives used in heavy duty, industrial applications, some basics need to be outlined.

First of all, the DC bus voltage is approximately equal to $\sqrt{2}$ x RMS AC input voltage. If the input voltage for example is 600V, the DC bus voltage becomes 848V. If the input voltage rises to 10% above nominal, i.e. 660V the DC bus voltage becomes 933V. If there are any transients on the line, the input voltage increases accordingly. When the drive slows the load down, the motor acts like a generator and transfers energy back to the drive further increasing the DC bus voltage. If a conventional 1200V PIV rated IGBT is used in a drive, it is apparent that the DC bus voltage can rapidly approach the PIV rating of the device.

Secondly, to make matters even more complex, reflected waves caused by the fast rise times of the IGBT interacting with the motor impedance and cable characteristics can cause additional over voltage stresses on the IGBTs. Output reactors or output filters attached to the output of the drive will help attenuate the voltages that the drive sees due to the reflected wave phenomenon. In the case of an output reactor, the buffering effect is due to the impedance mismatch between the cable and the reactor causing the reflected wave to reflect back to the motor. This can increase motor insulation stress. In the case of a properly designed RLC filter, most of the reflected wave is "sunk" through the capacitors and the energy is dissipated in the resistors.

Care should be taken on high performance applications, in order to fully utilize the advantages of vector control, these applications require that the drive be connected to the motor without output reactors or output filters. The reason being that the drive monitors output current magnitude and PF angle so that it can "read" the magnetizing current portion of the output. This is a vital key in proper vector control. Adding output filters or reactors will change the equivalent circuit that the drive sees and therefore will provide inaccurate information to the microprocessor. Drives that utilize low rated IGBTs, especially in constant torque, industrial applications, should have output reactors or preferably output filters to increase the reliability of the drive to acceptable levels.

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Finally, if the DC bus trip voltage is set too close to the PIV rating of the IGBTs, they will be subjected to undue stress, which can easily lead to premature failure. If the DC bus trip voltage is set too low, the drive is subject to nuisance tripping on over-voltage whenever a voltage transient occurs or when the drive decelerates the motor. In order to provide a reliable, **600V** industrial duty drive, the DC bus trip voltage needs to be well above the 933V level discussed in item 1 above.

Industrial drives employ dynamic braking transistors which “dump” the energy that the motor provides into an external dynamic braking resistor when it is decelerated quickly. In order to provide nuisance free, high performance braking, there has to be some significant headroom above the firing voltage of the dynamic braking transistor and the DC bus trip voltage. If the dynamic braking transistor firing voltage is set below 933V, the drive will try to regulate the system voltage every time the voltage exceeds $600V + 10\% = 660V$. This will cause nuisance trips or damage to either the dynamic braking transistor or the dynamic braking resistor.

Toshiba's 600V G3 drive has the following characteristics:

- 1700V IGBTs (7th generation IGBTs)
- 1179V DC Bus trip voltage.
- 937V firing voltage for dynamic braking (242V headroom to allow for instantaneous voltage excursions during extremely fast dynamic braking).

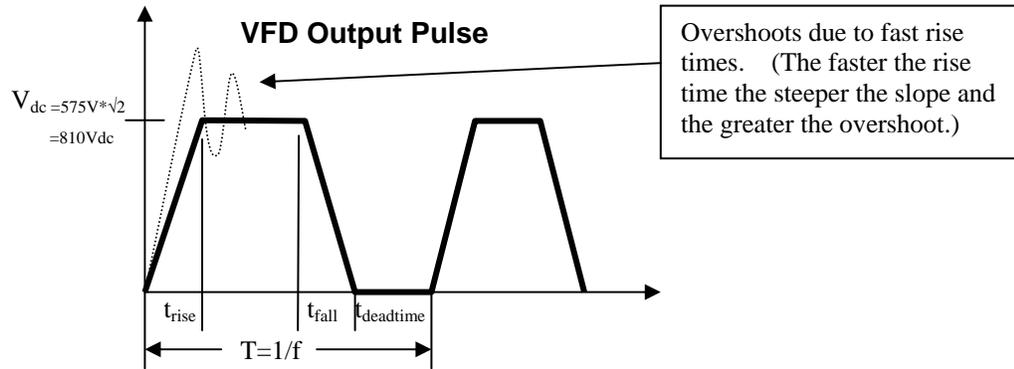
In quick summary, the decision to use 1700V IGBTs in the Toshiba G3 series of 600V drives was made for reliability and performance.

- Reliability of the IGBTs by operation well below the stress level of the devices
- Reliability of the system by virtually eliminating nuisance trips due to high input voltages, voltage transients and dynamic braking.
- Optimum use of vector control by not having to protect the drive with output magnetics.
- Improved headroom for aggressive braking capability.

IGBT Current/Overload Ratings

1700V devices is not the only issue in reliability and performance. Transistor size is just as important to not only drive reliability but also to motor or system reliability. In heavy industry, many applications require the ability to provide extra current for transient overloads. Some applications require large amounts of current for relatively short periods of time. If transistors are "optimally" sized, the drive will trip. Worse, in the event of a phase to phase or phase to ground fault, optimally sized transistors may be damaged due to the very fast rise in current and the subsequent instantaneous I^2t heating. Transistors which are "oversized" can handle significantly more transient current before tripping and have additional thermal capability to prevent damage due to the transient I^2t heating during a fault condition. In short, larger output transistors translate into improved ability for a drive to accommodate overload stresses without damage or partial damage. This is a key feature of an industrial duty drive. Increased output transistor sizing provides increased reliable overload capability. Toshiba G3 drives up to and including 100HP for example provide 150% overload for 120 seconds. This is twice the industry average. Drives >100HP provide 150% overload for 60 seconds. In addition, all Toshiba G3 series drives can output 110% current continuously (i.e. the drives have a 1.10 SF).

Larger output devices allow for less aggressive switching times. This is significant from a motor point of view. Drive designers are faced with many decisions. One decision is how fast the IGBTs are turned on or off. When a transistor goes from the non-conducting state to the fully conducting state, or vice versa, it has an effective resistance. Current flowing through the transistor during this time generates heat, therefore, every time a transistor is switched on or off, heating occurs. This heating is a function of current squared times time (I^2t). The faster the IGBT is switched, the less the heat generated therefore the smaller the device can be. The problem is that faster switching means faster rise times. Faster rise times result in some important issues.



As rise times **decrease (rate of rise or slope increases)**, the probability of a reflected wave increases with shorter and shorter cable lengths. This increases the voltage levels seen at the motor terminals. In theory, the voltage at the motor terminals can almost be doubled. (In actual installations, we have seen the voltage levels much higher, especially with multiple motors powered by one drive.)

Output pulses with very fast rise times do not distribute evenly across the turns in a motor winding. When a motor is powered by a sine wave the voltage, turn to turn is the peak voltage = $\frac{\sqrt{2} \times \text{AC RMS Voltage}}{\# \text{ of turns}}$. This is a relatively low voltage. When a pulse with a very fast rise is applied across the motor, a huge percentage of the voltage is initially distributed across the first and second turns, a smaller amount between the second and third turn etc. This problem is amplified if a reflected wave is present resulting in significantly increased voltage at the motor terminals.

The faster the rise time, the more difficult it is to design a completely effective snubber circuit. A snubber circuit is used to dampen the output pulse so that it does not overshoot the DC bus voltage level. If the snubber circuit is not effective, the over voltage at the motor terminals can be further increased..

Because Toshiba utilizes oversized transistors for improved reliability and performance (typically 150% of the industry average size), it is possible to **increase** the output pulse rise times (**reduce the rate of rise**). NEMA MG1 Section 31 (guideline for inverter duty motors) refers to motor insulation being required to accommodate output voltage pulses with a rise time of 0.1 μsec or higher with a pulse voltage of 3.1 times the AC RMS voltage. Toshiba's rise times are 0.2 μsec or higher. Some drive manufacturers use rise times as fast as 0.05 μsec (50 nanoseconds). As well, the faster the rise times the higher the order of harmonics present in the waveform. The higher the order of harmonic, the harder (more expensive) it is to build an effective RLC filter. The faster the rise time the shorter the cable is before the likelihood of a reflected wave will occur. This means filters may be required on more applications, in order to protect motor insulation.

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