Test Guidelines for the Measurement of Voltage Transients Applied to Motors Fed by Modern Low Voltage PWM Inverters

Safety: DANGER The measurement of motor voltage should only be performed by qualified personnel familiar with both the electrical as well as rotational hazards associated with this equipment. Failure to use appropriate precautions could result in severe bodily injury or loss of life.

Background: It has been recognized for some time that the relatively fast turn on time of the output transistors of modern low voltage PWM inverters can create transient voltages at the motor terminals which may stress the motor insulation system. Two basic characteristics of the waveforms arriving at the motor are critical, the peak voltage and the rate of change of voltage (dV/dt). The turn on time of the inverter output transistors directly controls the dV/dt. The combination of lead length and transistor turn on time (along with modulation issues) are critical factors controlling the peak voltage (Fig 1 and Fig 6).

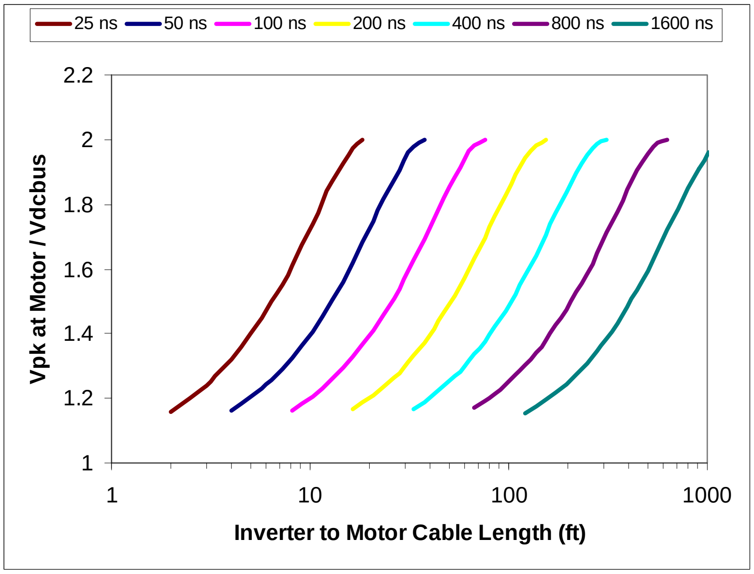

Figure 1a – Relationship between turn on time, cable length, and peak voltage overshoot

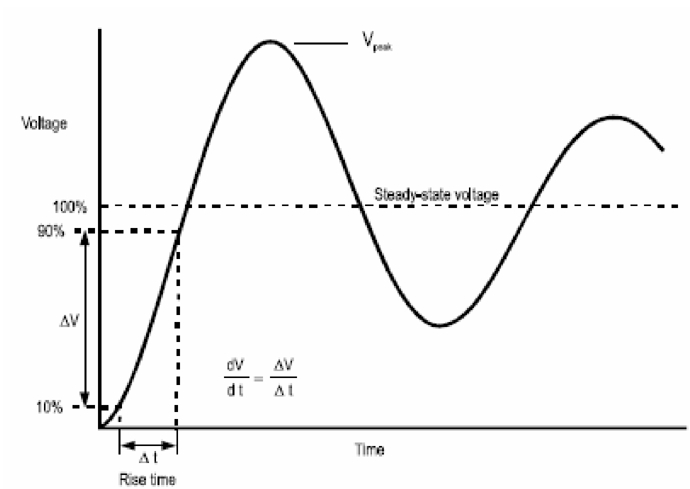

Figure 1b – Relationship between Peak Voltage, Rise Time, and dV/dt (from NEMA MG1-30)

C/R	DR MJM	46101-XXX
Re-issue Date	CK RFS	
	APP RFS	
	DATE 2/2004	Sheet No. 1 of 6

RC200TS

Measurement Goals: The intent of the measurements is to quantify the highest peak voltages (both line to line and line to ground) and to also document the greatest time rate of change of the voltage (dV/dt). In regard to the dV/dt, while the steepest slope of the voltage versus time relationship is of interest, of greatest interest are the fastest transitions which span a voltage change of at least 500 V (Fig 1b).

Instrumentation (hardware and usage):
Hardware: The hardware required for these requirements includes the following.
Oscilloscope – Since the waveforms are not strictly repetitive, the scope should be evaluated based on "single shot" bandwidth or sampling rate. At least 10 MHz bandwidth, or a 10 million samples per second (10 MS/sec) acquisition rate is required. A digital storage scope is assumed.
Scope Probe – A minimum of 10 MHz frequency response is needed, though closer to 50 MHz would be preferred. A probe input voltage capability of 2500 V is typically required.

Usage: Equally as important as the hardware for these measurements is the usage of that hardware. First, since the voltage probe is likely to be a 100x type, and since the readings are fast rising transients, it is important to match (adjust) the probe impedance to the scope input impedance through the internal square wave calibration signal of the scope. This insures that the combination of probe and scope neither dampen transients nor create additional distorting "ring-up" effects.

Second, since the intent is to identify the most extreme transients, proper use of scope triggering is critical. The simplest technique is to use dc triggering (based on the scope channel making the reading) and adjust the trigger level high enough such that triggering events are infrequent. It should be kept in mind that while there may be repetitive transients which are approximately twice the dc bus voltage (Fig 2), there may also be less frequent transients that go well beyond that level (Fig 6). Such transients may occur only for specific conditions of operating speed, load, and incoming line conditions. Patience and proper triggering is required to capture these transients when they do occur.

Third, while it may be tempting to set the scope time base to show a full fundamental cycle of voltage, that setting would not result in a sufficient sampling rate to accurately capture the fast transients (Fig 5). A minimum sampling rate of 10 million samples per second (10 MS/sec) should be used. While a given scope may be rated for 500 MS/sec or more, the actual rate for any measurement is a function of the scope record length and the total time record duration. For example, if the scope has a record length of 500 points, then a total record time duration of 50 µsec would represent a sampling rate of 10 MS/sec. With a display of ten horizontal divisions, if the full record is displayed, then this would amount to a time setting of 5 µsec per division. Alternatively, if the scope had a record length of 10,000 points (spread over 10 time divisions), then the time base could be 100 µsec per division (and still achieve 10 MS/sec). In order to quantify the dV/dt of a waveform with a 50 nsec risetime, however, a time setting of 100 µsec/div would be too slow (the transition would look like a vertical line). When the time record consists of a file of 10,000 points, then the waveform could be captured at 100 µsec/div, then zoomed in to a level of 50 or 100 nsec/div in order to establish the dV/dt magnitude (Fig 3).

Fourth, in order to measure line to line voltages, either the probe needs to be a differential type, or the scope must have inputs which are completely isolated from the scope ground. The technique of "floating" a scope that does not have isolated inputs is not recommended due to safety considerations.

Finally, it is important to obtain readings of the voltage transients AT THE MOTOR TERMINALS, rather than at the inverter output. This is due to the substantial impact of lead length (Fig 1). Readings should be taken both of line to ground and line to line transient voltages. For the line to ground readings, it is important to have a good ground reference, which is not "polluted" with transients. For this reason, while it may be tempting to use the inverter to motor cable ground termination point in the motor conduit box as the ground reference, this should be avoided due to the fact that this point carries the return common mode current (CMC). Rather, another nearby ground point, such as a base safety ground is preferred.

Table 1 (at the end of this document) can be used to record specific data.

Example waveforms: The following traces show some of the situations which may be encountered when making these measurements.

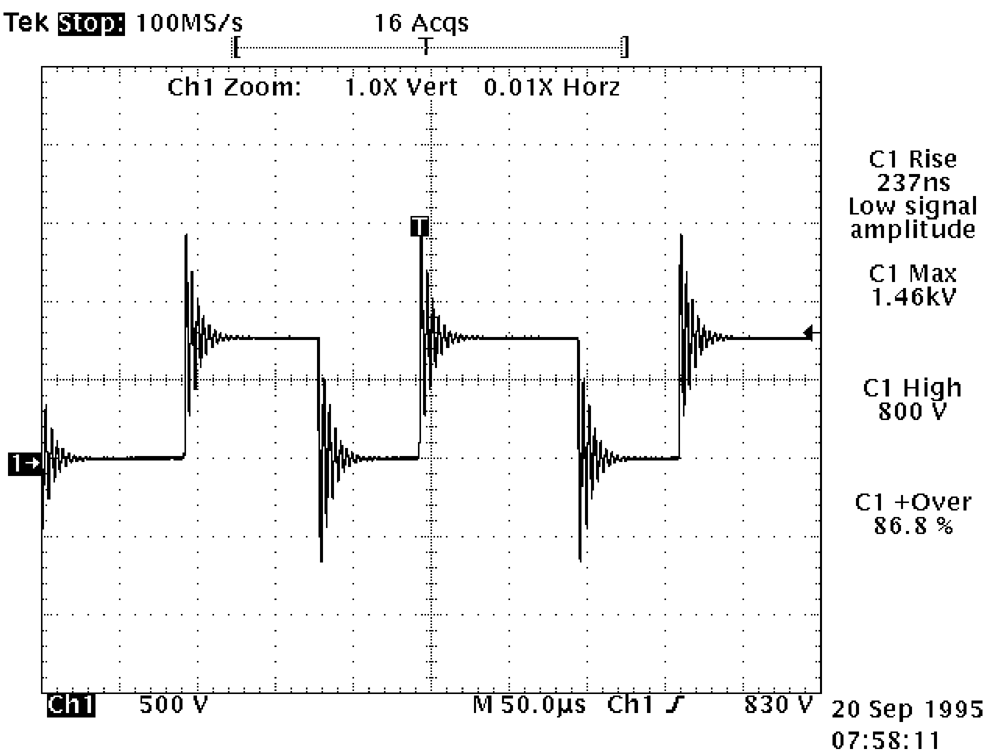

Figure 2 – Line to line voltage on 575 V motor with repetitive 87% voltage overshoots
Vpk = 1,460 V.

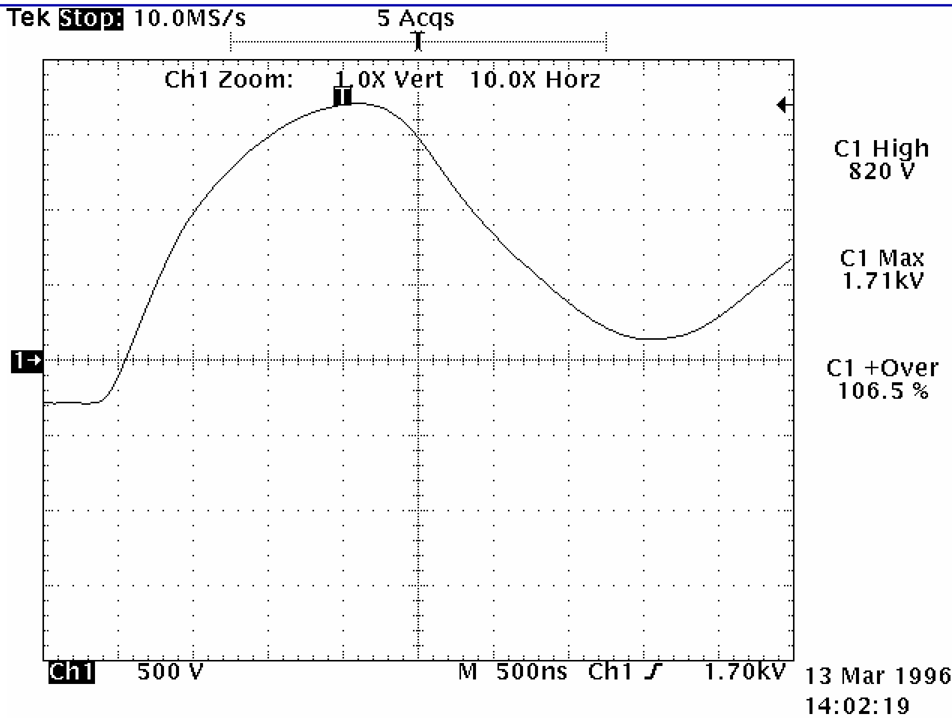

Figure 3 – Line to line voltage sampled fast enough to allow 10x time base zoom to allow quantification of dV/dt. Vpk = 1,710 V. dV/dt = 2,450 V/µsec.

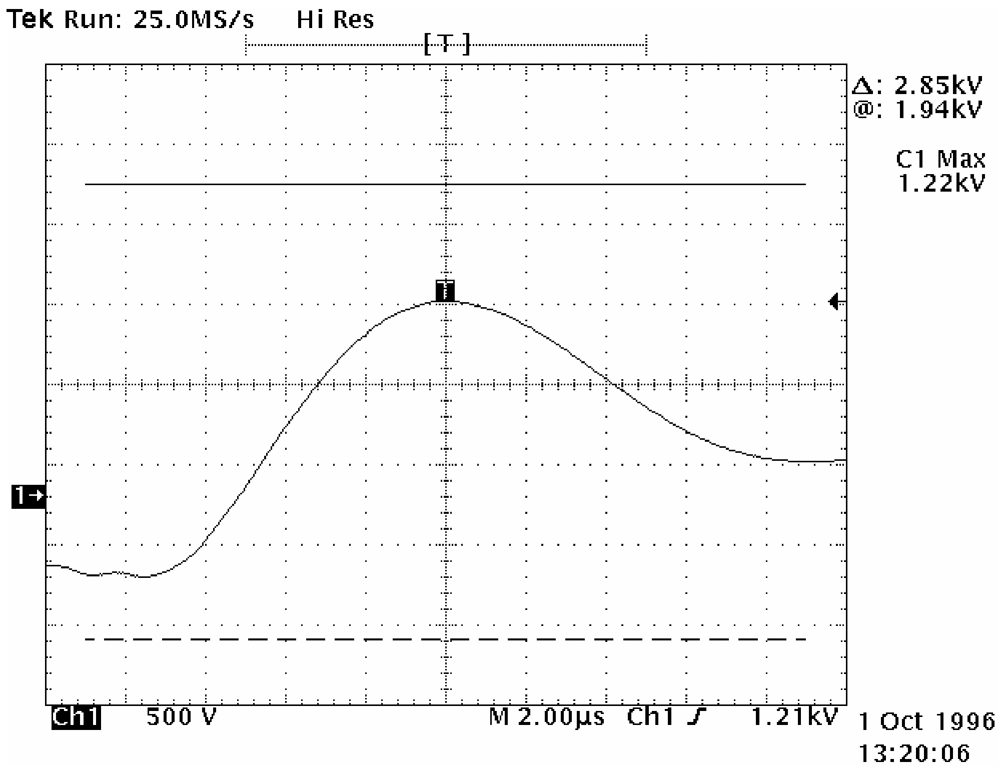

Figure 4 – Line to ground voltage with ability to quantify dV/dt
Vpk = 1,220 V. dV/dt = 383 V/µsec.

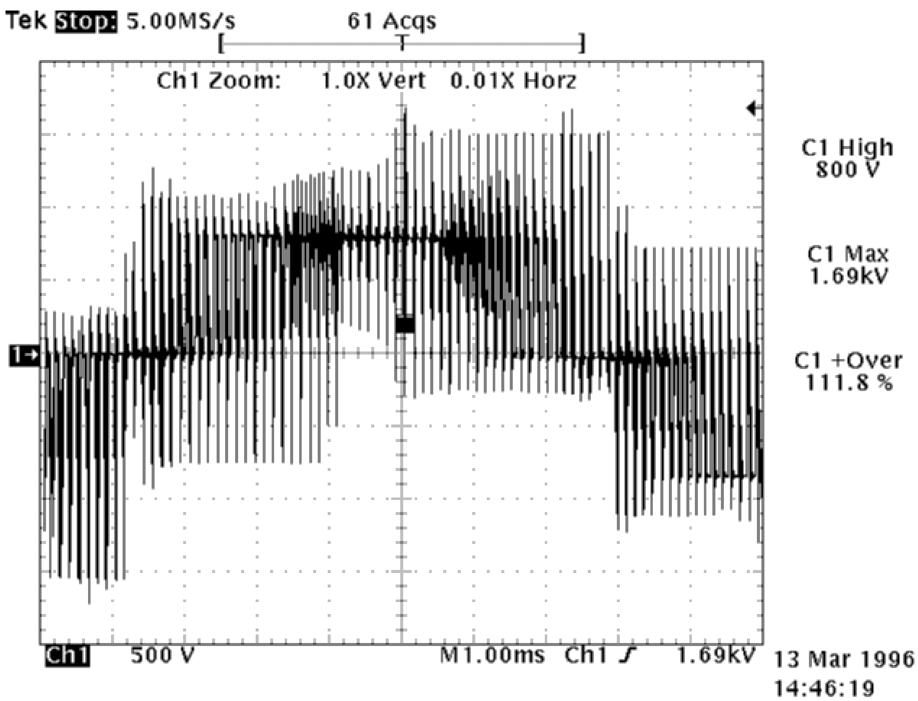

Figure 5 – Waveform taken with insufficient sampling rate due to incorrect time base

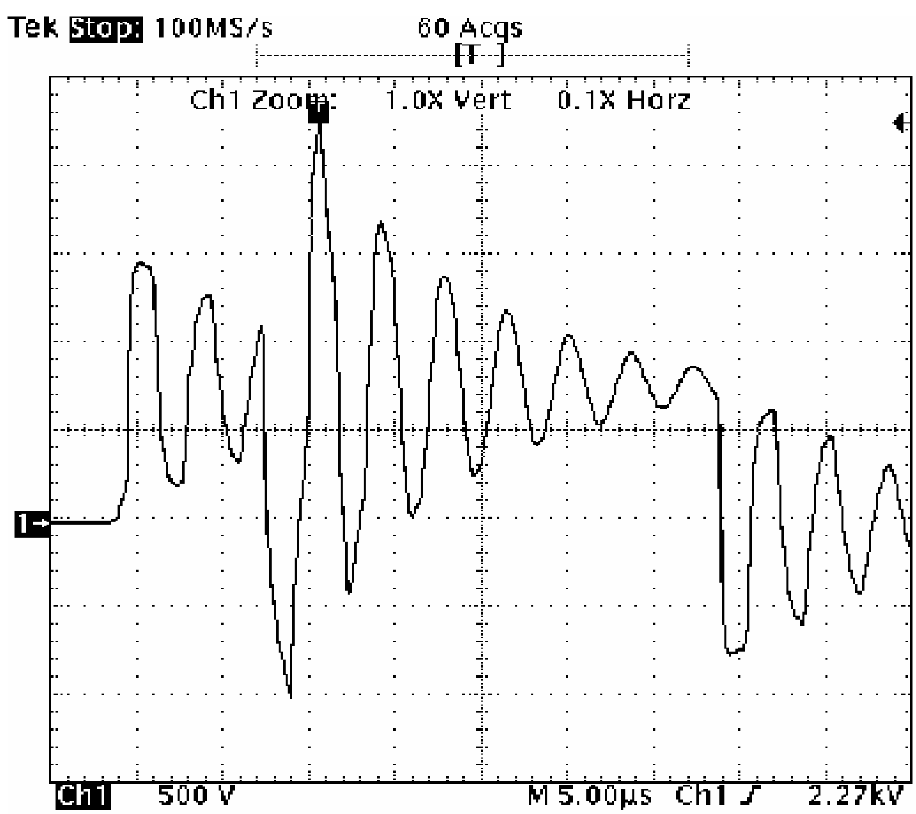

Figure 6 – Line to line voltage with infrequent "double pulsing" event.
Vpk – 2,270 V.

Reading	Scope probe connection point (e.g. T1)	Scope probe ground conn. pt. (e.g. T2, etc or gnd)	Measured Vpk	Double pulsing present? Y/N	Delta V (min of 500 V desired)	Delta t (corresponding to delta V of column to left)	dV/dt = $\Delta V/\Delta t$	Scope trace ID (filename or time stamp)

Table 1