Reduction of dv/dt and Vpeak by using output reactors

A drive converter supplies at its output, a voltage which consists of voltage blocks with the amplitude of the DC link voltage (line supply voltage peak value). The rate of rise - dv/dt - of these voltage blocks is extremely steep and is determined by the switching speed of the IGBT used. Minimum switching times range from 0.08 to 0.1µs. For a DC link voltage of $V_{DC\ link} = 1.35 * V_{supply}$ voltage rates of rise of up to, e.g.: dv/dt = 525 * 1.35 V / 0.1µs ≈ 7kV/µs for a 525V supply voltage, are obtained. This is the absolute worst-case value but the dv/dt under normal circumstances is between 3kV and 5kV/µs.
If an output filter is not provided, and especially for long motor feeder cables, this results in additional stressing, both in the drive converter (additional current spikes) as well as in the motor (increased voltage stressing which can damage the motor winding insulation). Both of these effects will now be separately discussed.

Both dv/dt and Vpeak "kill" motor insulation – it is not sufficient to just take care of one of them. Vpeak destroys the interturn insulation and dv/dt destroys the insulation on the winding overhang. There is no possibility to influence the dv/dt and the Vpeak values via software-parameters. This is also valid for the pulse frequency setting of the converter. The only possibility is to use an output reactor, dv/dt filter or sinusoidal filter. The changing of the switching frequency has no influence on the Vpeak, or dv/dt. All changing the pulse frequency means is that, for e.g. the motor gets 5000 switches per time period with e.g. 5kHz and 2500 switches per time unit at 2.5kHz (not actual figures, merely to give an indication), thus the motor will fail, it may just take a bit longer. When the IGBT's are switched they will always generate the same dv/dt, the frequency of their switching only determines how often they generate the dv/dt, per second, µs, or whatever time period. The reason for this is that the dv/dt is a function of the time it takes for the IGBT to switch from an OFF to an ON state, which is pulse frequency independent.

An output reactor (choke) can reduce the dv/dt, especially when longer motor cables are used. Without a reactor the dv/dt has typical values of 3-5kV/µs. With a reactor and 50-100m motor cables dv/dt can be reduced to 1500V/µs-500V/µs (from a worst case 7kV/µs). So dv/dt should be no longer a problem in this case. More critical is the Vpeak. For a 525V supply the DC link voltage is about 709V (for 690V level we have a DC link voltage of approximately 900V and here output reactors are not sufficient).

Motor cables have a specific capacitance. The longer the cable, the higher the resulting cable capacitance. These capacitances are re-charged at each commutation. This involves a charging current due to the cable capacitances, which is superimposed on the actual motor current - refer to the figure.

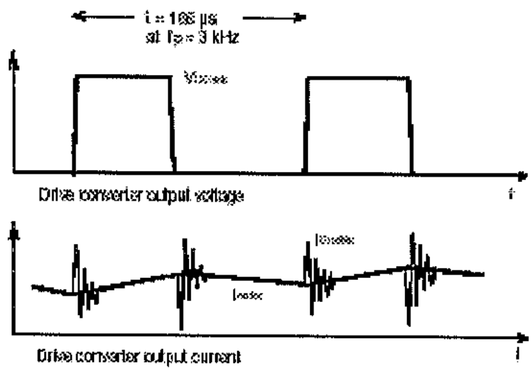

Fig. Instantaneous values of the drive converter output voltage and current

The drive converter must, in addition to the motor current, also supply these capacitive re-charging currents, which decay after approx. 1 µs. The amplitudes of these capacitive re-charging currents are higher, the higher the cable capacitance, and thus the longer the cable. Smoothing reactors or filters must be provided at the drive converter output, so that it is not fault tripped due to over current when long motor feeder cables are used.
If motors are fed through longer cables, then increased voltage levels are obtained at the motor terminals due to steep voltage increases at the drive converter output (high rate of rise). Thus, the motor not only sees the voltage blocks with the DC link voltage amplitude (= 1.35 x of the line voltage), but brief, maximum peak values up to almost twice this value. The figure below briefly explains how these voltage peaks occur.

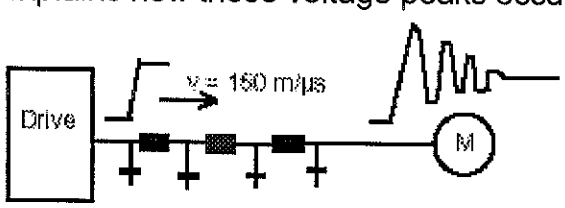

Fig. Motor feeder cable and voltage characteristics at the drive converter output and at the motor

The high rate of rise of the voltage at each commutation (e.g. 6000 times per second in each phase for a 3000 Hz pulse frequency) at the drive converter output can be considered to be a moving wave. It is propagated along the motor feeder cable with a speed of approximately 150 m/µs (≈half the speed of light!). The characteristic impedance suddenly changes at the motor: (R_W motor ≈10-20 x R_W cable). Thus, the moving voltage wave received from the drive converter is reflected back to the drive converter and then back to the motor again, etc. The initiated stabilization sequence decays to the steady-state value, e.g. the DC link voltage, after approximately 1 µs. This results in the motor voltage characteristic illustrated in the right-hand half of the figure above The maximum motor voltage in rated operation, i.e. under load, taking into account full voltage reflection, is given by: $V_{peak\_motor} \approx 1.9 \times V_{DC\ link} = 2.6 \times V_{supply}$.

The following multipliers can be used for calculating the Vpeak for various kW ratings of MASTERDRIVES:

- ≤ 100W 1.85 to 1.90 x Vdc
- > 100kW 1.8 x Vdc
- ≥ +/- 800kW 1.6 to 1.65 x Vdc

The reflection at the motor creates peaks of 1.9 x 709V ≈ 1350V without a reactor – this may be too high for the insulation for certain “standard” motors. With a reactor the voltage peak will be slightly reduced to values 1.7x709V to1.5 x 709V, meaning down to 1200V to 1070V (20-30% reduction is possible). But the value of 1070V is very optimistic. Without dv/dt-filter there is no possibility to reach Vpeak values of less than 1000V. If a dv/dt filter is used both dv/dt and Vpeak are defined as there are definite cut-off points for which the filter is designed.