VARIABLE SPEED DRIVES
HARMONIC EFFECTS
&
EFFECT OF USE WITH LONG CABLES (100 – 300m)

ZEST

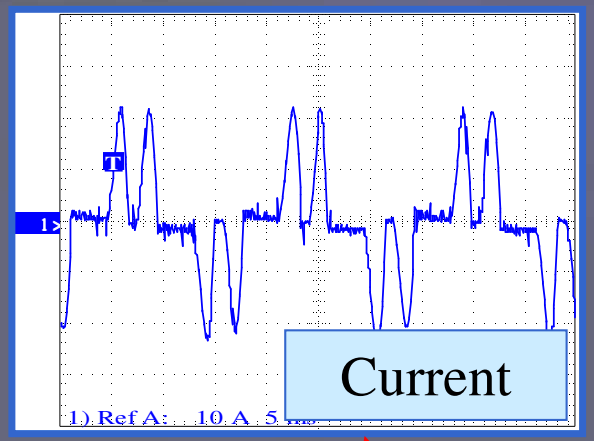
Electric Motors & Drives

….OUR VISION, YOUR SOLUTION …….

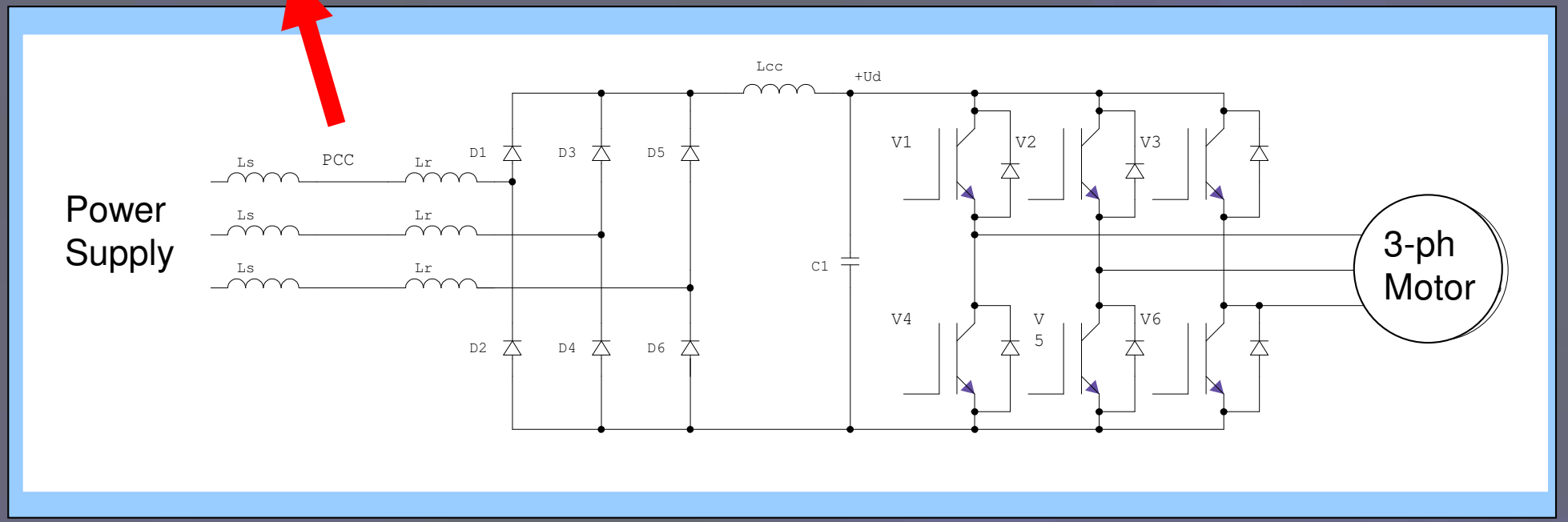
TOGETHER WE DRIVE THE FUTURE!

HARMONIC EFFECTS

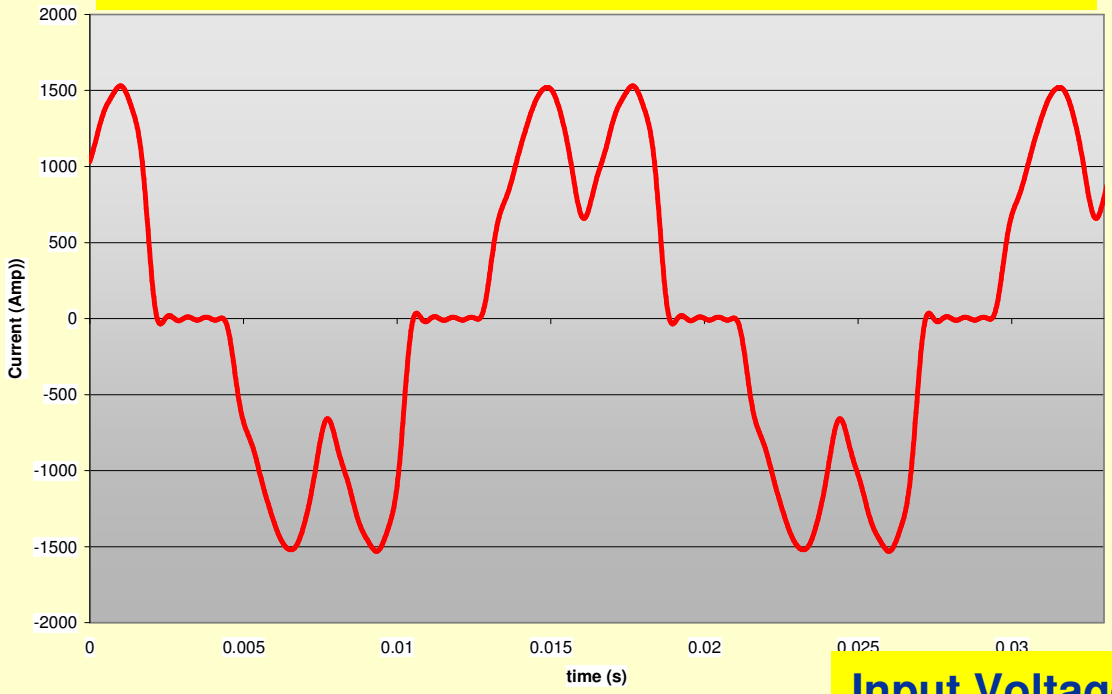
VSD Typical Input current wave form



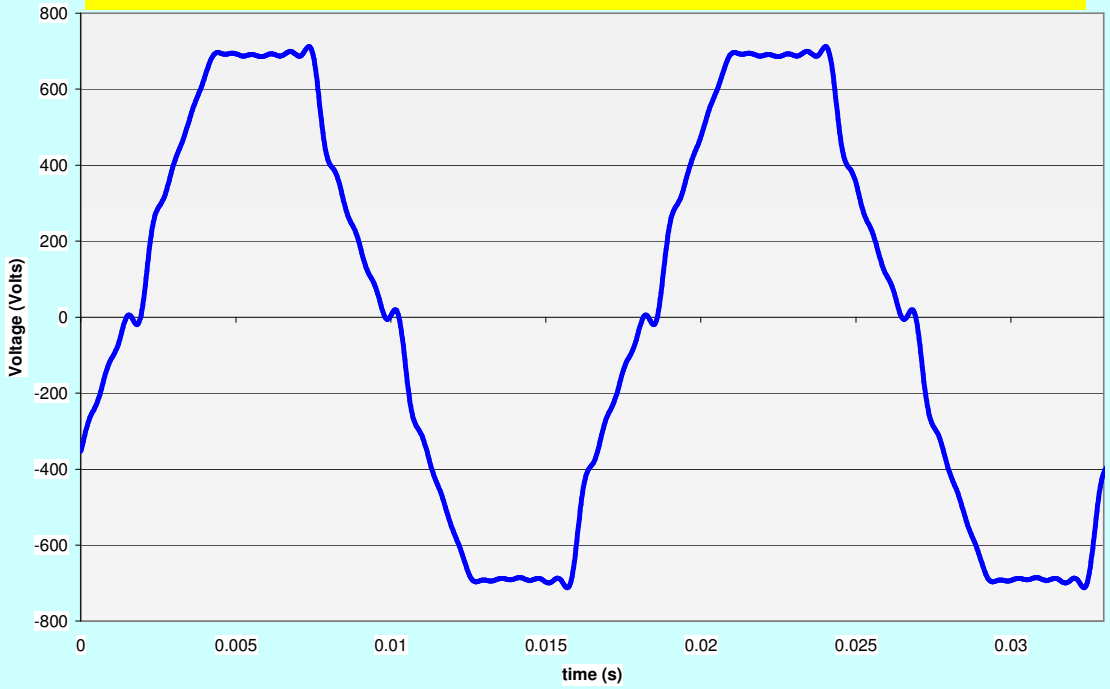
N.B. This effect is common and similar to all Voltage Source PWM VSDs



Input Current distortion resulting from a VSD



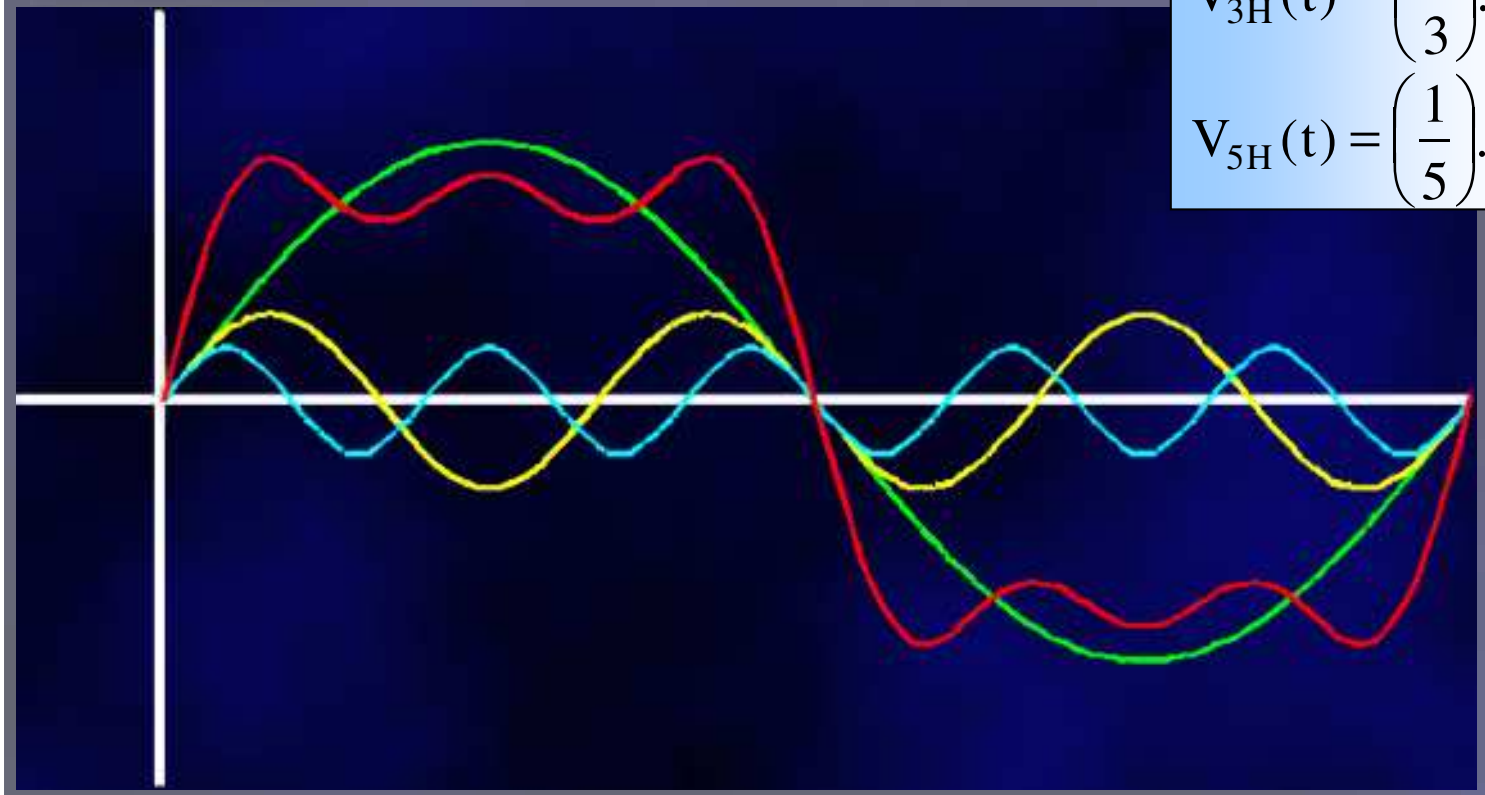
Input Voltage distortion resulting from a VSD



$$V(t) = \sqrt{2}.V_{rms}.\sin(\omega.t) +$$

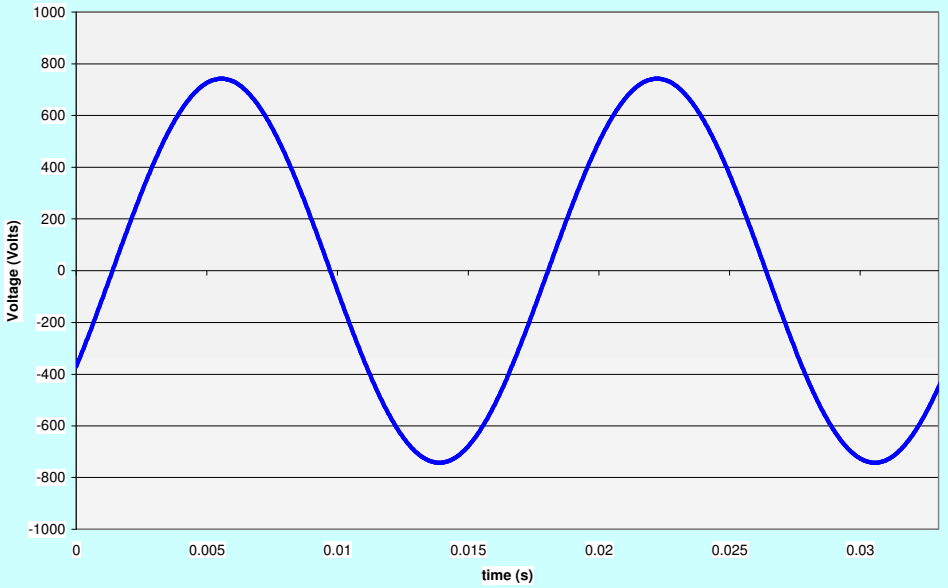
$$V_{3H}(t) = \left(\frac{1}{3}\right).\sqrt{2}.V_{rms}.\sin(3.\omega.t) +$$

$$V_{5H}(t) = \left(\frac{1}{5}\right).\sqrt{2}.V_{rms}.\sin(5.\omega.t)$$

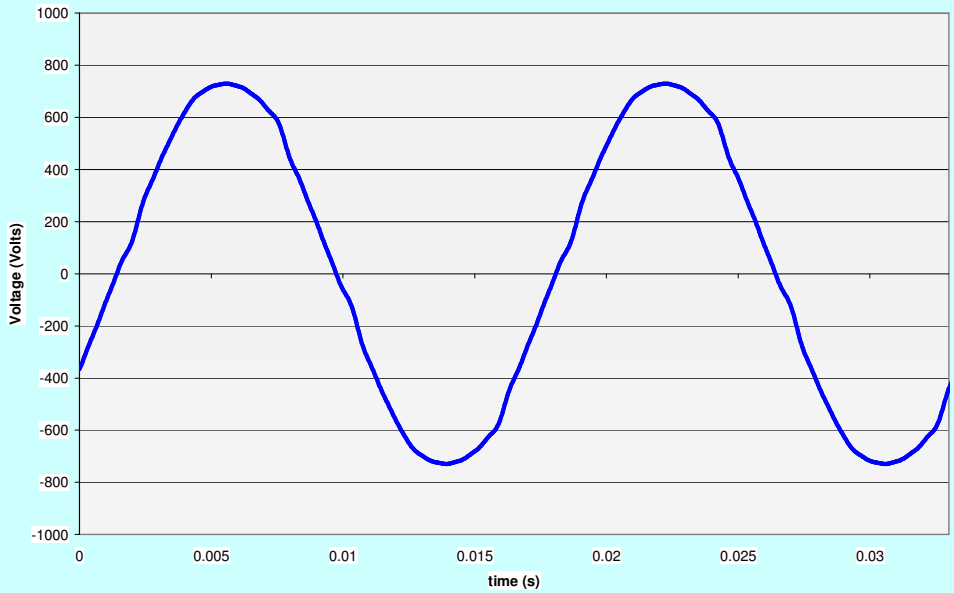


$$V_{tot}(t) = \sqrt{2}.V_{rms}.\left[\sin(\omega.t) + \frac{1}{3}.\sin(3.\omega.t) + \frac{1}{5}.\sin(5.\omega.t) + \frac{1}{7}.\sin(7.\omega.t) + \ldots\right]$$

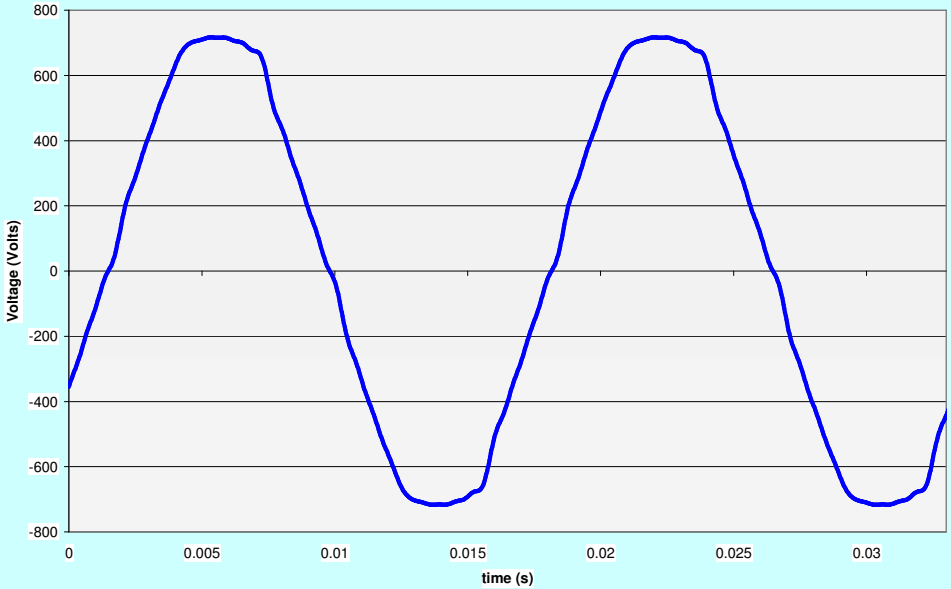
Input sine wave 0% THD



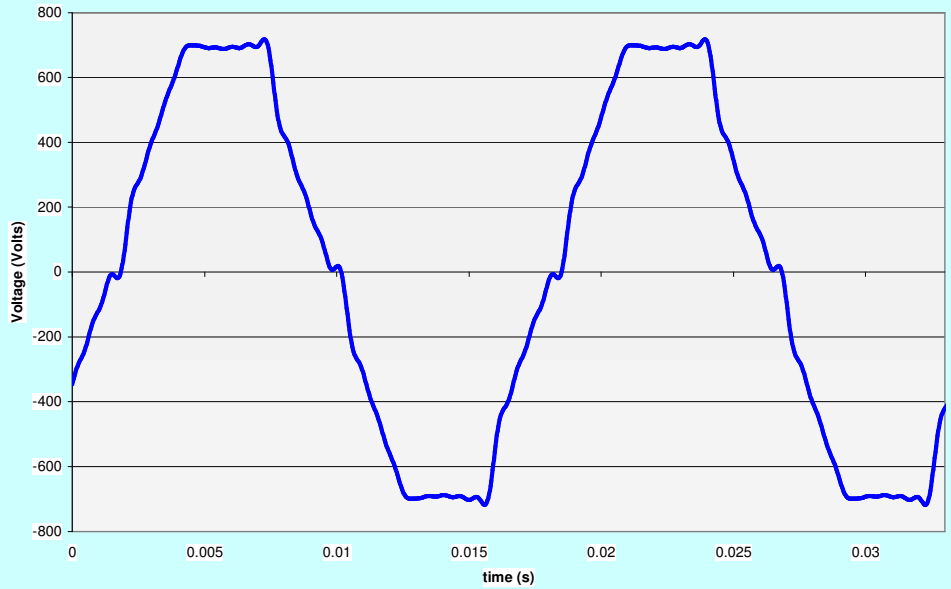
Input sine wave 4% reactor, 2.4% THD



Input sine wave 1% reactor, 3.6% THD



Input sine wave 8% THD



HARMONICS – POSSIBLE SOLUTIONS

1. Use an AC line reactor
2. VSD design with built in DC choke
3. Install harmonic filters
4. Use 12 pulse VSD
5. Use regenerative / active front end VSD design

HARMONICS – POSSIBLE SOLUTIONS SUMMARY

VSD Type	Typical I THD	Cost
Standard 6 pulse	101%	100%
6 pulse with 2% reactor	56%	103%
6 pulse with 4% reactor	39%	105%
12 pulse	12%	200%
Regenerative	3%	250%

HARMONICS – THE WEG SOLUTION:

1. All 525V WEG VSDs >32A have a built in DC choke.
2. In all other cases, or for greater harmonic reduction use a line reactor of 2 – 4% rating. In most installations this is an acceptable solution.
3. For high power ≥500kW applications consider a 12 pulse VSD or active front end design if harmonics levels are a cause of concern.

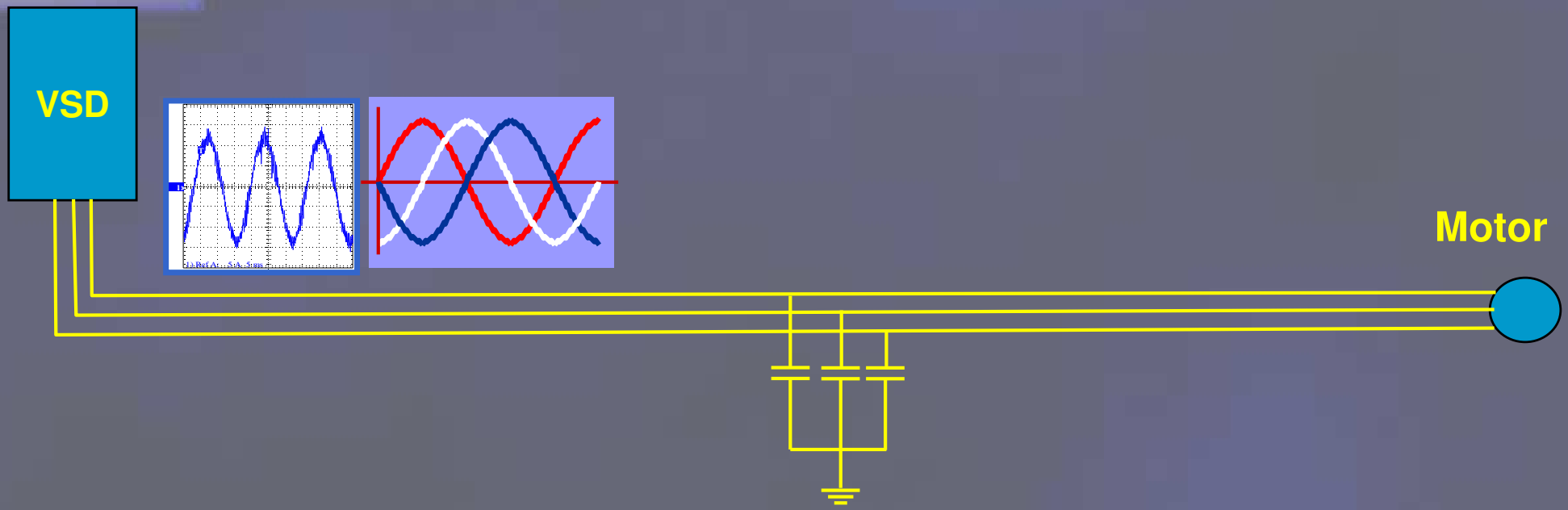
INPUT REACTORS – WHAT IS IMPORTANT TO REMEMBER:

1. The harmonic values for all reputable AC VSDs are very similar.
2. The Voltage harmonic distortion value is affected by the customer supply transformer rating and electrical network – We cannot give a value without knowing his system detail
3. Built in AC reactors have little technical value – it's mostly a marketing exercise
4. Built in DC chokes have technical value
    1. Give a similar result to a 2% AC line reactor
    2. Do not cause a volt drop (as an AC reactor does)
    3. *All the WEG 525V VSDs >32A have a built in DC choke*
5. Input reactors are also useful to reduce the effect of dips, sags, swells, transients and other line side disturbances

MAIN PROBLEMS ASSOCIATED WITH LONG CABLES BETWEEN VSD AND MOTOR

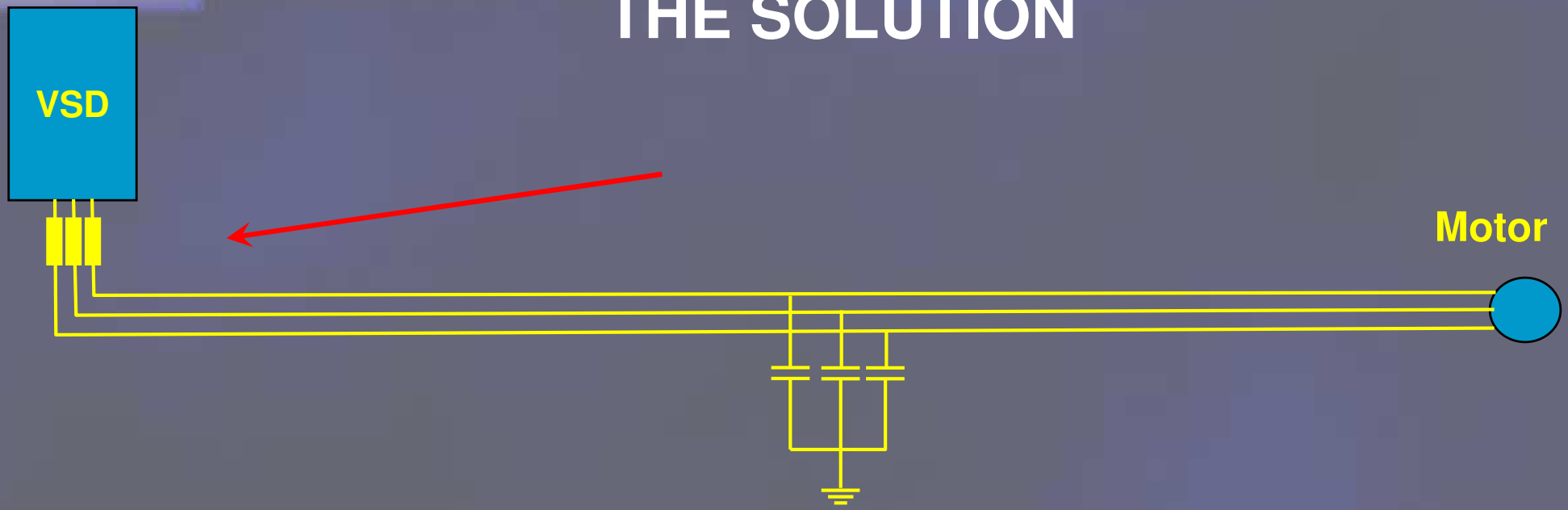
1. Capacitive leakage current
2. Voltage reflections causing high Vpeak and dv/dt values

CAPACITIVE LEAKAGE CURRENTS



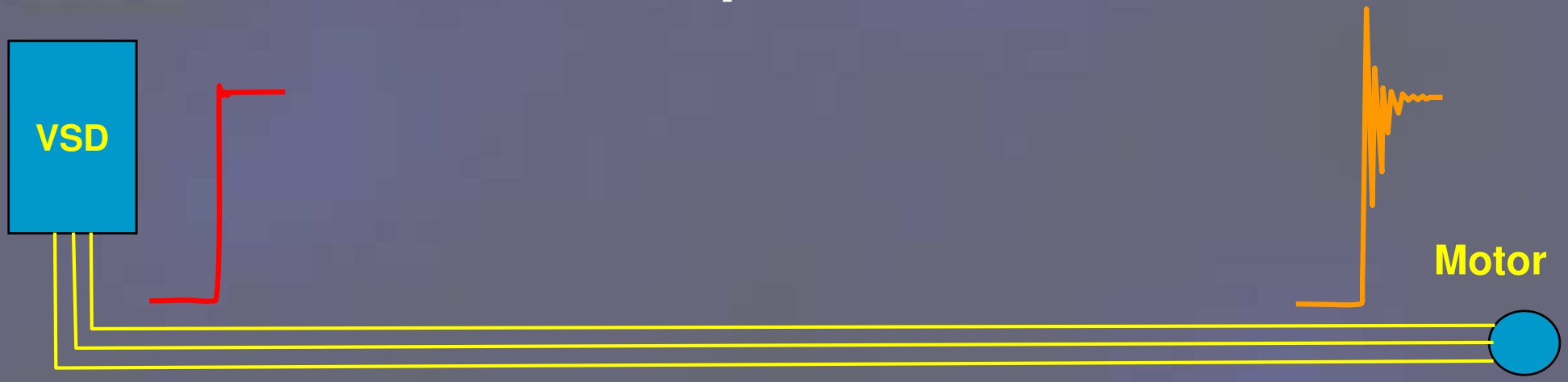
1. The VSD output is not a pure and balanced sinusoidal waveform as supplied by Eskom
2. On long cables the cable conductor and insulator properties combine to behave like a capacitor
3. The combination causes capacitive leakage current of significant values in cables > 100m
4. *This effect is common to all PWM VSDs*

CAPACITIVE LEAKAGE CURRENTS
THE SOLUTION



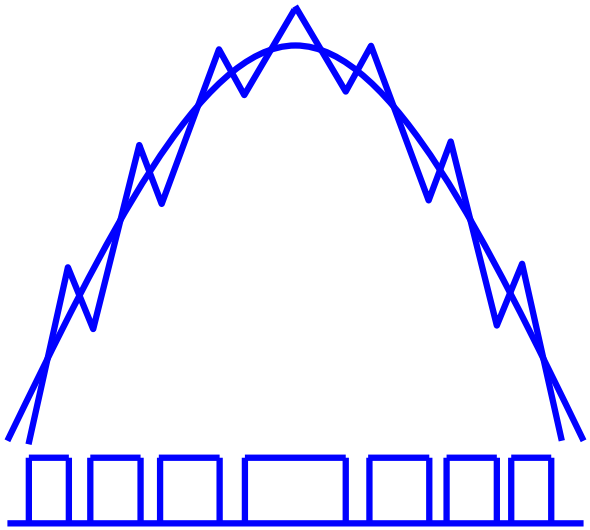
1. Compensation techniques within the VSD (This avoids nuisance VSD tripping, but does not necessarily eliminate the capacitive leakage currents)
2. Additional reactance in the VSD output circuit to counter the capacitance, i.e. an output reactor

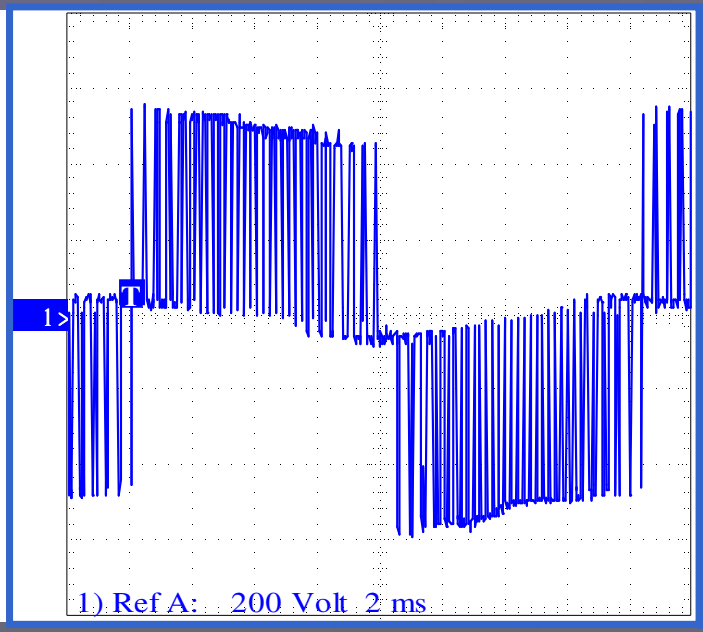
VOLTAGE REFLECTIONS CAUSING HIGH Vpeak & dv/dt

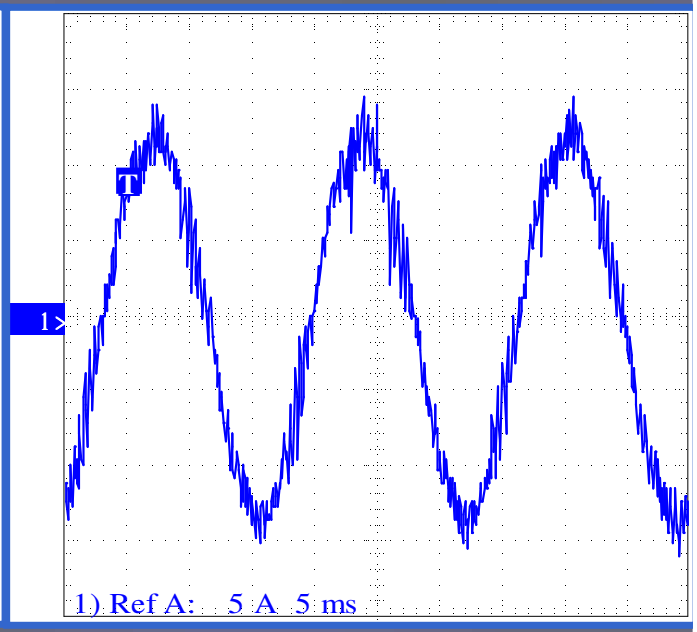


Voltage pulses from the PWM on the VSD output are reflected at the motor terminals causing voltage pulses significantly higher than the motor nominal voltage

VOLTAGE REFLECTIONS – THE REALITY



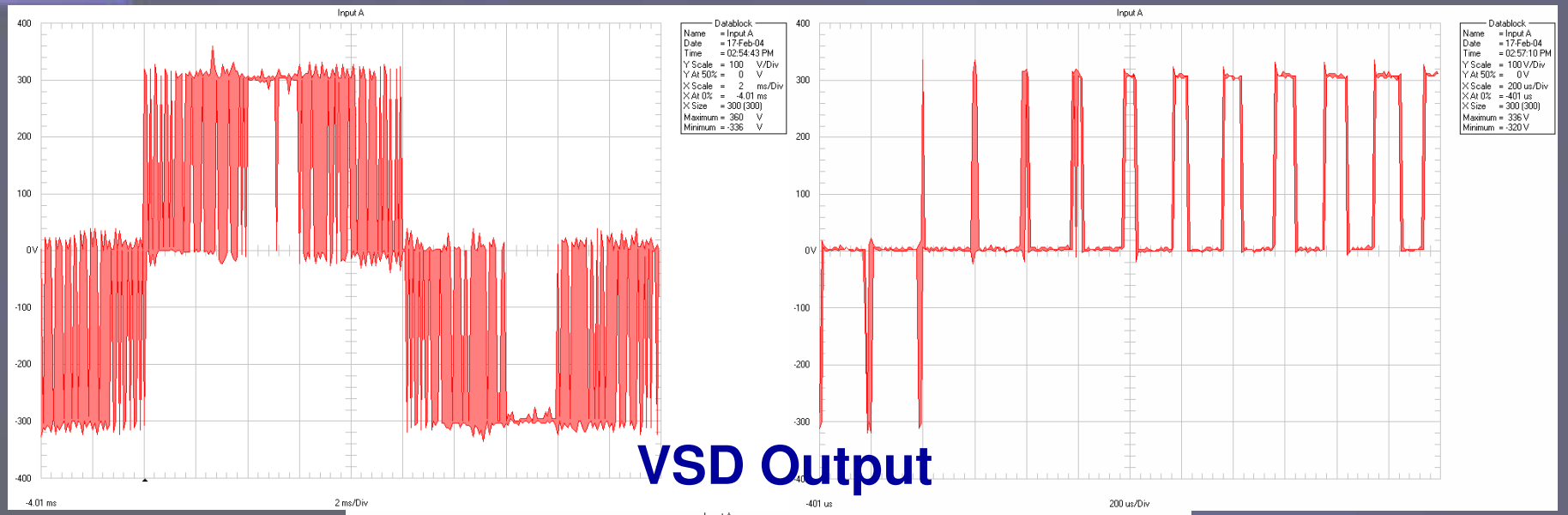




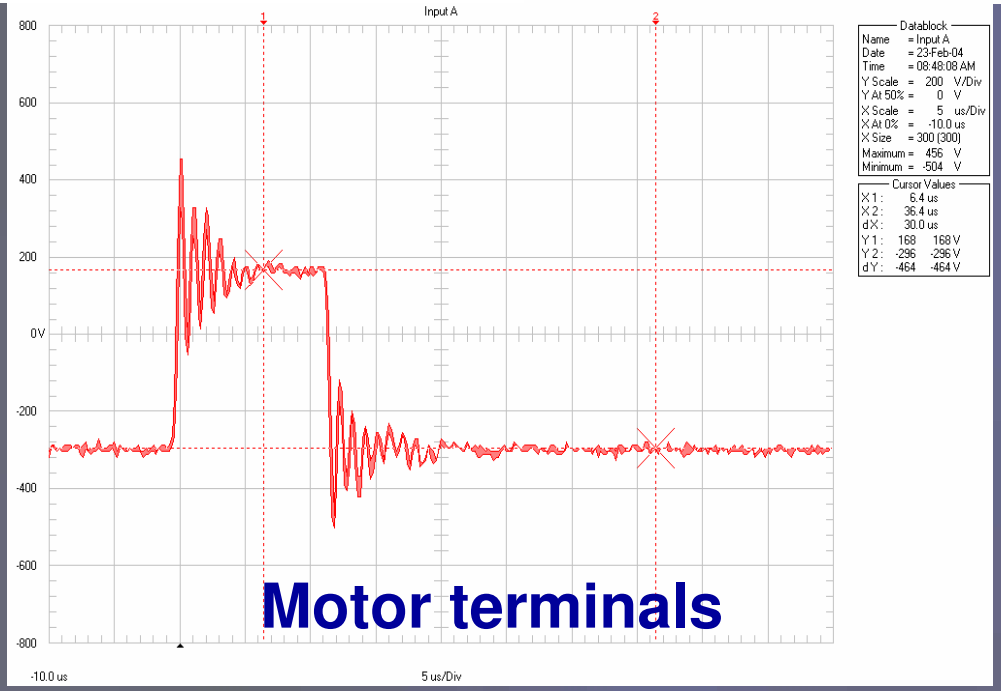
PWM theory

Actual VSD output measurement

Voltage reflection measurements

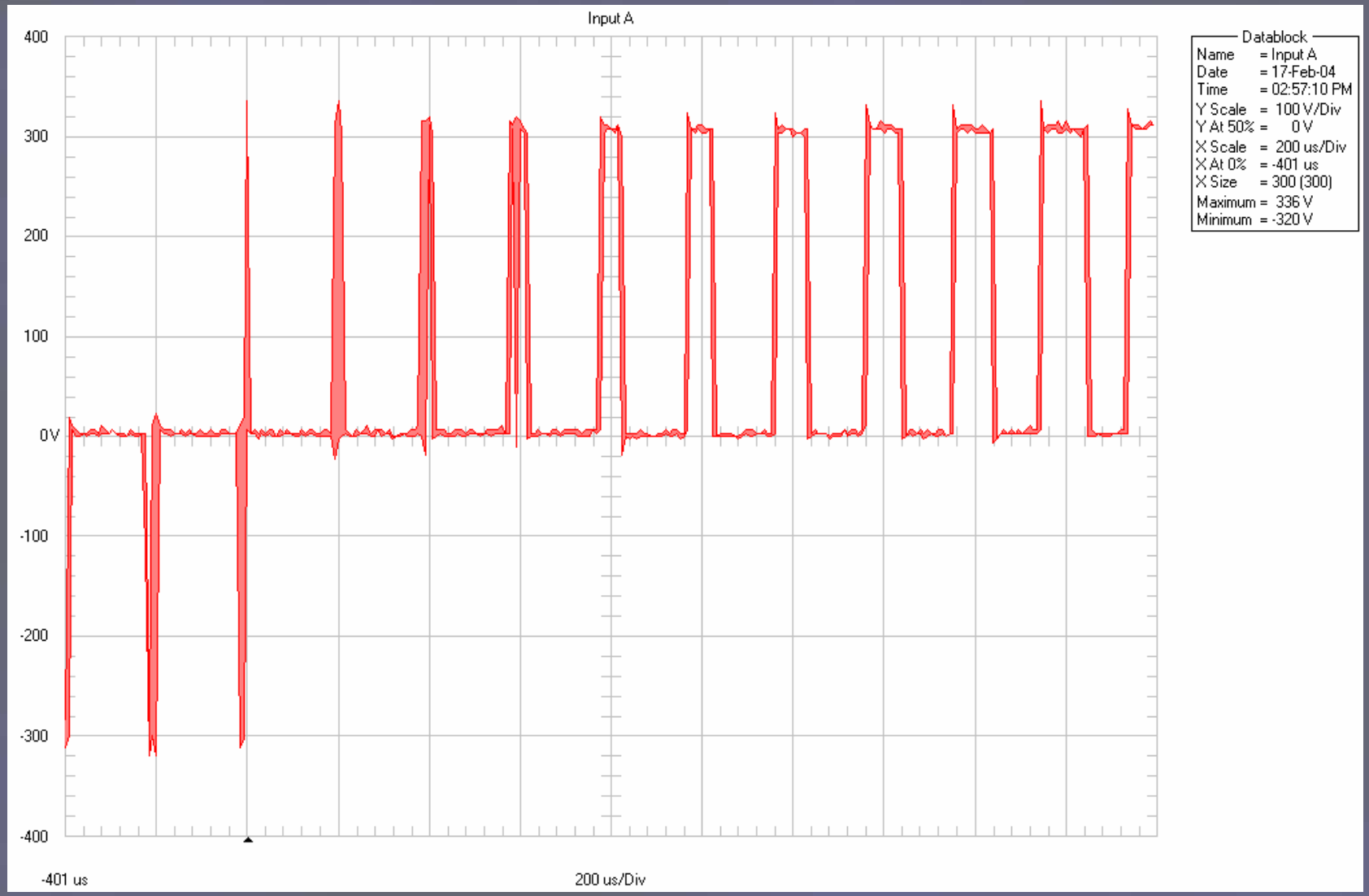


VSD Output



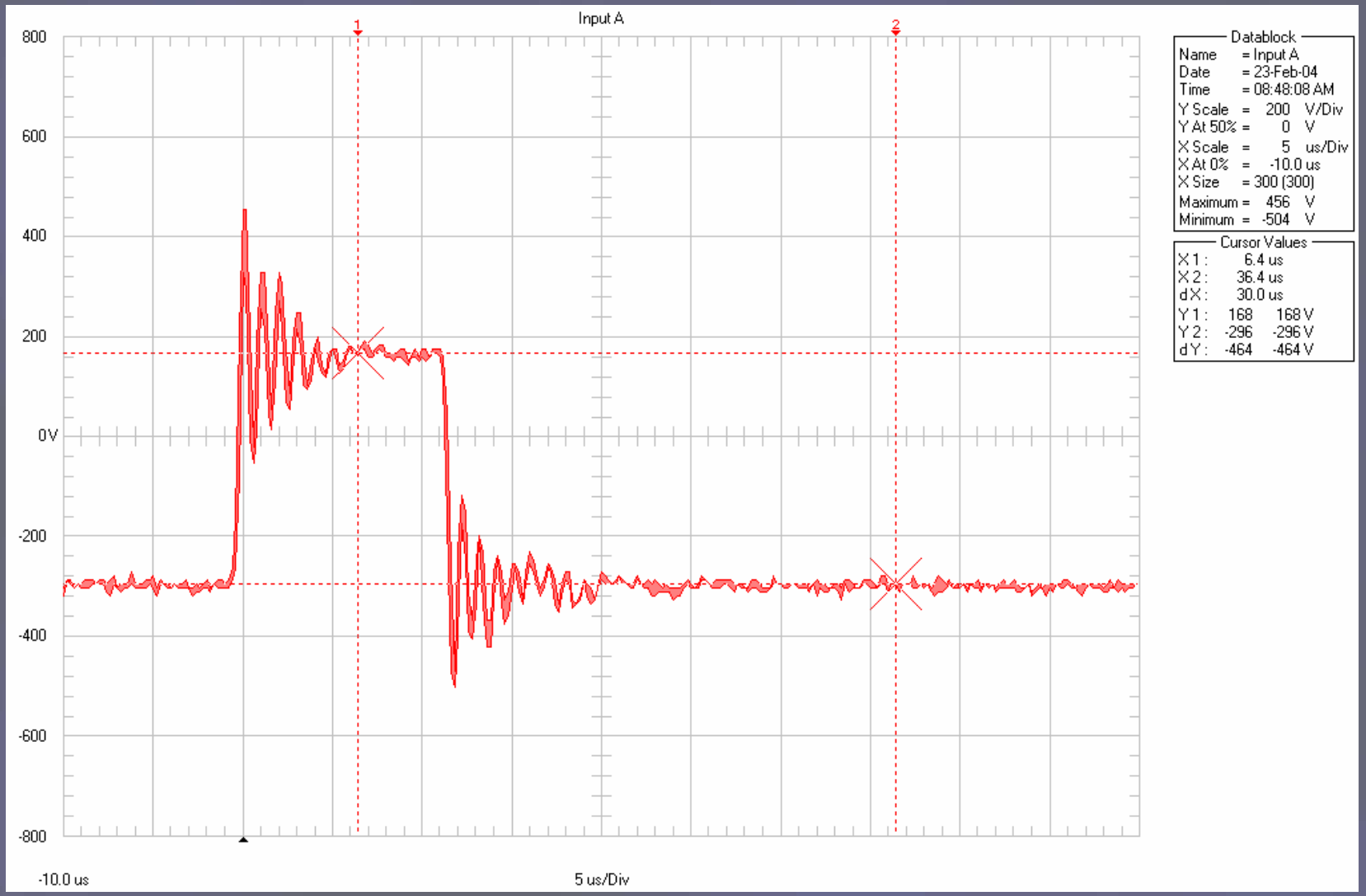
Motor terminals

VOLTAGE REFLECTIONS – Actual measurements



VSD Output

VOLTAGE REFLECTIONS – Actual measurements



Motor terminals

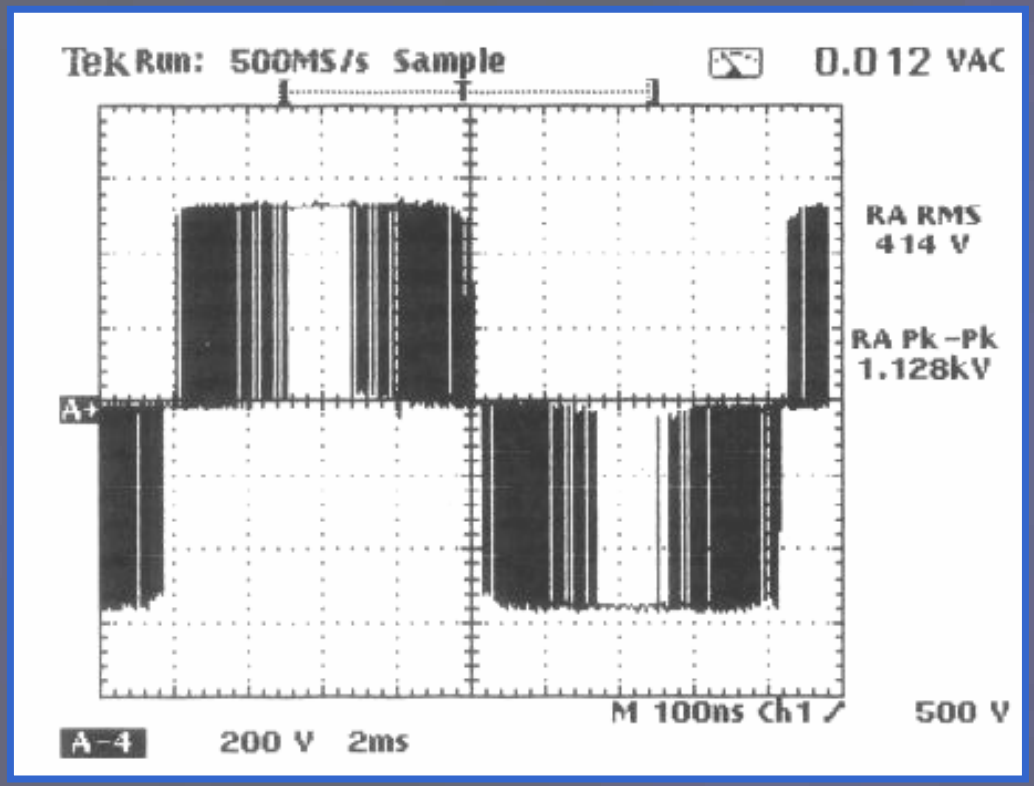
Influence of the cable length

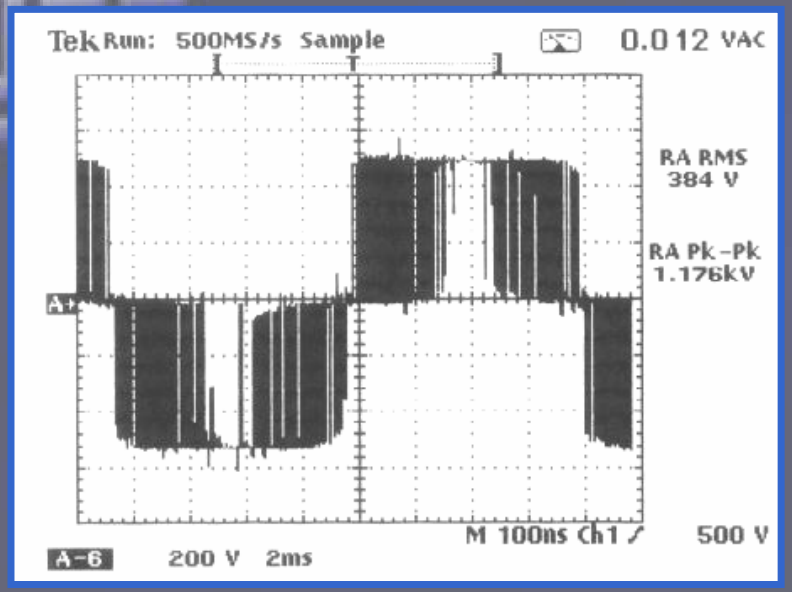
According to NEMA application guide:

- **1.5m cable** ⇒ *overshoots* beginning *(overvoltages)*
- **15m cable** ⇒ may reach 2 times $V_{DC\ Link}$
- **Over 120m** ⇒ peaks could be higher than $2V_{DC\ Link}$ (longer time)

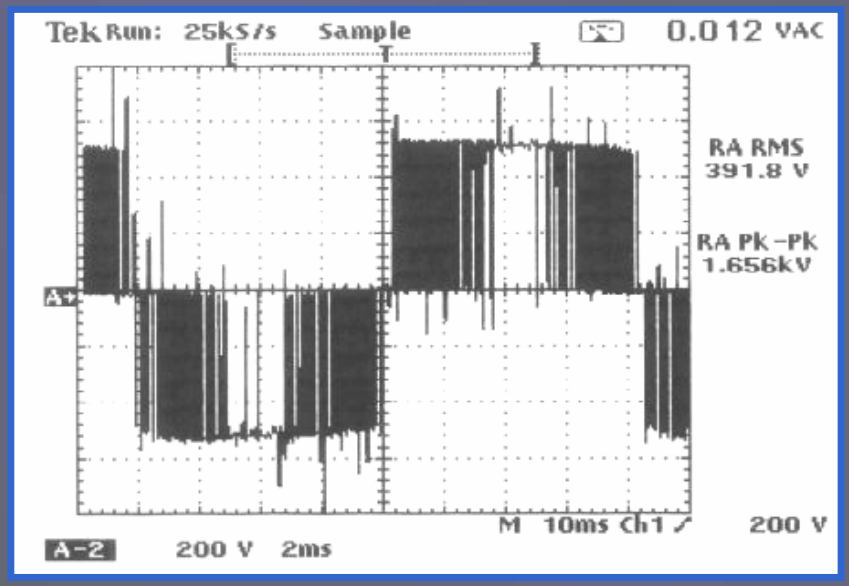
VSD + Standard Motor (7.5kW-380V- IV p)

VSD terminals without motor

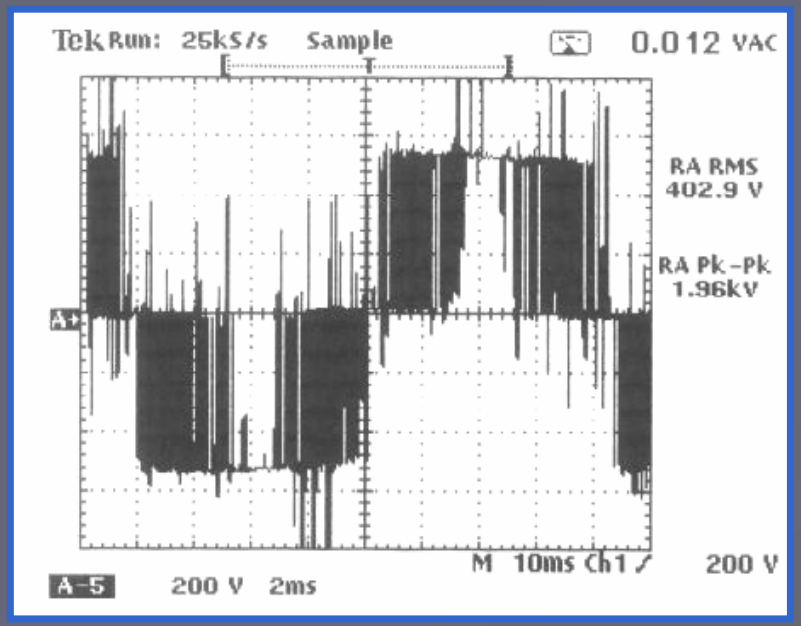




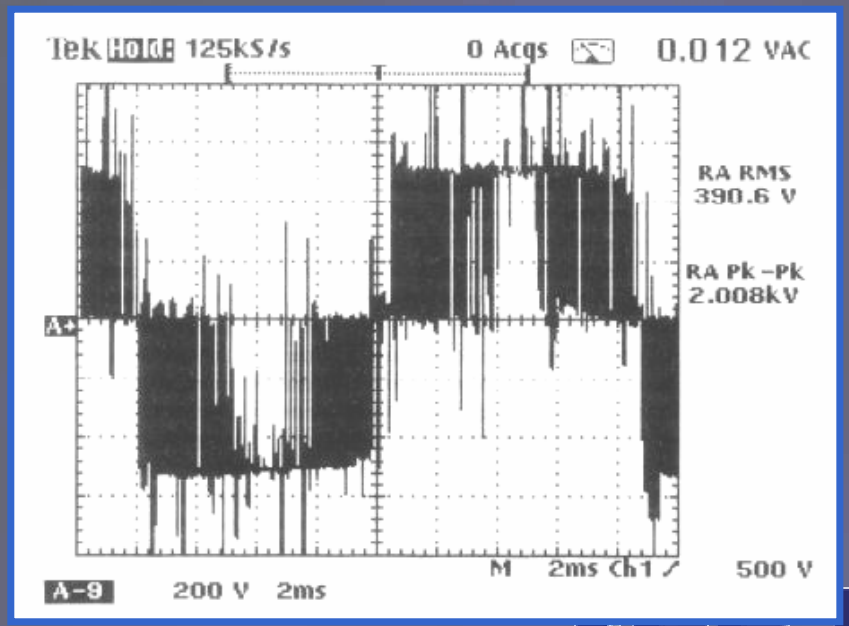
1.5 m cable



15 m cable



34 m cable



54 m cable

VOLTAGE REFLECTIONS – Actual measurements

380V supply, 65 m armoured cable, 5.5kW motor & VSD

No reactor

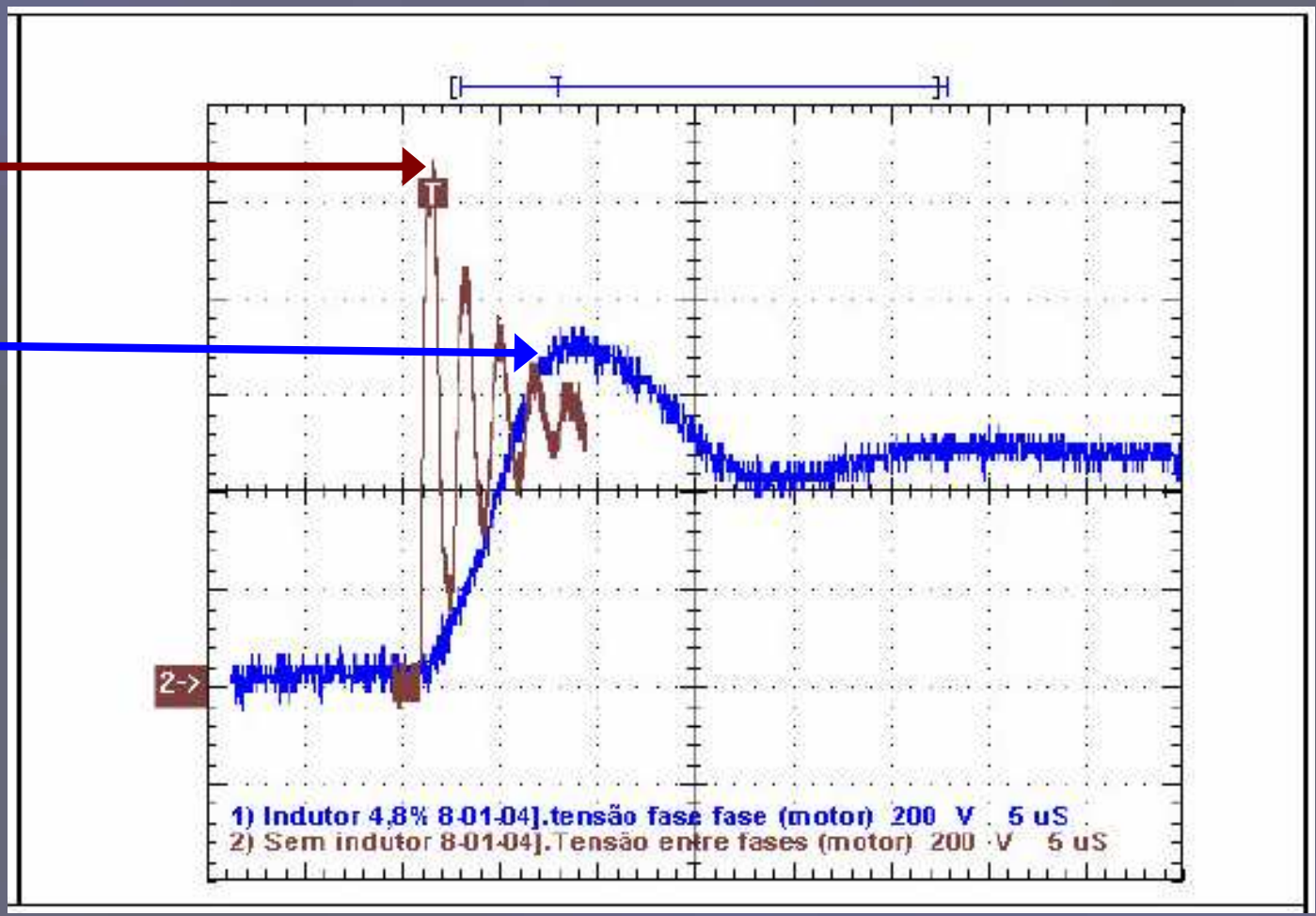
Vp = 975V

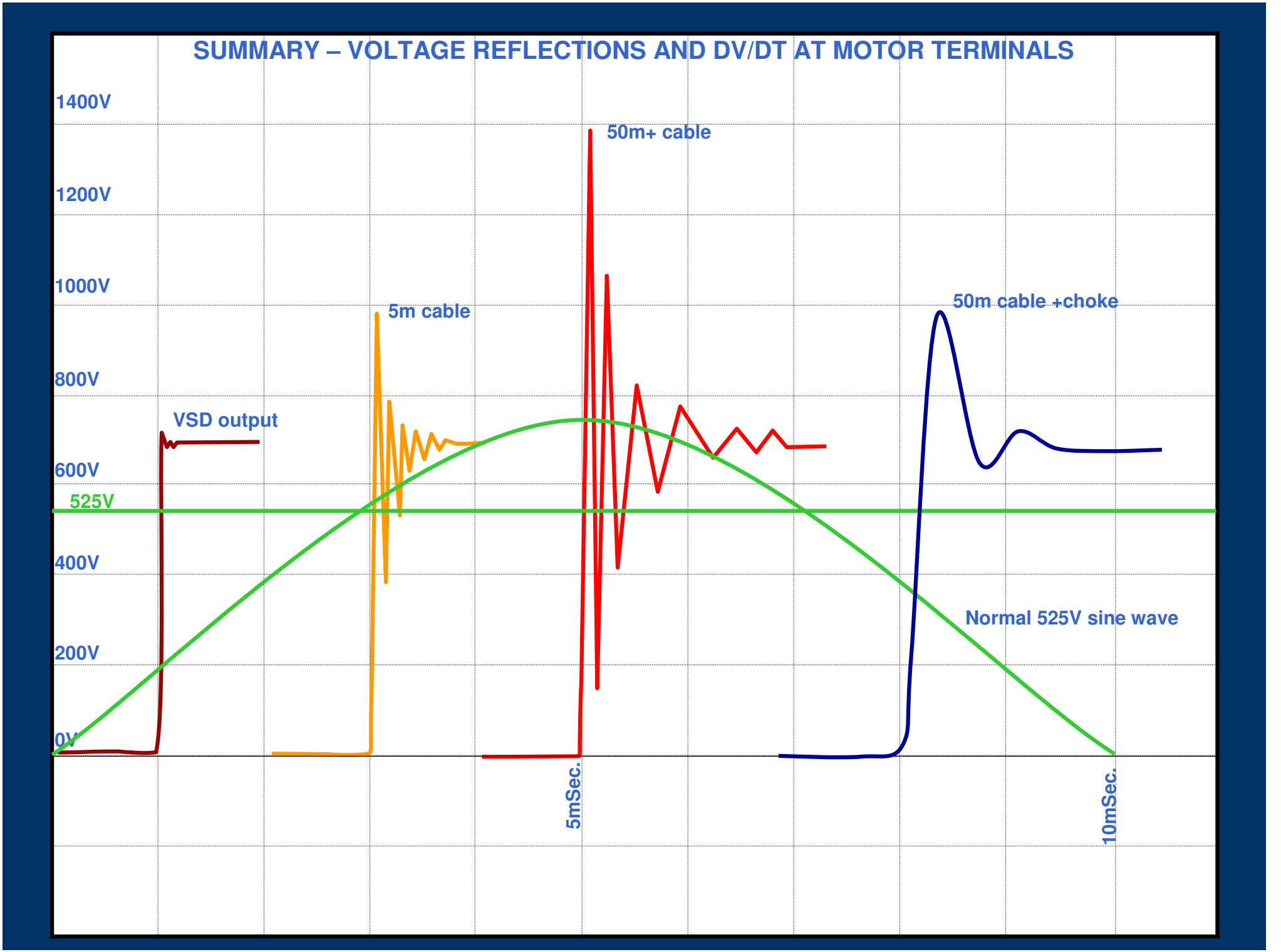
±2.6 x Vsupply

5% reactor

Vp = 667V

±1.8 x Vsupply




SUMMARY – VOLTAGE REFLECTIONS AND DV/DT AT MOTOR TERMINALS
1400V
1200V
1000V
800V
600V
525V
400V
200V
0V
50m+ cable
5m cable
50m cable +choke
VSD output
Normal 525V sine wave
5mSec.
10mSec.

VOLTAGE REFLECTIONS & DV/DT – THE WEG SOLUTION:

1. Design the VSD so that the VSD output dv/dt is low enough to minimise the Vpeak and dv/dt at the motor terminals
2. Design the motor insulation to withstand Vpeak and dv/dt values in excess of that which the VSD will cause –
    1. Generation 2 wire – Vp ≤ 1430V & dv/dt ≤ 5200 V/µsec.
    2. Generation 3 wire – Vp ≤ 1780V & dv/dt ≤ 6500 V/µsec.
3. Output chokes are always advisable and beneficial to use, but not always mandatory
    1. Counteract capacitive leakage currents
    2. Reduce Vpeak
    3. Reduce dv/dt
    4. Simple and cost effective to use

END