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

APPLICATION GUIDELINE #30

(Neutral Shift Voltage Stress)

Brought to you by your Motor & Drive Specialists……

Neutral shift is a phenomenon that occurs with both voltage source, and current source drives. Neutral shift causes a motor's neutral voltage potential to shift with respect to the system neutral. Although not damaging to a 230V, 460V or 575V motors, it will cause premature failure of 2,300V and 4,160V motors and thus should be alleviated on applications using MV drives.

Figure 1 shows a typical construction of a voltage source PWM Variable Frequency Drive. The purpose of the drive is to convert AC to DC then DC back to variable frequency, variable voltage AC. The converter section produces a positive and a negative DC Bus. The DC is converted to three phase AC by switching the transistors in the inverter section.

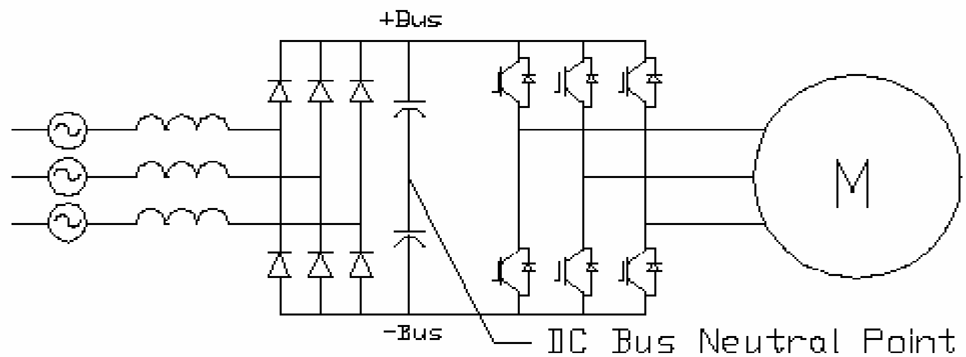

Fig. 1 Simplified schematic of a typical PWM drive showing "DC Bus Neutral Point"

There are 8 possible switching states that transistors use to produce a magnetic field at 0˚, 60˚, 120˚, 180˚, 240˚ & 300˚ they are referred to as K1 to K6 respectively. In addition there are 2 combinations (K0 & K7) which produce no output voltage. States K1 through K6 are active and cause current to flow through the motor windings. During states K0 and K7 the line to line voltage will be zero because all three phases are configured the same.

For the purposes of this discussion, it is important to understand that in states K1 through K6 there are either 2 transistors closed on the positive bus and one closed on the negative bus or vice versa. During states K0 and K7 all three transistors are closed on the positive bus and all three open on the negative bus or vice versa.

During switching state K1 for example, one switch is closed on the positive bus and two closed on the negative bus. The equivalent circuit for switching states K1, K3 and K5 is shown here on the right in figure 2. Note that the neutral of the motor is more negative than the neutral of the DC bus. This means that the neutral of the motor is shifted 0.5 P.U. times 0.33 P.U. = .1667 or 1/6th of the DC bus voltage from neutral in the negative direction.

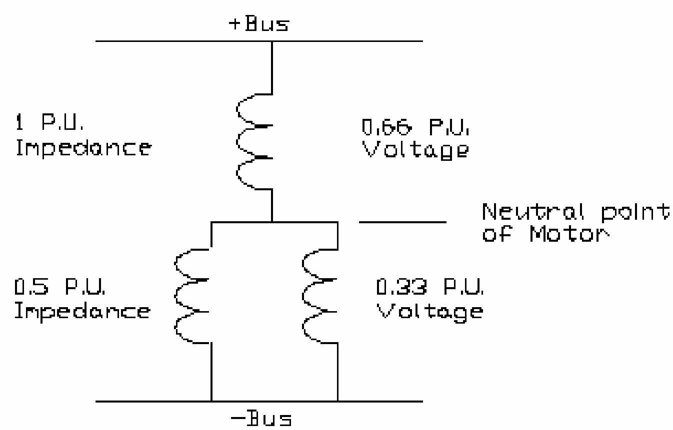

Figure 2: Switching States K1, K3 and K5

Switching states K2, K4 and K6 produces the opposite neutral shift effect as shown in figure 3.
The neutral of the motor is now more positive than the neutral of the DC bus. This means that the neutral of the motor is shifted 0.5 P.U. times 0.33 P.U. = .1667 or 1/6th of the DC bus voltage from neutral in the positive direction.

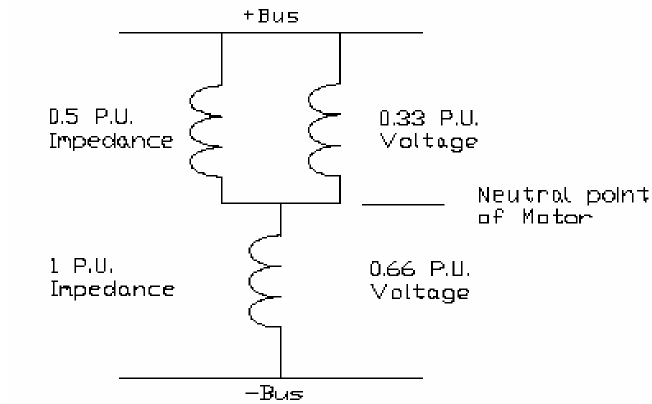

Figure 3: Switching States K2, K4 and K6

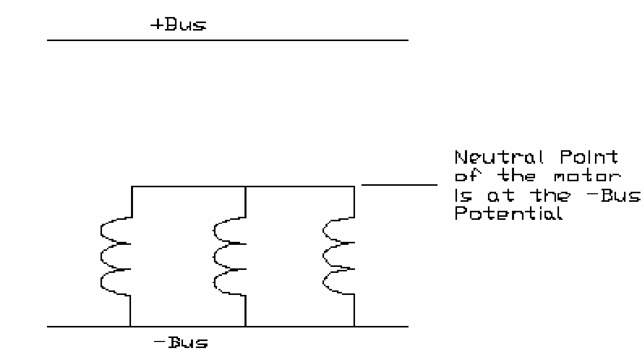

Figure 4: Switching State K0

Switching state K0 produces an equivalent circuit as shown in figure 4. The neutral of the motor is now at the same potential as the negative DC bus. This means that the neutral of the motor is shifted 0.5 P.U. from neutral in the negative direction.

Switching state K7 produces an equivalent circuit as shown in figure 7.

The neutral of the motor is now at the same potential as the positive DC bus. This means that the neutral of the motor is shifted 0.5 P.U. from neutral in the positive direction.

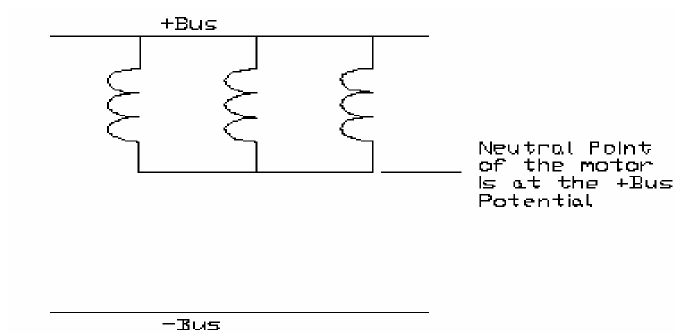

Figure 5: Switching State K7

The DC bus voltage is approximately √2 x VAC RMS. With neutral point shifting, the instantaneous peak voltage from phase to ground can be the peak phase to ground voltage plus the neutral shift voltage where:
Peak phase to ground voltage = ($\sqrt{2} \times V_{AC\ RMS} \div \sqrt{3}$) = 0.816 $V_{AC\ RMS}$
Maximum neutral shift voltage = ($\sqrt{2} \times V_{AC\ RMS} \div 2$) = 0.707 $V_{AC\ RMS}$
0.816 + 0.707 $V_{AC\ RMS}$ = **1.52** x $V_{AC\ RMS}$.

If a motor is operated by sine wave power, the phase to neutral voltage is: $V_{AC\ RMS} \div \sqrt{3}$. The peak voltage is ($\sqrt{2} \times V_{AC\ RMS} \div \sqrt{3}$) = **.816** x $V_{AC\ RMS}$.

Motors powered by drives therefore, can subject the motor phase to ground insulation to peaks of 1.86 times the voltage stress phase to ground that the insulation would normally be subjected to. (1.52 ÷ .816 = 1.86 times) The phase to ground (slot liner) insulation in Toshiba low voltage motors is capable of withstanding this additional voltage stress.

Note that on medium voltage motors, especially 4,160V motors, the additional phase to neutral stress cannot be accommodated by standard motor insulation systems. It has also been demonstrated in actual field applications that 4160V motors powered by variable frequency drives without an input isolation transformer can develop problems related to partial discharge in the RTDs.

NEMA MG1 refers to the neutral shift phenomenon in section 31.40.4.4 'Definite-Purpose Inverter-fed motors'. It reads as follows: " When inverters are applied to motors, the motor windings can be exposed to higher than normal voltages due to the neutral shift effect. Neutral shift is the voltage difference between the source neutral and the motor neutral. Its magnitude is a function of the total system design and in the case of some types of current source inverters can be as high as 2.3 per unit, resulting in motor line to ground voltages of up to 3.3 per unit, or 3.3 times the crest of the nominal sinusoidal line to ground voltage. In the case of a typical voltage source inverter, the magnitude of the line to ground voltage can be as high as $\sqrt{3}$ times the crest of the nominal sinusoidal line to ground voltage. The magnitude of the neutral voltage can be reduced if the inverter is connected to an ungrounded power source or, if this is not possible, by isolating it from the source ground by using an isolation transformer, by using separate reactors in both the positive and the negative direct current link, or by connecting the motor neutral to the ground through a relatively low impedance. Proper selection of the method to reduce motor line to ground voltage should be coordinated with the system designer."

Conclusions

Neutral point shift can be caused by conventional drive topologies which can cause excessive stress on motor phase to ground insulation. Although this is not normally a problem with low voltage motors, it can be a real issue with medium voltage motor / drive systems.

An input isolation transformer should be used with medium voltage drives unless a specially designed motor (6.6 KV insulation system) is used or the drive has a topology that does not produce excessive neutral to ground stresses. Note that an input isolation transformer can also be used to create a 12, 18 or 24 pulse drive converter section, which dramatically reduces harmonic impact on the electrical system. The input transformer basically shifts the voltage stress issue from the motor winding to the transformer windings. The transformers windings are more immune to the neutral shift issues because unlike a motor's stator slot windings and it's close proximity to ground (windings are tightly wound inside narrow stator slots), a transformers impedance to ground is higher and therefore less prone to the neutral shift phenomenon.

Toshiba's T300MV drive addresses the above issue with:

1) A 14 winding input isolation transformer equivalent to a 24 pulse drive converter section
2) Neutral point clamping diodes
3) Firing algorithm which avoids firing patterns that create neutral shift phenomenon.