

## Three Phase Voltage Variation & Unbalance - Part 2

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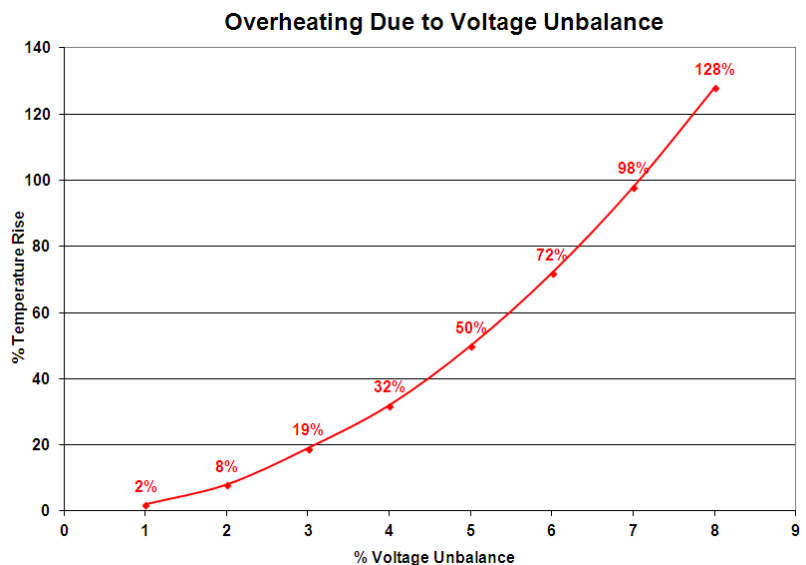
As we saw last month, three phase voltage variation can have a significant effect on several AC motor characteristics. If that variation is large it can also reduce motor life. That said, voltage unbalance can be an even bigger problem and is one of the major causes of premature motor failure. A relatively small unbalance of just 2% can reduce expected insulation life by one half.

Unlike voltage variation, unbalanced voltage occurs when the three phases are not at the same voltage. An example of perfectly balanced phase voltage is L1/L2 = 460V, L2/L3 = 460V and L3/L1 = 460V. The average voltage is 460V. An example of unbalanced phase voltage is L1/L2 = 462V, L2/L3 = 468V and L3/L1 = 450V. Again, the average voltage is 460V but the unbalance is 2.2%. Voltage unbalance is calculated by the equation below.

$$\% \text{ Unbalance} = 100 \times (\text{Maximum Voltage Deviation from Average} / \text{Average Voltage})$$

In the example above the maximum voltage deviation from the average voltage is 10V (460-450). NEMA motors are designed to tolerate no more than 1% of voltage unbalance.

Why does voltage unbalance shorten motor life? Each 1% of voltage unbalance can result in 6 to 10% of current unbalance. The phase with the lowest voltage will exhibit the highest current which increases the operating temperature of the winding serviced by that phase. It will also increase the overall operating temperature of the motor. Figure 1 shows the increase in operating temperature versus voltage unbalance. As shown, an unbalance of just 3% can increase operating temperature by almost 20%.

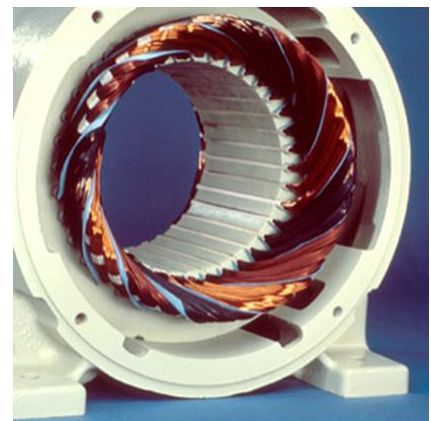


At 5% unbalance, operating temperature will increase by 50%.

Motor operating temperature is the sum of the ambient temperature surrounding the motor and the temperature rise due to the motor load. The temperature rise is usually measured via the resistance method. Each insulation class has a specific temperature rating. For example, Class F is rated at 155°C (311°F). The temperature rating is the maximum operating temperature allowed in order to meet an average insulation life of 20,000 hours. Now, 10° C of that rating is reserved for something called the "hot spot allowance". The resistance method measures the average temperature rise in the stator windings but there are places, such as the stator slots, where the temperature can be higher than the average measurement. The hot spot allowance is reserved to protect these areas. This reduces the actual operating temperature (ambient plus measured average) to 145°C. For each 10°C over 145°C, insulation life is reduced by one half. For each 10°C below 145°C, insulation life doubles.

Suppose we have a motor with Class F insulation operating at an ambient temperature of 40°C. The measured temperature rise at full load is 90°C. Therefore the operating temperature is 130°C. The expected insulation life would be about 50,000 hours or about 2.5 times the life at 145°C. But, what happens if the phase voltage becomes unbalanced? At 3% unbalance the operating temperature increases by 19% (155°C) and insulation life is reduced by 50%.

Figure 2 (courtesy of EASA) shows the windings of a motor that failed due to high voltage unbalance. You may have seen windings that failed due to "single phasing". When a motor loses one phase, the other two phases have to carry the entire load. The result is that two sets of phase windings burn up and the one that lost power is unharmed. In the case of unbalance, the winding with the highest current fails and, usually, the other two are still functional. In Figure 2 we see that one of phases has failed, one is normal and the third is beginning to show the effect of higher temperature. Note to self: measuring voltage unbalance and fixing its cause is much less costly than having it diagnosed in a motor shop! See my July 2008 Pumps & Systems column for instructions on diagnosing the source and cause of unbalanced voltage.



Although it is always best to correct voltage unbalance, there are a couple of

"fudge factors" that can allow operation in unbalanced applications. For example, if the leg with the highest current is under the nameplate FLA (full load amperage) it will operate safely. If it is above nameplate FLA but still within the service factor (SF) it may still operate safely. Also, as a rule of thumb, if the high current leg is less than 10% higher than the average current it will probably operate safely. A less desirable alternative is to derate the motor's nameplate horsepower. NEMA suggests derating horsepower to 75% of nameplate at an unbalance of 5%. At 4% unbalance it is derated to 82%, at 3% it is derated to 88% and at 2% it is derated to 95%.

In addition to reduced insulation life, unbalanced voltage can also increase your electrical costs by reducing motor efficiency. At 1% unbalance, efficiency remains at the nameplate nominal efficiency. But at 3% unbalance, actual motor efficiency can be reduced by two percentage points.

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