This App/Upgrade note applies to AC drives

The Input and Output Current and Power Required for an AC Drive

Often the question arises as to why manuals, catalogs and rating tags often specify the input current of a drive to be lower than the output current rating. Also what current and KVA power source is needed to supply it?

AC drives powering induction motors:

Induction motors draw current that lags the applied voltage. This current can be thought of as being the sum of two currents: a portion in phase with the voltage, that accounts for all the mechanical power that the motor produces, and a portion that lags the voltage by 90^o that maintains the magnetization in the motor. The in phase, or so-called torque producing current has a perunit[1] magnitude, relative to the total current, equal to the power factor rating of the motor. Typical motors have a power factor value between 0.8 and 0.95. Meanwhile the magnetizing current will usually be between 0.31 and 0.60 perunit of the total current[2]. Guided by the switching of the drive's output power transistors, the magnetizing current oscillates between the DC bus cap bank in the drive and the motor, producing no real power except some resistive heating losses. Because of this, very little current is needed from the power system feeding the drive to sustain the magnetizing current. The torque producing current, however, times the voltage is creating real mechanical power in the motor. Neglecting harmonic currents produced by the drive's input rectifier, if the output and input voltage of a drive would be the same, it would be expected that the drive's input current would be approximately equal to the torque producing portion of the motor current only. Nevertheless, if the output voltage is lower than the input voltage then the input current will be less.

Except for relatively small losses in the drive all the power that is delivered to a drive is transferred to the motor – this allows the input current to be calculated for any operating speed of the motor. To complicate to problem a bit more, however, because the AC line is being rectified by a full wave diode bridge, the current into the drive is not sinusoidal – it contains many harmonics. These harmonic currents, like the magnetizing current in the motor, cause no real transfer of power except for causing some small additional resistive losses. For a typical drive, all the harmonic current, in total, may be on the order of 35% of the total current going to the drive. This means that the total RMS current will be approximately 1.06 PU higher than if the harmonics would not be present[3].

Given this harmonic RMS factor, knowing the rated power and efficiency of the motor, and the efficiency of the drive, the required drive input current can be calculated for the motor running a rated speed:

$$I_{Line} := \frac{P_{motor} \cdot H_{rms}}{\sqrt{3} \cdot V_{LtoL} \cdot Eff_{drive} \cdot Eff_{motor}}$$

Where P_{motor} is the rated motor power in watts (HP•746), H_{rms} is the harmonic RMS factor (e.g. 1.06), V_{LtoL} is the line to line voltage, Eff_{drive} is the drive efficiency (e.g. .99) and Eff_{motor} is the motor efficiency (e.g. .95).

If the rated motor current and power factor are known, the same answer can be found from:

$$I_{Line} := \frac{I_{motor} \cdot V_{motor} \cdot PF \cdot Eff_{drive} \cdot H_{rms}}{V_{LtoL}}$$

I_{motor} is the rated motor current, V_{motor} is the rated motor voltage (e.g. 460 Vac), and PF is the motor power factor (e.g. .89).

A typical example would be for a 50 HP USEM motor running at full speed:

P_{motor} = 50•746 = 37300 W, I_{motor} = 57A, V_{motor} = 460 Vac, Eff_{motor} = .95, PF = .88, Effdrive = .99, V_{LtoL} = 480 Vac,

From each of the above equation the value of line current would be:

$$\frac{37300 \cdot 1.06}{\sqrt{3} \cdot 480 \cdot .99 \cdot .95} = 50.565 \quad A_{rms}$$

$$\frac{56 \cdot 460 \cdot .89 \cdot .99 \cdot 1.06}{480} = 50.123 \quad A_{rms}$$

For the above example the **RMS line current is about 88%** of the rated motor current.

As mentioned previously, if the motor speed is less than full rated speed the drive input current will be less, even if the motor is producing rated torque because the mechanical power output is less. Because the losses in the motor (slip and resistive losses) do not change much with a change in speed, the equation for the required drive input current for a motor running at less than rated speed becomes more complicated. It is:

$$I_{Line} := \frac{P_{motor} \cdot H_{rms}}{\sqrt{3} \cdot V_{LtoL} \cdot Eff_{drive}} \cdot \left(\frac{Speed}{Speed_{rated}} + \frac{1 - Eff_{motor}}{Eff_{motor}} \right)$$

In the previous example with the 50 HP motor, if the motor speed had only been 10% of rated, the above equation gives a result of I_{Line} = 7.3A.

Power supply:

The total power to a drive, $\mathbf{P_{Total}}$, is the VA rating that is needed for sizing a supply transformer, for example. It is a larger number than the so-called real power that the drive actually consumes. The real power, however, is what utility suppliers presently measure to assess power usage costs**.** The real power, $\mathbf{P_{Real}}$, does not take into account the harmonic currents so it is smaller by the previously mentioned harmonic RMS factor, $\mathbf{H_{rms}}$. The actual power consumed by the drive is:

$$P_{Real} := \frac{\sqrt{3} \cdot I_{Line} \cdot V_{LtoL}}{H_{rms}}$$

Where I_{Line} is the RMS line current at rated motor speed and voltage.

Transformer sizing:

Although the harmonic currents are not measured for assessing power usage costs, they must be taken into account in sizing distribution transformers, wire sizes, and fusing. The power source needed (VA) for an AC drive will be:

$$P_{Total} := \sqrt{3} \cdot I_{Line} \cdot V_{LtoL}$$

From this equation (and one of the previous ones for line current), it can be found that for a 480 Vac power source and a 460 Vac motor a reasonable guideline for sizing a transformer is 0.9 KVA per horsepower of motor load. Because the harmonic currents cause even more heating in the transformer laminations and windings than the RMS calculation of line current, I_{Line}, would indicate, a transformer harmonic K factor rating of at least 13 is recommended.

Power Factor:

The total power factor would be: $PF_{Total} = P_{Real} / P_{Total}$, which would typically be a number such as .94 perunit. Nevertheless, the power utility suppliers do not measure this power factor. Instead the so-called displacement power factor is measured, which only considers the power as a result of the component of line current at line frequency (60 Hz). For the typical AC drive with a bridge rectifier input stage followed by a DC bus inductor, there will be some lag between the input current and the line voltage, but it is usually a value such as 5º. This would make the displacement power factor: $PF_{displacement} = \cos(\theta_{disp}) = \cos(5^o) = .996$ perunit.

[1] Perunit (abbreviated PU) – similar to percent but part of 1 (or a unit), rather than parts of 100. E.g.: **85% = .85PU**.

[2] The total current is the square root of the sum of the squares of the torque and magnetizing currents. E.g.: $\sqrt{(.6^2 + .8^2)} = 1$.

[3] The RMS current is the square root of the sum of the squares of the current at line frequency (fundamental) and the sum of the squares of all the harmonics. If the fundamental is said to have a magnitude of **1** and the harmonics have a value of **.35**, then: $I_{RMS} = \sqrt{(1^2 + .35^2)} = 1.06$.