Rightsizing Your Motor: A Simple Method

By Chuck Yung
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Contrary to popular opinion, bigger is not always better. A case in point is the electric motor. Industrial users tend to want a little extra power, “just in case.” That’s why auto makers still sell cars with 300 hp engines, when the speed limit may be under 70 miles per hour. But, like those gas-guzzlers, oversized electric motors cost more to run—sometimes a lot more. Besides wasting energy, they often trigger expensive demand charges on utility bills due to low power factor and high inrush currents.

Fortunately, it’s easy to determine how much horsepower a load requires—without expensive equipment or engineering expertise. In collecting the data, just make sure the motor is operating at maximum load. (A load that varies widely is a separate issue and often is a good candidate for a variable-frequency drive.)

How Loaded is Your Motor?

Figure 1 illustrates the essentially linear relationship between percent load and current from no-load amps up to nameplate current of the motor. Notice, though, that zero load does not equal zero current. Assuming it does will cause mistakes in determining the required horsepower, with the error inversely proportional to the load. That means that the biggest errors will occur when evaluating motors most in need of “rightsizing.”

![Figure 1. The shaded area represents the margin for error if no-load current is not measured.](image)

While the percent load a motor carries could be determined from a graph, it is easy (and more accurate) to calculate the actual load using Equation 1.

**Equation 1**

$$hp_{\text{required}} = hp_{\text{nameplate}} \times (1 - (\text{FLA - actual amps} / \text{FLA - no load amps}))$$

Where: FLA = full load amps

hp = horsepower

To obtain good input data, run the motor uncoupled at no-load (0 %) and measure the current with a clamp-on ammeter. Don’t take any shortcuts here. The “no-load” current will be higher if the motor is coupled than if it isn’t. Even though the driven equipment might not be doing work some hp is required for the motor to drive it. To avoid errors, use the uncoupled current.

Next, document the nameplate current and the current at the motor's actual load. Since an undersized motor presents other problems, the safest method is to measure the current over the entire operating cycle of the process. If the load is seasonal, record the current during peak load.
Real Life Example

It’s not hard to find oversized motors in industry. In one case, a plant had a 125 hp motor driving a fan to provide “make-up” air. The motor had a nameplate current rating of 148 amps and drew 44 amps when operating uncoupled—i.e., slightly less than a third of full-load amps (FLA). When driving its normal load, it drew 63 amps. A quick calculation using Equation 1 showed the actual load was less than 23 hp.

Equation 1

\[
\text{hp}_{\text{required}} = \text{hp}_{\text{nameplate}} \left(1 - \frac{\text{FLA} - \text{actual amps}}{\text{FLA} - \text{no load amps}}\right)
\]

\[
= 125 \left(1 - \frac{148 - 63}{148 - 44}\right)
\]

\[
= 22.8 \text{ hp}
\]

Substituting a 25 hp replacement motor decreased full-load current from 63 amps to just 29 amps. The plant had been paying for and wasting a lot of electricity.

How much does that “safety margin” cost?

Still thinking it’s better to have a little extra power, “just in case”? Consider this. Utilities often impose demand charges for poor power factor when a motor is seriously under-utilized (more about this later). They also may subject cyclical power users to demand charges based on peak usage. The way it usually works is that one episode of high usage raises the kW/hr cost of electricity for the entire billing period. That means severe penalties for starting large motors across-the-line. Identifying oversized motors can help many users reduce peak demand charges.

The hidden costs of oversized motors

Inrush current—the current a motor draws at the moment of starting—is not load dependent. It is the same for a given motor regardless of actual load. That means a 125 hp motor starting uncoupled will draw the same current as it would when starting a 125 hp load. Starting current is roughly 6 times the nameplate current (depending on the NEMA code letter), so it represents a lot of energy—much of it wasted if a motor is oversized.

**TABLE 1. NEMA CODE LETTERS FOR LOCKED-ROTOR KVA**

The letter designations for locked-rotor kVA per horsepower as measured at full voltage and rated frequency are as follows.

<table>
<thead>
<tr>
<th>LETTER DESIGNATION</th>
<th>KVA PER HORSEPOWER*</th>
<th>LETTER DESIGNATION</th>
<th>KVA PER HORSEPOWER*</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0.0 - 3.15</td>
<td>K</td>
<td>8.0 - 9.0</td>
</tr>
<tr>
<td>B</td>
<td>3.15 - 3.55</td>
<td>L</td>
<td>9.0 - 10.0</td>
</tr>
<tr>
<td>C</td>
<td>3.55 - 4.0</td>
<td>M</td>
<td>10.0 - 11.2</td>
</tr>
<tr>
<td>D</td>
<td>4.0 - 4.5</td>
<td>N</td>
<td>11.2 - 12.5</td>
</tr>
<tr>
<td>E</td>
<td>4.5 - 5.0</td>
<td>P</td>
<td>12.5 - 14.0</td>
</tr>
<tr>
<td>F</td>
<td>5.0 - 5.6</td>
<td>R</td>
<td>14.0 - 16.0</td>
</tr>
<tr>
<td>G</td>
<td>5.6 - 6.3</td>
<td>S</td>
<td>16.0 - 18.0</td>
</tr>
<tr>
<td>H</td>
<td>6.3 - 7.1</td>
<td>T</td>
<td>18.0 - 20.0</td>
</tr>
<tr>
<td>J</td>
<td>7.1 - 8.0</td>
<td>U</td>
<td>20.0 - 22.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>V</td>
<td>22.4 &amp; up</td>
</tr>
</tbody>
</table>

*Locked kVA per horsepower range includes the lower figure up to, but not including the higher figure. For example, 3.14 is designated by letter A and 3.15 by letter B.


To calculate the range of inrush current (locked rotor amps) for a motor, determine its NEMA code letter from the nameplate and solve Equation 2 for the corresponding kVA/hp values shown in Table 1.

Equation 2

\[
\text{LRA} = \text{CL} \times \text{hp} \times \frac{1000}{1.732} \times \text{voltage}
\]

Where: \(\text{LRA} = \) Locked rotor amps
CL = kVA/hp  
hp = hp

For a 125 hp motor with code letter G (5.6 - 6.3 kVA/hp), the LRA will fall between 878 and 988 amps:

LRA = 5.6 x 125 x 1000/1.732 x 460 = 878
LRA = 6.3 x 125 x 1000/1.732 x 460 = 988

In the example cited earlier, substituting a 25 hp replacement motor (code letter G) for the oversized 125 hp model not only decreased full-load current from 63 to 29 amps, but also dropped starting current from 888 to 198 amps. That saved energy, helped cut demand charges and reduced wear and tear on motor starters, contacts and other parts due to unnecessarily high inrush currents. The substitution also improved power factor (PF) noticeably.

**Power Factor and Efficiency**

Power factor goes hand-in-hand with efficiency, so it’s no surprise that the power factor of the three-phase 125 hp motor in our example measured 0.7 when driving the 22.8 hp load. As Equation 3 shows, that motor was wasting more than half of the input power.

**Equation 3**

\[
\text{Efficiency} = \frac{746 \times \text{hp}}{(1.732 \times \text{volts} \times \text{amps} \times \text{PF})} \\
= \frac{746 \times 22.8}{(1.732 \times 460 \times 63 \times .7)} \\
= \frac{17008.8}{53153.4} \\
= .484 \text{ or } 48.4\% \text{ efficiency}
\]

By comparison, the replacement 25 hp motor operated very efficiently:

\[
\text{Efficiency} = \frac{746 \times \text{hp}}{(1.732 \times \text{volts} \times \text{amps} \times \text{PF})} \\
= \frac{746 \times 22.8}{(1.732 \times 460 \times 29 \times .80)} \\
= \frac{17008.8}{23104.9 \times .80} \\
= .920 \text{ or } 92\% \text{ efficiency}
\]

The power factor can be measured directly with a power factor meter. If a power factor meter is not available but a watt meter is, Equation 4 can be used to calculate the power factor of a three-phase motor.

**Equation 4**

\[
\text{PF} = \frac{\text{input watts}}{(1.732 \times 460 \times 63)} \\
= \frac{35135.4}{50193.4} \\
= .7
\]

The original 125 hp motor was operating at only 48% efficiency—a far cry from the 92% efficiency of the correctly sized EPACT* replacement motor. According to the MotorMasterPlus® software available from the U.S. Department of Energy (DOE), if the motor operated 8700 hours/year (that’s 24/7), the original motor would have used over 457,700 kWh/year, versus 167,200 kW/year for the 25 hp EPACT model. At $0.07/kW hour, that’s a savings of over $20,000 the first year. Where do you want to spend your money?


**About the Author**

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