Motor Energy Efficiency in Manufacturing Plants

Motors represent the backbone of industrial operations, consuming an estimated 85% of all electricity used in the industrial sector (*source: DOE estimation*). While direct motor modifications offer somewhat limited energy-saving opportunities, the majority of electricity savings projects ultimately reduce motor energy consumption through system improvements. This article will discuss some fundamentals of AC motor energy and discuss some strategies to save energy by making changes directly to motors.

Fundamental Motor Equations

AC motors function by converting electrical power input into rotary mechanical power output. Input power is calculated using voltage and amperage:

$$\boldsymbol{kW_{elec,\ 3-phase} = \frac{Volts * Amps * PF * \sqrt{3}}{1000}}$$

$$kW_{elec,\ 1-phase} = \frac{Volts * Amps * PF}{1000}$$

kW = electrical power in kilowatts
Volts = voltage supplied by building electrical system
Amps = amperage, electrical current supplied to motor
PF = power factor
$\sqrt{3}$ *= 1.732, constant for 3-phase power*

Output power from the motor delivers the mechanical work required by driven equipment. It is quantified by the shaft rotational speed times its torque (rotational force). This can also be referred to as brake power or shaft power.

$$\boldsymbol{kW_{brake} = (lbf * ft) * RPM * \frac{2\pi}{44,200}}$$

kW_{brake} *= power output at the motor shaft*
*Lbf*ft = units of torque, or twisting force*
RPM = revolutions per minute, or rotational shaft speed

It is worth noting that motor speed (RPM) for AC motors is fixed based on the electrical frequency (60 Hz in the US) and number of pairs of motor poles. Therefore, the only way to modify a motor's speed is to manipulate the electrical frequency to it. This is done with a variable frequency drive (VFD), which is a key component in reducing motor energy for many systems.

$$\boldsymbol{RPM = \frac{Hertz * 60}{\#\ pole\ pairs}} = \frac{3600}{\#\ pole\ pairs}$$

Motor efficiency is the ratio of output power to input power, indicating how effectively the motor converts electrical energy to mechanical work. Efficiency is a unitless number represented by the Greek letter, eta.

$$\boldsymbol{\eta_{motor} = \frac{kW_{brake}}{kW_{elec}}}$$

$\eta_{motor} = motor\ efficiency$

From the equations above and the fact that power is energy divided by time, the total energy consumption formula for a motor is shown below. This provides the framework for efficiency improvements that can be made.

$$kWh_{motor} = \frac{kW_{brake}}{\eta_{motor}} * hours$$

This equation reveals three primary approaches to reducing motor energy usage: decreasing output power requirements, increasing motor efficiency, and reducing operating hours.

Decreasing Motor Power Output

AC motors run at a fixed speed, and they naturally output the required amount of torque to drive a system. Their torque output can be reduced by making changes to the system being driven; not by making changes to the motor itself. Therefore, there are no project ideas to discuss in this category for this article. Articles that discuss specific systems (pumps, compressors, chillers, etc.) will have energy saving strategies that ultimately reduce torque on their motor.

Motor Efficiency Improvements

While system-level modifications typically offer greater energy savings potential, several direct motor improvements can enhance efficiency and reduce energy consumption.

High-Efficiency Motor Replacement

The most straightforward approach involves replacing existing motors with ones that have similar specifications other than their efficiency rating. Modern premium efficiency motors incorporate improved materials, optimized magnetic design, and enhanced manufacturing techniques that can increase efficiency by 2%-5% compared to standard motors.

When evaluating replacements, consider the motor's duty cycle and loading patterns. Motors operating continuously at high load factors provide the best return on investment for efficiency upgrades, while intermittent or lightly loaded motors may not justify the replacement cost through energy savings alone.

Proper Motor Sizing

Motor oversizing represents one of the most significant efficiency problems in industrial facilities. Ideally, motors are sized to run at high load factors, as this is where they are most efficient. Load factor is the ratio of actual motor output power to rated output power. As motor load factor decreases, especially below 50%, efficiency drops dramatically due to increased losses relative to useful output. It is not uncommon to find motors operating at 30-40% of rated capacity, resulting in poor efficiency and higher energy costs. Motors consistently operating below 50% capacity should be evaluated for replacement with properly sized units. This approach not only improves efficiency but often reduces maintenance costs and extends equipment life. The efficiency improvement from proper sizing can be substantial. A motor operating at 30% load might achieve 75% efficiency, while the same motor at 75% load could reach 92% efficiency. Right-sizing captures this improvement while potentially reducing initial equipment costs.

DC to AC Motor Conversion

Facilities with legacy DC motor installations should evaluate conversion to AC induction motors. Modern AC induction motors typically achieve 5%-10% higher efficiency than comparable DC motors.

Runtime Reduction

The other lever that can be pulled to reduce a motor's energy consumption is reducing its run-hours. This effectively means to turn a motor off when it's not required to run. This is usually done by interlocking the motor power with the process. Depending on the process, sensors such as laser sensors, flow switches, pressure switches, etc. can be used to turn a motor off when it is not required. This reduces run hours. Again, these sensor-based control strategies and system-level modifications will be discussed in more detail when covering specific manufacturing systems.