Centrifugal Pumps and Variable Speed

Driver Constants

Growing concerns over energy use and efficiency have fueled more widespread use of variable speed systems to power centrifugal pumps. There are several factors at play, but the design freedom permitted by breaking the bonds to fixed electrical frequencies can help get closer to the pump Best Efficiency Point, or BEP. However, there are some mathematical sharks lurking below the surface that need to be considered.

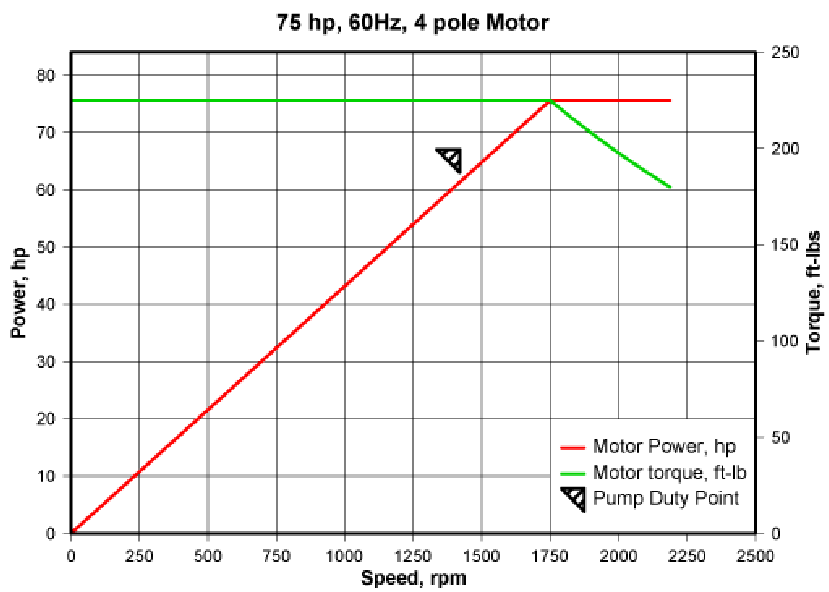
Electric motors are the most common (electro-) mechanical devices used worldwide. In particular, induction alternating current (AC) motors are the most common pump drivers and fortunately they exhibit some relatively simple traits. When operated below rated speed, they produce constant torque; above rated speed the power output is constant.

The relationship of power output to torque is defined as:

$$T = \frac{HP \times 5250}{rpm} \qquad T = \frac{kW \times 9545}{rpm}$$

(US units, ft-lb) (SI units, N-m)

For example, a 75 hp / 1,750 rpm motor is capable of 225 ft-lb of torque. Similarly, a 55 kW / 1,450 rpm motor is capable of 362 N-m of torque. Considering the traits and equation above, a motor's output can be graphically demonstrated below:



Most pump manufacturers choose to fix the pump diameter at maximum values when sizing for variable speed applications to reduce the number of iterations and maximize efficiency. And inconveniently enough, the resultant speeds rarely fall at or near fixed frequency motor speeds.

Consider a pump that requires 67 hp (50 kW) at 1,420 rpm, for illustration. What motor do you choose? Would the example motor above provide enough power at the rated pump speed? Knowing that torque is constant below rated frequency, we can use the equation above to determine if this motor will work.

$$T = \frac{HP \times 5250}{rpm}$$

$$225 = \frac{HP \times 5250}{1420}$$

$$HP = \frac{225 \times 1420}{5250}$$

$$HP = 60.9$$

Therefore, a 75 HP, 1750 rpm motor can only produce 60.9 HP at 1,420 rpm and will not work. But a 100 HP, 1750 rpm motor is capable of producing 81.1 HP at the rated pump speed and therefore will work.

Service is a Factor

The rotational speed of an AC motor is dependent on the number of magnetic poles it was designed with (which is a fixed value such as 2, 4, 6, etc) and the electrical frequency (50 Hz, 60Hz, etc). The equation for determining synchronous speed is:

$$N\ (rpm) = \frac{120 \times frequency}{\#\ of\ poles}$$

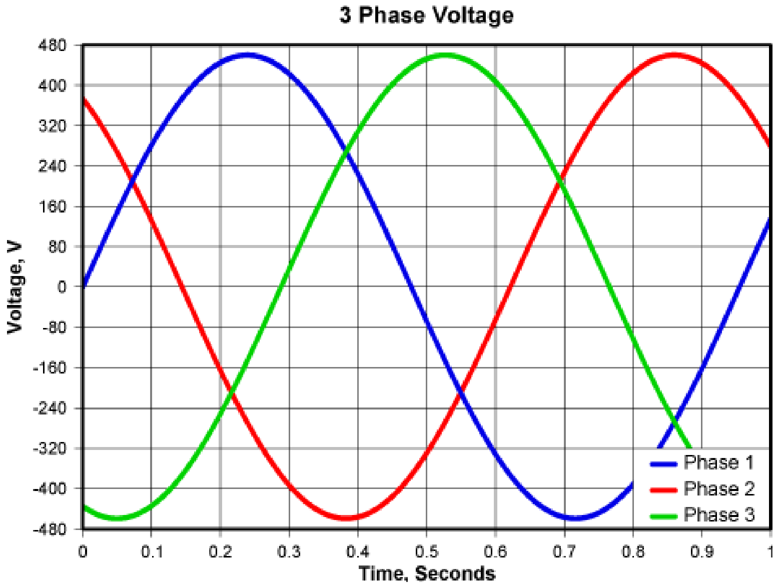
As you can see from the table below, there are significant speed gaps between the synchronous speeds. It may be desirable to run a centrifugal at its most efficient point between these speeds, even with a trimmed impeller.

Number of Poles	Synchronous Speed at 60Hz	Synchronous Speed at 50Hz
2	3,600	3,000
4	1,800	1,500
6	1,200	1,000
8	900	750
10	720	600

Therefore, in order to change the speed of the motor you must change the electrical frequency, which is fixed on the electrical grid. This is where VFDs come into play, as they take the fixed input frequency and permit a variable output frequency to the motor.

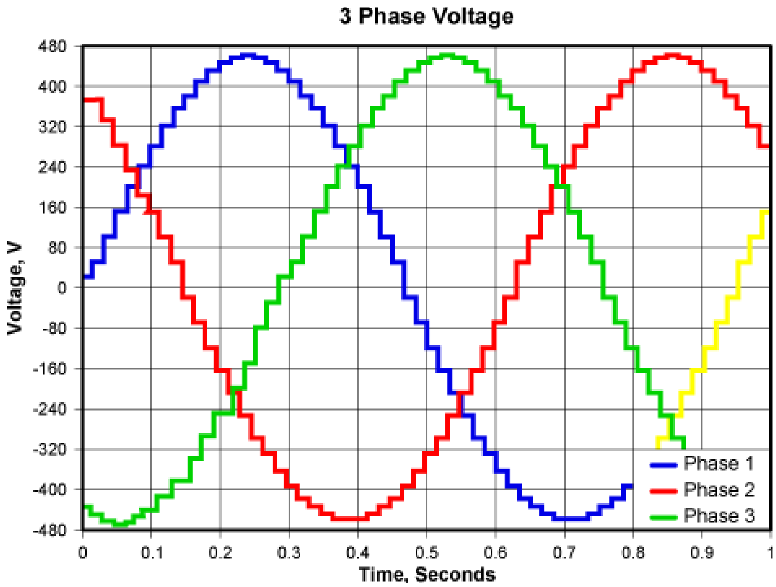
Three phase AC electric motors are nominally designed to be powered by a sine wave signal as shown below, as provided by the electrical grid (direct on-line connection):

Synchronous Speed



Notice the harmonious and smooth nature of the pure sine wave from the grid. Modern microprocessor controlled VFDs unfortunately can not generate a natural sine wave. Instead, they typically rely on simulating a sine wave using Pulse Width Modulation (PWM), which looks like this:

Variable Speed



The resolution of the jagged steps in the simulated sine wave is a function of the resolution or PWM frequency setting. These relatively sudden voltage spikes and the resulting harmonics can break down the motor insulation and increase heat inside the motor.

NEMA motors are often nameplated with a service factor of 1.15, meaning that the motor can continuously supply 115% of rated power and operate within the stated temperature rise. Conversely, IEC motors are rated with no service factor. However, unless the nameplate explicitly indicates VFD rated, the stated values are based upon a natural sine wave.

When power is supplied from a VFD, the service factor is lost or decreased in order to maintain the nameplate temperature rise.

So when sizing a VFD for your centrifugal pump application, beware relying on the service factor. Also, don't overlook elevation limits, belt losses and transient conditions.