Pump ED 101

Motor HP & Torque Versus VFD Frequency

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My January P&S article focused on the reduction in motor HP as frequency is reduced by a VFD. I had several requests to revisit this subject and explain the relationship between HP and torque across a broad range of frequencies.

The relationship between the HP and torque produced by an electric motor can be a bit perplexing. When that motor is controlled by a VFD, it can be downright confusing! In a linear environment, work is the product of the force applied to an object and the distance the object travels due to that force ($w = fd$). In a rotational environment torque is the equivalent of work but, its value is a bit more complex. Torque is equal to the force applied, its distance from the axis of rotation (radius) and the angle (θ) at which the force is applied ($t = f(r \sin \theta)$). In the US, torque is expressed in pound feet (lb-ft). When I was in school, it was foot pounds (ft-lbs) and I still use the old value. Torque tells us how much work is performed but it says nothing about how quickly that work is done.

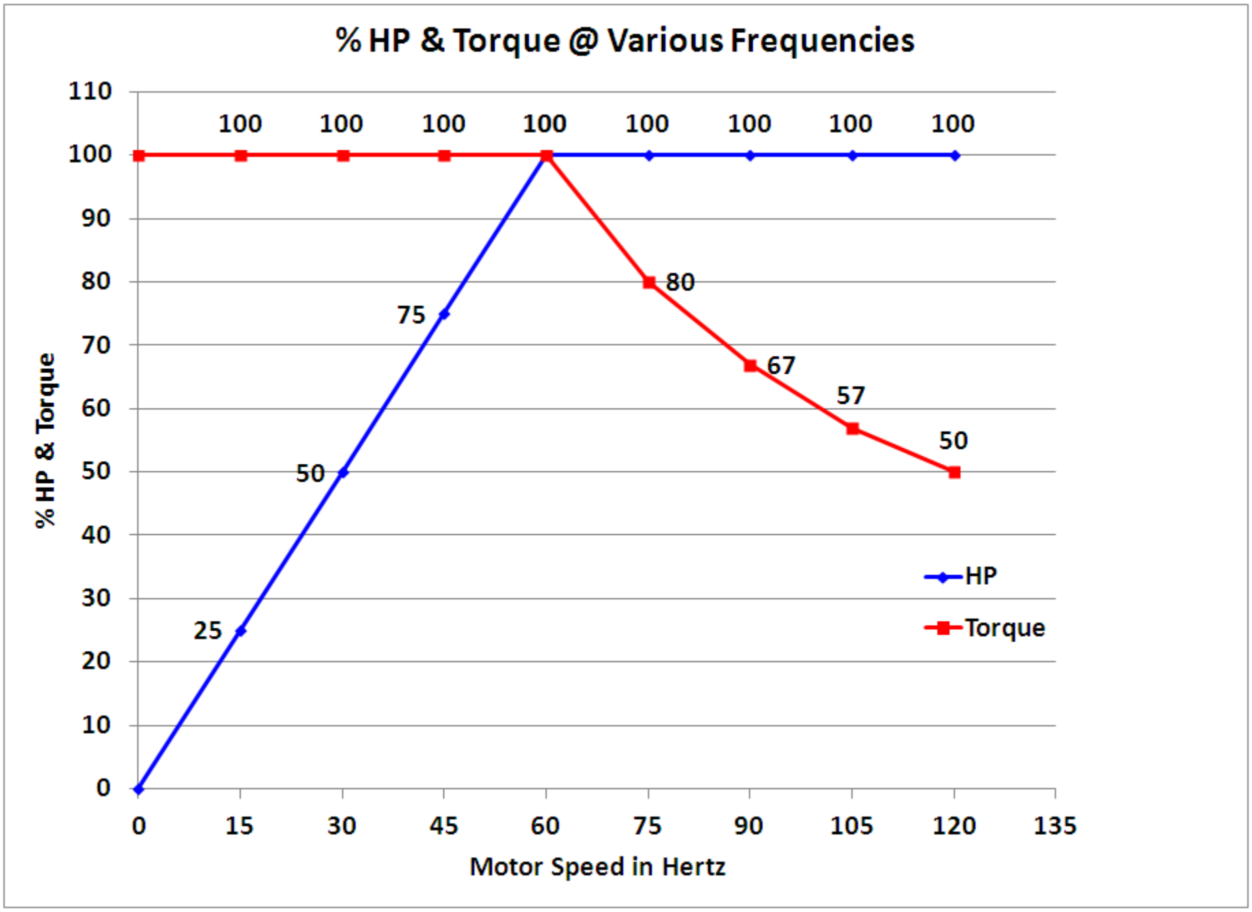
Power is the rate at which torque (work) is performed ($p = t/time$). In the US we use HP as a unit of power. The two equations below show the relationship of HP and torque when a motor's speed changes. The constant, 5252, is the result of dividing James Watt's original test data (33,000) by 2 pi.

$$HP = (t \times rpm) / 5252 \qquad t = (HP \times 5252) / rpm$$

Based upon the relationship, torque must double if HP is to remain constant when speed is reduced by one half. In order to produce the same HP at the lower speed, a motor has to do twice as much work per rotation which requires twice as much torque. That is why the shaft and frame of a 900 rpm motor are usually larger than those of an 1800 rpm motor of the same HP.

When the speed of an AC motor is controlled by a VFD, HP or torque will change depending upon the change in frequency. Figure 1 provides a graphical illustration of these changes. The X axis is motor speed from 0 to 120 hz and the Y axis is the percent HP and torque. At 60 hz (base motor speed), both HP and torque are at 100%. When the VFD reduces frequency and motor speed, it also reduces voltage in order to keep the volts/hertz ratio constant. Torque remains at 100% but HP is reduced in direct proportion to the change in speed. At 30 hz, HP is just

50% of the 60 hz HP. The reason this occurs is because the total torque produced per unit of time is also reduced by 50% due to fewer motor rotations. You can use the HP and torque equations to verify this relationship.



When a VFD increases frequency above 60 hz, HP and torque do a complete flip-flop. HP remains at 100% and torque decreases as frequency increases. Torque reduction occurs because motor impedance increases with increasing frequency. Since a VFD cannot increase voltage above its supply voltage, current decreases as frequency increases thus decreasing available torque. Theoretically, torque is reduced by the ratio of the base speed to the higher speed (60 hz / 90 hz = 67%). In real life other factors can reduce the actual available torque well below the theoretical values shown in the chart. These include increased bearing friction, increased fan loading and additional rotor windage. A motor's full load torque must be derated when operated at speeds above 60 hz. Typical manufacturers derating guidelines suggest using the base frequency to maximum frequency ratio for speeds up to 90 hz. At speeds above 90 hz, the square of the ratio is often used.

Check with the manufacturer before operating a motor above its base speed. Rotor balance, bearing life and critical speed are typical concerns. High quality 1800 rpm and 1200 rpm motors up to 200 HP should be able handle up to two times the base speed without problems. Over speed is usually not allowed on 3600 RPM motors over 50 HP. NEMA MG1 provides several over speed guidelines that manufacturers must meet.

Have you ever made the mistake of running a 230V motor on 460V? If so, you probably noticed a lot of smoke in the room! There are, however, applications where this can actually work. A novel way to provide constant torque at higher than base speeds is to run a 230V motor on a 460V VFD. In these applications, the drive is programmed to provide full voltage at 120 hz and then reduces voltage proportionally as speed is reduced. At 90 hz the output voltage would be 345V and at 60 hz it would be at the motor nameplate voltage (230V). The volts/hertz ratio remains at a constant 3.83 throughout the speed range.

Joe Evans is responsible for customer and employee education at PumpTech Inc, a pump & packaged systems manufacturer & distributor with branches throughout the Pacific Northwest. He can be reached via his website www.PumpEd101.com. If there are topics that you would like to see discussed in future columns, drop him an email.