By Stewart Kasper, KRWA Technical Assistant

Efficient Operation of Variable Frequency Drives

A variable frequency drive (VFD) dictates motor speed and torque by controlling the ratio of frequency and voltage — commonly referred to as the volts/hertz curve.

In the 1880s during the war of currents, Nikola Tesla and Thomas Edison had a constant dispute about which form of current was the best. Was it Direct Current or Alternating Current? Both had their merits. DC was more adjustable, making speed control much more manageable. On the other hand, AC could travel over longer distances, making electricity more readily available to the masses. Had Edison won out, there would be a generation station on every city block, and the idea of a national grid system that we rely on so heavily today would not exist. AC was not ideal due to its inherent danger; just look up Topsy the elephant sometime. The other downside to AC was that to change the speed of a motor or pump, the moto operator would have to change the poles in the motor or change the frequency, and since manufacturing motors with an unlimited number of poles, the only efficient way to change motor speeds was by changing the frequency. Thus, the invention of Variable Frequency Drives or VFDs.

VFDs have been used to control the speed of electric motors for over 40 years. However, many pump end users were initially slow to adopt this technology, which has proven to have a beneficial effect on system efficiency and life cycle costs.[1]

VFDs work by bringing in AC current and changing that to DC since it is easier to adjust the frequency and back to AC once the frequency is changed. Throughout many systems, I have encountered many different VFDs installed on motors and pumps throughout my travels. I wanted to take this opportunity to review how to make more efficient use of motors using a VFD.

While I was a water and wastewater utility operator, I only thought of VFDs as a control device to manipulate a plant to operate as long as possible. Often the major point of upset for plants is during start-up, so the less frequent a plant needs to start up, the fewer upsets. However, after getting into the energy efficiency game, I have come to realize that VFDs are a more valuable tool than I knew.

The biggest problem I see with VFDs in the field is systems running their VFDs at 100 percent, or 60 hertz (standard frequency in the USA). When a VFD runs at 60 hertz, it's a lot like plugging a bank of batteries into an AC receptacle, then installing a power inverter onto the batteries to run an AC power user. You wouldn't do that because it is inefficient. There is actually a formula to calculate the amount of power a VFD loses to heat whether the unit runs at 100 percent or 50 percent, it will always lose heat. The formula is HLoss = Pt (1-n), where HLoss equals the amount of power lost to heat, Pt equals the power going through the drive, and n equals the efficiency of the drive. Here's an example, using a 40 hp motor with a VFD rated at 97 percent efficient (VFDs typically range from 95 to 98 percent).

HP	kW/HP	kW	Pt	(1-n)	Hloss in kW	kWh/day
40	0.7457	29.828	29.828	0.03	0.89484	21.47616

This table show heat loss through the VFD over a 24-hour period.

[1] 2014. *Variable Frequency Drives: Guidelines For Application, Installation, and Troubleshooting*. Parsippany, New Jersey: Hydraulic Institute, p.IX.

Hloss in kW	kWh/6 hr	Days/yr	kWh/yr
0.89484	5.36904	365	1959.70

This table show kWh of heat loss on a VFD running an average of six hours a day for one year.

So let's break this down a little bit. Each hp requires 0.7457 kW of power; with a 40 hp motor, we need 29.828 kW to operate for one hour. So as the formula progresses, we find that we only lose 0.89 kW of power to heat, which is not so bad, but if that motor operates 24 hours a day, we can see that's 21.47 kWh/day. Most water treatment plants in Kansas do not operate 24 hours a day, so let's make this calculation on a plant that operates six hours per day.

percent (60 Hz) to 80 percent (48 Hz) we can find the amount of power savings by cubing 80 percent or 0.80, which is 0.512 or 51.2 percent power savings. By decreasing the output by only 20 percent, we can save 50 percent of the electricity needed, which is only half of the equation. Reducing the speed to 80 percent, we must square that (0.80) to calculate or flow. By decreasing the VFD to 80 percent, we decrease our flow to 61percent of maximum flow. Using

Please consult the pump curve with the manufacturer before making significant changes, or reach out to me. I would be happy to assist you with your energy savings projects. If you would like a more in-depth analysis of a water and wastewater system, KRWA would be glad to offer an energy efficiency report at no cost to the system. An energy efficiency report would illustrate the things a utility could do to reduce costs, approximately how much the modifications would cost, and what period would be needed to recover the investment in the improvements. VFDs are only a small aspect of an energy efficiency report.

HP	Flow	kW	Hloss	HRS/Day	kWh/day	GPM	HRS/216,000 Gallons	kWh/Day2	Cost/Day	Cost/Month	Cost/Yr
40	100%	29.83	0.89484	6	184.33704	600	6	1106.02	$ 102.20	$ 3,108.48	$ 37,302
40	90%	21.74	0.89484	6	135.83671	486	7.4	1006.20	$ 92.97	$ 2,827.92	$ 33,935
40	80%	15.27	0.89484	6	97.000656	384	9.4	909.38	$ 84.03	$ 2,555.82	$ 30,670
40	70%	10.23	0.89484	6	66.755064	294	12.2	817.41	$ 75.53	$ 2,297.33	$ 27,568
40	60%	6.44	0.89484	6	44.026128	216	16.7	733.77	$ 67.80	$ 2,062.26	$ 24,747

This table shows the cost savings by slowing the motor down in 10 percent increments.

In Kansas, the average commercial rate for electricity is $0.0924/kWh. To operate a pump at 60 Hz with a VFD installed costs a utility an additional $181.08 per year just to have a VFD installed in front of the motor. When multiplied by the number of pumps in the system, it does not take long to incur significant costs.

To get the most cost savings from the VFD we must lower the speed, and we can calculate the power savings by the "Cube Law". A simplified version of this is: speed reduces flow by the square and reduces power by the cube. So if we reduce the VFD output from 100 the same example of a motor at 40 hp running for six hours per day. We can calculate that if we know the flow output. We will use a flow of 600 GPM at 100 percent for this example.

Using a flow of 600 GPM with an average of 6 hours of operation per day, the plant would produce 216,000 gallons/day. Reducing the speed will, of course, reduce the flow. In this example, reducing the flow by 80 percent would require 9.4 hours of operational run time to produce the same amount of water; however, over a year would save $6,632. The larger the plant with more motors involved, the savings accumulate significantly.

KRWA appreciates the partnership with Energy Solutions Professionals to provide as much electricity savings as possible to water and wastewater systems in Kansas.

Stewart Kasper joined KRWA staff in August 2020 as Technical Assistant/Trainer. He holds a Class IV operator certification for water and Class IV operator certification for wastewater in Kansas. Prior to joining KRWA, he was water plant operator at Rural Water District No. 2, Miami County.

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