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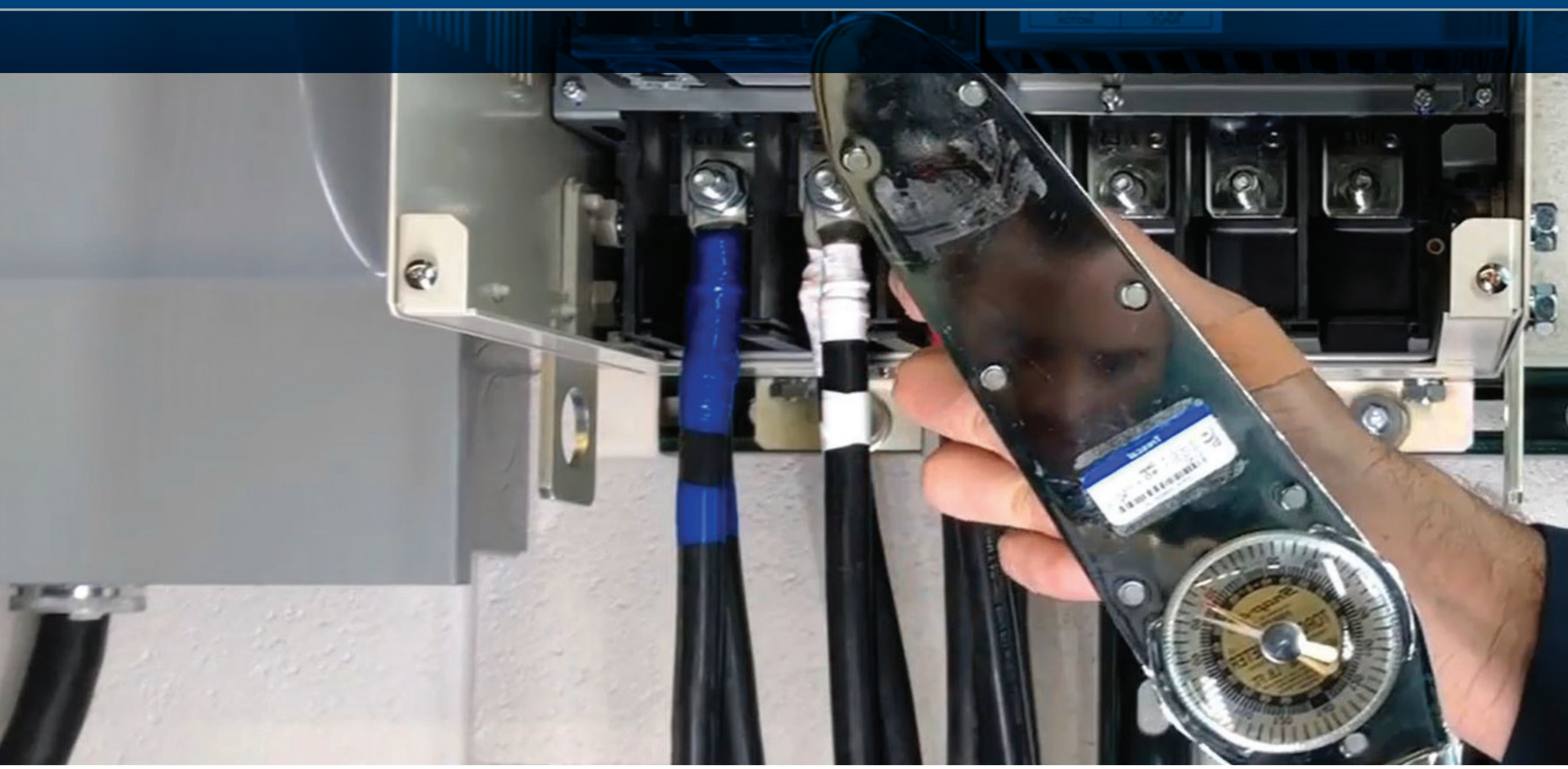
HOW TO GET THE MOST OUT OF YOUR VFD

BEYOND THE PURCHASE: SYSTEM EFFICIENCY AND PREVENTATIVE MAINTENANCE CONSIDERATIONS



Author: Paul Avery, Drives Technical Training, Yaskawa America, Inc.

Controlling motor speed with variable frequency drives (VFDs) can save energy. But it’s not as easy as just adding a VFD. What else needs to be considered for motor control system efficiency and what preventative maintenance is recommended to get the most out of your VFD purchase?

VFDs inherently save energy and money for you, but there are a variety of best practices that should be followed to maximize energy savings and extend the life of your VFD.

INTRODUCTION

Besides the many other features on of a modern Variable Frequency Drive, the simple ability to run an AC induction motor at speeds other than 60 Hz is a very wonderful thing.

By slowing the motor down to meet the demand of the application, you are reducing the power required to keep the load moving. Power usage over time equals energy so the bottom line is that you are saving energy when you are not running at full load.

Most people are already familiar with all the information in the previous paragraph so maybe we don't need to sell you on the idea of using a VFD. So let's assume that you already purchased your brand new VFD. Time to save all of that lovely moolah. But is that all there is to properly using a VFD to save money? Just buy it and mount it on the wall? Like most things in life, there is slightly more to it. So let's discuss how to best utilize your VFD to optimize energy savings.

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PROPER INSTALLATION

Let's start with a brief discussion of a proper VFD installation. You aren't really saving money through energy cost reduction if you have to buy another VFD to replace the first VFD that you blew up or melted down.

Many VFD manufacturers are happy to offer extended warranties on their products if they are installed and wired by people that they have vetted or factory trained.

Figure 1: Proper torquing of power wiring done by a certified installer is one of the steps that help the drive's lifespan and increase ROI.

As a factory trainer myself, I emphatically endorse using installers that have been sent to the factory to practice and learn all the ins and outs of proper VFD installation. We throw many different scenarios at the students so that they get the experience they need to avoid pitfalls.

Proper installation can avoid problems and short VFD lifespans.

Proper installation can avoid problems and short VFD lifespans. A good installer will notice environmental issues that can lead to premature VFD failures like high ambient temperatures, long motor lead lengths, and power factor correction capacitors. If an early demise can be avoided, some VFDs can last a very long time, making the investment ROI very high indeed.

MOTOR AND CABLE

The VFD by itself can be integral to energy savings but the drive is only one part of the whole installation. Two other parts that really matter are the motor driving the load and the cable connecting the VFD and the motor.

Motor Considerations

Let's consider the motor first since it is probably the more important of the two items. First, make sure that the motor is up to the job of handling the PWM voltage that the VFD will be sending it.

Some older motors, besides being inefficient, were manufactured with inferior insulation systems that may not be able to handle the voltage created by a VFD and exacerbated by a long motor lead.

Figure 2: An output reactor is sometimes necessary.

Generally any application that has motor leads over 100m should consider an output reactor between the motor and VFD to help protect that first turn in the stator (where the insulation is thinnest) from failing.

Like many things, there is a tradeoff to be considered. Any kind of output filtering, like that load reactor, will come with their own losses. The slight decrease in efficiency is worth the extended life of the motor.

Another motor consideration is the size. Of course we need a motor capable of continuously delivering the torque that the load requires. A properly sized motor is preferable to an oversized motor.

An under loaded motor can suffer from a poor power factor which greatly decreases the efficiency of the whole system. Again we face a tradeoff. An oversized motor might give us peace of mind that our system will not fail any time soon since heat losses in all of the components are well below their thresholds but the properly sized motor will be more efficient.

If correctly selected and installed, the properly sized motor will also live a long life so the tradeoff is heavily weighted towards the properly sized motor.

For new installations, the motor selected will most likely be very efficient due to government regulations regarding motor efficiencies. Generally the closer the rated speed of the motor is to the synchronous speed, the more efficient the motor is.

To optimally run a motor, a VFD needs an accurate value for the motor's rated slip. A good auto-tune done by the VFD while attached to just the motor, can yield a very good value for motor slip. We will discuss auto-tuning later and how it applies to VFD control methods.

Large changes in impedance can cause a point of reflection for the PWM pulses coming from the VFD.

Motor Cable Considerations

Motor cable considerations generally relate to the cable length and gauge. The proper cable gauge should be found by consulting the VFD manufacturer's installation documents. As we mentioned earlier, long lead lengths can actually lead to premature motor failure unless precautions are observed.

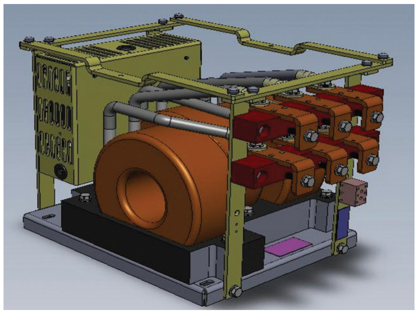

Figure 3: A dv/dt filter will sometimes be necessary in applications with very long motor lead lengths.

Large changes in impedance can cause a point of reflection for the PWM pulses (with their corresponding high dv/dt values) coming from the VFD. It is not an all or nothing thing. The greater the difference in impedance, the more pulse are reflected.

Sometimes the only fix is to dampen the steep dv/dt of the pulses through filtering. Again the filtering components come with their own set of energy losses and additional installation costs.

AUTO-TUNING

To get the best torque per amp performance out of your new VFD you need to perform a proper auto-tune. What a good auto-tuning routine for a VFD will do is help the drive build a good motor model in the VFD.

From the factory, the drive is most likely set up for a typical motor that matches the VFD size. That means that the rated motor amps value in the VFD will be based on NEC values for that voltage and horsepower motor.

On top of that, the motor model will require values for expected losses in windings and magnetic fields. Values like losses are rarely specified on the motor nameplate. These loss values are named things like "Line to Line Resistance (Ω)" and "Leakage Inductance (%)".

It is highly recommended that the auto-tuning function be run on a motor without any load attached.

It is probably best left to the VFD to run its own tests on the motor after some of the typical nameplate values are input to the drive. The end result will most definitely show a reduction in output current while running the same speed and load as the pre-tuned motor.

It is highly recommended that the auto-tuning function be run on a motor without any load attached. An attached load will skew the current and slip measurements.

It is also preferable that the auto-tuned motor's internal temperature is close to its normal running temperature due to resistance changing with temperature.

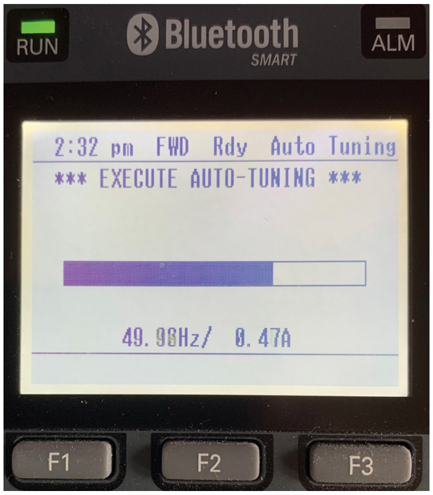

Figure 4: An auto-tune operation for a new drive installation is simple and will lead to a more efficient control of the motor.

HOW TO DEAL WITH LIGHT LOADS

Another way to help a VFD get the best efficiency out of the application is to train it on how to deal with situations where the load fluctuates. During operation at low loads, decreasing the output voltage to an optimal point can help minimize the power consumption and maximize efficiency.

An Energy Savings mode in a VFD can help maximize the efficiency, especially for V/Hz applications like fans and pumps. It can be helpful to think of Energy Savings as the inverse of Torque Boost. One increases the voltage from the normal levels in order to increase the output torque and the other decreases the voltage to minimize power usage, which results in a more efficient use of energy.

Sometimes it may be further desired that the VFD stops running if the load becomes too low. This is referred as Sleep. It is called Sleep because despite the drive output turning off, the VFD remains in a run state and monitors to see if the conditions of the applications warrant waking up to start driving the load again. This type of operation is common on pumping applications where the demand on the pump can change based on usage or time of day. The VFD will need to be programmed with what states, like speed output and/or pressure are when the drive needs to sleep or wake.

During operation at low loads, decreasing the output voltage to an optimal point can help minimize the power consumption and maximize efficiency.

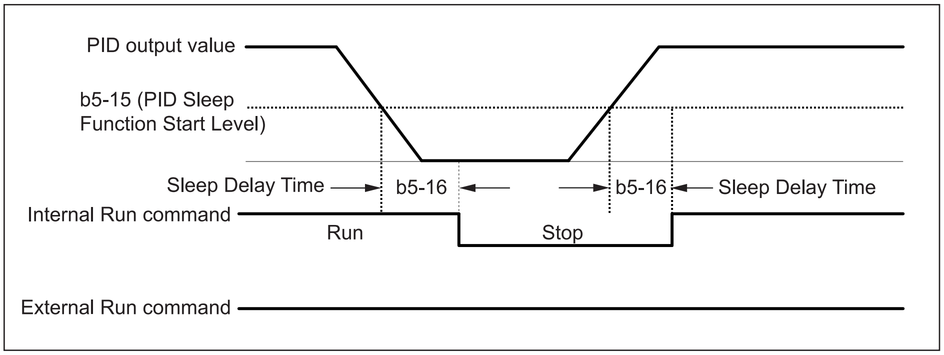

Figure 5: Stopping the VFD during low demand times can help with energy savings.

VAMPIRE POWER

A final energy savings possibility relates to what is colloquially called "vampire power". It refers to the power that devices draw even when they are not turned on. Consider your LCD flat panel TV. Even when you are not watching it, there is a certain residual power that is drawn.

Maybe it is not enough power by itself to warrant your concern but then consider how many devices in your house are also drawing power while they are off. Then multiply that by all the houses and businesses there are in the world and you can see the concern.

How does this relate to VFDs? Same with a VFD. Even when the VFD is sitting there powered but not running, it is drawing some current in through its rectifier and bus capacitors. Some manufacturers have created a function that uses a small DC power supply to keep the VFD "brain" alive while opening up an input breaker when it has not been running for a long enough time.

Because the brain still has power, it can close the input breaker whenever a new run command is received. Maybe a single drive's non-running power draw doesn't warrant the extra equipment but what if you have fifty or a hundred VFDs. The power waste could be appreciable.

Heat is the number one enemy of the drive. So it is important to understand where it comes from how to prevent it.

KEEPING YOUR VFD IN TIP TOP SHAPE

The dream when you buy industrial electronics is that they will work right out of the box, never need any attention, and last forever. Unfortunately, sometimes the first one is kind of true, but the next two wishes are just wishful thinking.

So let's discuss what things a conscientious VFD owner should do to keep their equipment in good condition.

Before we dive in maybe we should admit one important fact. Heat is the number one enemy of the drive. Drives, potentially, only have a couple of moving parts.

Even motors that turn for a living only have a few parts that actually move. They are just more noticeable in the motor than in the drive. And some drives don't even have a single moving part.

Motors have to worry about heat as well, but also need to worry about rapid physical motion that is dependent on healthy bearing operation. Luckily, our VFD may only have cooling fans and relays that may have moving parts. However, they will figure into our regular maintenance, so we will discuss them further in a bit.

SOURCES OF HEAT AND HOW TO IDENTIFY

Heat issues come from two distinct sources, ambient temperature and heat caused by passing large enough amounts of current through metal conductors.

Maybe this would be a good time to show a formula detailing heat (watts loss) per foot of conductor but to be honest, the amount of variables involved makes the accurate calculating more of an IEEE paper topic.

Since we are discussing a modern variable speed drive, it's nice to know that we can get a pretty good idea of watts loss at full load from the technical manual provided by the manufacturer.

2.5 Drive Watt Loss

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Table 2.1 Drive Watt Loss (Heavy Duty)

Model	Carrier Frequency kHz	Interior Unit Loss W	Cooling Fin Loss W	Total Loss W
2004	8	35	19	54
2006	8	37	26	63
2008	8	40	36	76
2010	8	44	43	87
2012	8	50	61	111
2018	8	47	82	129
2021	8	56	105	161
2030	8	74	174	248
2042	8	88	183	271
2056	8	112	267	379
2070	8	145	373	518
2082	8	179	478	657

Figure 6: Typical drive watt loss data found in a VFD technical manual.

Modern IGBT modules also have built-in thermistors measuring the heat that the module is experiencing, making it easy to monitor heat in your VFD.

The unit to measure heat loss is Watts. On top of that, devices used in the manufacturing of modern variable frequency drives feature temperature measuring devices built in!

Most of the current that will go to creating that nasty heat will at some point pass through the VFD's insulated gate bipolar transistors. What are they, you say? They are the very fast, very efficient output switches that create the PWM waveform that is applied to the motor to create torque and power.

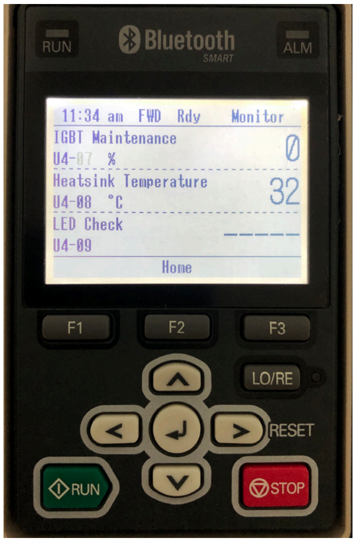

Figure 7: VFD Keypad showing temperature

Why is this fact important? Because modern IGBT modules also have built-in thermistors measuring the heat that the module is experiencing. No formulas are required. At most, you will just have to check a keypad monitor for the exact drive temperature or maybe just read it over a network connection in real time.

The only issue with real time temperature monitoring is that it can't differentiate between heat rise due to usage and the heat due to ambient temperature. So part of any installation and subsequent maintenance is to always control the ambient temperature around the VFD.

Even when not being used, the drive can never cool down any lower than ambient. The higher the ambient, the less of the heat rise that is allowed before your VFD has to shut down on a temperature fault. It is safe to assume that if you trip on over temp fault too often, it probably won't be good for your drive components. Moral to the story: try not to cook your VFD!

Now that we've spent some time reviewing the importance of heat considerations are for a VFD, let's start thinking about what VFD preventative maintenance measures we should consider and perhaps a link to heat will become clearer..

Cleaning the heatsink is an easy task and essential for cooling the devices attached to it.

Any filter damage, even the smallest of tears, will require the filter to be replaced instead of cleaned.

PREVENTATIVE MAINTENANCE

A typical preventative maintenance list for a VFD includes the following

- Clean the heatsink
- Clean the filters (UL Type 12 enclosures especially)
- Check fan operation
- Check the load
- Check and re-tighten power and control connections
- Replace fans as needed
- Replace capacitors as needed
- Replace soft charge contactor as needed

Before we delve into these items, we should make clear that only qualified personnel with the proper knowledge of VFD operation should be performing these checks and maintenance. Capacitors retain energy for a while after lock-out/tag-out and heatsinks take a while to cool down enough to touch.

CLEANING THE HEATSINK

Since the heatsink is essential for cooling the devices attached to it, the heatsink needs to be kept in optimal shape. Luckily this is an easy task.

Simply keep the heatsink fins clean and unclogged and they will do their job to wick heat away from sensitive electronics like IGBTs and diode modules.

Generally compressed air of sufficient pressure blown down through all of the fins will clear and dislodge any foreign matter that may be impeding the dissipation of heat.

Because of the thermistors built into the output transistors, you can check the actual heatsink temperature with a keypad monitor or by reading the proper register contents over any kind of network connection to the drive.

If your environment involves oil mist or equivalent substance, the mist combined with the dirt and the dust in the air may make a substance that can cling to the heatsink fins and take more than just air to clean up. Consult with the manufacturer regarding proper cleaning techniques.

CHECKING THE FILTERS

If your drive is of the UL Type 12 variety, there will be filters that need to be checked and kept clean. Filters will normally only be on the openings that are meant to draw cooler ambient air into the box.

Either vacuuming or compressed air can be used to clean the filter media but be careful to not use too much pressure/suction or the filter media can be torn and damaged.

Any filter damage, even the smallest of tears, will require the filter to be replaced instead of cleaned. The frequency of the filter cleaning is very dependent on how dirty the environment is.

Spare filters will aid in getting up and running quickly and many enclosures will allow safely changing the filter while running.

In many cases, heatsink fans are critical for trip-less operation and long VFD life, making it important to keep them clean.

CHECKING THE FANS

For the heatsink to do its job of cooling the drive devices adequately, sometimes it requires ambient air to be constantly blown across the fins in order for them to cool down more quickly which in turn allows them to absorb more heat from the drive.

This makes heatsink fans critical for trip-less operation and long VFD life. Some smaller drives don't require heatsink fans while some larger drive might require three of four large fans.

The proper amount of cubic feet per minute (CFM) necessary was calculated by the drive designer based on heat loss of the current carrying devices running at the drive's temporary overload ratings. Therefore at normal operation (not in overload) there should be a slight excess of airflow. Still, all fans will need to be turning at their rated speed and in the proper direction.

Fans can be checked to be sure that they spin freely while un-powered and simple observation during a drive run state should show all fans spinning. Modern fans are probably hardier than some even a generation ago and most now include hall-effect sensors that will assure that the fan is spinning when it is supposed to be.

If the fans do have sensors, the VFD will either trip when a fan fails or will warn the user that at least one fan is not operating properly. Even if the drive doesn't trip for a failed fan, if the temperature of the VFD cannot be maintained within the VFD specification, the thermistor in the IGBTs will report the temperature to the control board and the control board will shut down the drive to save the components in the drive. Still comes back to heat, doesn't it?

CHECKING THE LOAD (CURRENT)

It might seem like doing a load check is not part of a maintenance routine but hear me out. Variable frequency drives have continuous and overload current ratings. The continuous rating is like it implies, all day, every day. The overload rating is just for short term and intermittent usage.

The more time spent overloading the VFD current, the more likely the drive will not live as long as intended.

The more time spent pumping overload levels of current through the VFD, the more likely it is that the drive won't live as long as it was intended. Occasional overload, especially for accelerating large loads, is okay and what it is intended for. But overuse of the overload capabilities can be detrimental.

Some drives offer monitors that will track the peak current during each run state and inform the user at what frequency the drive was operating at when the peak was hit. If your VFD offers this kind of information, it may be a good part of vetting the health of the drive to run the application and let the drive tell you the peak current pushed through it during a typical operation.

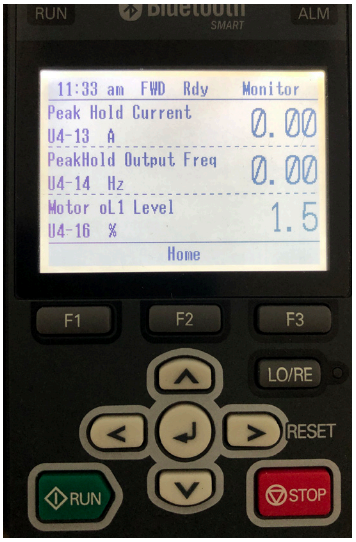

Figure 8: VFD Keypad showing overload level

Control and power connections can become loose due to vibration and usage.

Thermal scanning for all power connections are part of a good preventative maintenance plan.

CHECK THE CONNECTIONS

Why check all of the power and control connections on your VFD? Weren't they properly torqued down to exacting specifications during install? Well we hope they were. All the more reason to have personnel that are factory vetted performing the VFD installation. But due to vibration and usage, the control and power connections may become loose.

Figure 9: Connections may become loose due to vibration and usage

What kind of issues can a loose control connection create? Most control connections are of low power types, like 24Vdc or 4-20mA, for example. The loose connection can cause intermittent or inappropriate operation of the application.

Loose power connections are a whole different story. Due to the larger currents passed through power connections, loose connections can cause heat and even a combustion issue. When a power connection is loose, there is less connection area passing the current between conductor and the connection surface. This increases the heat produced by the current passing through, a type of bottle neck. Think of it as trying to pass too much current through an undersized conductor (thin wire).

The result is a level of heat that will cause thermal damage and possibly fire. It is why part of any good preventative maintenance program is using thermal scans of power connections to look for inappropriate levels of heat around power connections.

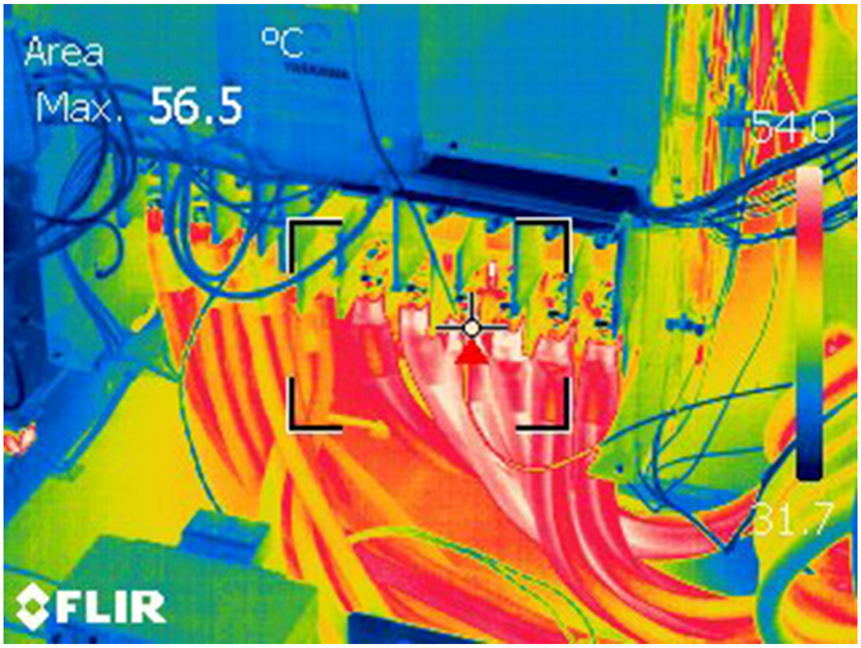

Figure 10: Thermal scans can be used to detect inappropriate heat around power connections

Replacing components nearing the end of their service life during planned shutdown is good practice to keeping your VFD up and running.

REPLACING COMPONENTS

I am of the school of "if it isn't broke, don't fix it". However, when it comes to an important application, and let's face it, what application isn't important, it may be prudent to replace components that are nearing their service life expectancy when the chance is there, a chance like a yearly PM downtime or while changing something else about the application.

Modern VFDs offer some maintenance monitors that count down the expected life expectancy of major components like fans, contactors, capacitors, and output transistors.

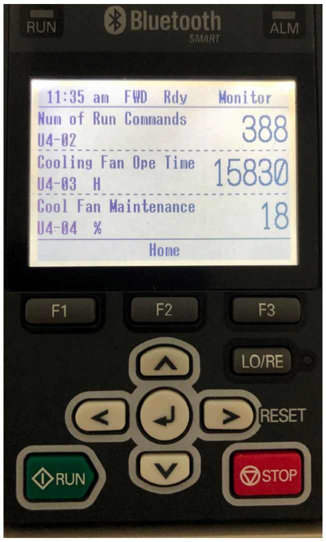

Figure 11: Cooling Fan operation time monitor

FUTURE IMPROVEMENTS

It is now law that any technical article published must at least mention Artificial Intelligence. Just like the rest of the world, AI may become a facet of Preventative Maintenance.

As with other uses of AI, the more information, in this case application, drive, and motor performance information, the better AI will be in predicting component failure. Using all the information, like current, temperature, bus voltage, for example, the VFD will be able to warn of impending issues.

Think of it like a little professor inside the drive watching bus ripple or overload frequency and helping the user catch anything out of the ordinary. When will we see this AI as a feature of the drive? Maybe not tomorrow, but sooner that you think!

CONCLUSION

A VFD all by itself on an application can be a big win for energy savings due to the nature of how it can run the motor to only meet the load demands. However, there are additional things such as motor sizing, cable selection, auto-tuning, and energy saving functions that can further the energy savings and enhance the return on investment.

Preventative Maintenance is, of course, part of every good VFD installation. Mitigating heat issues by maintaining proper operation of heatsinks, fans, and the application itself, will make it so that you only have to worry about your VFD once in a while.

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Yaskawa is the leading global manufacturer of low and medium voltage variable frequency drives, servo systems, machine controllers and industrial robots. Our standard products, as well as tailor-made solutions, are well known and have a high reputation for outstanding quality and reliability.

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