



Mechanical & Electrical

FALL EDITION



Contents

- 3** — How to ensure reliable motor operation with variable frequency drives
- 14** — How choosing the best grease can reduce mechanical failures
- 21** — Revolutionizing Gas Filling: The Success of Dry Vacuum Technology
- 25** — Design first: the foundation of electrical safety in industrial facilities
- 28** — NFPA 70E requirements: The baker's dozen of electrical safety
- 39** — What's your electrical maintenance plan? Learn how to build one

How to ensure reliable motor operation with variable frequency drives

☰ [Back to TOC](#)

A variable frequency drive (VFD) is the industry's standard technique for controlling the speed and torques of induction motors. To ensure reliable operation of motors with VFDs, the user must consider various measures and best practices.

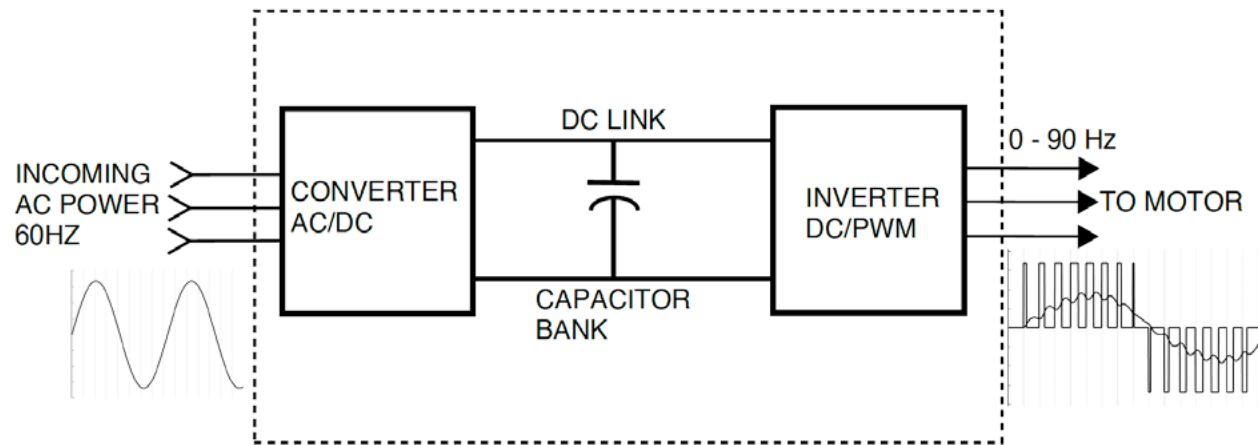
Induction motors use the principle of electromagnetic induction to convert electrical energy to mechanical energy to rotate or turn the motor shaft. And although a variable frequency drive (VFD) can be integral to efficient motor operation, there are many factors to consider before you install one.

VFDs can be used to adjust the frequency and voltage of the alternating current (ac) power applied to the stator and then control the speed, torque and power of the motor. There are two main control methods that VFDs use to control the operation (speed, torque, power) of an induction motor: vector control and scalar control. While the vector control provides more precise speed control, it is more complex and adds additional feedback devices monitoring the shaft rotation. Thus, the most common and widely control method used is scalar control, also known as volts per hertz or V/f.

The main components of a VFD (see Figure 1) are:

- The ac-dc converter, which converts the incoming 60 Hz ac signal to direct current (dc) using rectifiers or insulated-gate bipolar transistors (IGBT).

- A dc link that smooths the dc signal using capacitors.
- A dc-ac converter that takes the dc and converts it back to ac at the desired voltage and frequency using pulse width modulation (PWM) technique with IGBT transistors.



As energy saving and more operation controls are desired, VFDs are becoming more widespread for driving motors in industrial and commercial facilities.

When using VFDs, there are extra factors and considerations to be taken for a reliable facility and system operation. Understanding and applying these factors will help prolong the lifespan of the motors and VFDs as well as minimizing shutdowns due to unexpected equipment failure.

The following are key factors and best practices to consider when selecting or using motors with VFDs.

Figure 1: Variable frequency drive block diagram. Courtesy: CDM Smith

How to coordinate VFDs with the driven equipment

For the equipment to operate reliably and properly, it is essential that the motor characteristics and application be coordinated with the driven equipment during the motor and VFD selections. In addition to voltage and phase compatibility of the motor and VFD, the VFD needs to be compatible with the motor and the driven equipment.

One main characteristic is the torque application, for example centrifugal fans and pumps are variable torque application and a normal duty VFD is adequate, while conveyors and positive displacement pumps are constant torque application and require heavy- or severe-duty rated VFDs, which have higher overloading capability.

An additional application to be discussed is the lowest speed the load will be operating at and making sure the motor turndown ratio can accommodate that application and can be safely operated at that low speed without overheating and compromising the operations. For example, a 10:1 turndown ratio for a 3,600 revolutions per minute (rpm) motor is 360 rpm.

Another important item is the motor full load amperage (FLA) and making sure the VFD can provide equal or greater current than the motor FLA. The motor horsepower should not be used to select the VFD and the motor service factor should not exceed 1.0.

Choosing the proper environment for VFDs, motors and drives

Like with anything else in industrial facilities, such as structural supports and pipes or other electrical equipment, motors and drives must be suitably rated for the environments in which they are installed. Process areas in industrial facilities can be subject to

physical damage, sprayed or standing water, high humidity, dust, corrosive chemicals and extreme temperatures, all of which can damage or rapidly degrade VFDs containing sensitive electronics.

The VFDs can be protected from their environment with a properly rated National Electrical Manufacturers Association (NEMA) enclosure, such as 4X stainless steel. However, these enclosures come with their own drawbacks. They have larger footprints, add additional cost and make it harder to remove excess heat generated by the VFD. For these reasons, it is recommended to install VFDs in dedicated, climate-controlled electrical rooms (see Figure 2).

Equipment heat degradation

When it comes to electrical and mechanical equipment, one of the biggest reasons for degradation of equipment is heat. The power electronics that make up VFDs generate heat and if this heat builds up within the VFD enclosure, the components can be damaged, operate inefficiently or cause the VFD to shut itself



Figure 2: Variable frequency drives installed in environmentally controlled room. Courtesy: CDM Smith

down for protection, forcing equipment downtime. Most VFD enclosures are equipped with fans and air filters to ensure the flow of clean air across the components.

As with home air filters or on-facility heating, ventilation and air conditioning equipment, the air filters will become clogged with particulates and dust, inhibiting airflow. Even when the VFDs are installed in an air conditioned space and the heat cannot escape the VFD enclosure, the damage will be done.

It may seem like a small thing, but changing the air filters on VFD enclosures regularly, as well as verifying the functionality of the fans and ensuring a clear space around the vents can extend the longevity of the VFDs.

When a VFD is installed in a harsh environment, it is important to remember that the NEMA-rated enclosure only provides protection when used and maintained appropriately. For example, a NEMA 3R outdoor enclosure protects the VFD from rain, but if the door is left ajar, it may as well have a NEMA 1 enclosure rating. Enclosures that provide stronger protection (3R, 4X, 7), tend to have more and heavier duty latches and bolts to keep the doors closed.

These are the areas where the environment can do the most damage to the VFD, so it is crucial for the longevity of the drive to make sure the doors stay closed, ensuring the integrity of the enclosure is maintained.

The importance of disconnecting contacts

Safety disconnecting means are required for each motor to be located within sight of the motor location, per NFPA 70: National Electrical Code Article 430.102. However, a

code exception is included that allows for the elimination of the motor disconnect if it is impractical or would introduce additional hazards, with an informational note clarifying that motors associated with VFDs meet this condition.

Despite the exception bypassing the need for a separate disconnect, many facilities' operational staff still prefer to have them, as they can provide a safer working environment allowing technicians to open the disconnect and maintain visuals on the disconnect while they service equipment.

A consideration when including local motor disconnects for motors driven by VFDs is to include auxiliary "break-before-break" or "early break" contacts within the disconnect switch to connect to the VFD and send a signal to the VFD immediately to shut down before the switch is opened. When the motor load is abruptly removed from the load side of the VFD while running, transient voltage and current spikes are created that can damage the transistors in the drive.

Rarely, the damage can be rapid and catastrophic, destroying the drive, but more likely the surges will wear down the VFD electronics, lowering their lifespan. The addition of these auxiliary contacts allows the drive to shut off its output immediately before the load is lost, saving it from unwanted transients. For existing installations without early break contacts, it may be worth stopping the VFD before opening the local disconnect (see Figure 1).

Gauging VFD and power quality

Harmonics in electrical systems are high-frequency sinusoidal currents that get added to the main power wave at multiples of the power frequency (60 Hz). They are created when ac power is converted to dc, which is the first stage of a VFD.

The concern with harmonics is often on their upstream effects, such as increased heating of transformers, nuisance tripping or issues with the electric utility provider. With VFDs, there are also concerns with power quality downstream. As mentioned above, the ac output of a VFD is constructed from the dc bus by PWM, rapidly turning the output transistors on and off. The high-speed switching interacts with the inherent inductance and capacitance of the cable feeding the motor and the motor itself to create what are known as standing waves or reflected waves. The standing waves cause the cables and motor to experience a higher voltage than normal, sometimes higher than the rating of the insulation, causing premature breakdown of the insulation.

There are multiple causes and symptoms involved with power quality issues from the VFD outputs, so there are multiple tools to address them and the best ones will depend on the situation. To minimize reflected waves, it is best practice to keep cable runs between the VFD and the motor as short as possible.

Added length of cable increases the inductance and capacitance, also increasing the magnitude of the reflected waves. The high-frequency noise carried by the cables creates electromagnetic interference (EMI) that can affect nearby analog signals runs with power cable, like pressure or level transmitters signals. Using multiconductor, shielded VFD cable, especially when installed in cable tray or PVC conduit, will make sure those adjacent analog readings are not impacted by the EMI generated in the VFD cable.

With the prevalence of VFDs, industry leaders and motor manufacturers have designed motors with more robust insulation to be used with VFDs, as described in the NEMA MG1 standard and are labeled as inverter-duty.

The VFD output also induces stray currents in the rotor that discharges through the shaft and damaging bearings, causing vibrations bearing failure. To prevent stray currents and the unnecessary vibrations, heating and damage they cause, motors should be equipped with shaft grounding straps, insulated bearings or both.

Whether some of these extra measures are necessary will depend on individual circumstances, such as the VFD manufacturer and technology used, facility layout, motor size and process criticality. Proper protection will curb the negative effects from the PWM output of the VFD and extend the life of the motor.

Other filtering equipment such as sine wave and DV/DT filters may be used to eliminate transients between the VFD and the motor and protect the motor windings from voltage spikes. It is important to consult the VFD and motor manufacturer for recommendations on the proper filtering selection based on individual applications and setup.



*Figure 3: Totally enclosed, fan-cooled motor on variable frequency drive with winding thermal protection and safety disconnect.
Courtesy: CDM Smith*

Monitoring and protecting VFDs and motors

Similar to VFDs, heat buildup is an issue for the motors. The flow of electrical current is resisted by the motor windings, converting the electrical energy to thermal energy. In a motor, a fan blade is attached to the rear of the shaft to expel hot air while the motor is spinning. This kind of motor construction is called totally enclosed, fan-cooled (TEFC) (see Figure 3) and it works well to remove excess heat from the bearings and stator at rated speed.

However, when used with a VFD to reduce the speed of the motor, as the fan is attached to the shaft, it will spin slower, which reduces the effectiveness and allows heat to build up. Generally, it is not recommended to operate TEFC motors below 25% of rated speed without additional cooling or verifying the rating of the motor.

For motors driven by VFDs especially, monitoring the temperature can help identify problems before they do too much damage. The most basic method is to install thermostats constructed from bi-metallic switches around the stator windings. As the two distinct types of metals heat up, they expand at different rates, eventually breaking contact, letting the control circuit know the motor is getting too hot.

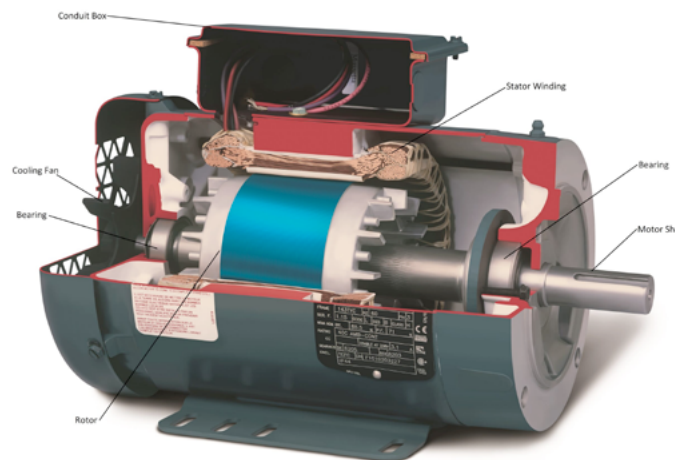


Figure 4: Cutaway view of an induction motor. Courtesy: ABB

However, this discrete signal occurs only after reaching the setpoint and provides no additional diagnostics. Another method is using resistance temperature detectors that

continuously vary their resistance as the temperature changes, which can be sensed and monitored remotely, giving more opportunity for proactive intervention to extend the life of the motor (see Figure 4).

If the facility has a supervisory control and data acquisition system that allows the networking of VFDs via Ethernet or fiber, the additional VFD parameters, signals and statuses can be remotely monitored, such as real-time voltage, current, power, output frequency, motor speed, motor torque and runtimes. This kind of data is valuable for operators and maintenance to ensure the health and longevity of their equipment.

Routine VFD and motor maintenance considerations

All equipment deteriorates over time, so it is crucial to test and maintain it regularly to ensure it remains in good condition. Performing proper maintenance is another key item that enhances the reliability of motors/VFD operations. This includes preventive maintenance and visual inspections, cleaning filters and vents from dust and debris. Motor and VFD inspections include checking for proper ventilations, unusual noises and smells, corrosion and excessive vibrations. Some preventive maintenance measures include applying lubrication, tightening connections and replacing parts.

For detailed maintenance and testing procedures, consider following the manufacturer's instructions and adhering to the recommended maintenance guidelines from the InterNational Electrical Testing Association and NFPA 70B: Standard for Electrical Equipment Maintenance.

Taha Mohammed and Cole Casteel

Taha Mohammed, PE, and Cole Casteel, PE, are electrical engineers with CDM Smith.



Leybold Dry Vacuum Pumps

The Clean, Reliable Choice
for Gas Filling

OE Meyer, a leading U.S. supplier of industrial and specialty gases, transformed its operations by replacing oil-sealed pumps with Leybold's **VARODRY dry screw vacuum** technology.

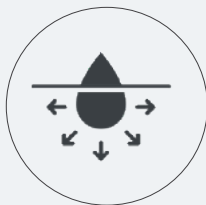
The switch eliminated costly oil leaks and safety hazards, cutting nearly **\$40,000 annually in oil and maintenance costs** while **improving uptime, efficiency, and workplace safety**—especially critical for medical gas filling.



[Learn More](#)

100%
OIL FREE

Oil-free technology



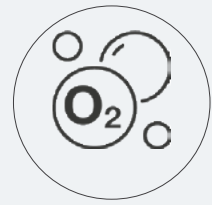
Minimal risk of
contamination



Low-maintenance and
operational efficiency



Sophisticated rotor
design for high energy
savings



Third-party certified
O₂ safe

How choosing the best grease can reduce mechanical failures

☰ [Back to TOC](#)

Choosing the right grease and proper grease application are essential for implementing a sound lubrication strategy and preventing costly mechanical failures.

One of the most important components in any manufacturing plant is the lubrication of its machinery and equipment. Lubricants play a vital role in the performance and longevity of any machinery.

Unfortunately, a significant percentage of mechanical failures are caused by lubrication issues, often due to improper grease selection, contamination or breakdown under stress. Bearings seize, robotic joints fail and construction equipment grinds to a halt, not because of mechanical defects, but because the wrong grease was applied or the right grease couldn't withstand extreme conditions.

The good news is that these failures are entirely preventable with the proper grease selection and application.

Understanding the science behind grease and how its key components impact load performance and shear stability in varying applications can help optimize equipment performance and liability. Choosing the right grease helps avoid common lubrication pitfalls, reducing failures and improving machinery longevity.

The science behind grease: a precision-engineered solution

Whenever a new machine or component is installed, one of the first things to be ad-

dress is the type of lubricant or grease to use. Lubricating grease is a semi-solid structure that consists of three main components: oil, additives and thickener and it is used primarily to reduce friction in several critical components and applications.



Understanding the key properties of grease can help operators in the selection of the right lubricant for their operational needs. There are three main properties:

Base oil type: The base oil type is crucial in selecting the right grease for machinery as it determines the grease's performance under different operating conditions, such as temperature, load and speed. Base oils make up 80% to 90% of grease, so their properties impact the grease's ability to lubricate effectively. The American Petroleum Institute has five base oil designations and characteristics:

- Group I, II and III are base oils derived from crude oil, suitable for general applications but can break down at extreme temperatures or loads.
- Group IV and V are synthetic base oils that are ideal for a wide range of temperatures and extreme conditions, providing greater resistance to oxidation, tempera-

Figure 1: A ball wear test shows the wear scar measurement on a lubricated surface. A smaller wear scar indicates better protection against metal-to-metal contact. High-performance extreme pressure greases with molybdenum disulfide or other anti-wear additives help extend component life by reducing friction and wear. Courtesy: CITGO Petroleum

ture changes and wear.

Base oil viscosity:

Grease is made up of 80% to 90% oil, which makes the viscosity of the base oil crucial. Viscosity affects the oil's resistance to flow and plays an important role in maintaining proper lubrication, preventing wear and reducing excessive heat.

Additive package: Additives enhance grease with antioxidants and corrosion inhibitors, modify base oils properties with pour-point depressants and viscosity index improvers and provide grease with extreme pressure characteristics and metal deactivation.

Consider extreme pressure greases

An extreme pressure (EP) grease is specifically formulated to handle heavy shock loads and high-pressure environments, providing protection against wear, contamination and environmental factors while prolonging the life of bearings and other components.

EP greases are enhanced with additives like graphite and molybdenum disulfide

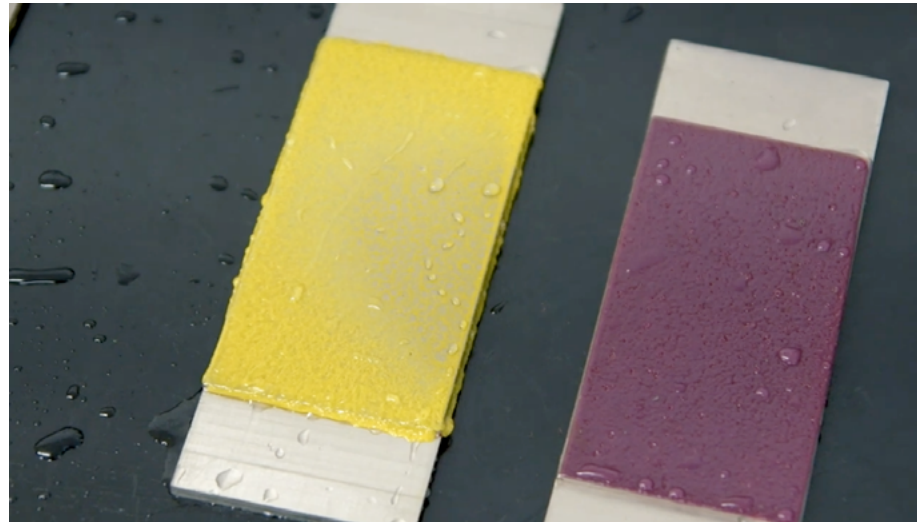


Figure 2: The grease on the right maintains its protective layer, resisting removal under high-pressure water exposure, while the grease on the left shows significant breakdown. Choosing grease with strong water spray-off resistance ensures continued protection in wet conditions and prevents premature lubrication loss.
Courtesy: CITGO Petroleum

(known as “moly”), creating an extra barrier between machine surfaces. These greases can withstand extreme temperatures and pressures and offer water resistance to wash-out and corrosion in moist environments.

EP greases are rigorously tested for water resistance and pressure handling ability, with grading based on performance.



Why greases fail: common lubrication pitfalls

When implementing an ineffective lubrication strategy, plant operators often make mistakes that can negatively impact equipment wear, lifespan and overall efficiency. These errors can also lead to costly repairs and unplanned downtime.

Figure 3: Grease color is often determined by dye additives and does not indicate performance characteristics. The choice of thickener, base oil and additives is what determines grease suitability for different applications. Courtesy: CITGO Petroleum

- **Failure mode 1:** Lack of EP protection: High-load applications such as robotic automation, construction equipment and hydraulic systems require EP additives to prevent excessive wear. Non-EP greases without moly or calcium sulfonate shear under pressure, leading to metal-on-metal contact and overheating.
- **Failure mode 2:** High-temperature breakdown: An important indicator of quality in grease is its dropping point — the temperature at which it passes from a semisolid

state to a liquid under defined test conditions. A grease should have a dropping point that is safely above the highest operating temperature to avoid run-out during application. Using a grease that exceeds its dropping point leads to the grease losing its ability to lubricate and creating wear and potential machinery failure.

- **Failure mode 3:** Contamination and water washout: Using greases with low water resistance can create washout and increase risk of contamination. Water can weaken the structure of grease, washing away lubrication and leading to higher friction and wear.

How high-performance greases improve equipment longevity

Implementing a sound lubrication approach featuring the right high-performance greases can help operators enhance equipment longevity, as these formulations offer specialized protection against common wear factors. Key benefits include:

- EP greases with moly additives reduce wear under extreme pressure, making them ideal for heavy equipment, manufacturing machinery and industrial robotics.
- Calcium sulfonate thickeners provide built-in EP protection, ideal for industrial bearings and hydraulic systems.
- Synthetic base oils prevent oxidation and breakdown in extreme heat, while lithium- and aluminum-complex greases have higher dropping points to ensure continuous lubrication.
- Polymer-enhanced greases improve water resistance, preventing contamination-related failures.



Best practices for grease selection and application

To maximize machinery performance, efficiency and lifespan, operators should follow these best practices when selecting and applying grease:

- **Follow original equipment manufacturer recommendations:** It is recommended to follow manufacturer guidelines or consider load, temperature and environmental conditions when choosing a grease.

Figure 4: Routine maintenance and proper grease application techniques are essential for ensuring equipment longevity. Selecting the right grease and applying it at the correct intervals prevents premature wear and unplanned downtime. Courtesy: CITGO Petroleum

- **Choose the right formulation:** It's important to choose the right grease for the application, such as EP greases for high load conditions and synthetic-based greases for extreme temperatures.
- **Implement a preventive lubrication strategy:** Regularly monitoring and addressing potential contamination risks will help maintain ideal grease performance.

Lubrication as an engineering strategy

Lubrication is not just a maintenance task; it is a critical engineering strategy that directly impacts equipment lifespan, operational efficiency and cost savings. Proper grease selection is crucial in reducing premature equipment failures, as it ensures optimal performance and longevity of machinery components.

With the right grease, equipment runs longer, breakdowns are reduced and businesses save money. Instead of treating lubrication as an afterthought, companies should integrate lubrication into their performance and reliability strategies.

To take lubrication strategy to the next level, assess a production facility's current grease selection and determine if it is optimized for load, temperature and contamination risks. Upgrade to an EP, high-temperature or polymer-enhanced formulation where needed.

Brandon Thompson

Brandon Thompson is a product manager at CITGO Petroleum.

Revolutionizing Gas Filling: The Success of Dry Vacuum Technology



Leybold dry vacuum pumps enable better operational safety and savings

Dry vacuum technology presents many benefits for industries with its proven design for reliable performance and increased uptime for various applications.

OE Meyer, a prominent leader in specialty gases, residential and industrial propane, welding supply, and automation solutions in the Midwest United States, highlights the beneficial operational improvements it has seen by switching to Leybold's VARODRY dry screw vacuum pumps.

About OE Meyer

OE Meyer is a 100% employee-owned company based in Ohio, USA, with around seven different centers across the state. The company's commitment to providing top-quality products and services to its customers has helped it flourish and maintain its proud legacy for over a century.

OE Meyer primarily supplies industrial and specialty gases, welding, and fabrication equipment to businesses. The company supports various industries, from manufacturing and agriculture to hospital and beverage service applications. Whether it's a start-up or an industry giant, OE Meyer is dedicated to offering the same level of personal service, on-time delivery, and quality product every time.

The challenge

OE Meyer focuses on gas filling, cylinder filling, medical gas filling, oxygen filling, inert gas filling, and industrial gas filling. The challenges with the company's previously-owned vacuum pumps and systems were notably centered around oil leakage, a concern that incurred substantial costs and posed safety risks in the work environment. Regular oil changes, costing approximately \$1,600 each, were a significant financial burden. Furthermore, the persistent issue of oil leakage became a hazard, leading OE Meyer to seek an alternative solution.

The Leybold solution

To keep up with operational needs and mitigate oil consumption and costs, a new vacuum system was needed. We introduced the Leybold VARODRY HD/O₂ dry vacuum pumps. The adoption of Leybold's VARODRY series of dry vacuum pumps marked a transformative shift in OE Meyer's operations. The VARODRY series has proven to be

quiet, clean, and efficient and also addressed the oil leakage issue experienced with previous installation. Opting for dry vacuum technology eliminated the risk of oil contamination and back streaming, providing a cleaner and safer work environment. Maintenance tasks, such as belt changes, now require 15 minutes per pump. More importantly, the VARODRY HD/O₂ seamlessly integrated into OE Meyer's current processes, leading to operational effectiveness and savings.

VARODRY dry screw vacuum pumps

Leybold VARODRY vacuum pumps have a robust and proven design with reliable performance and increased uptime for industrial applications. Designed to be energy efficient, the VARODRY series increases production yield and allows for continuous production in a demanding process with minimal risk of contamination thanks to modern, oil-free technology.

The outcome

OE Meyer's switch to VARODRY vacuum pumps resulted in savings of approximately \$19,200 in PFPE oil use alone. Additionally, the elimination of maintenance challenges associated with oil changes contributed to a further \$19,000 in savings. The VARODRY pumps have not only enhanced operational efficiency, but have also alleviated concerns and streamlined processes, making operations cleaner and more cost-effective.

Crucially for OE Meyer, where medical gas filling is a substantial portion of their business, the safety of their workers and facility is paramount when working with oxygen. Third party certification for operation in oxygen rich processes gave them peace of mind needed to make the switch to dry vacuum technology.

Hear from OE Meyer

"Regarding Leybold's services, our experience thus far has been positive. The customer support provided by their team has been timely, and our interaction with maintenance personnel has proven invaluable. Not only have we received effective solutions to our challenges, but we've also gained insights, tips, and tricks that enhance our ability to undertake future servicing independently. As a result, our overall satisfaction with Leybold's products and services remains high."



Compact and
easy to install



Minimal risk of
contamination



Oil-free
technology



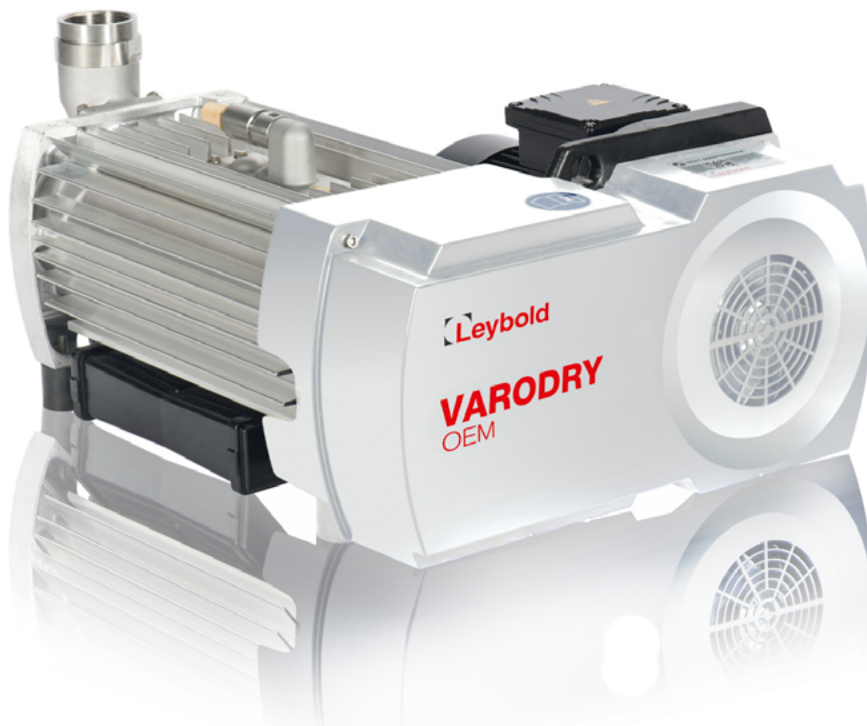
Oil-free
technology



Third-party tested
O₂ safe dry pump



Sophisticated rotor design
for high energy savings



Design first: the foundation of electrical safety in industrial facilities

☰ [Back to TOC](#)

Without the proper design, electrical safety cannot be achieved.

In industrial and manufacturing plants, electrical safety isn't just a set of procedures — it's built into the fabric of the facility and its systems. Proper planning and thoughtful integration of safety measures during the building's or system's design phase are critical to protecting personnel and maintaining smooth operations.

A manufacturing facility's staff can show off its adoption of NFPA 70E: Standard for Electrical Safety in the Workplace in many ways. Here are three key strategies for electrical system success:

1. Plan for both de-energized and live work

Safety-focused facility design starts with understanding operational needs and shut-down tolerances. While de-energized work is ideal, live work may sometimes be necessary to avoid service interruptions. Decisions about live work policies should influence system design, from phasing to temporary power conditions, and must be clearly documented in construction specifications.

Safe and efficient operations depend on the reliability of power systems, and maintaining that reliability starts with a robust electrical maintenance plan. NFPA 70B: Standard for Electrical Equipment Maintenance provides a systematic approach to ensure operational safety, minimize unplanned downtime and meet compliance requirements. As organizations embrace these guidelines, it's essential to balance safety and operational needs while addressing challenges like resource allocation and system complexity.

Table 2: This provides a reference table to NEC Articles for commonly used power cables. Courtesy: Peter Basso Associates Inc.

Table 2: Power cable quick reference

TYPE	CABLE DESCRIPTION	NEC ARTICLE
AC	Armored	320
MC	Metal-clad	330
NM	Nonmetallic-sheathed	334
TC	Power and control tray	336

2. Incorporate arc flash mitigation strategies

Arc flash hazards represent one of the most severe risks in electrical systems. Design engineers — specifically electrical engineering consultants — can reduce these risks by specifying advanced equipment and safety features. Technologies such as arc quenching relays, zone-selective interlocking and maintenance switches not only meet minimum requirements outlined in standards like NFPA 70: National Electrical Code but also go above and beyond to safeguard workers. Including arc flash analysis early in the project ensures the selection of devices with appropriate ratings and the identification of high-risk areas.

3. Design with maintenance and emergency preparedness in mind

Maintenance and safety overlap in facility design. Providing lockable switches, remote operation options for high-power equipment and disconnecting means in sight of critical systems ensures safe maintenance practices. Additionally, incorporating emergency lighting, accessible electrical rooms and clear labeling enhances both safety and operational efficiency during power outages or emergencies.

Electrical designers and ongoing facility personnel should have:

- Clear roles for responsible personnel.
- Detailed maintenance intervals based on equipment condition.
- Comprehensive documentation and record-keeping policies.

To elevate electrical safety, plant engineers and safety professionals must champion a design-first approach. By engaging with project stakeholders early in the design phase, referencing key standards like NFPA 70 and 70E and investing in advanced safety features, engineers can create facilities where safety is seamlessly integrated. Start by collaborating with your design team to identify areas where proactive measures can protect your workforce and streamline operations.

Amara Rozgus

Amara Rozgus is the Editor-in-Chief

NFPA 70E requirements: The baker's dozen of electrical safety

☰ [Back to TOC](#)

First published in 1979, NFPA 70E, Standard for Electrical Safety in the Workplace, has evolved tremendously over the years. The standard offers 13 electrical safety standards every worker needs to know.

When it comes to electrical safety, the National Fire Protection Association's (NFPA) 70E Standard for Electrical Safety in the Workplace is lengthy and informative. The current 2024 edition is 113 pages, three chapters and 19 Informative Annex sections.

Many sources of information and safety knowledge are embedded in these pages, but which ones should you really know the most about? Which parts are the most important?

1. Turn it off

Easily the most important requirement and aspect of NFPA 70E is quite simple: Turn it off!

Turning it off means to create an “electrically safe work condition” as defined in NFPA 70E Article 100 Definitions:

A state in which an electrical conductor or circuit part has been disconnected from the energized parts, locked/tagged in accordance with established standards, tested for the absence of voltage and, if necessary, temporarily grounded for personal protection.

Article 120, Establishing an Electrically Safe WorkCondition, provides guidance on what you need to know and provides step-by-step instructions on how to achieve a safe condition in which to work.

If you don't do anything else, study and understand all the elements of Article 120. It might just save your life.

2. Live-Dead-Live

You might call this more of the first rule, and even though it's part of the information in Article 120, make sure it's off before starting work. It's worth noting and repeating.

Absence of voltage must be verified through a three-step process, as stated in 120.6 Process for Establishing and Verifying an Electrically Safe Work Condition. How do you do this?

1. Check your voltage test instrument by applying it to a known source.
2. Check the conductor or circuit part you are about to work on.
3. Verify that your voltage detector still works by testing it a final time on a known source.

That's the live-dead-live process. It's critical to conduct this test every time.

Here's a tip. After going through the process of establishing an electrically safe work condition, including locking



Figure 1: Arc-rated clothing and rubber insulating gloves. Courtesy: Sermco Industries

it out, testing for the absence of voltage and temporarily grounded it for personal protection, step back and to the side, turn your head, and tap the bus or whatever you are about to work on with the back of your hand through your fingernails.

You're about to work on it anyway and, if for some reason, something went wrong and the part was still energized, you might receive a shock or worse, but you won't clamp down on the part, and you hopefully will survive the blast. Also, this is the point in your life when you might consider that career in accounting.

3. Be qualified

Only qualified electrical workers with the necessary training and experience should do electrical work, especially when working on or near energized electrical equipment. Even though employers are required to verify and document someone's qualifications and ensure employees are properly trained and equipped with the correct personal protective equipment. Who is the best person to determine whether you are qualified? Well, look in the mirror, because that would be you.

If you are asked to do something that involves electrical equipment, make sure you completely understand the definition of a qualified per-



Figure 2: Locks and tags applied during a maintenance outage.
Courtesy: Shermco Industries

son, found in Article 100 General Requirements for Electrical Safety-Related Work Practice, which states:

One who has demonstrated skills and knowledge related to the construction and operation of electrical equipment and installations and has received safety training to identify the hazards and reduce the associated risk.

Before you begin a task, ask yourself, “Am I qualified to do this?” If the answer is “No” or “I’m not sure,” then step back and reassess the situation. Don’t put yourself in harm’s way.

4. Lock it out/tag it out (LOTo)

This is part of establishing an electrically safe work condition, but it is such an important rule to follow every time you work on a piece of equipment.

Locking equipment or power sources in the off position is to prevent unintentional energization. It seems like a simple and reasonable thing to do, but it happens all the time. A worker doesn’t lock out a piece of equipment and gets hurt or killed.

The section 120.5 Lockout/Tagout Procedures is an excellent piece under Article 120. If you treat this section as a training and education guide for your personal use and understand it completely, not only will you be a safer worker, but you’ll also resonate as a leader to those around you. Treat it as energized until you know it’s not. Lock it out/tag it out.

5. Assess the risk

Always assess the risk before beginning any electrical work. Section 110.3(H) provides the essential elements of risk assessment, including:

- Key elements of the risk assessment procedure
- Potential for human error
- The hierarchy of risk control methods

Also refer to Informative Annex F Risk Assessment and Risk Control, which provides a wealth of information on the subject.

6. Know your boundaries

One of the most important aspects of electrical work is applying rules and actions about how close you can safely approach a piece of equipment without getting shocked or burned. You do this by performing an electric shock assessment, which is detailed in 130.4 Electric Shock Risk Assessment. This section details the electrical approach boundaries, including:

- Electric shock
- Limited approach
- Restricted approach

You'll find that these are the minimum safe distances for both qualified and unqualified personnel to safely work on or approach energized electrical equipment. If the 70E's rules related to these boundaries are followed, it will help protect employees from electrical shock and arc flash hazards. These are essential components of NFPA 70E and serve as a foundational element for creating a safer working environment.

Figure 3: Proper PPE is a must when working on energized equipment.
Courtesy: Shermco Industries

7. Personal protective equipment (PPE) is a must

When it comes to your last line of defense — personal protective equipment (PPE) —



you must read, understand and review 130.7 Personal and Other Protective Equipment. Within this section, you'll find specifics for selecting and using appropriate PPE, including arc-rated clothing, face shields, gloves and other protective gear. It's a very informative part of the standard — so know it well.

8. Plan your work

If you are a scuba diver, you have probably heard the phrase, "Plan your dive, dive your plan." The same goes for electrical work: You should always have a safety plan before commencing work, even for the most (perceived) trivial tasks. In the process of formalizing your plan and reviewing your tasks, you will go through several key safety steps. You can find a wealth of information in 110.3(I) Job Safety Planning and Job Briefing. The key safety planning components are:

1. Completion by a qualified person
2. Documentation
3. Additional information:
 - a. Description of the job and tasks
 - b. Identification of the electrical hazards
 - c. An electric shock risk assessment
 - d. An arc flash risk assessment
 - e. Work procedures, special precautions, energy source control
4. Job briefings
5. What to do when there are changes in scope

Planning your tasks is essential. Be sure you always have a plan in place.

9. Understand the calculations

As an electrical worker, you should know the significance of an incident energy value of 1.2 calories per centimeter squared (1.2 cal/cm²) to our industry. Why is this important? Because according to 130.5(E)(1), this is the point at which an arc flash boundary begins.

What's the significance? Incident energy is heat. Humans are extremely vulnerable when exposed to heat, especially at the temperatures that can be generated by elec-

trical equipment. The experts agree that if you limit your incident energy exposure to 1.2 cal/cm^2 , you most likely can recover from the exposure. It should be noted that it might not be without serious injury or even hospitalization, but it should be survivable.

Wear PPE to limit your exposure to arc flash hazards. NFPA 70E gives guidance on two methods for risk control: 130.7(C)(15) Arc Flash PPE Category Method and 130.5(G) Incident Energy Analysis Method.

The arc flash PPE category method requires you to identify the maximum available fault current, the maximum fault-clearing times, and the minimum working distances for the type of equipment you are working on. This is done using one of two tables: Table 130.7(C)(15)(b) for dc systems or Table 130.7(C)(15)(a) for ac systems.

The incident energy analysis method requires a calculation to determine the arc flash boundary and specific incident energy values at a defined working distance. This is the information you will see on arc flash hazard warning labels. For more information, see Informative Annex D Incident Energy and Arc Flash Boundary Calculation Methods.

10. Low voltage is dangerous

Low voltage does not mean low danger. From someone who knows firsthand what a 480-volt transfer switch can do to you, know that low-voltage equipment — even 120-volt equipment — is dangerous and can kill you.

Section 110.2(B) directs you to place energized electrical conductors and circuit parts that are “operating at voltages equal to or greater than 50 volts” into an electrically safe work condition.

When you step back and think about it, why would a threshold of 50 volts be a point of demarcation in a safety standard? Because that's the point at which you can experience severe injury or death. The message here is simple: Respect all levels of voltage you work on, whether it's a 120-volt residential circuit or a 138-kV power transformer.

11. Know your equipment

Remember that the definition in Article 100 of a qualified person is someone who has “demonstrated skills and knowledge related to the construction and operation of electrical equipment.” This means you must understand what you are working on before you work on it.

Electrical equipment is dangerous. It can kill you. Knowing the construction, operation, clearances, key components, insulation methods, interlocks, indicators, sights, sounds, smells is all part of being qualified and knowing what you are doing.

Take the time to study and understand how something works before you work on it. Go slow, and if you don't understand it, ask for help.

12. Maintenance is important

You should have a thorough understanding of the safety-related maintenance requirements in NFPA 70E, which can be found in Chapter 2 Safety-Related Maintenance Requirements. You should especially understand what “condition of maintenance” means, as electrical workers must be assured that equipment will operate as intended and as designed. Article 100 defines condition of maintenance as:

The state of the electrical equipment considering the manufacturers' instructions, manufacturers' recommendations and applicable industry codes, standards and recommended practices.

Section 130.5(B)(2) talks about arc flash risk assessment and the considerations you should take when estimating the likelihood and severity of injury or damage. It specifically states that you should consider the electrical equipment's operating condition and the condition of maintenance.

The condition of maintenance directly impacts system performance, reliability and, most importantly, the safety of those working on or near the equipment. We are seeing an increased awareness in the industry regarding maintenance and how the significance of proper electrical maintenance plays to the overall safety of personnel and equipment.

13. Have fun

While it's not specifically addressed in NFPA 70E, enjoying your work is important to your overall health and safety. If you enjoy what you do and go about your day with a good attitude, you will be more likely to:

- Engage in continuous learning and hone your skills
- Lead others through your experiences and demonstrate your skills
- Reduce your stress levels, enhancing productivity
- Work better as a team player
- Increase your creativity and problem-solving skills
- Be more productive, which translates to working safer

- Make the customer feel better, so if momma is happy, everyone is happy
- Manage the whole work-life balance aspect of your soul

Enjoy your job, learn about these important aspects of NFPA 70E, have fun — and do so safely.

Ron Widup, Shermco Industries

What's your electrical maintenance plan? Learn how to build one

☰ [Back to TOC](#)

Businesses need an NFPA 70B-compliant electrical maintenance plan to ensure operational safety and reliability to protect their people, property and processes

Safe and efficient business operations depend heavily on the reliability of power systems. In the United States, NFPA 70B: Standard for Electrical Equipment Maintenance outlines the requirements for an effective maintenance plan for the practical safeguarding of persons, property and processes.

Power system owners and operators now may be expected to meet this standard — along with NFPA 70: National Electrical Code for any new installations and NFPA 70E: Standard for Electrical Safety in the Workplace when designing and implementing maintenance plans.

Even if equipment is installed correctly, it may not be considered safe to operate unless it is maintained according to the manufacturer's instructions or industry-accepted practices in a manner consistent with NFPA 70B. Owners should be aware that the Occupational Health and Safety Administration (OSHA) can now request documentation that complies with NFPA 70B during site audits and for various certifications.

The primary objective of a robust maintenance planning process is to develop an electrical maintenance plan (EMP) that delivers operational safety and optimal reliability while minimizing the operational cost of ownership. NFPA 70B provides a standard that, when followed, assists equipment owners and maintenance teams in this critical endeavor.

NFPA 70B-2023 for electrical maintenance plans

The NFPA 70B standard describes a systematic approach to electrical system maintenance, starting with the creation of an EMP and emphasizing the importance of preventing unplanned equipment failures to help drive safe operations and minimize downtime for greater efficiency. It outlines the requirements for an effective EMP, including:

- Roles of responsible personnel.
- Survey and analysis of electrical equipment.
- Documented maintenance procedures.
- Plan of servicing.
- Records-retention policy.



Figure 1: NFPA 70B assists equipment owners and maintenance teams in the development of electrical maintenance plans that deliver operational safety and optimal reliability while minimizing the operational cost of ownership. Courtesy: ABB Electrification, Service Division

The 2023 revision, which converted the previously published guide to a standard, provides detailed installation and operating condition-based maintenance intervals for many common types of electrical equipment. The condition assessment of the equipment is critically important to the EMP and, ultimately, to the total cost of ownership. The document defines three types of equipment conditions, with the highest of the three categories driving the maintenance interval per NFPA 70B, Sections 9.3.1, 9.3.2 and 9.3.3:

- Equipment physical condition.
- Criticality.
- Operating environment.

In addition to guidance on when the maintenance interval should occur, the standard details when system studies should occur, the content of the maintenance work scope and the type of testing that is approved (NFPA 70B, Chapter 6, Chapters 11 through 36 and Chapters 7 and 8, respectively).

Electrical maintenance plan design

Using NFPA 70B as a guide, let's explore how an organization creates and executes an EMP and what challenges should be considered before beginning a maintenance planning project.

Step 1: Complete power system site assessment

The first major step in designing a maintenance plan is a complete power system site assessment per NFPA 70B, Section 4.4.1. Each piece of equipment must be evaluated for its condition as defined in NFPA 70B, Chapter 9 of and any other parameters that impact safety and operational efficiency. Equipment characteristics, age and maintenance history may all impact the need for maintenance activities.

Challenge 1: Resource allocation: Allocating sufficient resources, including personnel, time and budget, for the development and implementation of an EMP can be challenging, especially for organizations where resources with the correct skill set may be

Figure 2: Original equipment manufacturer documentation and industry standards can provide data needed to develop an effective electrical maintenance plan. Courtesy: ABB Electrification, Service Division



limited. Personnel who develop and implement the EMP must understand the electrical equipment, its value to the process that it powers and the impact of the environment on that electrical equipment and its respective process.

Step 2: Define tasks and tests for each equipment scope of work

The tasks and tests for each equipment scope of work at each maintenance interval must be defined in detail according to NFPA 70B, Section 4.4.2. This is critical to determine the proper risk controls for any identified hazards, i.e., what safety measures must be taken should the required tasks expose personnel to electrical hazards, how long the tasks will take and how many trained employees will be required. This information will inform operational management about required shutdown times.

Challenge 2: Complexity of electrical systems: Many organizations operate complex electrical systems with diverse equipment, making it challenging to develop and document a comprehensive maintenance program that addresses the specific needs of each power system component in a cost-effective manner.

Step 3: Record keeping and review

During the execution of the maintenance plan, accurate and consistent records must be kept of what tasks and tests were carried out, their results and any discrepancies from plan (see NFPA 70B, Section 8.6).

Lessons learned and other findings must be documented and reviewed in an after-project review with enough time to plan or adjust before the next round. The ability to notice trends is important to assess

when the next maintenance activity is needed or when equipment may need to be replaced. Good trending depends on good record keeping.

Challenge 3: Compliance monitoring: Ensuring ongoing compliance with NFPA 70B standards requires continuous monitoring and updates to the maintenance program, which can be resource-intensive and time-consuming.

Step 4: Long-term record-keeping

Robust long-term record-keeping procedures must be developed or improved to



Figure 3: Single-source solution providers bring experience and expertise to help navigate potential roadblocks, identify cost-effective solutions and ensure the electrical maintenance plan meets reliability needs while keeping the total cost of ownership in check. Courtesy: ABB Electrification, Service Division

meet NFPA 70B requirements. This information is critical to retain and keep accessible. OSHA and other regulatory bodies will need these records to confirm the EMP is designed appropriately and has been executed per plan. Appropriate change management procedures must be followed to document adjustments and the impact of adjustments on the original plan considered.

Challenge 4: Change management: Implementing an EMP that meets the NFPA 70B standard may require significant changes in organizational discipline, culture, processes and workflows. Creating or updating the appropriate internal project management system can be a significant internal project in and of itself.

Electrical maintenance is flexible

The standard is not an inflexible document that defines only one way to do things.

NFPA 70B-2023 clearly states that it is not “intended to duplicate or supersede instructions provided by manufacturers.” This simple statement means that to adhere to the standard, the maintenance planning team must locate and synthesize original equipment manufacturer (OEM) documentation from different manufacturers and for a range of models potentially published over many years and with multiple revisions. Faced with this task for a complex power sys-

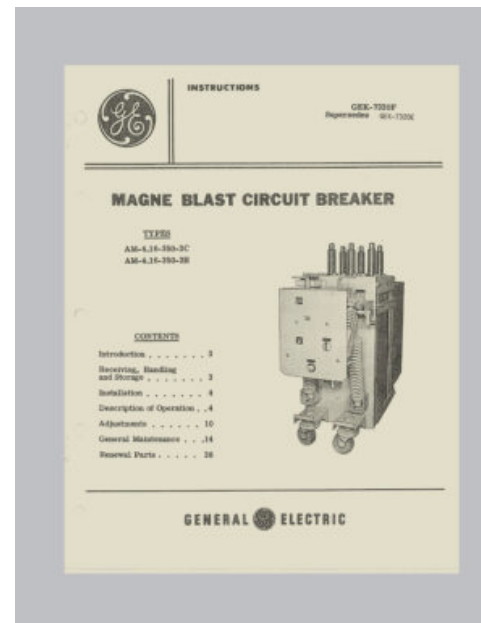


Figure 4: Power system technology from yesteryear is still highly prevalent and critical. Courtesy: GE/ABB Inc.

tem with a mixture of manufacturers and vintages, organizations can be forgiven if they seek an easier path.

How can you manage and reduce the impact of these challenges while designing an EMP? First, use data to improve the maintenance plan, interval and content. Data is the basis for any appropriate maintenance plan and a continuous feedback loop must be employed to improve the plan. This data can come from several sources.

- OEM documentation and industry standards.
- Lessons learned: Each round of maintenance performed on the power system will return a great deal of information about the equipment. Within a robust maintenance planning process, this information helps to determine if the maintenance intervals and scopes of work should be modified (see NFPA 70B, Section 9.1.2).
- Continuous monitoring: Modern equipment is often or can often be equipped to capture data. In some cases, the equipment can push this data to a cloud-based continuous-monitoring system that dynamically informs the maintenance plan. These systems are not new; however, with the prevalence of mobile devices and the comfort level rising with doing business digitally, these types of systems are becoming increasingly available. NFPA 70B-2023 allows continuous monitoring and predictive techniques to be used to determine maintenance intervals and what maintenance is performed, as shown in NFPA 70B, Section 9.1.1. These techniques must be based on OEM recommendations or accepted industry practices.

Ultimately, the maintenance planner must have a defensible and rational explanation for the plan that is put in place based on good data, manufacturer's recommendation

or accepted industry practice. During an audit, when discrepancies with how the NFPA standard may be interpreted and issues arise (and they invariably will), the auditor will look for the intention and thoughtfulness of the plan put in place.

While this may not change the outcome or what has transpired, it is far too easy to find examples of industrial accidents rooted in shortcuts taken to achieve cost reductions without understanding the consequences or what may be perceived as negligence.

A second approach to consider is partnering with a single-source solution provider. While designing the maintenance plan in-house can be tempting to save on near-term costs, consider the potential longer-term cost savings and risk control that come with hiring a qualified partner for the EMP creation process.

Maintenance organizations exist that have both deep maintenance and product manufacturing experience and that also possess the experience of having created similar plans successfully, avoiding costly mistakes and inefficiencies that can plague “home-grown” efforts. The expertise of these organizations may allow them to identify the most cost-effective solutions, navigate potential roadblocks quickly and ensure the plan meets reliability needs while keeping total cost of ownership under control. In the end, the upfront cost can be dwarfed by the long-term savings they bring through their specialized knowledge.

Future trends in preventive maintenance

Artificial intelligence and digital solutions are changing many aspects of our lives. Preventive maintenance is no different. Companies around the world are developing technologies to evaluate equipment operating conditions and model future poten-

tial needs to determine maintenance activities. Soon, based on predictive monitoring algorithms, operation processes may automatically adjust production schedules, contract maintenance work and order parts while adjusting for shipping constraints. This could be the last word in the just-in-time methodology.

Table 9.2.2 Maintenance Intervals				
Product	Scope of work	Equipment condition assessment		
		Condition 1	Condition 2	Condition 3
Switchgear	Visual inspection	12 months	12 months	6 months
	Cleaning	60 months	36 months	12 months
	Lubrication	60 months	36 months	12 months
	Mechanical servicing	60 months	36 months	12 months
	Electrical testing	60 months	36 months	12 months
	Special	60 months	36 months	12 months

Many technologies on the horizon or recently released enable such a digital future. Solid-state automatic transfer switches, industrial battery backup systems, on-site solar power generation and intelligent microgrids connected with aggregated virtual power plants and utilities are just some examples of these trends in the electrification space.

Table 1: An example of preventive maintenance intervals created using NFPA 70B-2023 Table 9.2.2 guidelines for equipment conditions. Courtesy: ABB Electrification Service

Additionally, many solutions are available to retrofit nondigital equipment to be a part of this digital future. Traditional equipment maintenance practices may seem like the most cost-effective solution, but they may also compromise performance targets such as reliability and safety, leading to economic setbacks as well.

Planning for maintenance

The importance of an effective EMP cannot be overstated. It is a critical component in ensuring the safety, reliability and efficiency of power systems. The NFPA 70B standard provides a comprehensive guide for creating and implementing an EMP, but it also presents several challenges, including resource allocation, system complexity, compliance monitoring and change management.

These challenges can be mitigated by using data-driven strategies, continuous monitoring and, most importantly, partnering with a single-source solution provider. These providers bring a wealth of experience and expertise, helping to navigate potential roadblocks, identify cost-effective solutions and ensure the plan meets reliability needs while keeping the total cost of ownership in check.

Power system owners and operators must take proactive steps now to design and implement an effective EMP. Don't wait for an audit or accident to highlight the importance of preventive maintenance. Contact a single-source solution provider and take the first step toward ensuring the safety, reliability and efficiency of your power systems. Your future self will thank you.

Ryan Roth

Ryan Roth is Global Product Manager for ABB Electrification Service.

CONTENT ARCHIVE

2024 Winter Edition

2023 Fall Edition

2023 Summer Edition

Mechanical & Electrical

Thank you for visiting the Mechanical & Electrical eBook!

If you have any questions or feedback about the contents in this eBook, please contact WTW Media at *marketing.wtwhmedia.com/contact-wtwh-media*

We would love to hear from you!

