APPLICATION EDGE

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TMEIC
We drive industry

SELECTING A MEDIUM-VOLTAGE VARIABLE FREQUENCY DRIVE

For an industrial or municipal user, selecting a Medium-Voltage Variable Frequency Drive (MV VFD) can be a difficult process. This paper will highlight several of the key factors to be addressed, and then suggest important criteria to be considered for a long-term successful drive selection.

Once a user has decided to pursue the many benefits of using an MV VFD (VFD for short), then his attention focuses on selecting the best equipment for his process. The simple graphic below illustrates the key factors to make that selection an ultimate success. Let's review each of these and their relative importance.

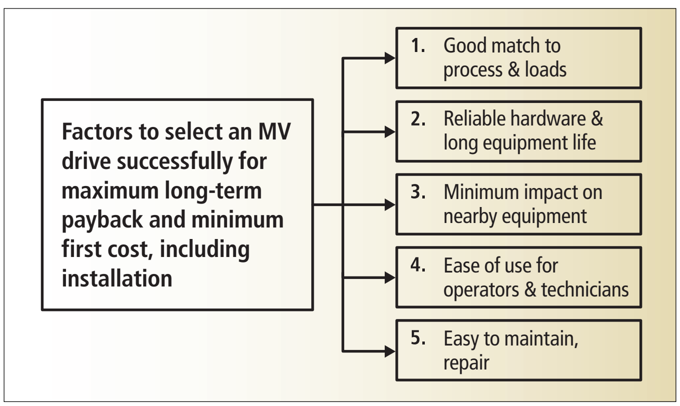

Figure 1. VFD selection success factors

1. Good match to process & loads.
This factor is the one most related to the work to be done, and is the one that requires a good technical background.

2. Reliable hardware & long equipment life.
The overall system should operate continuously without frequent breakdowns. To accomplish this, basic equipment design should maximize Mean Time Between Failures (MTBF). Maximum MTBF is designed in, not tested in or added by redundant components.

3. Minimum impact on nearby equipment.
The VFD will affect both electrical and mechanical systems in its environment.

4. Ease of use for operators & technicians.
This factor includes several areas, and when combined, they make the day-to-day operating personnel productive and content.

5. Easy to maintain.
No system is perfect, and all equipment requires some maintenance. Front component accessibility, rack-out components, etc. all contribute to rapid maintenance and repair.

Note that maximum long-term payback and minimum first cost, including installation, are the happy result of prioritizing all the other selection factors.

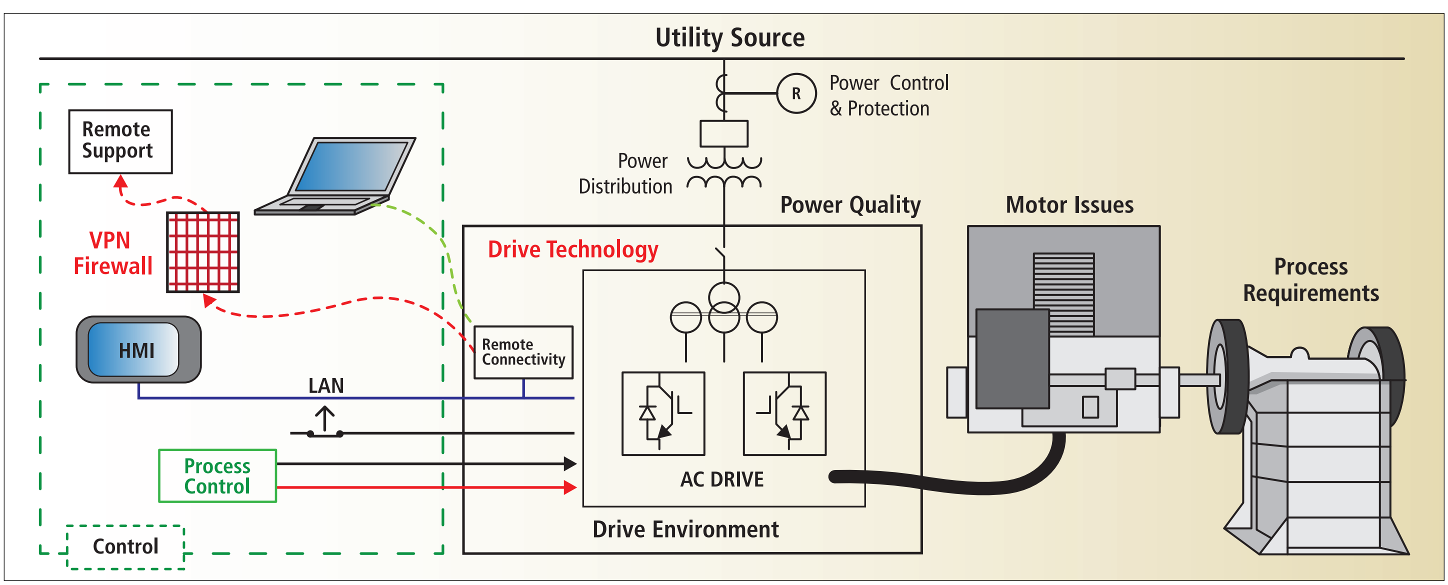

Figure 2. VFD System Diagram

Often, minimum cost and payback are purchasing department driven, and become primary selection factors. By default, then, the other critical primary selection factors are not given their proper priority. The result may be that neither minimum total cost nor good payback may be achieved!

Also, all of the above selection areas are related to application factors of the VFD itself and can be divided into two major groups: Electrical Factors and Design Installation Factors. In practice, these factors are somewhat interrelated, but it is helpful to look at them separately. Let's define these and then highlight the most important areas to consider, referring to the diagram in Figure 2 (pg. 1).

Electrical Factors

Electrical Factors require answers to these four questions:

1. **Process Loads**
   Does the VFD have both the peak and continuous capacity to support the process loads required?
2. **Drive System**
   Is the VFD compatible with the available electrical system and equipment and its requirements?
3. **Power System**
   Does the VFD produce a high input power factor and does it meet IEEE harmonics standards?
4. **Equipment Reliability**
   Does the VFD deliver the high 'Up Time' needed for industrial applications?

Load Factor 1: Load Type

Process loads are divided into two general types: Variable Torque (VT) and Constant Torque (CT). These refer to how the required motor and drive torque relate to motor RPM. The two simple graphs in Figure 3 below illustrate a typical VT load on the left and a CT load on the right. A VT load is typical of a pump or fan. Constant torque loads are of many varieties and include conveyors, grinders, crushers, piston pumps and others. Typically, VFD suppliers will provide 10% additional overload capacity above full torque and ampere rating for VT loads, and 50% additional capacity for CT loads, limited to a time of 60 seconds.

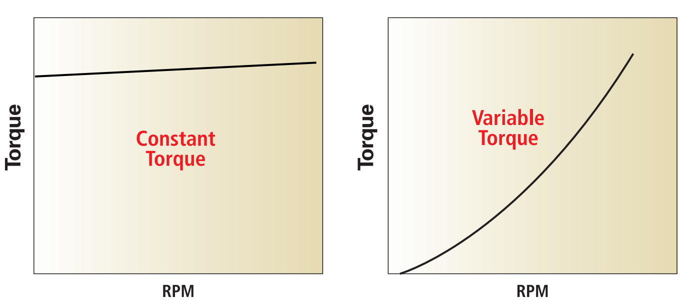

Figure 3. VT (left) & CT load profiles

Load Factor 2: Load Profile

Load mechanical horsepower (or kW) is the product of RPM (rotations per minute) and load torque.
For each motor design, this translates into motor voltage, frequency and amperes. See Figure 4:

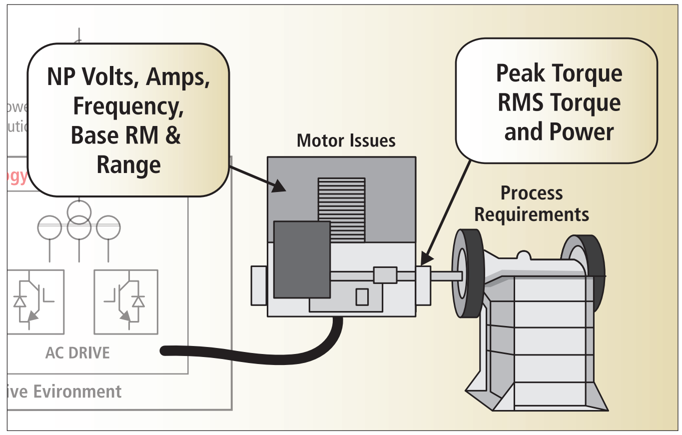

Figure 4. Motor and process load factors

The related term "duty cycle" refers to the time of varying values of torque and RPM, and their corresponding motor voltages and currents. The drive process determines this duty cycle, which allows both the peak and RMS (continuous) VFD loading to be determined. These are absolutely critical in selecting a reliable VFD for your application! As an example, refer to the mixer application duty cycle shown in Figure 5 below. This application requires both the motor and the drive to provide 200% normal nameplate torque during parts of the duty cycle.

This requires an oversized VFD output inverter section and a motor with at least 250% breakdown torque.

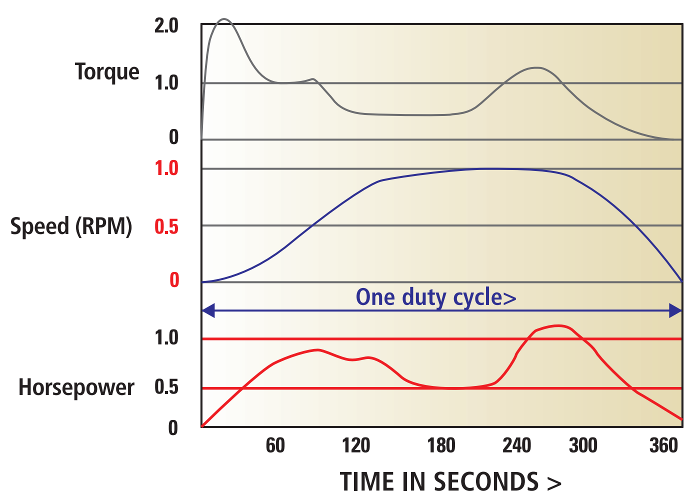

Figure 5. Typical rubber mixer duty cycle

Load Factor 3: RMS Loading

As a rule of thumb, the RMS (continuous) rating of the driven load is directly reflected in the rating of the motor (kilowatts or horsepower) and in the internal and feeder transformers of the system. The duty cycle in Figure 5 might result in a continuous rating of 2000 hp for motor and drive, with peak torque capability of 200% at any time during the cycle. Continuous RMS loading also determines the sizing of the current-carrying components of the system. These include switchgear and power system distribution equipment, transformer kVA, the continuous inverter and converter rating, and the size of the drive input and motor cables. Reference numbers #1 through #4 in Figure 6 show these areas.

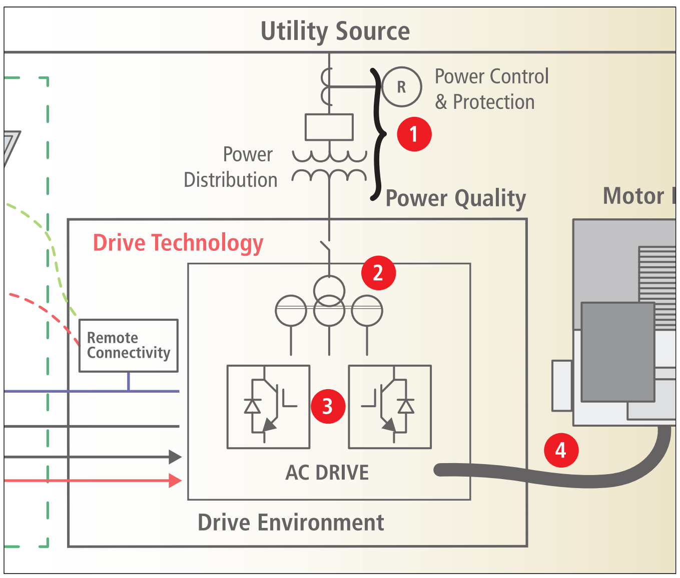

Figure 6. VFD system continuous loading areas

Load Factor 4: Regeneration

Some system loads require that energy be removed from the driven load to stop it, hold it back or reverse it. This drive feature is called regeneration. The energy from the load is returned to the utility system. Such loads include hoists, downhill conveyors, fans or pumps that are being over-driven by their gas or fluid, and others. Some modern VFDs offer this feature inherent in their design. Be sure to include this in your selection if needed.

Process Load Summary:

For proper VFD and system selection, determine and document the load type, load profile and duty cycle for the process to be powered, including regeneration requirements.

Drive System Factor 1: Isolation Transformer

Designs with isolation transformers should be favored over possibly lower-cost designs that eliminate this valuable component. Transformerless designs may be initially lower in cost, but are prone to misoperation and damage from lightning and line voltage surges. Output ground faults on the motor connections of VFDs on the same distribution network can trip adjacent units. Reports of multiple drives failing due to lightning surges are not uncommon, making isolation transformers an excellent investment.

Drive System Factor 2: VFD and Motor Voltages

The drive input voltage must match the available system voltage (#1 in Figure 7 below) and the nameplate voltage of the selected motor (#2 in Figure 7 below). If the motor is an existing motor, the drive output is selected to match that. The least expensive drive is usually one with system input and VFD output voltages equal to one another.

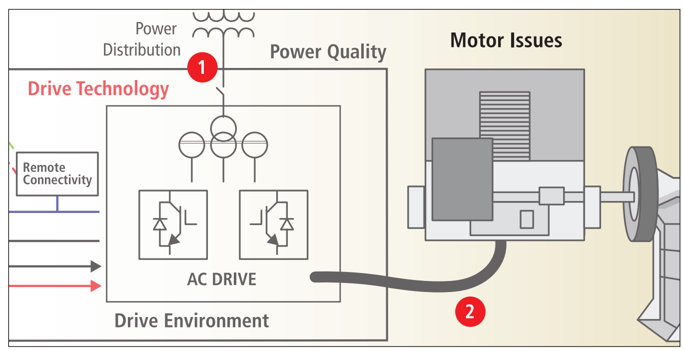

Figure 7. VFD and matching motor

Drive System Factor 3: Systems with New Motors

If the application requires a new motor, it is usually best to allow the VFD supplier to provide a matching motor. The motor voltage and ampere ratings determine the VFD rating required, so designing them together allows optimal equipment selection. This is particularly true when the motor will always be operated on the drive, and never connected to the utility directly. VFDs are available in proven designs up to 11,000 volts output, allowing the motor to match the most optimum drive. This can be an advantage. Otherwise a motor voltage rating is often defined by standard distribution voltages such as 4160 V.

Drive System Factor 4: Output Waveforms

Finally, the VFD voltage output waveform must be tolerated by the connected motor. Choosing a VFD with a smooth output voltage like the example in Figure 7 will virtually ensure compatibility with new or existing motors.

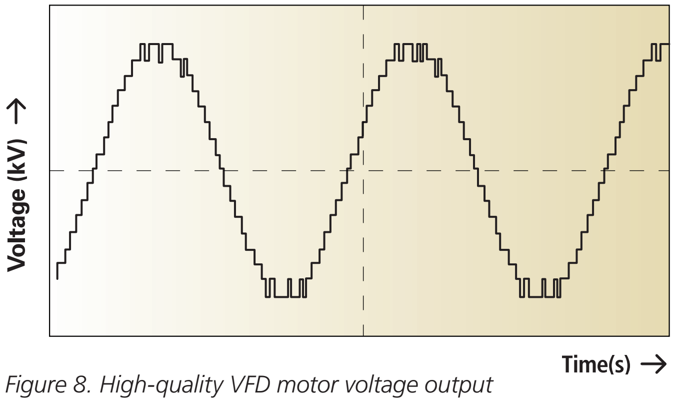

Figure 8. High-quality VFD motor voltage output

Drive System Summary:
In inquiries, define system voltage and motor voltage, and VFD waveform. State whether the motor to be powered is new or existing. Allow the VFD supplier to suggest what appears to be a non-standard motor voltage if the VFD and motor system can be more optimally selected. Finally, insist on an isolation transformer!

Power System Factor 1: Quality

The topic of "power quality" has two sides. As a power consumer, the VFD must be able to operate reliably in its power environment. As a "neighbor" to both in-plant and other utility users, the VFD selected must not cause other equipment to misoperate or be overloaded.

Power System Factor 2: Harmonics

When VFDs draw utility power, they create distorted voltages and currents, called harmonics. Harmonics are not at frequencies equal to the 60 Hz utility power. These harmonics can potentially cause misoperation and extra heating of other equipment connected to the same power system, including transformers and switchgear.

Recommendations for limits on allowable harmonic levels are contained in IEEE standard 519-2014. The most restrictive limit value for harmonic currents is 5% or less of fundamental current, and 5% or less distortion on voltages produced by this current. To avoid harmonic issues, VFD purchasers should require that these limits be met at the VFD without additional filtering.

In practice, such limits can be met by VFD equipment with either 24 pulse (or higher) diode converters (typically introducing 3% or less current distortion), or properly designed active rectifier converters, which can limit current distortion to 2% or less. Include vendor definition of harmonic data in the VFD requirements specs.

Power System Factor 3: Power Factor

One definition of power system power factor is "current efficiency" — the percentage of line power that actually produces useful work output. Modern voltage-source inverters actually reduce the power factor impact of a connected induction motor (not necessarily so with current source inverters!). For example, a direct connected motor may have a power factor of 0.85, while a drive powering an induction motor may present a power factor of 0.98 or even 1.0. This is a significant improvement!

Recent VFD designs with active rectifier converters can be set up to hold 1.0 (unity) power factor, or even be set up to export reactive power to correct the poor power factor of other nearby loads such as induction motors. In selecting a VFD, do a careful review of such advantages from such modern designs.

Power System Summary:
Carefully review VFD suppliers' power factor and harmonic impact on your power system. Take advantage of modern power factor correction capability provided by the latest VFD designs.

Equipment Reliability

In order to gain all the advantages provided by VFD equipment, they must be extremely reliable. At this point it is important to distinguish between equipment **reliability** and equipment **availability.**

Reliability Factor 1: Reliability

Reliability means continuous operation without interruption due to failures from misoperating or malfunctioning equipment. Reliability is built into the equipment design by minimizing component count and using all components at well under their published ratings.

The best measure of VFD reliability comes from actual fleet statistics, not from theoretical calculated numbers. Fleet data is only available if a manufacturer is so committed to quality that it does the hard work of keeping accurate records. Data must include both the number of VFD model fleet operating hours and the reported VFD failures resulting in equipment downtime. Then MTBF is a simple ratio of operating hours and failures during that same time. (TMEIC keeps such records, and the lowest MTBF of any of its models is 13 years based on fleet data).

Reliability Factor 2: Availability

Availability means that equipment will be available to operate at some level (not necessarily full performance) when needed. This could mean adding additional parts (which decreases basic reliability) to achieve hoped-for availability.

Equipment Reliability Summary:
Insist on measurable comparisons of VFD equipment reliability, based on fleet calculations.

DESIGN AND INSTALLATION FACTORS

Design and installation factors require answers to these questions:

1. **What physical environment is required by a particular VFD in terms of power control rooms, cooling and so forth?**
2. **Is any auxiliary equipment required to perform in the application?**
3. **How will the equipment be maintained, and what troubleshooting tools are available?**
4. **How will the VFD connect to the plant process system and operator controls?**
5. **What are the restrictions and requirements for connections to and from the VFD and its motor?**

We'll look at these one item at a time.

1. Physical Environment

Most VFD equipment is designed to operate in a clean environment, free of dust and corrosive gases. Temperatures in the VFD power control room need to be held to a range between 0 and 40°C, or sometimes 50° with derating. VFDs typically are rated at 1000 m altitude. Include room temperatures and site altitude in VFD selection specifications.

Air-cooled VFDs with integral transformers typically exhaust about 10,000 BTUs into their power control room for every 100 hp (75 kW) of the connected load. This requires about 0.85 tons of air conditioning for each 100 hp of load.

Above 4000 hp, it can be advantageous to change to water cooling for VFDs. The amount of heat remaining in the equipment room after heat is removed by coolant water is roughly 15% of an air-cooled drive. If the user site has available cooling water, this becomes even more attractive.

Lack of attention to dust removal from the environment can have serious consequences. Over time, this dust accumulates on the medium-voltage parts, electronics and heatsinks, and can result in unreliability and even equipment damage.

Physical Environment Summary:
During the purchase decision and installation, carefully consider the environmental arrangements for the selected drive. Discuss possible alternatives with the drive supplier.

2. Auxiliary Equipment

For some applications, additional equipment must be included to reliably perform the required VFD and motor functions. Examples include motor-mounted tachometers that are needed when the application requires very high peak torques (greater than 150% of rated). A second example may require feedback CTs and PTs for a VFD synchronized starting system to work properly.

Auxiliary Equipment Summary:
Review with the VFD supplier all additional equipment needed.

3. Maintenance and Troubleshooting

Computer tools for drive maintenance and troubleshooting have greatly progressed. The best tools include such advanced features as built-in trending with drag-and-drop variable selection, high-speed triggered capture buffers, email notifications to maintenance personnel when trouble occurs, robust fault logging, built-in troubleshooting help and more. See Figure 9 below.

Also look for vendors who provide 24/7 live call support and remote diagnostic centers. No system is perfect, and off-site support, in addition to the drive tool aids, can greatly reduce downtime if and when trouble occurs.

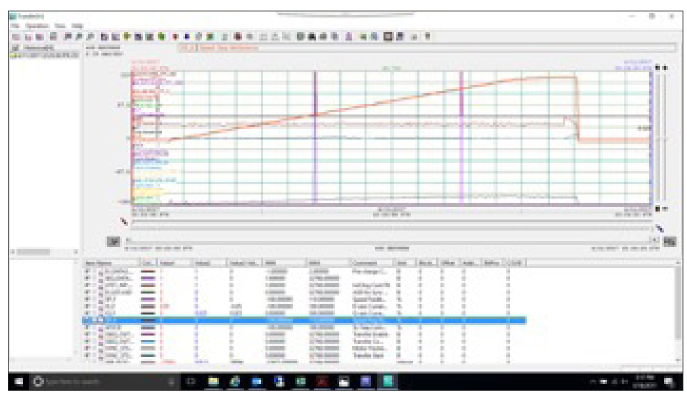

Figure 9. Drive tool trending example

Maintenance and Troubleshooting Summary:
Carefully evaluate and compare troubleshooting and maintenance support options.

4. Connections

A variety of different protocols are available to connect the plant process control system to the VFD. These are illustrated in Figure 10. Also shown is the connection to the remote diagnostic system discussed above. In selecting and specifying a VFD, carefully define the interfaces required.

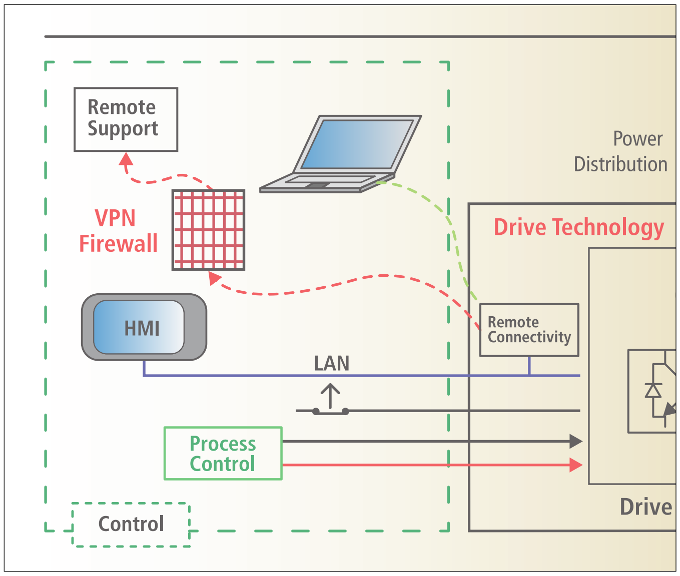

Figure 10. Drive control connections

5. Restrictions and Requirements

(See Figure 11 below) Most medium-voltage VFDs themselves are very tolerant of input and output connections and cables. EMI shielding on output cables is always recommended. Proper grounding as recommended by the VFD manufacturer is essential. Cabling recommendations must be considered when comparing MV VFD offerings.

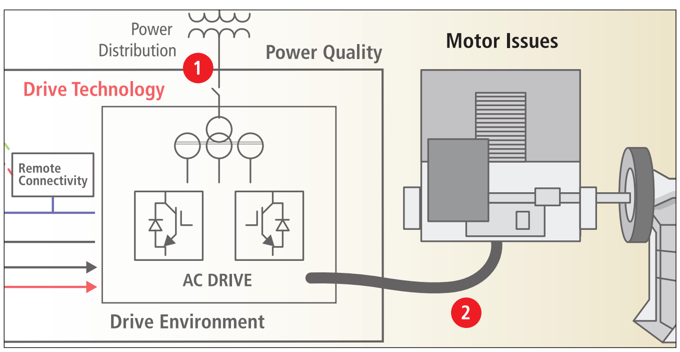

Figure 11. VFD and matching motor

Restrictions and Requirements Summary: Carefully review recommended control and power connections in planning and selecting an MV VFD.

Conclusion

A careful review of the important factors suggested will give assurance of a successful and economically sound MV VFD selection decision. Use an application checklist, often available from suppliers.

For specifications not mentioned here, contact TMEIC

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