Induction motor application guidelines for AC variable frequency drives

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Introduction

Modern variable frequency drives (VFDs) offer an almost dizzying range of capabilities that include output frequencies into the hundreds of hertz. It can be tempting to use a standard AC induction motor with one of these VFDs. But doing so requires a thorough understanding of the intended application and how the VFD will affect the motor. Since the most popular VFDs sold today are pulse-width modulated (PWM) type, the comments and recommendations in this article will assume that is the type used. Also, motor voltage will be 600 volts or less.

Those who have been around for a few decades remember the first motor problems associated with PWM VFDs; that is, winding failures. The lesson learned was that magnet wire insulation needed to be improved to withstand the higher peak voltages that resulted from many PWM VFD applications. This was a somewhat painful time with finger-pointing between the drive and motor manufacturers, if they were different companies.

Another problem this author witnessed, at the time working for one of the major motor manufacturers, was excessive rotor heating — enough to roast the stator winding insulation. In that case, the effect of the PWM drive was to crowd all the rotor bar current into the small upper section of the cast-aluminum rotor bars, closer to the rotor surface.

The next problem to surface was bearing failures attributable to shaft currents. Damage to bearings from shaft currents, especially from PWM inverters, has been well-documented. Research into the topic, which is extensive enough to warrant its own article, will show measures recommended to minimize the causes by using special cabling and specific grounding methods. The installation instructions from inverter manufacturers typically include specific wiring details. These include use of cable very different from common building wire, which also apply to the grounding from the motor back to the drive. One will also see methods of channeling the currents through shaft-grounding methods to provide paths other than the bearings of either the motor or driven equipment. Finally, insulating one or both bearings may be suggested since these will be the point of damage and eventual cause of a shutdown.

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Table 1. Typical motor speed ranges for variable and constant torque.

Enclosure	Frame Size	Variable Torque	Constant Torque
ODP	56-210	5 - 100%	10 - 100%
ODP	250-320	5 - 100%	20 - 100%
ODP	360-449	5 - 100%	50 - 100%
TEFC	56-210	5 - 100%	5 - 100%
TEFC	250-320	5 - 100%	10 - 100%
TEFC	360-445	5 - 100%	25 - 100%
TEFC	447-449	5 - 100%	50 - 100%

Speeds less than or equal to nameplate speed

The first motor type that may be considered is a motor built to NEMA MG1 Part 30, a general purpose motor used on a sinusoidal bus (hereafter a standard motor). A starting point could be to gain assurance the manufacturer used inverter-duty magnet wire and other insulation system components suitable for VFD power. The next consideration is motor cooling, since it is well understood the rotor fins or shaft-mounted external fan will provide less cooling as speed is decreased. With an understanding of the application load – the amount of torque at various speeds – one can reference manufacturer data similar to **Table 1.** Note these assume starting with a 1.15 service factor motor and de-rating to 1.0.

If a non-inverter motor is deemed suitable, modifications such as a shaft grounding brush and insulated bearing(s) provide insurance for a successful application. Drive manufacturer wiring instructions may suggest more than typical grounding capability, such as a drilled and tapped frame ground. Also, a standard induction motor may have a resonant response when operated continuously at less than nameplate-rated speed. One cannot assume the manufacturer-included provision for continuous operation at less than rated speed in their design or testing. Therefore, this possibility may

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be known only by test-running using VFD-power throughout the intended speed range. This author encountered several examples of this condition; the most significant entailed replacement of a 500 frame 6-pole with an 8-pole design. This concern is often seen with vertical motor applications due to the relative freedom of motion of the upper end. More detail is included in "Other considerations," later in this article.

In sizing the VFD and motor, one needs to know starting torque required. Generally, the VFD will limit torque available for break-away, regardless of the motor's across-the-line capability.

Speeds greater than or equal to nameplate speed

If a standard motor will be considered, one should have assurance its design is capable of continuous operation above normal rated speed. Some generally smaller size standard motors may be designed for continuous mechanical operation above rated speed, according to NEMA standards. However, larger sizes cannot be assumed to have over-speed capability. For instance, a 10 hp NEMA Design B drip-proof *2-pole* motor should be capable of 5400 rpm, but a similar 75 hp has no such capability. If the above examples are *4-pole*, the maximum continuous speeds are 3600 for the 10 hp and 2700 rpm for the 75 hp. (Data from *NEMA MG1-12.52, Table 12-6.*) NEMA standards should be checked for any new motor considered for operation above nameplate speed. If possible, check with the manufacturer. In terms of torque, the best one can hope for is constant power above rated speed, but de-rating will be required for speeds much above original rated speed. To know specifics about the torque capability, one should consult a qualified design expert. Another serious consideration should be determining critical speed of the rotor/shaft assembly, including any shaft attachment such as a coupling.

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Given the above discussion, a custom design may be more appropriate. What will or should end up being included in the motor design (and cost) are the following:

- Power capability throughout the speed range that meets or exceeds application requirements.
- Top speed that meets the application need.
- Critical speed above maximum speed. The manufacturer should provide maximum overhung weight of shaft attachment that can be used up to that maximum speed.
- Rotor and/or stator skew designs to minimize motor noise.
- Rotor construction capable of centrifugal forces encountered running to top speed.
- Design and construction that minimizes the possibility of resonant speeds within the operating range.

With the above comprehensive considerations, the manufacturer may not automatically include provisions to protect against possible damage from shaft currents. One should at least understand what the manufacturer offers before selection is made.

Other considerations

Mechanical Torsional Consideration. In many applications, system mechanical resonances (in the motor, coupling, or driven equipment) may be excited by the harmonics induced in the motor by the VFD. Many system torsional resonances have traditionally been in the 8-25 Hz range and may be excited by the drive when the output frequency is below 20 Hz. As a general rule, when a standard motor is to be operated below 33% of its normal constant frequency speed for an extended period of time, a review of the mechanical (torsional) system is recommended.

Standard vertical induction motor designs often run above the first lateral, critical speed (reed frequency) in constant speed applications. This means that the adjustable speed drive may cause the mechanical system to operate at or near a resonance (below the constant speed rpm) for extended periods of time and may result in mechanical damage. For this reason, it is necessary to always review the mechanical system for vertical induction motors applied in adjustable speed drives.

Electrical Torsional Considerations. The VFD may, due to electrical resonances, produce excessive torsional oscillations which can lead to mechanical problems. High electrical currents due to electrical resonances may exist at certain frequencies because of the combination of capacitances and inductances in the drive and motor electrical system.

Electrical filters in the system should include series resistors to provide damping, or drive operation at these frequencies should be avoided to prevent excessive motor heating and torsional stress.

Bearing Speed Limits. For given sizes of bearings, manufacturers publish limiting speeds. Operation above these speeds should not be considered without research from, and possible substitution by, the bearing manufacturer.

Lubrication Limits. For rolling element bearings, common greases using mineral oil may not be appropriate for higher speeds, and often asking a supposed grease "authority" may not yield good information. A good start-

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ing point is to determine the "speed factor," which is mean diameter in millimeters times the maximum speed in rpm. Consider alternative lubricants when the speed factor is above 350,000.

Estimating size equivalent applied to VFDs

To estimate the equivalent 60 Hz hp rating and size for induction motors applied to VFDs, you can use the following formulae to estimate the size and equivalent 60 Hz rating as well as the stator current at the base speed point of operation. (For 50 Hz, substitute "50" for "60" in the formulae shown below.)

Horsepower calculation.

$$hp_{60} = hp_{BS} \times \frac{60}{Hz_{BS}} \times \frac{\%OL_{BS}}{175}$$

Where: **hp_{60}** is the equivalent HP rating at 60 Hz

hp_{BS} is the horsepower rating at Base Speed

Hz_{BS} is the frequency in hertz at Base Speed

$\%OL_{BS}$ is the overload requirement in %, at Base Speed, minimum value 175

60 Hz example:

$hp_{BS} = 120$
$Hz_{BS} = 45$
$\%OL_{BS} = 175$

$$hp_{60} = 120 \times (60/45) \times (175/175) = 160$$

The next higher rating at the 60 Hz speed should be used to determine the motor frame size.

Current calculation. (For 50 Hz, use appropriate voltage values.)

$$Amp_{BS} = \frac{hp_{BS} \times 746}{Eff_{60} \times PF_{60}} \times \frac{1}{Volts \times \sqrt{3}} \times 1.15$$

Where: **hp_{BS}** is the horsepower rating at Base Speed

Eff_{60} is the standard motor efficiency at the equivalent 60 Hz rating, expressed as a decimal

PF_{60} is the standard motor power factor at the equivalent 60 Hz rating, expressed as a decimal

Volts is the rated motor voltage (575, 460, etc.)

Example continued from above:

$$Amp_{BS} = (120 \times 746)/(0.941 \times 0.915) \times 1/(460 \times 1.732) \times 1.15 = 150.01$$

Note: When operation at a frequency above the normal line power line frequency is required, the equations above select a higher horsepower. This higher hp accounts for the reduction in magnetic field to operate successfully at the higher end of the speed range, since the frequency must increase while the voltage should not exceed the machine's rated voltage. This is no longer a "standard" motor. ●

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