

THHN wire for HVAC and water drives

Is THHN a good idea for motor wire?

THHN wire is sometimes used on the output of variable frequency drives (VFDs) for HVAC and water applications. THHN, when selected for motor wiring, is typically chosen due to cost considerations and convenience. VFD manufacturers do not recommend THHN wire be used for motor wiring, but they will allow it as a non-preferred wiring method for HVAC and water applications. VFD manufacturers do not forbid the use of THHN wire for two reasons:

- 1) The final installation (and wiring) is not the responsibility of the VFD manufacturer.
- 2) VFD manufacturers know that if they forbid THHN, low-bid contractors are likely to use a different manufacturer of VFD that allows THHN to be used.

Technical Note 089 reviews THHN wire, the concerns of using THHN, and some alternative solutions. This document is intended to be informational and is not intended to state THHN is not allowed with ABB VFDs. THHN can be used with HVAC and water VFDs at the discretion of the engineer of record, contractor, and customer.

THHN wire overview

THHN stands for Thermoplastic High Heat-resistant Nylon. THHN is a 600 V wire that has PVC (polyvinyl chloride) insulation. PVC is considered a thermoplastic insulation. While multi-conductor THHN is available, installations typically use individual runs of THHN routed through conduit. THHN is known as a low-cost wire.

Concerns of THHN

As with any low-cost solution, there are technical and quality trade-offs to be aware of. In the case of THHN wire, those trade-offs are a combination of manufacturing quality, insulation characteristics, and the electrical characteristics of the wire when applied to the output of a VFD.

A 480 VAC VFD works by providing ~650 VDC pulses to the motor at a rate of 4000 times a second. This is known as pulse width modulation (PWM). This high frequency waveform provides more “challenges” to the motor wire than the traditional 480 VAC 60 Hz waveform that THHN was designed for. Minor technical or quality concerns with THHN, that may not be an issue with a 480 VAC 60 Hz sinusoidal waveform, can become an issue with a VFD PWM output waveform.

What are some of the concerns with THHN wire?

Manufacturing quality

The manufacturing process for wires with a thin insulation, such as THHN's PVC insulation, does not leave much room for error. A very slight deviation results in THHN wire being manufactured off center, which is not visible to the naked eye. Starting with a wire that is not ideally manufactured can make issues caused by the following topics more likely to occur.

Damage of the insulation during installation

The thinness of the THHN PVC insulation makes it more prone to damage during installation. Pulling wire through conduit, which often includes multiple bends/elbows, further increases the chance for the insulation to be damaged. This damage occurs because PVC insulation is known to be permanently deformed (cold flow) when applying a pressure, such as pulling wire through a 90-degree bend in the conduit. While the insulation may not be damaged to the point of an immediate direct short or arc, the deformed wire may result in other long-term nuisance trips with the VFD... problems that can take many hours to troubleshoot.

PVC insulation characteristics

The THHN PVC insulation is hydroscopic, which means the insulation itself can absorb moisture. Absorbing moisture results in a reduced voltage withstand rating of the wire. This is an important issue considering the 650 VDC PWM pulses from the VFD are already higher than the 600V general rating of the cable. Certain outdoor applications, such as HVAC cooling towers, are more likely to have motor wire exposed to moisture. For example, water getting into above or underground conduit can cause problems.

Long cable distance challenges

THHN has a high capacitance compared to other cable types. As an example, THHN may have up to 10-times more capacitance than a VFD cable. When factoring in the high frequency of the VFD output waveform to the motor, along with a long cable distance – this higher capacitance wire creates more stress (peak current) on the output of the VFD. This added stress may cause nuisance trips (i.e. ground fault, over current) on the VFD. Worst case, some VFDs may fail in lieu of a trip.

A standing/reflected wave and voltage overshoot are well-documented phenomenon with VFDs and long cable distances. These items can result in the ~650 VDC pulses to exceed 1300 VDC for very short periods of time. These voltages can result in corona discharges that create heat and damage the PVC insulation over time.

In lieu of THHN wire, what other wires are preferred by VFD manufacturers for motor wiring? The default answer is VFD cable. There are several manufacturers who make a quality VFD cable. VFD cables may include features such as (3) symmetric phases, (3) symmetric grounds, low capacitance, thermoset insulation, a high corona inception voltage (CIV), and a shield.

VFD cable does add additional cost. In commercial HVAC or water applications, which are often cost sensitive projects, there are alternatives to VFD cable. One should note that these alternatives are not an equal to VFD cable, but they are better than THHN. A typical alternative to THHN is XHHW-2. XHHW-2 while still only 600 V rated, does have a thicker insulation than THHN. XHHW-2 uses a thermoset insulation in lieu of THHN's thermoplastic PVC design, which results in XHHW-2 having a higher CIV rating. Thermoset insulation is more flexible (easier to work with) while stronger (less likely to be damaged when pulled through conduit) than thermoplastic. Whether the installation uses THHN or XHHW-2 through conduit, using a continuous grounded metal conduit from the motor to the VFD, is a best practice. VFD cable does not require conduit.

NFPA 79 Electrical Standard for Industrial Machinery (2018) paragraph 4.4.2.8 is also a good reference for additional alternative wire types. This paragraph states: "*Electrical conductors and equipment supplied by power conversion equipment as part of adjustable speed drive systems and servo drive systems shall be listed flexible motor supply cable marked RHH, RHW, RHW-2, XHH, XHHW, XHHW-2...*" While this standard is for industrial machinery, and not applicable to commercial HVAC or water applications, this standard does act as a good reference for alternative cable types. This standard also shows how industrial applications are moving away from the use of THHN wire between a VFD and motor. These alternatives use a thermoset insulation and do not use the thermoplastic insulation of a THHN.

Often a good-better-best comparison is used when comparing (3) offerings. In the case of comparing THHN, XHHW-2, and VFD cable, instead a tolerable-better-best comparison should be used. THHN should not be referenced as "good," and instead it should be viewed as "tolerable" for motor wiring in many VFD applications. Installation damage is more likely to occur with THHN due to the thin insulation and thermoplastic PVC characteristics of THHN. Longer THHN motor cable distances create additional challenges for both the VFD and the insulation itself. XHHW-2 is the "better" solution with only a small cost adder for a better cable compared to THHN. VFD cable is widely considered as the "best" solution for motor wiring between a VFD and motor.