New Requirements for Inverter to Motor Cables

THHN cable (PVC insulation with a nylon jacket) is widely accepted and used in residential, commercial, industrial, and OEM markets. The product has an attractive price point and excellent value for most installations. That said, THHN has long been known to be the source of issues in variable frequency drive (VFD) systems that significantly reduce productivity, uptime, and equipment life. THHN cable has been linked to several issues in VFD systems including electromagnetic interference (EMI) of other plant systems, drive overcurrent trips caused by excessive cable capacitance, and cable failure. The National Electrical Code (NFPA 70) provides no guidance on special cable requirements for the inverter to motor cable, but guidance now exists in the 2018 release of NFPA 79 the **Electrical Standard for Industrial Machinery**.

While NFPA 79 is not required to be followed for factory floor installations, the guidance provided regarding the inverter to motor cable is a welcome addition the standard. This addition is found in section 4.4.2.8 and reads:

> **Circuits Supplied from Power Conversion Equipment**
> 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 type RHH, RHW, RHW-2, XHH, XHHW, or XHHW-2 or selected based on the equipment manufacturer's instructions.

The clause above does not require users to install VFD cable, but it does require the use of thermoset insulated cable constructions only – unless the equipment manufacturer specifically states otherwise.

While THHN is the most common cable type used between inverter and motors, there are several shortcomings of installing this cable in drive applications. Several of these shortcomings can be addressed by using a cable type specified in NFPA 79 (RHH, RHW, RHW-2, XHH, XHHW, or XHHW-2). The list below summarizes important differences between THHN and the cables listed in NFPA 79:

- Curing Process
- Minimum Wall Thickness
- Corona Inception Voltage
- Wet Withstand Voltage
- Dielectric Constant

Let's review each of these differences in more detail:

Curing Process
All the cable types listed in NFPA 79 have one thing in common, they are all defined in the UL 44 standard, **Thermoset-Insulated Wires and Cables**.

Thermoset (or cross-linked) insulations have several benefits over thermoplastic insulations like the PVC used in THHN cables. For example, thermoset insulations cannot melt like thermoplastic insulations can. Thermoplastic compounds, like PVC, are melted, extruded around a conductor, and cooled to create an insulated cable. Thermoset compounds are melted, extruded, *cured,* and cooled. This curing, or cross-linking of the polymers in the compound, causes new chemical bonds to form that do not allow the insulation to be remelted like thermoset insulations can be.

Because of this cross-linking, thermoset insulations will not cold flow or deform like thermoplastic insulations. This reduces the chance of thinning the insulation wall thickness when pulling it through a bend in conduit.

Minimum Wall Thickness
THHN has a much thinner insulation wall thickness than any of the cables listed in NFPA 79. For smaller sizes, like #12 and #14, THHN has a minimum insulation thickness of 15 mils compared to the 30 mils required for 600V XHHW. 600V RHW has a thicker wall (45 mils) for these sizes and 2000V RHW has a wall thickness of 60 mils.

Throughout the entire size ranges available, 600V XHHW has thicker insulations than THHN. This can be a problem, especially in smaller size constructions where XHHW has double the wall thickness of THHN. Making matters worse, the thinner THHN insulation is more susceptible to cold flow which can cause its already thin wall to be reduced even more! XHHW is virtually impervious to cold flow as it is a thermoset insulation.

Corona Inception Voltage
Corona Inception Voltage (CIV) is the voltage level which when exceeded results in corona discharge. When corona discharge occurs in a cable, it degrades the insulation. Although a low energy process, over time, corona discharge can significantly degrade cable insulation, eventually leading to cable failure. Corona is a very destructive process causing heat, ozone, acid creation, and erosion of the insulation.

Testing shows[1] that thermoset insulated cables have a significantly higher CIV than THHN cables. When tested at 25℃, the CIV for dry #12 and #14 AWG THHN was measured to be 2723 volts peak. CIV for the same sizes of 600V XHHW cables was measured to be 4942 volts peak, or 82% higher.

Wet Withstand Voltage
Further testing was performed under wet conditions of 90% relative humidity for 48 hours. These tests revealed that, under these conditions, the CIV of THHN decreased by 50%, to 1362 volts, while XHHW decreased only 5%, to 4695 volts.

Given the nature of VFDs to create reflected waves with peak voltages between 2.0 and 2.4 times the DC link voltage of the drive[2], cables on 460-volt drive systems can be exposed to over 1,600 volts, exceeding the CIV of THHN in a humid environment (or possible of dry THHN with a thin wall due to cold flow). This will cause corona discharge leading to insulation damage.

Dielectric Constant
Different insulation compounds have different dielectric constant values. The dielectric constant quantifies the ability of a substance to store electrical energy. Cable capacitance is directly proportional to the cable's dielectric constant and inversely proportional to insulation thickness. Larger dielectric constants increase cable capacitance, as do thinner insulation wall thicknesses.

PVC has one of the highest dielectric constants of any cable insulation. Values vary based on the exact formulation, but the dielectric constant for PVC can be has high as 8. PVC, being thermoplastic, is not allowed as an insulation type in any of the cables listed in NFPA 79. Common insulations for these cables vary from 2.3 to 3.5.

This difference in dielectric constants, along with the differences in wall thickness, leads to significantly different cable capacitance between THHN and thermoset insulated cables. Using 14 AWG sized conductors, THHN in EMT can have about 8 times the capacitance of 600V XHHW. This 8x higher cable capacitance translates to an 8x higher charging current. This higher charging current is a common cause of drive overcorrect trips or failures. Using a cable with a lower capacitance (and therefore lower charging current) can increase productivity by reducing these trips or failures.

Summary
The benefits of thermoset insulations make using an NFPA 79 compliant cable between your drive and motor a smart choice to increase productivity and reduce issues. While the new NFPA 79 requirements do not require VFD cable to be installed, they go a long way to help ensure smooth operation of your

drive system. More system performance advantages may be gained by installing a shielded VFD cable which can address EMI, common mode current, and electrostatic coupling. To learn more about the advantages of VFD cables, see Southwire's application note **About VFD Cables.**

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[1] *NEMA Application Guide for AC Adjustable Speed Drive Systems IEEE Paper Number PCIC-2007-7 by David M. Brezesky and Scott Kreitzer, Siemens Energy and Automation.*

[2] *Riding the Reflected Wave - IGBT Drive Technology Demands New Motor and Cable Considerations Presented at: IEEE IAS-Petroleum & Chemical Industry Conference, Philadelphia, PA., Sept. 23-25,1996 pp. 75 - 84.*