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TECHNICAL NEWS

INDUSTRIAL SWITCHGEAR & AUTOMATION SPECIALISTS

NHP

OUTPUT CHOKES FOR USE WITH VARIABLE SPEED DRIVES

1.0 BASIC VSD THEORY

To understand the necessity for output chokes for use with AC variable speed drives (VSD's), it is useful to first understand the fundamentals of how a VSD actually operates.

A VSD is actually an AC inverter containing three main components:

- Rectifier circuit which converts the AC supply to DC at a constant amplitude
- Fixed DC voltage stage which uses capacitors and chokes for maintaining a steady DC output
- An inverter circuit which in the VSD's utilise Insulated Gate Bipolar Transistors (IGBT's) to generate the three phase variable frequency controlled output.

The basic sections of the VSD's can be seen in Figure 1.

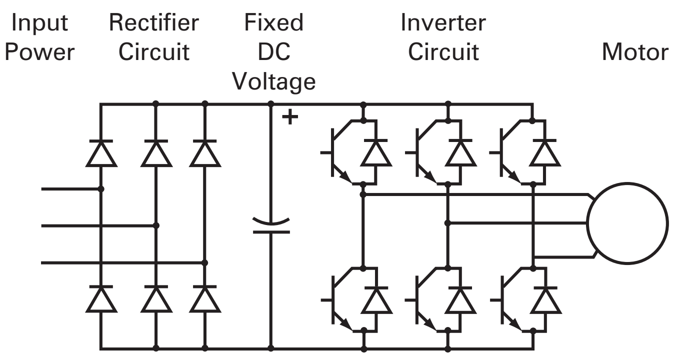

Figure 1 - VSD Fundamentals

All modern VSD's utilise Pulse Width Modulation (PWM) to change the output speed of the VSD by dividing the 'quasi-sinusoidal' output waveform into a series of narrow voltage pulses which modulates the width of the pulses. It is these pulses generated by the high frequency IGBT's switching on and off that cause problems on the output side of the VSD.

FEATURES

- **Basic VSD theory**
- **How does a VSD affect motor performance**
- **What are the benefits of using output chokes**

PLEASE CIRCULATE TO:

1.0 BASIC VSD THEORY

Unfortunately, the combination of rapid increases in voltage and current caused by the PWM operation (or the rate of change of voltage over time - dV/dT) cause massive stresses to both the conductors between the VSD and the motor and the motor itself. This, in addition to the stress caused by the internal energy-laden components and the motor's natural vibration, stresses the insulation of the motor windings causing a dramatic reduction in the motor's life and in some cases, premature motor failure altogether.

A graphical representation of the PWM process can be seen in Figure 2.

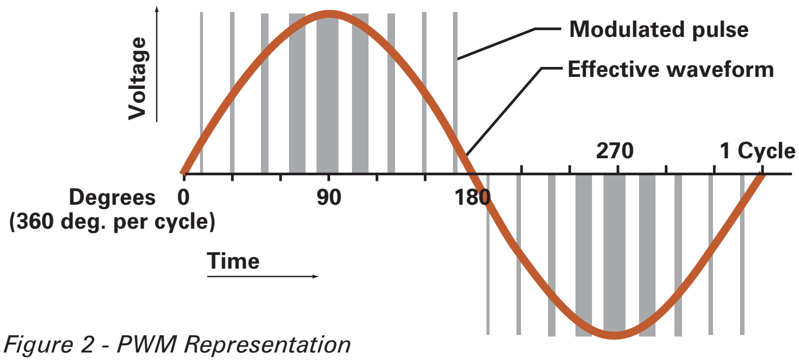

Figure 2 - PWM Representation

Considerations faced by an installer or end user of VSD's are generally separated into three areas:

1. Between the VSD and the motor,
2. Those on the input or supply side of the VSD
3. Caused by the operation of the motor itself

This is the first of a series of Technical News articles detailing design and installation considerations when utilising VSD's. In this issue, we will be concentrating on the common installation issues faced between the VSD and motor, what causes these issues and detailing simple and cost effective ways of dealing with them.

To understand what causes the above issues, let's look a little closer at the operation of the final stages of the VSD and how this affects the overall operation of the motor control system.

2.0 WHAT EFFECT DOES THE VSD HAVE ON THE INSTALLATION?

2.1 Voltage & current transients

When the IGBTs output the switched voltage pulses, there are inherent current spikes which occur when the connecting leads between the VSD and the motor become energised. The severity of the current spikes is totally dependent upon the length of the connecting cable - i.e. the longer the cable length, the more severe the damage caused to the motor itself. The cable used to connect the VSD to the motor must be effective in transferring the resulting voltage. However, this leads to excessive capacitive and load currents.

With lengthy cable runs, this capacitance can be extremely high and generally has a negative effect on the regulator circuitry of the VSD causing it to shut down under a protective trip condition. High voltage transients originate from long cable runs and as described above, the insulation of the motor windings will be stressed causing premature motor aging and in some cases, complete motor burn-out.

2.2 Motor Temperature Rise

The next consideration faced with driving motors using any type of VSDs is the increase in operating temperature. This increase in temperature can damage the motor windings and associated components. The increase in motor temperature under VSD operation is caused by the fact that the output waveform from the IGBT's is produced using the PWM method and is not a pure sinusoid as in a 'Direct-on-line' (DOL) situation.

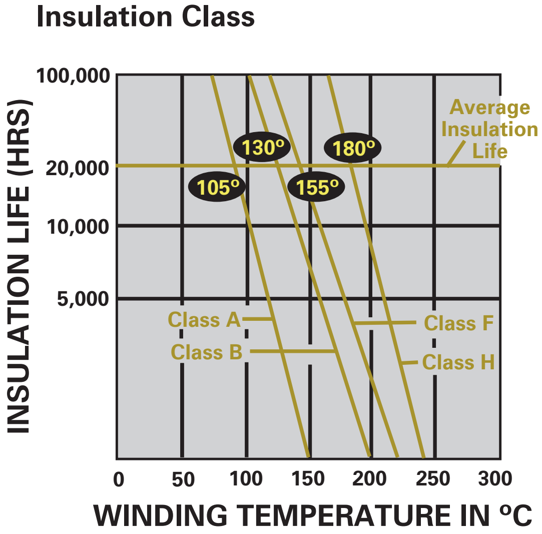

Figure 3 - Motor Insulation classes

The additional watts loss under VSD operation in both the copper and iron in the motor reduces the efficiency of the motor. This increase in heat results in a loss of actual mechanical power that can be derived from the motor, in comparison to driving a motor using the rated operating frequency under a DOL operating condition.

Many years ago VSD's were commonly blamed for the burning out of motors - and in most cases, rightly so. In the early days of VSD's, the insulation of the motor windings were not designed for the constant 'chopping' of the voltage wave caused by the PWM circuitry and the associated temperature rise this created within the motor windings.

Figure 3 shows the National Electrical Manufacturers Association (NEMA) motor insulation classes indicating motor insulation life in hours against the winding temperature in degrees Celsius. Older style motors were designed for a specific temperature rise and corresponding insulation class. It was possible to have no margin for over-temperature situations, ie Class B insulation was used for motors designed to Class B temperature rise. In a typical DOL application, motor operating temperatures were very low and the insulation life was hundreds of thousand of hours. Once VSD's arrived on the scene, the older style motors were being retrofitted with the new drives. This resulted in dramatic increases in motor temperatures and hence many motor burn-outs due to insulation failure on the motor coils.

These days, most AC induction type motors are much better insulated and are built to withstand the stresses placed on the motor when being used with VSD's. Generally, motors driven using a VSD will be rated as having an insulation rating of at least 'Class F', and a corresponding temperature rise of class 'B'.

2.3 Motor Audible Operating Noise

The third consideration faced by end users of VSD's is an audible 'whistling' noise heard from the motor when any VSD is being operated. The noise is caused by the vibration of the laminations in the steel stator core and rotor under the magnetic forces generated by the applied voltage. This problem was more prominent in early VSD's as they were designed using slow switching, low carrier frequency transistor output circuits instead of the much faster (frequencies up to 20kHz) IGBT set-up's used in todays VSD's. Modern VSD's allow the user to configure a higher switching frequency to reduce noise, but this reduces overall motor/VSD efficiency.

3.0 HOW DO WE RESOLVE THESE ISSUES?

So what can we do to rectify the above discussed installation considerations while not adding excessive cost to the overall installation?

Quite simply, the use of output chokes placed between the VSD and the motor will rectify all of the issues discussed above without compromising the overall performance from the motor. Output chokes generally consist of inductive loads to achieve a desired result depending upon the issue wishing to be rectified.

3.1 Voltage & current transients

Let's start with the first consideration in regard to the rapid rate of change of both voltage and currents (rate of change of voltage over time - dV/dT) and the generation of high voltage transients caused by the PWM process and the rapid switching of the IGBT's. A well made output choke will have a good storage capacity and works like a typical line inductor. The output chokes suppress the rapid voltage rise to levels less than 500V/ms whereas prior to adding a dV/dT limiting choke, the voltage rise levels would be in the vicinity of 1400V/ms when using an 8kHz switching frequency.

As discussed, high voltage transients originate from long cable runs causing stressing of the motor coil windings and eventually motor burn-out. Output chokes will prevent the high voltage transients over longer cable runs should they be required.

NHP's new range of Elettronica Santerno VSD's freely publish information relating to recommended cable distances with regard to the kW rating of the VSD's and use of output chokes - see Table 1. It should also be noted that the number of poles on the connected motor also has an effect on the resulting recommended cable length.

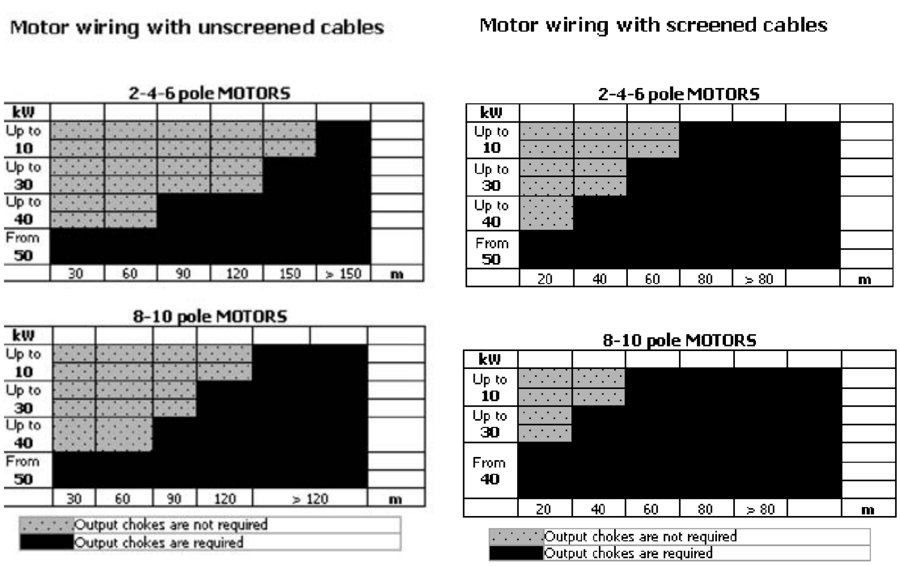

Table 1 - Recommended cable lengths

In addition, the use of screened cable (which may provide limited EMC protection to surrounding electrical installations) contributes to the voltage rise within the cable due to the inherent stray capacitance within the cable itself. The use of screened cables greatly reduces the available length of the cable as can be seen in Table 1. Ultimately, the decision to use screened cable is subject to both the EMC and the installation requirements as described above to avoid voltage and current transients. The installer must consider all aspects before selecting the appropriate cable for the installation.

3.2 Motor Temperature rise

The next installation consideration we faced was an increase in the motor's operating temperature due to the use of a VSD. In this instance, the use of output chokes will reduce the motor operating temperature by improving the shape of the output waveform. They smooth the asymmetric interference currents whilst maintaining the useful symmetrical currents. The output choke will also minimise the effect of reflections to reduce peak voltages and reduce the rise time of the current and voltage curves as described above.

Motor temperature rise in VSD installations without reactors have been documented to add heat values of up to 20° Celsius and in some cases even higher. Using output chokes in this instance can increase the life of the motor due to the fact that a rise of 10° Celsius can, in a worse case scenario, de-rate the insulation life of the motor by up to 50%.

Using an output choke will reduce the internal motor operating temperature thus improving the thermal performance of the motor (through a reduction of watts loss in both the copper and iron in the motor) hence having the ability to deliver more power to the load at a much improved efficiency.

3.3 Motor Audible Operating Noise

The third and final issue faced between the VSD and the motor was an audible 'whistling' noise heard from the motor when the VSD is in operation. Installing an output choke helps to convert the switched voltage pulses back into a more sinusoidal form forcing the phase currents into sinus with the 50Hz mains frequency, therefore reducing the audible sound commonly heard when using VSD's. Using an output choke can reduce the audible noise being emitted from the motor to between 3 and 6dB. The human auditory system works on a logarithmic scale and therefore a reduction of 3dB is an actual auditory reduction in noise of 1/2.

SUMMARY:

And you thought operating a VSD was an easy task! As you can see from the above discussion we need to:

- clean the artificially generated sine wave,
- limit the resulting voltage and current spikes during operation, and
- smooth the artificial output sine waves

Fortunately, all of the above can be achieved by simply using an output choke connected to the VSD.

Also, remember that the points above need to be addressed only between the VSD and motor - what about those on the input or supply side of the VSD? Or issues caused by the operation of the motor itself? These points will be covered in the next two issues of NHP's Technical News.

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