



The effect of Variable Speed Drives (VSDs) on External Rotor (ER) Motors

External Rotor Motors are used extensively by Fantech. These are compact, lightweight motors specifically designed for fans and ventilation products

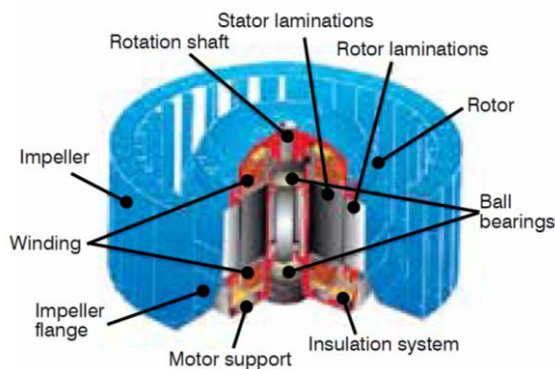


Figure 1 External Rotor Motor



Figure 2 Conventional Motor

To increase the life of three phase External Rotor Motors when controlled by a VSD, it is recommended that All-Pole Sinusoidal Filters be fitted to remove unwanted harmonics

Product codes of Fantech fans with 3 phase External Rotor Motors fitted

CD..D/V	CD..S	CD..VGL	CD..VGL-BFC	PCD..ER
WCD	TCD	TWCD	TILD	FLD..ER
JISU	JVWD			

Harmonics

Clean electrical power from the mains consists of a sinusoidal wave with a frequency of either 50 or 60 Hz.

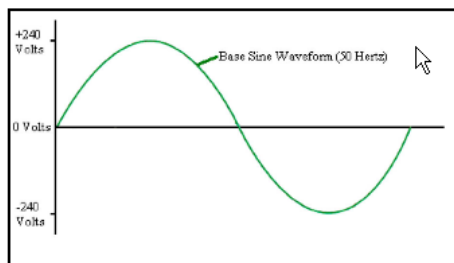


Figure 3. Base Electrical Waveform

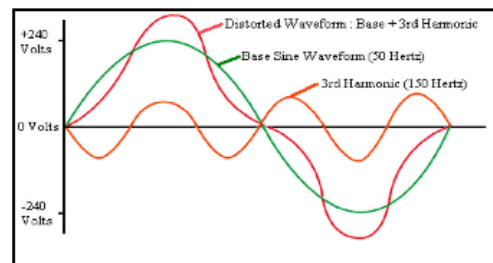


Figure 4. Base waveform with additional harmonic

There are many ways an electrical power supply can become “dirty”, and is caused by the introduction of a series of harmonics. Figure 4 shows the introduction of a third harmonic and resulting waveform. This is an example where harmonics are introduced to the waveform from a VSD.

A VSD contains switches that turn on and off very rapidly. This switching is called Pulse Width Modulation (PWM) and rise and fall times of these waveforms can occur in 50-500 nanoseconds (10-9 seconds)[1] providing an efficient way of controlling motor and fan speed. A side effect of PWM is the introduction of a rich spectrum of harmonics.

These harmonics are

- around the fundamental frequency of 10-60Hz
- At 10-20kHz due to the switching or carrier frequency (which is what we hear)
- or associated with rise and fall times of the switches implemented of the order of 10Mhz.

Why can a VSD damage motors?

Electric motors work at their optimum when a clean electrical signal is supplied. Their insulation systems are statistically designed to withstand normal conditions. Certain environmental conditions can damage or reduce the expected life the insulation systems, such as temperature, voltage, surface electric fields and contaminates in the windings. When VSDs are used in HVAC applications, some of these conditions are at an elevated level, and can reduce the life of the motor. A few mechanisms that can reduce or age the motor are presented below:-

1. The change in way components behave at higher frequencies will put stress on components unevenly, pushing some beyond their limits.
With a winding of the motor, at line frequencies around 50Hz, the voltage across the each turn in a coil is even across the whole coil winding. When the frequency is raised, the magnetic wire proximity to the stator which is earthed becomes a capacitive coupling. The combination of this capacitive coupling and the inductance of the winding means that the voltage is taken up in the first few turns of the winding [1,2].
With the winding acting as a capacitor (parasitic capacitance), and the lead inductance, there is potential of increasing the voltage as seen beyond that supplied by the bus through the two mechanisms[3]. The first voltage increase occurs because of the mismatch of impedance from the lead to the motor, which is explained using transmission line effects[2,3,4]. The second method is ringing due to the combination of motor capacitance and lead inductance, where initial charging of the winding builds up current in the inductance of the lead, and when the voltage in the motor matches that of the supply, the current in the lead starts to collapse the current. As the current collapses, the voltage across the capacitance of the motor winding continues to rise[3].
This capacitance will occur to earth, as well as across phases depending on how the coil is placed in the motor. If the coils are placed on top of each other in the head winding of the motor, then the failure will not only occur between windings of a coil but shorts between phases is possible.
With these high voltages occurring between coils, there becomes a high electric field which could result in a partial discharge or corona[2]
2. Motor windings are sized to withstand heat generated by the fundamental electrical frequency due to current flow. When higher frequency harmonics are present the temperature in the windings increase.
These harmonics have several ways of increasing the temperature of the motor. The first is that the only the fundamental current provides the power to the motor. The other harmonic currents will increase losses in the copper according to I^2R losses. The Second level of losses are due to higher frequency currents, where the current does not flow evenly through the copper due to the skin effect and proximity effect, which results in an effective increase in resistance. The third mechanism of increased losses is induced eddy current, or circulating currents in the stator core[1]. With higher temperatures, the expected life reduces, and it is estimated to halve for every 10 degrees above the insulations ratings[2].
3. VSDs can create a current through the bearings (known as electro discharge machining or EDM), which will break down the grease in the bearings and introduce pitting on the contact surface of the bearings.
The voltage that drives this current is created from common mode voltage. Voltages, or potentials of signals, are divided into common mode and differential, where typically two signals have a differential voltage to each other, or potential difference. Common mode is where both signals go up or down with respect to some other reference, in this case the safety ground or earth or rotor. As discussed before, components of an electrical circuit, when they are subjected to high frequencies, can exhibit capacitive effects instead of the lower frequency behaviour of an inductor. This is the case between the winding and the rotor. The potential of the common mode of the windings go up and down, and voltage is produced between the

stator and the rotor. This voltage is not necessarily at frequencies driven by the turn on and off frequencies or switching frequencies, but intermediate frequencies[1].

With common mode voltage being applied, and with motors being unlikely to be exactly symmetrical, this will result in potential voltage across the length of the rotor, and when this voltage exceeds the limits of the bearing grease, a current pulses through it. The current path is through the first bearing along the rotor back through the other side bearing and returning through the stator. Any current through the bearings can produce chemical changes of the grease[5] and pitting of the surface of the bearings.

Sinusoidal filters



Figure 5
Sinusoidal Filter

A Sinusoidal filter is a device which filters out high frequency harmonics. They are useful for eliminating the high frequencies as seen by the motors coils. They will eliminate or decrease the frequency of the inter-winding failures and reduce the switching frequency noise heard from the motor. However these filters do not eliminate the common mode voltages seen across the bearings, so may not improve the application without adequate additional protection[6].

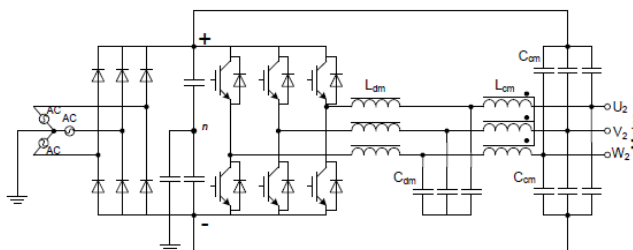


Figure 6 All phase Sinusoidal Filter

A more specialised filter called an All-Pole Sinusoidal Filter also prevents current flowing between the three phases and back to earth. The high switching frequency of the VSD can cause this type of current flow and it is therefore recommended that an All-Pole Sinusoidal Filter is used[6].

Another filter, that is available on the market, is a dV/dt (or Switching) filter which lowers the voltage rise-time of the VSD but still lets through the PWM waveform. Their main use is to mitigate transmission line effects, or the excess voltage produced with long supply leads[4]. These filters are not equivalent to an All-Pole Sinusoidal Filter and should not be used as an alternative.

Why is an External Rotor Motor different to a conventional motor?

When VSDs were first introduced, conventional motors began to have issues with insulation and bearing failure. The design of motors and the selection of materials they were made from changed to withstand the extra stresses placed on them by a VSD.

Some examples of improving the ability of the motor to withstand the stresses imposed on it from the motor include:

1. Selection of the magnetic wire to increase its dielectric strength and to be partial discharge resistant[2]. Thermal rating of the wire can be increased to overcome the issue of elevated ambient, or the de-rating of the motor for inverter loads. CMG PPA and PPC motors have a maximum rate of rise of the voltage of 3000V/μs[7]. With supply at 600V (415V rectified), and assuming an overshoot of 20%, this allows for a rise or fall time of 260ns. As this is in the range of IGBT rise times, care has to be taken in the selection of the drive. All drives supplied by Fantech are appropriate for use with these motors.
2. A sheet of Mylar, which is partial discharge resistant[2], can be placed between the coils which significantly increases the strength of the insulation system.
3. To prevent EDM in the bearings, the first step has to be ensuring good electromagnetic interference earthing coupling, which is difficult with the external range motors typically having their junction boxes made of plastic and having an earth point inside. Other strategies include an insulated bearing or ceramic bearing at one end of the motor, or earth strap/shaft grounding rings could be used[8], but as an external rotor motors is a very compact design,

there is no place to fit these products. The grease used in the bearings can be selected so that it can withstand higher voltages[2].

The first 2 modifications take up more space within the motor body, therefore due to an external rotor motor being more compact, and having less space available for these changes, they are unable to be constructed to include these additions and handle the increased stresses.

Conclusion

While using a variable speed drive can greatly improve the efficiency of your air movement equipment, using VSDs with an All-Pole Sinusoidal Filter on the External Rotor Motor will return the motor to the expected life of one without a VSD. Maintaining the life of the motor will reduce service calls and replacement costs which would have outweighed any expected efficiency gains with using of the VSD. Fantech products more compatible for VSD use, or our Electronically Commutated (EC) motor range are other potential solutions for speed controlling three phase fans. Using a voltage controller such as the 5 speed TC3 model, provides you with an alternative to speed controlling an External Rotor Motor with a VSD.

This article may be updated from Time to time, please see version number.

Glossary

Common Mode and Differential Mode - When referenced to the local common or ground, a common-mode signal appears on both lines of a 2-wire cable, in-phase and with equal amplitudes[9]. Differential is the remaining signal, or difference between the 2-wire cables.

Corona is the partial break down of the atmosphere around a conductor. This occurs when the electric field immediately around a conductor is too high causing ionization of the gas. Ozone and Nitrous oxide is produced, and can leave a white powder behind. Presence of Ozone and Nitrous oxide can age some insulation.

IGBT – insulated gate bipolar transistor, commonly used as the power switch in current inverters or VSDs.

Rise and fall – Rise and fall time is the time it takes for the voltage across the IGBT to rise and fall. The time does not take into account delay time, which is time taken for the switch to start turning off or on¹⁰

Skin effect – The skin effect is where high frequency currents do not flow evenly through a conductor, but just in the outer. Wires next to each other produce a similar effect called the proximity effect.

VSD is Variable Speed drive can be called a number of different things, including Variable Frequency Drive (VFD)

References

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⁹ <http://www.maximintegrated.com/app-notes/index.mvp/id/2045> Maxim Integrated TUTORIAL 2045 Understanding Common-Mode Signals

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