Partial Discharge; recent developments regarding IEC TS 60034-18-41 2006-10.

Keywords: Partial discharge, surge test, impulse test, hipot test, inception voltage, extinction voltage, corona discharge, electric stress, electrical aging, predictive maintenance, quality control, motor turn insulation, variable frequency drive, VFD, adjustable speed drive, ASD, PWM, cable impedance.

Abstract: This paper discusses some recent publications which describe the results of the present IEC TS 60034-18-41 2006-10 criteria for assessing insulation systems of low voltage stator or rotor windings. There is particular emphasis in recent articles regarding the presence and effects of partial discharge phenomena (often aggravated by VFD or voltage converters) on the insulation systems. Weaknesses in the qualification and type tests are commented upon, and recommendations from various parties for improving them are clarified.

1. Introduction:

Electric motors and rotation speed control – how? For such a simple question, there are many answers. Indeed, how do we provide for, and easily allow manipulation of the torque/speed curve of rotating electrical machines? 100 years ago, this may have meant implementation of a DC motor (with it's brush rigging maintenance requirements) or perhaps a more complex variation of the induction motor called a wound rotor motor. For speed control, the wound rotor may have had multiple poles on multiple stators on one shaft (with attendant slip rings, relaying, control and cabling complexities)

Times sure have changed since then. Variable Frequency Drives, providing the modern answer to the previous paragraph's question, have become vastly more capable and more complex in their application as a result.

It is presently a well accepted fact that the use of Variable Frequency Drives has proliferated widely in industrial applications. "VFD's" are generally selected/specified or marketed as a means to provide and simplify process control and provide resulting efficiency improvements. Public utilities in North America may even offer financial incentives to operators/implementers of motors with drives which provide such capabilities. For example:
http://www.xcelenergy.com/Save_Money_&_Energy/Find_a_Rebate/Motor_and_Drive_Efficiency_-_CO

These incredible improvements do not come without a price. Practical technical knowledge is often required to implement reliable VFD/Motor systems. If manufacturer's guidelines are not followed closely during an installation, certain costly problems may soon follow. Variable Frequency Drive implementations may require accompaniment of several techniques to mitigate sometimes un-anticipated side effects.

2. VFD side effect: Partial Discharge in low voltage motors

Partial discharge. Corona discharge. These words are often associated with medium and high voltage AC motors and alternators. These types of rotating machines operate at line-line voltages between 4kV AC to as much as 15kV AC. They are used for propulsion, mining, heavy industrial processes, or generation of public utilities electric power. They may serve high capacity pumps, compressors, crushers, blowers and myriad other applications. In medium and high voltage motors, the long known effects of PD and its cousin corona are generally negative, in terms of motor service life. PD events could be described as a series of steps before insulation breakdown occurs. Operators of such expensive, high capacity motors may go to great lengths to implement partial discharge monitoring systems for predictive maintenance purposes. This is monitoring electrical aging effects, and techniques including capacitive voltage dividers are used.

Yet, undeniable knowledge is building about the presence, and undesirable side effects of VFD aggravated partial discharge in low voltage motors.
Low voltage induction motors are designed to operate at line-line voltages of less than 690 V. In North America, a majority of these motors operate at 480 V. In terms of overall motor population numbers, it is comfortable to state that most of the motors presently in service worldwide are low voltage motors. Why would PD inception voltage be reached?

VFD and ASD drives are usually designed with the latest and most efficient power semi-conductor switches. At the time of this writing, for AC motor applications that usually means IGBT transistors. IGBT devices are optimized for very efficient switching. It is a design parameter for IGBT's to perform their switching on/off very, very rapidly. This rapid switching helps reduce the power dissipated in the IGBT, providing for efficiency and performance benefits. This adjustable speed drives characteristic will continue to improve.

In 2011 for electric motor applications, switching rise-time time of less than 50 nano-seconds is possible. Keep in mind that this rapid switching occurs at a rep rate (often user defined) at the VFD control panel. This could be 1 kHz, 2 kHz, 5 kHz, 7.5 kHz or even higher. Their fast switching rate may be referred to as the "carrier frequency", while the speed related to the motor rotational direction may be referred to as the "fundamental frequency or modulating frequency" as an example, they could be 5 kHz and 50 Hz respectively.

Generally, less audible noise is detectable by the operator at higher frequencies. But, each time the VFD switches, a very fast voltage spike or surge is generated. In the above example (5 kHz) 5,000+ voltage surges affect the windings every second. These highfrequency voltage surges (switching transitions) do not easily penetrate the inductance of the motor windings. These voltage spikes may "pile up" resulting in non linear voltage drops across the end turns in the motor windings. This uneven voltage distribution can provide stresses greater than design limits in the turn to turn insulation system. The phase to phase insulation system is also stressed. It has been shown by measurement, that it is possible for voltages spikes in excess of 2kV to be present across the phase terminals, in VFD installations with long cable feeds.

When present, these PD events occur from: turn to turn within coils, phase to phase, and sometimes, phase to ground. Wise choice: select a low voltage motor specifically designed for VFD application. Several parameters, including the rating of the phase to phase insulation system will probably be beefed up. For example, a VFD rated motor could be rated to withstand 2,000V line to line at 0.1uS rise time. Source: (ABB Motors and Generators | Low voltage motor manual 01-2009)

What sounds like a simple situation is complicated by practicalities. It is not generally possible to place the VFD drive nearby the motor. For example, the VFD may be in an air conditioned room. Motors may be nearly anywhere. A motor may be in a sump, down a shaft, up a chimney or long conveyor belt. So, a cable feed must be present between the motor controls and the motor. This distance could be well over 100 meters. As the very fast rise time VFD voltage spikes travel toward our motor from the drive output, they meet the end of the cable feed, where the high impedance (at high frequencies) cable end, and motor winding resides. A portion of the wave "reflects" back toward the source.
(The source is the output circuit of the VFD) At

that instant in time, a higher voltage may momentarily appear, leading to the appearance of a voltage greater than the nominal line. It could be 2x the nominal line, or even higher in certain resonant industrial applications.

3. TS 60034-18-41 and suggested improvements;

In 2003 the International Electrotechnical Commission (IEC) began to address the detrimental PD phenomena associated with the use of VFD and ASD voltage converters and released documents TS 60034-18-41 and TS 60034-18-42, intending to prevent motors with insufficient insulation from being connected to VFD or ASD converters. In the IEEE, WG1798 committee is in progress to address the same phenomena. It is possible that IEEE may adopt 60034-18-41 wholly - or as part of IEEE 1798.

Many, many advancements in technology related to the theory, design, construction and implementation of electric machines have been made. Yet, it may come as no surprise to some readers that new motors still fail electrically in service, sometimes within the period of the manufacturer's warranty! (Points that infer deficiency in quality control processes).

Incredibly enough, some evidence suggests that PD aggravated weaknesses in the turn to turn, and the phase to phase insulation systems may not be sufficiently revealed by diligent application of IEC TS 60034-18-41 2006-10. The inception voltage and extinction voltage should be monitored in a somewhat different fashion.

What has been confirmed (on a group of small 400V low voltage motors) in the laboratory environment, is that significant differences exist between the voltage profiles suggested and used during off-line testing, and those actually present during on-line service. Several suggestions were given to help provide for a higher degree of rigor in the test results.

One of the outstanding points I found while reading the article, is that unpredictable results may occur if the motor windings are tested with what is termed the 'open star' configuration. Higher voltages may appear because of reflections at the winding end. It is important to note that IEC 60034-18-41 2006-10 made little to no mention of this phenomena. Perhaps it will be discussed further in the IEC working group.

Another suggestion that I ferreted out from the article is that the overall wave shape of the applied impulse could be a more important parameter than previously documented.

From the author's point of view it was generally assumed that the most important surge test parameter was only the rise-time of the impulse. In IEEE 522, the rise time of the surge impulses was stated to be 0.1 micro seconds (100 nano seconds or less) This was not the rise/fall time impressed in the offline laboratory testing. It was 300 nano seconds.

Reference is made to the wave shapes in commercially available surge generators optimized commercially for electric motor testing. In these apparatus, the wave shape of the impulse front versus fall/tail time is generally somewhat triangular, with a fast rise time, and a much slower fall time.
In the laboratory based testing, the rise time/fall time (300 nano seconds) was constant, but the width of the pulses was varied. The pulse width becomes somewhat important as it is related to the converter switching speed, and the modulating frequency. In other words, it is not possible to have pulses wider than defined by the converter frequency. 10 kHz requires 4-6 µS. Anyway, extremely narrow (0.01 µS, 2µS and 25µS) pulses were supplied to the test samples.

Notable information reported was the effect of the very narrow impulses. If the star point was open, a reflected wave resulted in a higher voltage at the open winding end. The rise/fall time of this narrow pulse was reported as about 10 nS. *Of primary importance is that phase to phase hipot was directly mentioned as a test technique that may mitigate some of the surge PD detection deficiencies.* No solid reference to predictive maintenance applications was found in the publication.

Much thought to providing for this need is presently being given by very smart and dedicated technical people:

Forecast publication date of the new IEC TS 60034-18-41 specification is 2013-05.

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