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INFLUENCE OF INCREASED BUS VOLTAGE TO MOTOR INSULATION SYSTEM

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Summary: *The target of this paper is to document influence of increased bus voltage of power converter on motor insulation system. This is needed for evaluation of motors for 800V DC bus based servo-amplifiers. Increase of DC bus voltage is logical consequence of increase power need for servo-drive systems.*

1. Introduction

Life-time of the insulation materials evaluation is usually related to Thermal endurance. This Thermal endurance of film insulated magnet wire, stator varnishes, encapsulates and other insulating materials as components and as a system follow the combined standards of IEC60085, ASTM D2307 and UL1446.

These standards for the most part link the known Insulation Classes with 20,000 hrs as a base life from which to extrapolate from (for example per IEC Standard 60085, “Thermal Evaluation and Classification of Electrical Insulation.”, the temperature rating for a class of material is defined as the temperature at which the average life is 20,000 hours). Therefore use of the extrapolations should be considered for relative thermal comparisons, not exact life performance, since many other factors impact exact winding life.

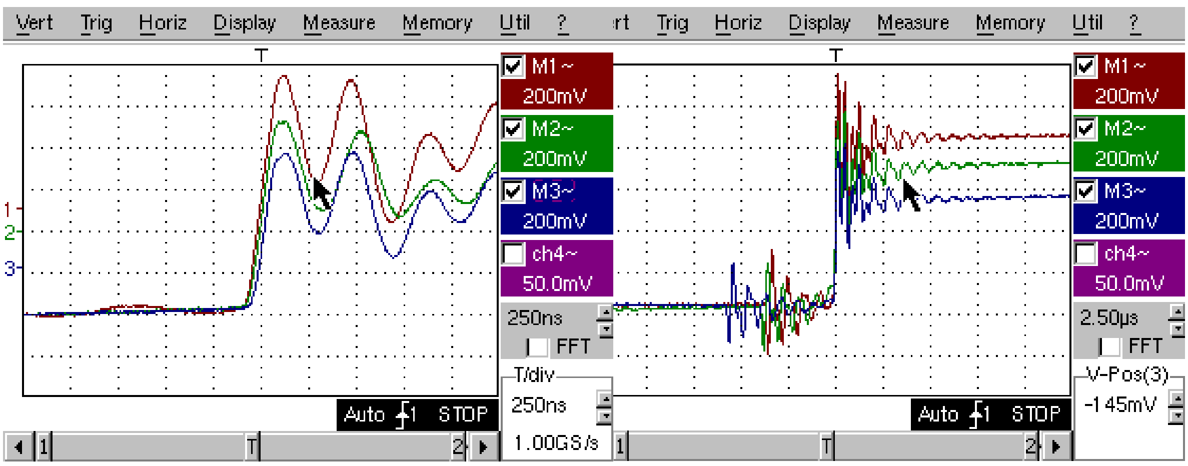

Fig. 1 and 2 Wave shapes at different drive power supply voltages (400, 500, 580V AC)

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2. Technical information

Especially stresses caused by voltage spikes (caused by line reactance also known as Traveling Wave, high frequency, high dv/dt spikes) can dramatically degrease the Insulation life-time. These voltage peaks may exceed 1700 volts for a 480-volt system and these voltage spikes are changing with the supply voltage (together with drive BUS voltage) increasing – see Fig.1.and 2. These voltage spikes may also cause an insulation break down.

Fig. 1. and 2. show wave shapes at highest BUS Voltage 825V DC at different scope time base. Usually there is the wave undulation also on low state of the signal before rise (red circle on Fig. 4.).

To check the impact of these voltage spikes to the insulation life time is a test proposal - by using a drive connected normally to a motor (no common mode choke). The connection between the motor and the drive is by cable of variable length to show its influence on peak voltages and dv/dt ratio.

The drive setting is standard setting for used motor with standard 8 kHz of the PWM frequency. It is important to keep the motor temperature at the same level and make periodical measurement all key factors.

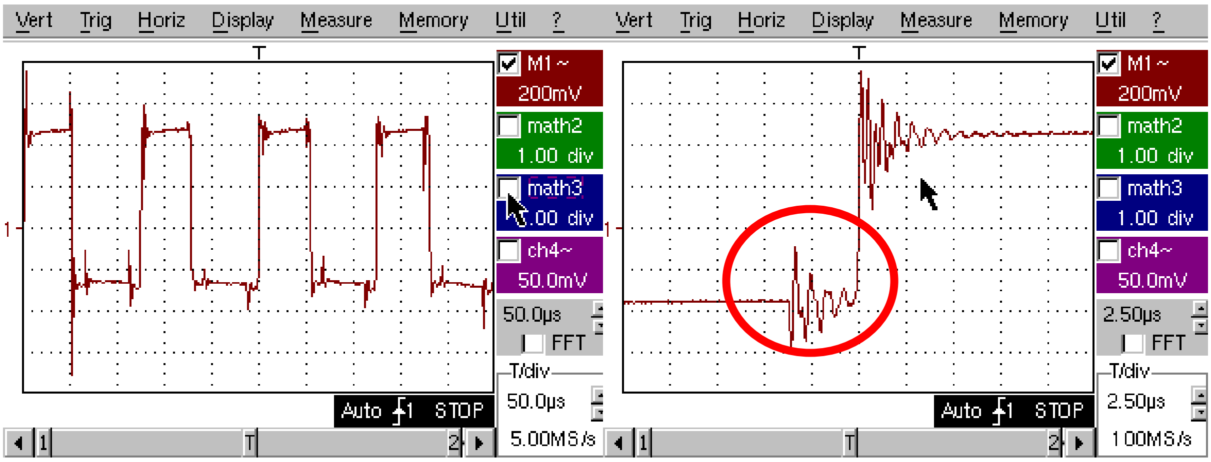

Fig. 3 and 4 Wave shapes (825V DC BUS) at 50µs and 2,5 µs scope time base

During the testing key performance indicators have to be monitored. Checking of insulation resistance is one of the basic methods of evaluation of insulating system. This check need to power off the measured motor, disconnection of cable at motor side.

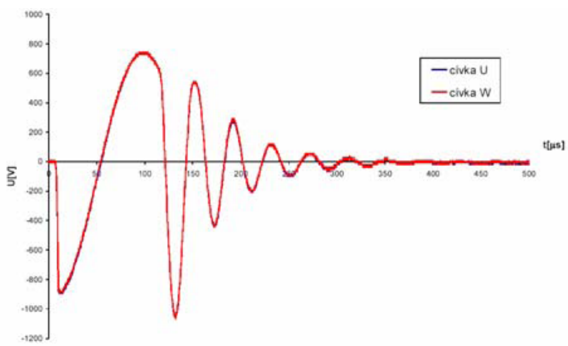

Fig. 5 Surge test of on-fault winding

Surge test is used for detection of short connection at winding. The shape of forward and backward surge is measured, compared and evaluated. This method is very reliable for detection of shortage within the one phase winding; even the insulation resistance to the ground is within the spec.

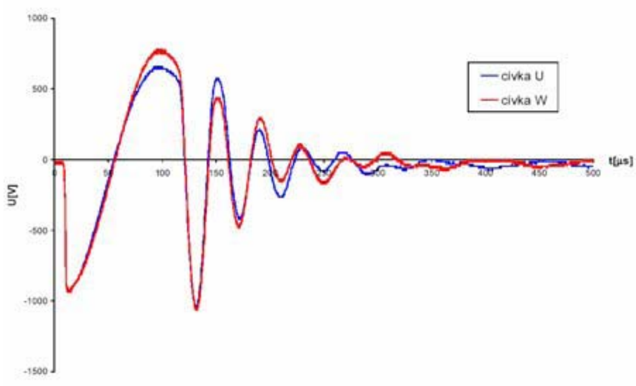

Fig. 6 Surge test of winding with shortage of one turn

Partial discharge (PD) is a localised dielectric breakdown of a small portion of a solid or liquid electrical insulation system under high voltage stress. While a corona discharge is usually revealed by a relatively steady glow or brush discharge in air, partial discharges within an insulation system may or may not exhibit visible discharges, and discharge events tend to be more sporadic in nature than corona discharges.

PD usually begins within voids, cracks, or inclusions within a solid dielectric, at conductor-dielectric interfaces within solid or liquid dielectrics, or in bubbles within liquid dielectrics. Since discharges are limited to only a portion of the insulation, the discharges only partially bridge the distance between electrodes. PD can also occur along the boundary between different insulating materials.

Partial discharges within an insulating material are usually initiated within gas-filled voids within the dielectric. Because the dielectric constant of the void is considerably less than the surrounding dielectric, the electric field (and the voltage stress) appearing across the void is significantly higher than across an equivalent distance of dielectric. If the voltage stress across the void is increased above the corona inception voltage (CIV) for the gas within the void, then PD activity will start within the void.

Once begun, PD causes progressive deterioration of insulating materials, ultimately leading to electrical breakdown. PD can be prevented through careful design and material selection. In critical high voltage equipment, the integrity of the insulation is confirmed using PD detection equipment during the manufacturing stage as well as periodically through the equipment's useful life. PD prevention and detection are essential to ensure reliable, long-term operation of high voltage equipment used by electric power utilities.

The equivalent circuit of a dielectric incorporating a cavity can be modeled as a capacitive voltage divider in parallel with another capacitor. The upper capacitor of the divider represents the parallel combination of the capacitances in series with the void and the lower capacitor represents the capacitance of the void. The parallel capacitor represents the remaining unvoided capacitance of the sample.

When partial discharge is initiated, high frequency transient current pulses will appear and persist for nano-seconds to a micro-second, then disappear and reappear repeatedly. PD currents are difficult to measure because of their small magnitude and short duration. The event may be detected as a very small change in the current drawn by the sample under test. One method of measuring these currents is to put a small current-measuring resistor in series with the sample and then view the generated voltage on an oscilloscope via a matched coaxial cable. The actual charge change that occurs due to a PD event is usually not directly measurable. Apparent charge is used instead. The apparent charge (q) of a PD event is not the actual amount of charge changing at the PD site. Instead, it is the change in charge that, if injected between the terminals of the device under test, would change the voltage across the terminals by an amount equivalent to the PD event.

3. Measurement

All of published measurements have been done with scope Tektronix TDS 3012 and high-voltage scope probe Tektronix P6015A 75MHz (line to ground) and high voltage differential probe Tektronix P5210 (line to line).

Two motors of different size and rating have been measured under comparable conditions.

AKM 22C-AN5NR-00		AKM 74P-AN5NR-00	
I_{cs}	1.39Arms	I_{cs}	18.6Arms
T_{cs}	0.84Nm	T_{cs}	52.5Nm
V_s	640VDC	V_s	640VDC
N_{rtd}	8000 rpm	N_{rtd}	2000rpm
P_{rtd}	0.57kW	P_{rtd}	7.52kW
R_{LL}	19.98Ω	R_{LL}	0.48Ω

Tab. 1 AKM2 (on the left side) and AKM7 measurements

Cable length	dv (peak) [V]	dv 10-90% [V]	dt [ns]	dv/dt [kV/µs]
100	1503	1202,4	360	3,3
90	1600	1280	340	3,8
80	1630	1304	310	4,2
70	1650	1320	330	4,0
60	1690	1352	280	4,8
50	1650	1320	250	5,3
40	1640	1312	240	5,5
35	1680	1344	250	5,4
30	1640	1312	133	9,9
25	1600	1280	120	10,7
20	1560	1248	110	11,3
15	1440	1152	102	11,3
12	1320	1056	82	12,9
10	1220	976	65	15,0
8	1100	880	70	12,6
6	890	712	61	11,7
4	870	696	75	9,3
2	730	584	118	4,9

Cable length	dv (peak) [V]	dv 10-90% [V]	dt [ns]	dv/dt [kV/µs]
100	1670	1336	415	3.2
90	1620	1296	405	3.2
80	1610	1288	330	3.9
70	1660	1328	350	3.8
60	1670	1336	259	5.2
50	1680	1344	248	5.4
40	1650	1320	228	5.8
35	1650	1320	217	6.1
30	1670	1336	122	11
25	1620	1296	125	10.4
20	1570	1256	107	11.7
15	1470	1176	88	13.4
12	1370	1096	81	13.5
10	1270	1016	71	14.3
8	1270	1016	66	15.4
6	1210	968	75	12.9
4	1020	816	80	10.2
2	970	776	140	5.5

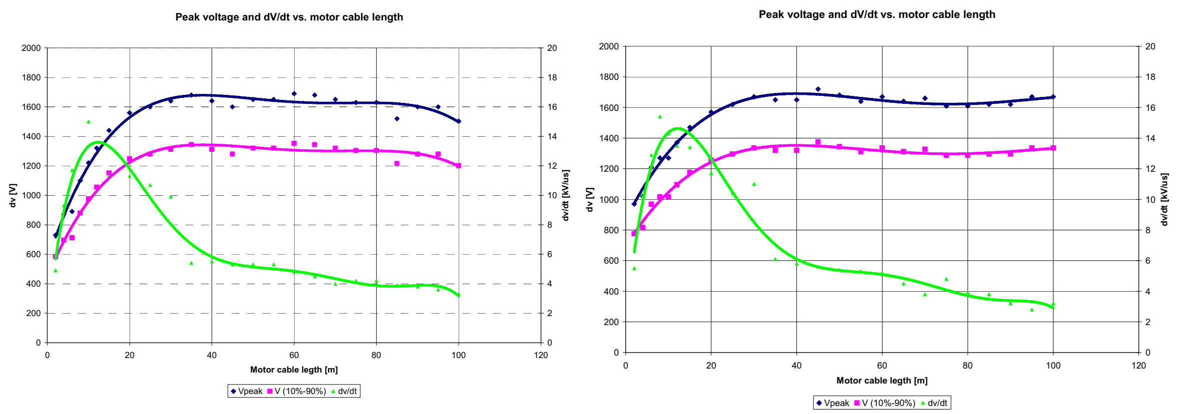

Fig. 7 and 8 dv/dt ratio and peak voltages for AKM2 (left side) and AKM7

4. Conclusions

Figures 7. and 8. show that maximum peak voltage and maximum dv/dt ratio does not occur at the same cable length. Peak voltage culminates at 36m of cable length, while the dv/dt ratio is highest at approx. 12m of cable length. Comparing both measurements is apparent the difference of dv/dt ratio which becomes worse at AKM7 motor, while the peak voltage remained comparable to AKM2. Also in this case the dv/dt ratio and peak voltage does not meet at the same cable length. Both of these parameters affect, the lifetime of insulation system and should be kept in focus for results evaluation.

5. Acknowledgement

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6. References

Barták, A., Mravináč, L., Vařák, J.: Diagnostika poruch izolací elektrických strojů., SNTL 1984, Praha, ISBN 04-523-84

IEEE 400-2001 "IEEE Guide for Field Testing and Evaluation of the Insulation of Shielded Power Cable Systems"

IEEE 1434-2000 "IEEE Trial-Use Guide to the Measurement of Partial Discharges in Rotating Machinery"

IEC 60270:2000/BS EN 60270:2001 "High-Voltage Test Techniques - Partial Discharge Measurements"

Engineering Dielectrics, Volume IIA, Electrical Properties of Solid Insulating Materials: Molecular Structure and Electrical Behavior, R. Bartnikas, R. M Eichhorn, ASTM Special Technical Publication 783.

IEC 60085:2004 Electrical insulation. Thermal classification