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A NEW WINDING WIRE FOR INVERTER DRIVEN MOTORS

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The demand for inverter driven motors has increased rapidly in the past and is supposed to continue growing in the near future with an annual rate of 10%. Reasons for this development are the need of power and speed controlled motors in automated production processes and an identified need for energy saving. Using pulse width modulation (PWM, see figure 2) of the electrical supply fed to AC motors results in improved constant flux control which permits optimisation of the developed torque speed characteristic across the operating speed range.

The PWM waveform from the inverter output generates voltage peaks which stresses the conductor insulation of the motor windings. These surge voltages can be about 2 to 3 times higher than the nominal voltage of the motor. This causes partial discharges and dielectric breakdown. To achieve live times of inverter drives equal to those of AC induction motors with fixed speed suitable solutions for the insulating system have to be developed.

This paper gives details and test results of a mica based insulated winding wire for inverter driven motors and a comparison with other winding wires existing on the market.

WHY USE INVERTER DRIVEN MOTORS

There has always been a large demand for drives with adjustable speed. During the 50‘s this segment was dominated by DC motors because it was easier to adjust DC voltages since only one voltage had to be controlled instead of three in AC motors. Nevertheless these machines had a relatively low efficiency, they were quite large and not very robust. During the following years the three-phase AC motor became more and more popular due to its robust construction, simplicity and little need for maintenance. But the vast majority of AC motors had fixed speed and a change became only possible in the mid 80‘s when technical solutions for frequency inverters became less expensive and more compact. This was the breakthrough of inverter driven motors which are now available in the range of 100 W to 1000 kW.

The introduction of the inverter driven motor (Figure 1) caused a problem which was underestimated for a long time: The increased stress on the motor winding insulation generated by surge voltages resulted in motor winding insulation failures, mostly in systems using AC supply voltages above 400 V. These stresses are caused by the interaction of the fast rising voltage pulses of the drive and transmission effects in the cable. They are dependent on the pulse frequency and rise time of the inverter, the motor cable length and the design of the stator winding of the motor. The pulse rise-times are so short (0.25 μs – 1 μs) that their propagation along the motor cable to the motor can change the pulse shape and may produce a voltage overshoot (Figure 3). Due to this effect the terminal voltage of the motor may reach peak values of two times the pulsed output voltage of the inverter.

In addition to this there is an uneven voltage distribution in the motor windings depending on motor and winding parameters. This has little effect on the main motor insulation systems between phases and from phase to earth – which are generally designed to withstand large over voltages - but it causes high stresses of the insulation between turns. The voltage potential between turns, especially between randomly touching conductors within a coil or – in the worst case - between coil ends may reach peak values of 40 to 70 % of the incident terminal voltage.

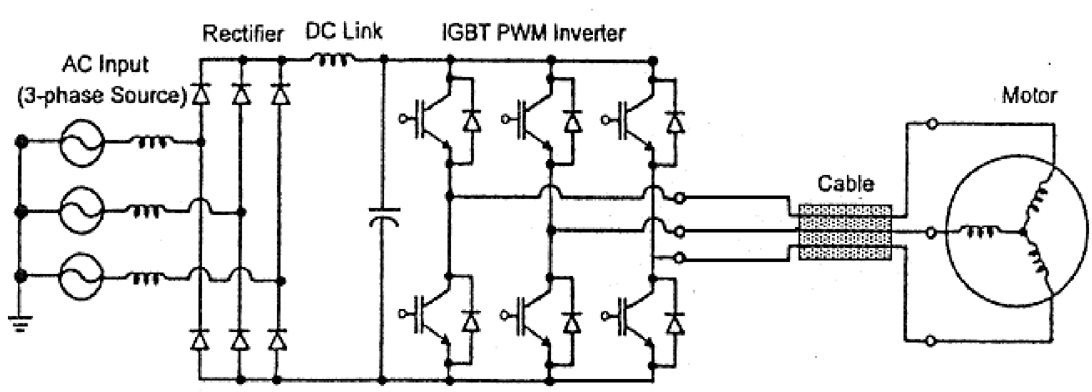

Figure 1: Electric system of an inverter driven motor

Table 1: Surge voltages in inverter driven motors

Insulation	**Surge Voltage Factor**	**Surge Voltage**		
		Un = 400 V Ud = 565 V	Un = 575 V Ud = 815 V	Un = 690 V Ud = 975 V
Phase - Earth	2,0 x Ud	1130 V	1630 V	1950 V
Phase - Phase	2,3 x Ud	1300 V	1870 V	2240 V
Conductor - Conductor	(0,4 ... 0,7) x 2,0 x Dd	450 ... 790 V	650 ... 1140 V	780 ... 1365 V

Un = Nominal Voltage Ud = Intermediate Circuit Voltage = SQR2 x Un

There is a constant search for faster power switching devices with higher pulse frequencies, shorter rise-times and steeper wavefronts.

Higher pulse frequencies have several benefits: The speed control of the drive is smoother and harmonic losses and the audible noise from the motor are lower. The power losses from the inverter are mainly in the switching point when we have a currant and voltage over the IGBT. Therefor the pulse rise time will get higher in future. A higher rise time means higher frequencies in the switching point. This aggravate the problem of reflections in the wires what creates the voltage peaks. The problem of surge voltages in low voltage inverter drives will therefore remain an important issue.

Voltage

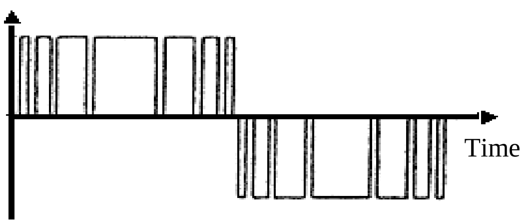

Figure 2: Output of the inverter

Voltage

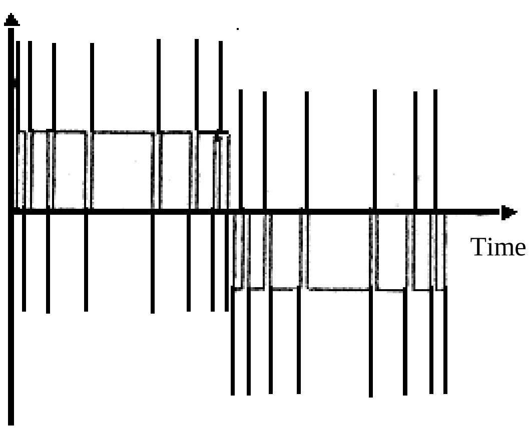

Figure 3: Input of the motor

QUALITY OF WIRES FOR INVERTER DRIVEN MOTORS

A good quality of a wire for inverter driven motors is given by

- a high level of partial discharge inception voltage (PDIV)
- a high resistance for PDIV

Table 1 shows that surge voltages in inverter driven motors reach peak values up to 3 times higher than the nominal voltage of the motor. The standard insulation systems used for the main motor insulation between phases and from phase to earth are generally able to withstand these surge voltages. Much more critical is the conductor insulation which has to endure high electrical stresses and which may be destroyed if partial discharge occurs and if conventional enamelled wires for low voltage applications are used.

MICA

For more than a century mica is a well known material for high voltage insulation. The superior resistance to corona makes it unreplaceable in high voltages motors and generators.
Organic materials show a decrease of break down voltage after partial discharging (corona) because the carbon generated thereby is conductive. This means that the wire insulation is ageing. Mica is an inorganic material and will not generate any carbon when it is affected by partial discharge. Mica is a crystalline material which consists of splittings. From these splittings mica paper is produced which consists of fine mica platelets with a perfect planeparallel orientation like the brick wall model shown in figure 4. This results in an insulating material with a high corona resistance and excellent longterm break down voltage compared to organic polymers. Even if polymers are filled with inorganic fillers – e.g. aluminiumoxide which is used as a filler for corona resistant enamelled wires – the electric breakdown path through spherical particles is much shorter (Figure 5).

For thin wires the conventional mica insulation is too thick. This would give a high increase of insulation thickness due to wrinkles caused by the stiffness of the

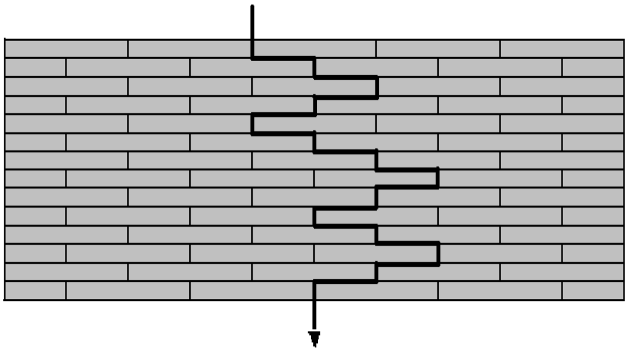

Figure 4: Brick wall model of mica insulation

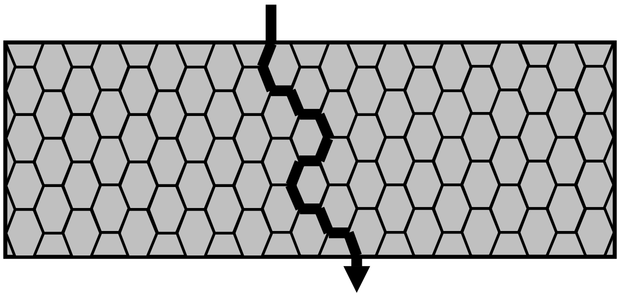

Figure 5: Electric breakdown path through spherical particles

mica tape. Von Roll Isola therefore developed SamicaShield®, a winding wire with a new type of mica insulation which is very thin. The thickness of the insulation of SamicaShield® wires varies between 0.09 and 0.11 mm depending on type and application.

VOLTAGE LEVEL OF CORONA

The detrimental effect of surge voltages in inverter drives is caused by partial discharges in air gaps between conductors which destroy any insulating material based on organic polymers such as wire enamels. The partial discharge inception voltage (PDIV) is a function of the distance between two conductors, the permittivity of the insulating material in between and ambient factors such as temperature and humidity.

In a twisted pair test performed at room temperature with 50 Hz AC we measured the increase in insulation thickness and PDIV of some typical winding wires (Table 2). The table shows that enamelled and filled enamelled wires have a much lower PDIV than lapped or taped wires. The maximum PDIV is obtained if the SamicaShield® winding is impregnated with a suitable resin, e.g. polyesterimide resin 3340.

Table 2: PDIV voltage for various insulations

Type of insulation	Increase due to insulation [mm]	PDIV [V]
Enamelled Grade 2	0,09	800
Filled enamelled	0,09	790-940
Enamelled + PETP taped	0.18	1350
Glass lapped	0.20	1250
Polyimide taped	0.15	1300 up to 1400
SamicaShield®	0.18 0.22	1000 1300
SamicaShield® impregnated*	0.18 0.22	1500 1700

* with polyesterimide resin 3340

RESISTANCE AGAINST PARTIAL DISCHARGE

Round wires with different insulations for low voltage motors were stressed in a pulse endurance test with a pulse width modulated voltage of 2 kV (3 kV) at 20 kHz and a rise-time of 0.025 µs using an impulse generator. The round wire had a diameter of 1.18 mm (bare copper) and was applied in a twisted pair arrangement. Time was measured till electric breakdown. Measurements were done with 2 kV and 3kV and results are shown in table 3.

Table 3: Ageing test results at 20 kHz

Type of insulation	Live time for 2 kV [h]	Live time for 3 kV [h]
Enamelled Grade 2	0,5	0
Filled enamelled	50	0
Enamelled + PETP taped	>100	0.5
Glass lapped	2	0
Polyimide taped	>100	0.03
Polyimide taped with higher corona resistance	>100	1,2
SamicaShield®	>100	1,5
SamicaShield® impregnated*	>100	>10

* with polyesterimide resin 3340

The comparison in table 3 shows that SamicaShield® with a high corona resistance is significantly better than the standard wires (enamelled wire, filled wire, polyimide, glass lapped). It also clearly shows that for nominal voltages higher 400 V enamelled or filled wires are not sufficient. No organic or filled material can reach the outstanding corona resistance properties of mica.

FIELD TEST

In a field test the lifetime of five inverter driven motors with different enamel coated wires and with SamicaShield® wire was compared under accelerated ageing conditions. The motors with enamelled wire and filled enamelled wire showed partial discharge in the coil windings, whereas the motor with SamicaShield® wire was free of partial discharge. Lifetimes till motor failure were approx. 100 h with standard enamelled wire and approx. 200 h with filled enamelled wire. The ageing test of the motor equipped with SamicaShield® wire was stopped after 4000 h without motor failure.

The Korean Electrotechnology Research Institute (KERI) tested 26 inverter driven low voltage induction motors for elevator application. Six different types of insulating materials were used including SamicaShield® and PDIV, maximum PD magnitude Q_m, Δ I, Δ tan δ and breakdown voltage were measured of each motor. The motors with SamicaShield® gave the best results in all measurements. The results were published at the IEEE 2000 conference in Los Angeles.

SEGMENTATION

Table 4: Segmentation of wires for inverter driven motors

Segment	Enamelled wire	Enamelled Filled wires	Lapped and taped wires	SamicaShield wire
<= 400V < 75kW motors	-	+	+ / -	+ / -
<= 400V > 75kW motors	-	+ / -	+	+
> 400V motors	-	-	+ / -	+
High performance motors	-	-	+ / -	+
Special application's *	Dependent on Application			

* e.g. wind mill generator

\+ fulfills requirement   +/- fulfills partly requirement   - does not fulfill requirement

The segmentation in table 4 gives an overview on the wire applications for inverter driven motors.

An enamelled wire should not be used in inverter driven applications. Due to its low increase of insulation thickness the filled wire is a good solution for inverter driven motors up to 400V. For motors with high performance like elevator motors or crane motors SamicaShield® gives a much better quality in life time. SamicaShield® also gives a real cost advantage because no filter is needed.

In motors > 400V there is strong partial discharge and therefore SamicaShield® is the most resistant wire and will ensure a long life time of the motor. This has also to be considered when a 400V motor can be switched from star to delta.

In many non motor applications peaks from electronic switching may occur which can stress the wire and reduce the life time dramatically such as in wind mill generators. SamicaShield® enables innovative solutions.

SUMMARY

Today adjustable speed power units with frequency converters and 3-phase current induction motors are a standard. However the coil windings of these motors are exposed to surge voltages caused by the fast rate of voltage changes which may – in motors with nominal voltages between 400 V and 1000 V - lead to partial discharge, inter-turn short circuit and finally total failure of the motor. To prevent these motors from failure several solutions are proposed:

- The use of filters or other units which are placed between inverter and motor. These solutions need correct matching to the application, they also need extra space and they reduce the efficiency of the power unit.

- The use of filled enamelled wire. The problem with this solution is that it has no or little effect on the partial discharge inception voltage, but it will slow down the rate of erosion under corona conditions. Furthermore filled enamelled wires have limited mechanical strength due to the brittleness of the coating.

- Von Roll Isola developed SamicaShield®, a winding wire with a new type of very thin mica insulation. Mica is the preferred insulating material in high voltage machines and is known to have superior electrical and thermal properties. Partial discharge inception voltage of SamicaShield® wire is 1500 V which is above all surge voltages between conductors to be expected in inverter driven motors with nominal voltages between 400 V and 690 V. Pulse endurance tests simulating the stress generated in inverter drives resulted in a outstanding lifetimes of SamicaShield®. These results were confirmed by field tests with inverter driven motors.

- With SamicaShield® no filter is needed. Therefore the total motor cost will be lower.

Von Roll Isola offers a complete family of insulating materials especially developed for inverter drives with rated voltages of 400 to 690 V. The product range includes:

- SamicaShield® wire in diameters of 0.63 – 2.00 mm and with an increase in insulation of 0.18 to 0.36 mm.

- Slot insulation Myosam, which is a 160 g/m^2 Samica® mica paper coated on both sides with Aramide paper. The mica paper ensures the long term corona resistance of the slot insulation.

- Phase insulation Myoflex PF, which is a PETP–film coated on both sides with PETP–fleece. The fleece absorbs the impregnating resin and reduces the risk of resin run-off.

- Impregnating resins 3032 and 3340 (both rigid) or 3037 (flexible) which are all UL approved class H polyesterimide resins. These resins combine good tank stability with a fast gel time (1.5 – 2.0 min. at 120 °C) to be used in high throughput production.

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