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Frequency Dependent PD-pulse Distortion in Rotating Machines

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Abstract: **In this contribution will be presented results from investigations on the distortion of PD pulses in the stator winding of a 10kV asynchronous motor.**

In order to determine the distortion of PD pulses from different, well defined parts in the winding, the following two techniques were used simultaneously:

a) Ultra wide band detection in the frequency range of 20-400MHz by means of stator slot couplers under the stator wedges, in order to localize and quantify the discharges.

b) High frequency measurements in the frequency range of 1-100MHz by means of high frequency current transformers at the machine terminals.

The results show a variation of the attenuation of the discharge pulses inside the machine of about 20dB, highest for pulses from the far end, i.e. the neutral point. The capability of exact localization of the discharges in the winding gives a correct measure of the range of the current transformer based detection method, when being applied to rotating machines.

The results will be discussed with regard to the practical application of PD-detection systems on rotating machines. In particular, will be discussed aspects of range and applicability of systems in the high frequency ranges.

INTRODUCTION

On-line measurements of partial discharges (PD) in rotating machines are difficult, due to high electric noise level normally present in the environment of the machine. Due to the large number of inductances and stray capacitances inside the machine, the relationship between the originally generated pulse, inside the slot with the discharge, and the pulse detected at the terminals of the machine, will depend on the electrical distance between discharge and coupling point. Earlier investigations on pulse propagation in rotating machines, based on artificially injected pulses somewhere in the winding [1,2,3] showed that typical signals at the terminals often consisted of a number of frequency components and that the pulse attenuation was highest for the high frequency part of the signal. This attenuation can be considered as a measure for the range of the detection system, which is known to be highest for detection systems in the lower frequency range as 50 - 500kHz and most limited at the high frequencies in the MHz-range. On the other hand, high frequency methods are still interesting, since noise reduction is considerably easier at frequencies in the MHz-range as at lower frequencies.

More recent work was done with pulses from discharges as a reference [4].

Besides the range of the detection system, aspects such as electric access to the machine have to be considered. In general, it might be difficult - for technical or other reasons - to permanently apply coupling devices on a machine. A solution that minimizes changes in the existing installation will always be preferred by the user. High voltage motors in Denmark are usually not equipped with surge capacitors, and a coupling without galvanic contact to the terminals is still the optimum solution of the coupling problem. For that reason, inductive coupling by means of a high frequency current transformer was used in the present investigations.

The purpose of the investigations was to determine the distortion of PD pulses from different, well defined parts in the winding, under conditions that met with commercially available detection systems.

When comparing different detection systems, a usual problem is the lack of a realistic reference pulse. After the development of stator slot couplers [5], new possibilities were given to approach this problem.

Therefore, the following two techniques were used simultaneously:

a) Ultra wide band detection in the frequency range of 20-400MHz, by means of stator slot couplers under the stator wedges, in order to localize and quantify the discharges.

b) High frequency measurements in the frequency range of 1-100MHz, by means of high frequency current transformers at the machine terminals.

It was our intention to do measurements in the low frequency range (40-400kHz) as well, but the discharge activity in the machine was to high to be able to separate the pulses from single discharges in the low frequency signal.

By placing the coupler in turn in most of the 24 slots in one phase, it was possible to investigate the pulse distortion of the originally very fast pulses as measured by the SSC, when transferred through the high impedant endwinding and the path to the terminals.

The origin of the discharges, in the slot or inside the insulation, was not known and is not of relevance in this case.

TEST SET-UP

Motor

Two different PD measurement techniques were applied on a 35 year old 10kV squirrel cage induction motor with the following specifications:

Voltage:	$10kV_{rms}$
Stator Current:	71A
Output Power:	1MW
Speed:	980 $min.^{-1}$

Stator winding:

Poles/phase:	6
Coils/pole:	2
Turns/coil:	18
No. of slots:	72
Slot length:	66cm

The investigations were made with the rotor removed from the motor and the neutral point disconnected. One stator phase was energized the other two phases grounded. This voltage distribution along the winding is another one as the distribution under normal operation.

Moreover, the ventilation and the temperature will have influence on development on the discharges in the stator, and certain kinds of discharges, such as contact noise due to bar vibration, could occur. But, as mentioned above, the purpose of the investigations described her was to determine the pulse characteristics inside a rotating machine and not to estimate the overall condition of the machine. Such an estimate, of course, should be made on-line under normal operation.

The motor was connected to a 04./10kV transformer by means of a 2m long, three conductor PEX-Cu cable with usual terminations i.e. 0.5m unshielded incl. field grading at both ends. The metallic shield of the cable was grounded at transformer and motor end.

The test voltage was set to just above inception voltage for the discharges in a specific slot.

SSC

The stator slot coupler, SSC [5], was installed in the stator phase L_3 in one of 18 different slots at a time. In the following description, the notation of the slots is 1 to 24, referring to the electrical distance from the terminal end, i.e. slot 1 is the first slot as seen from the terminals and slot 24 is the one closest to the neutral point.

The 2 outputs were directly coupled to the 50Ω-input of a 500MSampl/s digitizing oscilloscope.

Fig.1 shows the test set-up.

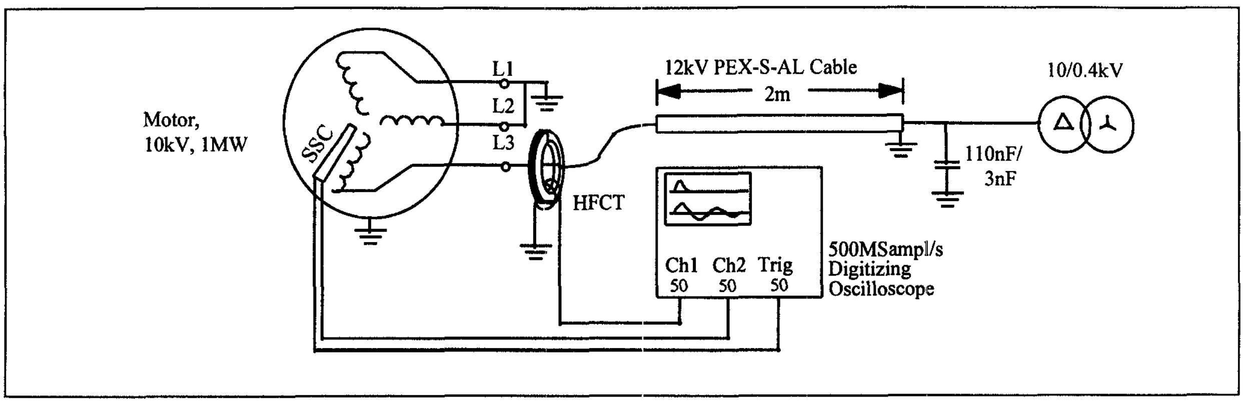

Fig. 1: Test Set-Up

HFCT

The high frequency current transformer (HFCT) was a Rohde&Schwarz EZ-17 clamp-on transformer with the following specifications:

Bandwidth:	1-100MHz
Transfer Impedance:	3.16Ω
Saturation current (50Hz):	$300A_{peak}$

The current transformer measures the high frequency part (>1MHz) of the current from the power supply necessary to compensate for the charge induced into the winding by the discharge process. As can be seen in fig.1, the HFCT was used to measure the current in one phase line directly. This current depends on the impedances inside the motor and the impedances in the power supply. The shape and the amplitude of the current pulse, therefore, will depend on all inductances and stray capacities between discharge site and power supply.

The low frequent capacity of the cable was 0.3nF, terminated at the supply end with two different capacitors, 3nF or 110nF. The purpose of different capacitors was to determine if the far end of the cable has any influence on the detected signal.

The high frequency equivalent of the stator in a rotating machine is a very complex system, in particular, when a broad frequency spectrum has to be considered and we will not try to establish such an equivalent.

Measuring Procedure

Due to the SSC's capability of localizing single discharges at a specific point in a specific slot, the SSC signals acted as reference pulses for all the comparing measurements.

In order to make reproducible measurements, the reference pulses chosen always came from the coupler's slot end and originated from a discharge directly under the SSC, in the middle between the two outputs. In that case, the development of the original electrical pulse at the discharge site can be considered to be independent of the impedance discontinuity formed by the slot end and the endwinding.

There is a possibility of pulses from other slots arriving at the same time, but these can easily be excluded, since they will always show some oscillations [4].

The correlation between the signals from the SSC and from the HFCT is ensured by the pulse transition time which easily can be controlled on the oscilloscope.

RESULTS

In all the slots investigated, PD activity could be observed. The inception voltage varied between 2.5 and 7 kV_{rms}.

In fig. 2 can be seen a typical pulse from the SSC and the response from the HFCT on the same discharge.

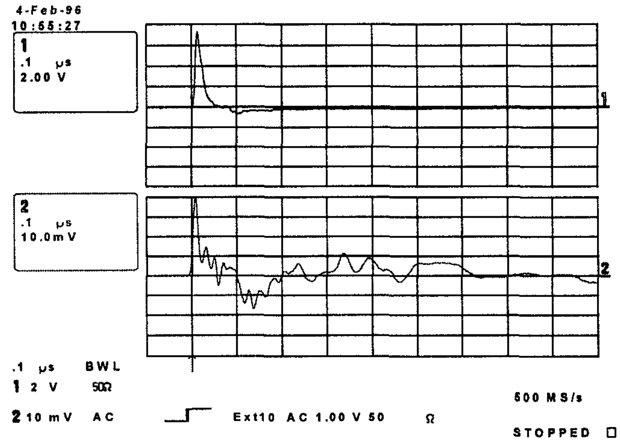

Fig. 2: Ch1: SSC-signal from discharge in slot#1
Ch2: HFCT-response
Cable terminated with 110nF.

The pulse shape from the SSC's was similar from all slots, the amplitude varied between 100 and 4000mV.

The pulse shape from the HFCT consisted, for most slots, of a number of different frequency components. Since a detection system usually detects the peak value of such a complex pulse, the peak value also, in this case, is taken as the response to a discharge defined by the SSC-signal. The HFCT peak amplitude varied between 0.1 and 15mV. The influence of the terminating capacitor can be seen in fig .3.

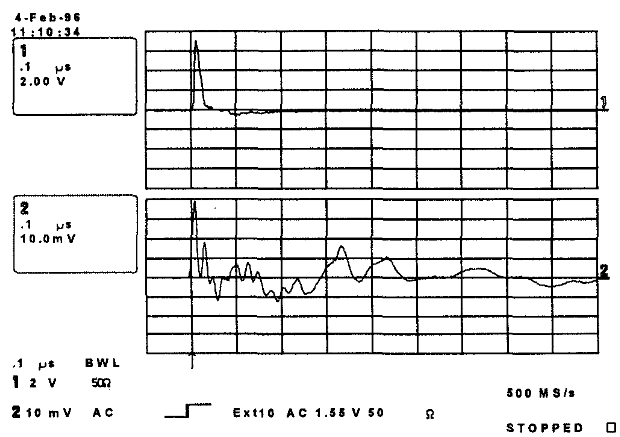

Fig. 3: Ch1: SSC-signal from discharge in slot#1
Ch2: HFCT-response
Cable terminated with 3nF.

Comparing the HFCT pulse shape with the one in fig.2, the pulse shape can be seen to be only slightly affected by the termination of the cable. The peak values of the detected pulse are identical.

The attenuation of the pulses through the machine is shown in fig. 4. It is evident that the attenuation is increasing from 48dB in the slot closest to the terminations to 58 to 68dB in slot 9 and 10, whereafter the response is kept within this range. An exception is slot 11 with an attenuation that is about 10 dB higher than for the other far end slots.

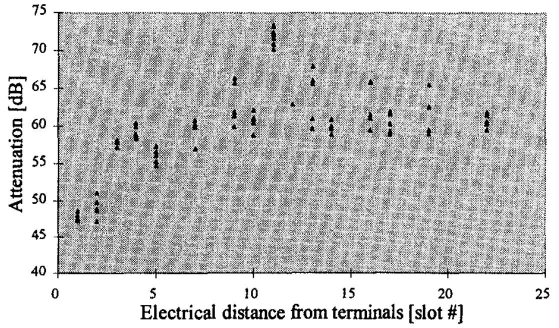

Fig. 4: Pulse Attenuation, SSC - HFCT

The correlation between SSC-peak and HFCT-peak is shown in fig. 5. Since this relationship is a function of the location dependent attenuation, it is only shown for the constant attenuation region, i.e. slot 12 - 23.

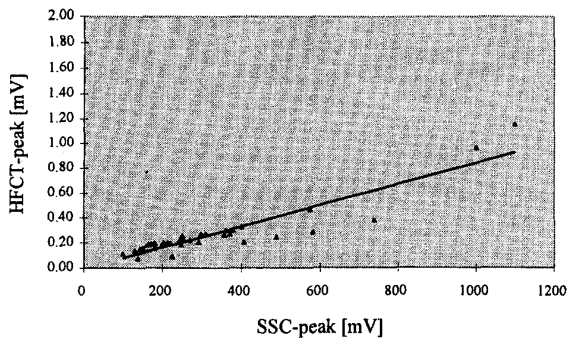

Fig. 5: Relationship SSC-peak - HFCT-peak

DISCUSSION

The measuring results confirm earlier investigations which show a non-negligible attenuation of the high frequency part of the PD-pulse. The attenuation increases with increasing distance from the measuring point, but reaches a maximum point, which was about 20dB higher than the attenuation of pulses from the first slot.

This means that the pulse magnitude at the discharge site can only be predicted by HFCT measurements to within a factor of about 10.

The magnitude of the detected SSC-signal [up to few volts] cannot be directly related to the discharge mechanism, since this magnitude will depend on the whole electrical configuration around the discharge. Nevertheless, the signals, as detected by means of an SSC, give a very clear indication of single discharges taking place in the slot. This fact, together with the somewhat linear relationship between SSC and HFCT signal, confirms the usefulness of the SSC-signal as a reference with these kinds of measurements.

The reason for peak independence of the cable termination is most likely, the high frequency range. This is very interesting, with respect to on-line measurements, where a single current transformer directly on the supply cable normally is the most attractive coupling method for economic reasons, since additional components can be avoided and - not least - for safety reasons.

A coupling method in a lower frequency range must be expected to be more dependent on cable length and termination. Moreover, voltage- against current measurements have to be analyzed. In this case, the cable acts as a low impedance transmission line, which justifies the current measurements and makes the first peak of the signal independent of the far end of the cable [figs. 2 &3].

Under measurements in the low frequency range, voltage measurements might be more appropriate, but, in that case, cable length and capacity can no longer be ignored.

As can be seen from the present investigations, aspects such as pulse attenuation, linear relationship between discharge size and detected system and the applicability of the coupling device must be considered when choosing detection system. A frequency range > 1MHz is applicable if 20dB uncertainty can be accepted or if relative, tendentious investigations on a specific machine are the underlying policy for the PD-measurements.

The major advantage of the HFCT-detection method, with the current transformer directly on the supply cable, is that no additional components are necessary. The disadvantage, of course, is an uncertainty of the result within 20dB. This might be acceptable if, for example, the noise conditions on-site make high noise suppression necessary.

CONCLUSION

PD-measurements in the range of 1-100MHz, by means of a high frequency current transformer directly in the supply line to a 10kV, 1MW asynchronous motor, showed:

a) attenuation of the high frequency part (>1MHz) of the PD-pulses inside the motor which depended on the PD location and increased 20dB within the first 9 slots as seen from the motor terminals.

b) a detected peak-current independent on a cable termination 2m from the motor terminals,

c) the possibility of use of stator slot couplers for detecting a reproducible discharge signal at a specific location inside a rotating machine and using this signal as a reference source for investigating PD-detection systems. Hereby, pulse propagation can be measured in a simple way.

More work will be done in the future with the aim to come closer to the relationship between the discharge process itself and the response from different detection systems.

Next, other current transformers in a lower frequency have to be applied on our system and have to be compared with the actual conditions on danish power plants with respect to cable type, length and termination.

REFERENCES

[1] M. Henriksen, G.C. Stone, M. Kurtz. "Propagation of Partial Discharge and Noise Pulses in Turbine Generators." IEEE Transactions on Energy Conversion, Vol.1, No.3, pp.161-166, 1986.

[2] H. Zhu, I.J. Kemp. "Pulse Propagation in Rotating Machines and its Relationship to Partial Discharge Measurements". Conf. Rec. of IEEE International Symposium on Electrical Insulation, Baltimore, USA, pp.411-414, 1992.

[3] A. Wilson, R.J. Jackson, N. Wang. "Discharge Detection Techniques for Stator Windings". IEE Proceedings, Vol.132, Pt. B, No.5, pp. 234-244, 1985.

[4] J.T. Holbøll, M. Henriksen, A. Jensen, F. Sørensen. "Motor Insulation Diagnostics by High Frequency PD Detection". International Conference on Electrical Machines, Paris, France, 1994.

[5] H.G. Sedding, S.R. Campbell, G.C. Stone, G.S. Klempner. "A New Sensor for Detecting Partial Discharges in Operating Turbine Generators". IEEE Transactions on Energy Conversion, Vol.6, No.4, pp. 700-706, 1991.

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