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The longterm view-point at the partial discharges activity in the insulation of the pump motors

Streszczenie. (Długoczasowe spojrzenie na aktywność wyładowań niezupełnych w izolacji silników pomp). *Artykuł opisuje badania wnz prowadzone w trybie off-line w celu diagnozowania uzwojeń stojanów silników na napięcie 6,3kV. Badano silniki pomp w różnych stadiach ich użytkowania. Interpretacja uzyskanych zbiorów danych wskazuje na dwa znaczące parametry związane z aktywnością wyładowań niezupełnych: czas eksploatacji silnika oraz technologię wykonania uzwojeń stojana. Zaobserwowano związki pomiędzy czasem eksploatacji i ładunkiem maksymalnym wyładowań niezupełnych. Studium przypadku zakończono opisem uszkodzeń izolacji oraz wynikami diagnostyki.*

Abstract*. The off-line PD tests applied to the stator windings diagnostics of the 6.3 kV pump motors are described in the paper. The pump motors in various stages of the lifetime were tested. The dataset interpretation shows concurrently two significant parameters due to partial discharge activity: the service time of the motors and stator bar rewinding technology. The observable relation between time of service and maximal values of the apparent charge is presented. The case study ends by description of the insulation deterioration and diagnostic results.*

Słowa kluczowe: polimerowy układ izolacyjny, starzenie izolacji, wyładowania niezupełne (wnz).
Keywords: Polymeric insulating system, insulation aging, partial discharges (PD).

Introduction

The reliable work of asynchronous motors is required in number of the technology and industry branches. The regular motor maintenance has become the standard for premature failure prevention. The content of the maintenance workpack can differ from the case to the case. The maintainers always look for better tools for motors life cycle description. The service conditions and hours actually worked for motors are usually known information which creates specific background for life cycle analysis and takes responsibility for ageing dynamics. It includes electrical, mechanical, thermal, chemical and radiating influences.

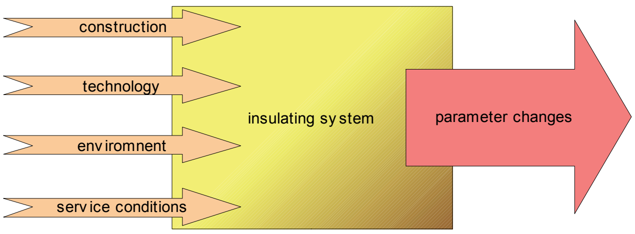

Fig.1. Overall influences application to insulating system aging

The partial discharges quantities are reliable indicators of insulation aging. The implementation of the regular partial discharge measurements and analysis can reveal some important problems and defects in the insulating system. It is interesting to compare partial discharge analysis results with respect of the measurement history. Partial discharge measurement and phase resolved analysis can identify some kinds of insulation failure. Voids development in the material bulk, semiconductive protection failure on the bar surface, discharges in the stator slots which are caused by slot wedge releasing. The number, the intensity and phase correlation of partial discharges give several information on insulation deterioration. With having respect to difficulties related to realisation of the partial discharge measurement procedure the trend analysis based on phase resolved partial discharge analysis patterns differences observation is used. The change in pattern reveals the change in the insulation state. The changes criticality is pointed by defect characteristics from pattern structure observed [1]. The continuity of the trend analysis is interrupted at time of stator repair and by rewinding technology used. If new technology is applicated the new trend would be expected.

Object description

The stator polymeric insulation systems of six identical asynchronous pump motors were observed. The insulation systems had the similar load characteristics and different on-load time. They were signed as M00, M01, M02, …, M05. The MICA in combination with resin is the base material in insulating system of the stator bars, thermal class F. The winding bars in stator body are shown in Fig. 2.

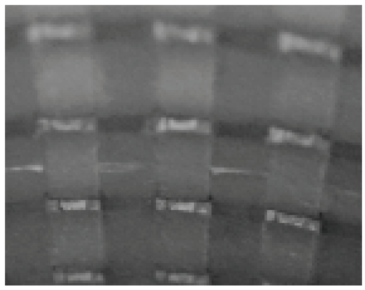

Fig. 2 The winding bars wedged into stator body

Rated voltage is 6 kV and rated power is 2.1 MW. The windings connected to triangle configuration. The time of operation of the motors and activity of partial discharges were saved. The dates of rewinding the motors were saved, too.

Table 1. Object summary

Code	Time of service (months)	Technology #
M00	88	?
M01	0	2
M02	24	2
M03	40	2
M04	88	1
M05	32	2

Object summary: there are six insulation systems, constructed by two different technologies and different operational times.

Experimental

The off-line tests were done. Analog PD signal was digitized and stored for further post-processing analysis. An a.c. voltage of 0 to 5 kV was applied to the objects. The test voltage was increased up to partial discharges ignition. Then the partial discharges were recorded at ignition and rate voltages. A PD pattern was formed from the PD data. The measurement was repeated for all of the motors. The test circuit configuration is shown on Fig. 3.

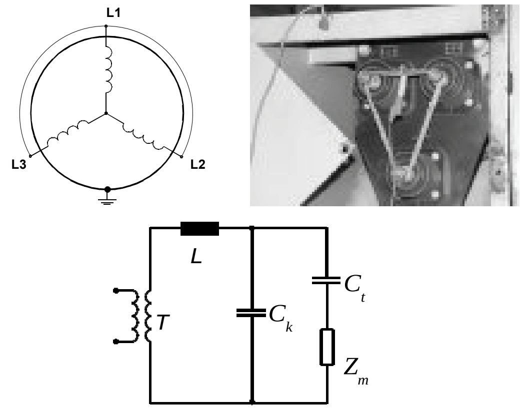

Fig. 3 The terminal connection and PD measuring circuit: C_k – capacitive coupler; C_t – tested object; Z_m – measuring impedance; Z – low-band filter

The terminals were connected mutually. The insulation of the motor becomes one capacitive load and this capacity has been included into measuring circuit. The test procedure has consisted of partial discharges recordings at each of applied test voltage magnitude values. We consider that the important are the recordings at ignition and rate voltages.

Partial Discharge Phase Resolved Analysis

Each of partial discharges can be represented by: apparent charge and ignition voltage values and phase angle of a.c. test voltage [2]. The main goal of the PD diagnostics is to recognize defects in the insulation which cause internal discharges in voids or surface discharges, corona, treeing, etc. In general, there are six types of PD [3]:

1. Corona discharges occur at sharp points of electrode body in gases and liquids.
2. Surface discharges in gases or oil if there is strong stress component parallel to the dielectric surface.
3. Internal discharges in gas filled cavities.
4. Discharges from electric trees development in solid insulation. Tree can start to grow from a cavity or from sharp conducting particles.
5. Floating part discharges can occur in cases badly grounded components neat high voltage circuit.
6. Discharges form contact noise in the case of bad contacts of poor grounding of the test samples.

Partial discharge phase resolved analysis (PDPRA) is general tool for partial discharges activity evaluation and analysis. The PRPDA exploits the statistical mathematics and was described in several works, i.e. [2]. Three distributions describe partial discharge activity for all of test records: the number of partial discharges, the maximal magnitude of the apparent charge distribution and the mean magnitude of the apparent charge distribution. The evaluation and analysis in turn leads to decision making, i.e. rejection, repair or next operation of the motors.

Mapping of degradation changes

The mapping techniques, long term aging until breakdown is discussed here [3, 4]. Partially, the technique was applied in this case analysis. The next text describes degradation process of insulation system signed as no. 2 technology in the Table 1. The digital recordings of partial discharges were stored at four stages of lifecycle. New insulation M00, hereafter M02 at 24 months in service and so on M02-24 months, M05 32-moths and M03-48 months.

Electrical detection shows the presence and the magnitude of partial discharges. Detection was performed with a discharge detector working in bandwidth 250 kHz. Next come statistical tools. The classical patterns of phase resolved data were studied. The process of pattern changes is drawn as set of patterns, see Fig. 4.

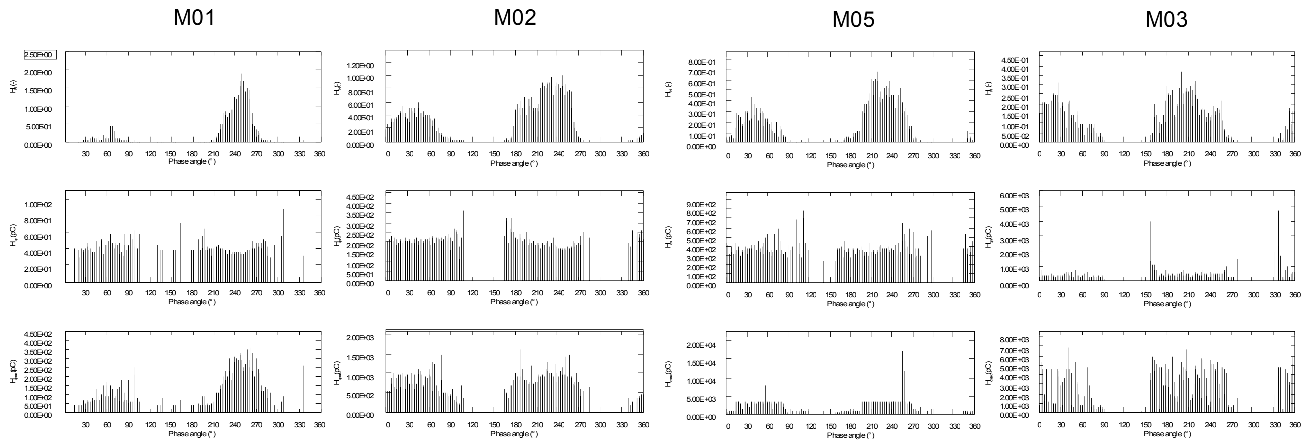

Fig. 4: PD patterns of four life stages of the insulation system

Table 2. PD quantity development at nominal voltage

Code	Time of service (month)	Qmax (nC)	Qmean (pC)	I (μA)
M01	0	0.36	24.94	0.10
M02	24	1.64	138.88	0.74
M05	32	17.24	266.45	0.85
M03	40	6.86	391.11	0.61

The charge development is essential feature for insulation deterioration. Maximal (Q_{max}) and mean (Q_{mean}) apparent charge development at nominal voltage is shown in the Table 2. Although the trend shown has not simple increasing values of charge with the time, as would be expected, activity of partial discharges goes high. It is partial result from comparison Q_{max} and Q_{mean} values. The average discharge current values I (μA) are shown in last column of the table.

More complex view is given by observation apparent charge development in relation to test voltage steps. In the Fig. 5 can be seen relation of maximal (Q_{max}) and mean (Q_{mean}) apparent charge to test voltage steps. The test voltage varies from 2 kV to 5 kV.

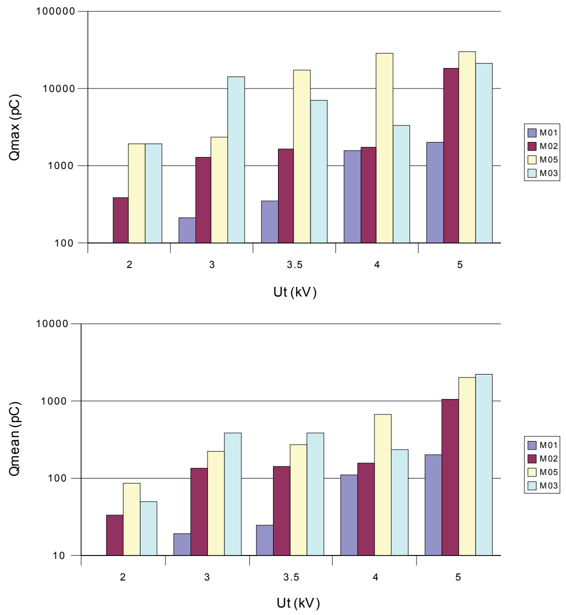

Fig 5: Development of maximal (Q_{max}) and mean (Q_{mean}) apparent charge

Higher statistical moments

Higher moments are used to analyse PD data more precisely. The third and fourth moments represent the shape of the PD distributions. The skewness is related to the asymmetry of distribution around the mean value. The kurtosis represents the sharpness or the amount of the concentration of the distribution around the mean value [4].

The author of reference below notes that the skewness of the phase distribution of the apparent charge is effective to discriminate the kind of discharge PD fingerprints in the phase angle domain. The kurtosis can provide discrimination for multiple cavities and treeing processes.

As an example of higher statistical moments change, data of two equally aged insulations are presented. The insulations differ by production technology.

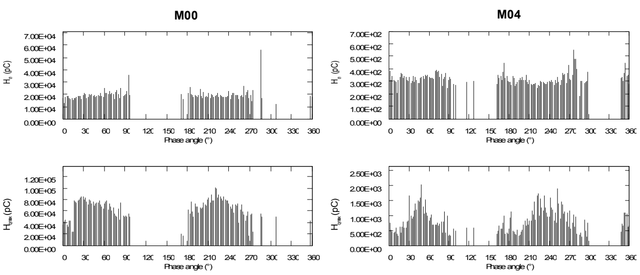

Fig 6: PD distributions of M00 and M04 at nominal voltage

The statistical moments were calculated for both cases, separately for positive and negative voltage half cycles. Results are placed in the Table 3.

Discussion

Tested objects represent set of insulations at various stages of the lifecycle. Insulation system of the motor signed as M00 were for 88 months in the operation and it is characterised by high value of apparent charge. Mostly PD are active in the slots of the stator. The ionisation caused by discharges was viewed by eye. Due to magnitude of discharges the insulation is at the end of lifecycle.

Table 3 Kurtosis (K) and Skewness (S) of PD distributions

	M00	M04
K,H_{qmean+}	-1.59	-1.63
K,H_{qmean-}	0.90	-0.81
S,H_{qmean+}	-0.01	-0.50
S,H_{qmean-}	0.52	-0.67
K,H_{qmax+}	-1.74	-0.38
K,H_{qmax-}	-1.72	-0.81
S,H_{qmax+}	0.13	0.57
S,H_{qmax-}	0.07	0.33

Phase-resolved analysis of the M01 (new system) sample confirms voids in the insulation system of the stator bars. Amplitude of the apparent charge is low. The degradation of the semiconductive protection in the stator slots insulation of sample M02 (24 months in the operation) can be seen. Sample M03 (40 months in the operation) – the intensive activity of PD in voids in the insulation of stator bars, nonregular PD in the stator slots. There is developed degradation of the semiconductive protection in the stator slots. There were indicated low PD activity localised in the voids of the M04 (88 moths in the operation) insulation system of the stator bars and regular PD activity on the surface of the stator winding.
The intensive PD activity on the surface of the M05 (32 moths in the operation) stator winding was detected, irregular discharges in stator slots. It means presence of developed degradation of the surface protection in the stator slots of M05 sample.

Conclusions

Partial discharge analysis in phase domain offers wide range of parameters and relations to the electrophysical phenomena. The two parameters can differ in value but are equal in case that a PD pulse takes place in a phase window every voltage cycle [4]. The lifecycle management of power devices can use particular decisions from regular diagnostic measurements. However there are differences between artificial problems for laboratory modelling and industrial cases. An automated decision system can be applied by means of expert systems and neural networks. More complex view can be reached by combining PD analysis with another diagnostic method, i.e. isothermal relaxation current analysis, which offers a destruction free possibility to investigate the degradation processes of polymeric insulation system.

This article was supported by APVV 20-006005 and VEGA 1/3142/06 projects.

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