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Latest Findings at Transformer Bushings Condition Evaluation by Dielectric Response Methods

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ABSTRACT

Transformer bushings have to feed the high voltage from the portal field in the substation to the winding in the transformer. For this reason the bushing has a high responsibility for the save operation of a transformer. If any problem arises in the insulation system a shut-off in minor case or a consequential damage on the transformer can occur.

Especially at aged bushings the failure probability is significant high. For the detection of failures in bushings the ordinary diagnostic inspection by oil analysis is not sensitive enough. Additional dielectric response measurements have to be applied. With these kinds of measurements the humidity of the insulation system can be determined in a proper way, but there were also other ageing parameters.

To minimize the risk of transformer outages the utilities often keep spare bushings stored. However the storing conditions over a long period often result in degradation due to humidity absorption of the insulation system.

In this paper the applicability of different dielectric response measurement circuits for on-site testing was investigated as well as the effect of different storing conditions of transformer bushings.

KEYWORDS

transformer, bushing, condition assessment, dielectric response, diagnostic measurement, FDS / PDC Analysis

INTRODUCTION

From the customers point of view electricity should be available without outage, cheap and delivered in a high quality. In the chain of electrical power production and transmission power transformers belong to the main components. Transformers were built of several components: active part with winding, core and the insulation system as well as the tank, on-load tap changer and the bushings, which are necessary to lead the energy in and out of the transformer in a save way. During operation in the grid transformers are inspected in frequent intervals by the means of oil analysis which is a proper way to determine the general condition and to find possible failures. However the condition of the bushings cannot be evaluated with this method and it has to be pointed out that bushings are critical components at transformers. In the case that a problem in a bushing keeps unseen hazard consequences for a save transformer operation arise. Defect bushings can result in an unplanned shut-off of the transformer in the marginal case or to a burn-off of the bushing or the whole transformer accompanied by a total fall out of electricity which results in high costs for delivery failure and transformer replacement. For this reason the status of the equipment is of high priority.

For evaluating the condition of transformer bushings only few guidelines can be found in literature [1, 2], but little information is available about how to measure and evaluate the actual condition as well as how to store spare bushings over a long period.

In previous work [3, 4, 5] the Frequency Domain Spectroscopy (FDS) and Polarization Depolarization Current (PDC) are verified as proper possibilities to assess the humidity content of bushings under laboratory condition. In the present investigations additional criterions beside the humidity should be established and the practical applicability of the mentioned methods should be carried out on-site.

The goal of this paper is to compare the mentioned dielectric methods with different measuring circuits at on-site measurements. The scope of the work is to apply the chosen method at spare bushings, which were stored in the workshop under different conditions, as well as at transformers in operation on-site in substations. A further main point of interest is how to interpret the measuring results and which failures can be detected. Finally the recommendations for condition based maintenance of transformer bushings were suggested.

METHODS

For the evaluation of the transformer bushings a comprehensive method was applied. Beside diagnostic measurements also a visual inspection and an analysis of the insulation system were done. The dielectric response methods FDS and PDC were applied in a workshop of the sponsoring utility and on-site. For the FDS method a DIRANA device from OMICRON was used, which allows to measure in frequency or time domain or in both modes. For the PDC method a PDC-Analyzer from ALFF Engineering was used.

At the FDS method the dissipation factor (tan δ) in dependence of the frequency and capacitance (C) at rated frequency were evaluated. With the tan δ the information about humidity in the bushings can be extracted and the C gives the information about short circuits between the insulation layers of the bushings.

At the PDC method the current of charging and depolarization of the bushings in dependence of time was observed. The starting level of the currents gives the information about the general condition (insulation resistance) and the difference of polarization and depolarization about the humidity.

The results of both methods were compared by transformation of the time domain results into frequency domain by the software of the FDS device. For the visual inspection the transformer bushings were investigated optically on-site or in the lab. To analyze the insulation system following types of insulation systems were distinguished: resin bonded bushing (RBP), resin impregnated bushing (RIP) or oil insulated bushing (OIP). This discrimination was necessary due to the fact that the older types (RBP and OIP) have a maximum life time of 35 years according to the producer's specification.

For the finally evaluation a schematic strategy was developed according to the benchmark system: the parameters age, insulation system, results of measurements (tan δ and C) and results of visual inspection result in a cumulative mark between 1 and 5, while 1 means new condition and 5 that the bushing has defects and should be replaced.

Investigated Objects

At 42 transformer bushings of different type the measurements and condition analysis were carried out. The tests were done mainly in the laboratory at the spare bushings but also on-site which are built-in in transformers. Most of the spare bushings were of RBP type, about halve of them have a rated voltage of 110kV or more, the rest are medium voltage bushings with a maximum rated voltage of 23kV. The average age was more than 30 years.

Applied Measuring Circuits

The measurements with the FDS and PDC method can be carried out in two ways: with or without guard ring connection. The result can differ significant and the phenomena of a negative tan δ can appear at FDS method respectively polarity reversals at the PDC method. At the actual measurements both methods are carried out and the applicability is compared.

In Figure 1 the test set-up for the circuit without guard ring connection and results in time domain with both measuring devices are shown. The blue line in the right diagram is the depolarization current of the PDC-Analyzer and the yellow line that one from the DIRANA. The reason for difference at the first 20 seconds can be found in the different operation modus of both devices, after 20 seconds both instruments deliver identically signals.

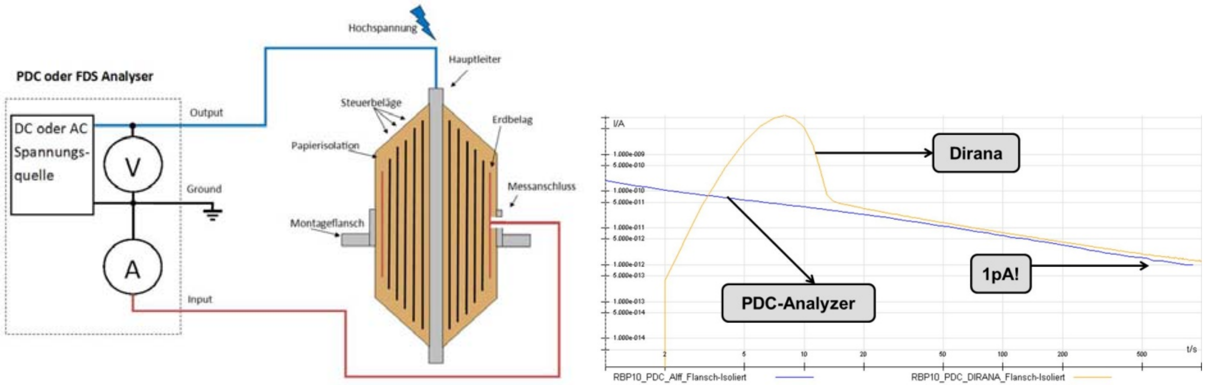

Figure 1: test set-up without guard ring connection (left) and comparison of measuring results (right)

Measuring with guard ring arrangements the circuit and results where shown in Figure 2. In this case the green line is the result of the DIRANA and the violet line of the PDC-Analyzer. At both measurement methods polarity reversals can be observed twice.

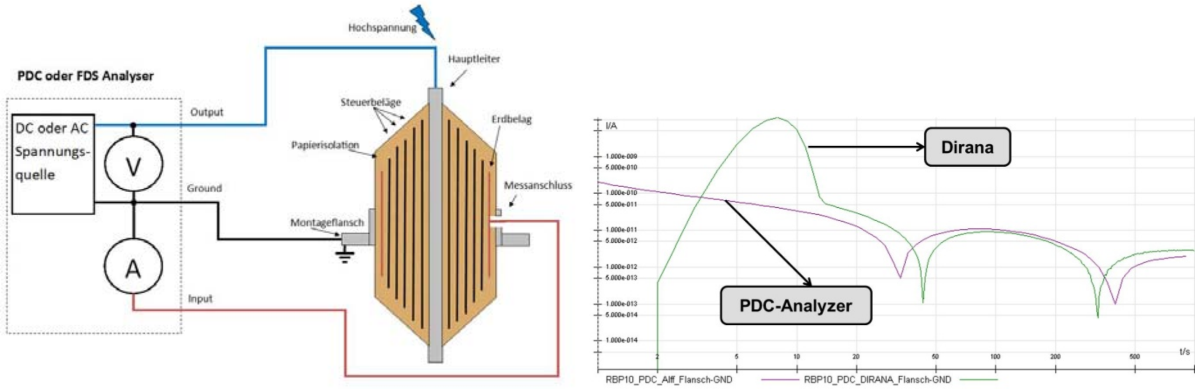

Figure 2: test set-up with guard ring connection (left) and comparison of measuring results (right)

Due to the fact that the measurements are carried out in a workshop a high noise level was present. It was necessary to construct a shielding with metallic barrels (faraday cage) for reducing the noise level, see in Figure 3.

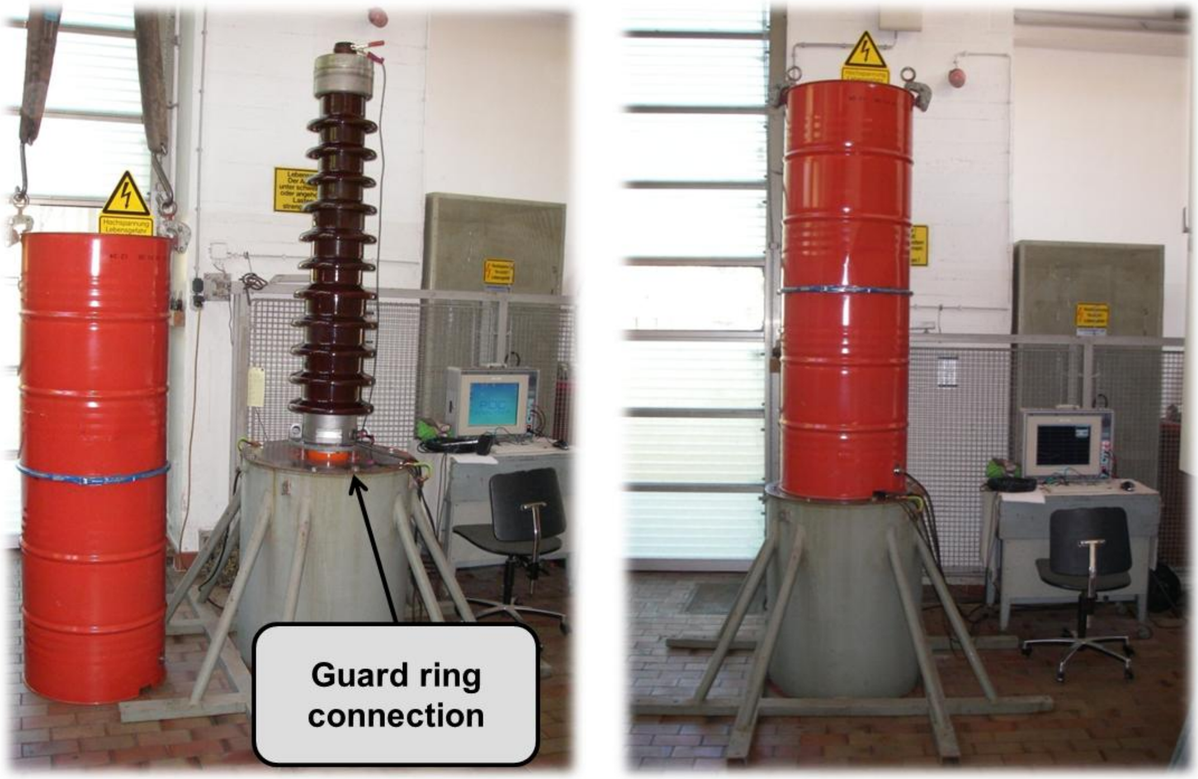

Figure 3: test setup and shielding of transformer bushing

RESULTS

From all executed measurements two meaningful measuring results are picked out for this section. At first spare bushings of a medium voltage transformer from RBP type were investigated. The two compared bushings were stored over a long period in a different way. The first was stored within oil containment so that humidity cannot effect to the insulation system. The second was stored without enclosure and so the air humidity could diffuse into the bushing during the years. At these bushings two examinations were done: Comparison of FDS and PDC results and influence on storage conditions.

At first the results for the comparison of different measuring methods were given in Figure 4. The results of PDC measurements were transformed from time to frequency domain that they can be displayed beside the FDS results in the same diagram. The frequency domain behavior of the dissipation factor of both bushings is shown in this graph. The continuous lines represent the FDS and the dashed lines the PDC measurements. The deviations where within one decade and the curves showed a similar characteristics. The accordance of these results was satisfactory so that future measurements could be done only with one method. It was decided to apply the FDS due to the shorter duration and more comfortable software support of the DIRANA device.

The second investigation of the primarily tested bushings result in following observation: The lines with the lower dissipation factors were the bushing stored with oil containment, the upper lines represent the bushing which was stored with air contact. The bushing with housing has a significant lower tan δ which means that it is in a good and dry condition. It can be used further more. The other bushing has a much higher tan δ especially at lower frequencies. This means it is humid and it is not recommended to use it anymore.

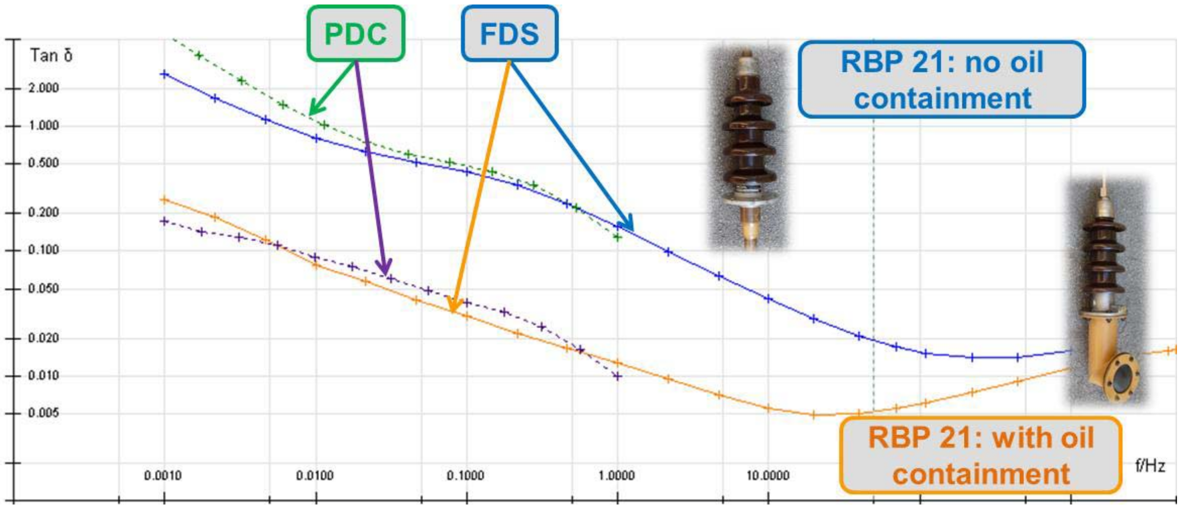

Figure 4: comparison of bushings under different storage conditions

In the second example the measurement results of four 145kV RBP bushings are shown in Figure 5. The tests were done at the dismantled bushings in the workshop with the FDS device. Three of the four FDS curves were almost identically, the bushing “RBP6” showed a remarkable increase of the curve at 50Hz with a value of 1,17%. This behavior can be interpreted as a failure in the insulation system which was caused from humidity. A second possibility could be short circuits of two field control layers, where the capacitance is an indicator for these typical failures. Further measurements showed that the capacitance was ok, so that the suspicion of dry areas within the insulation rose. The bushing was disassembled and cut into thin layers where dry arrears could be found, as shown in the small picture in Figure 5. The dry layers are indicators of poor impregnation and are initial points for ageing mechanism (partial discharges) with the risk of breakdown.

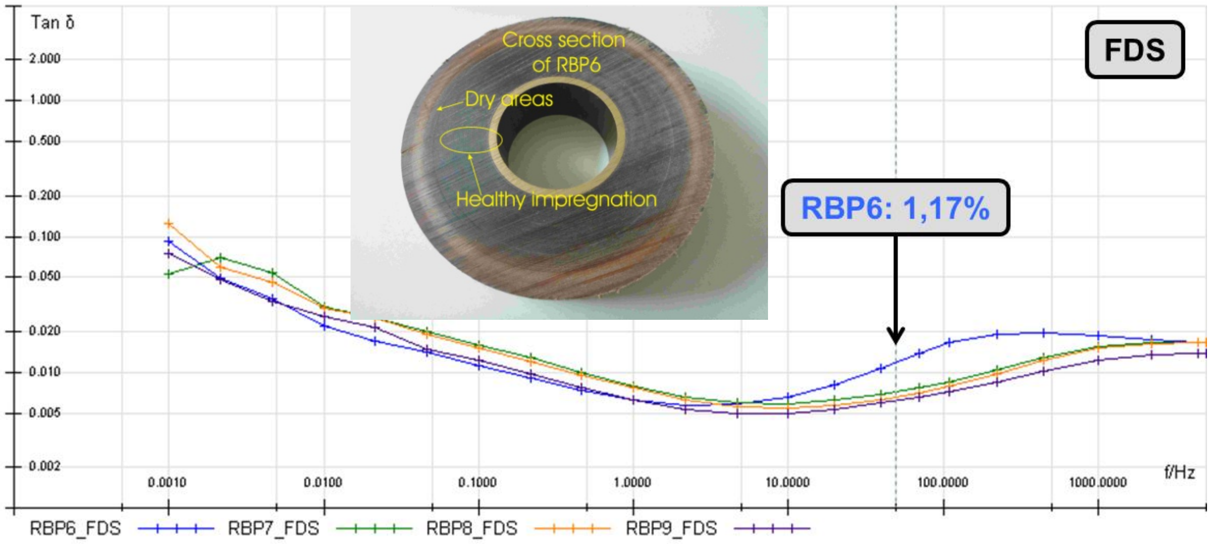

Figure 5: stored RBP bushings of a 145kV transformer

DISCUSSION

Undetected weak spots in bushings can initiate a transformer outfall or if the worst comes a burn-out of the whole transformer can happen. To detect hidden faults dielectric response measurements have to be carried out and the results have to be interpreted and evaluated accurately.

To assess the condition and to find additional assessment criterions beside insulation humidity 42 bushings were measured in the practical tests. As example the shape of the tan δ curve at FDS as well as the absorption current at PDC comprises good information about the general condition, the insulation resistance or surface tracking can be derived or the rise of the capacitance which may find its reason in a short circuit of filed control layers can be mentioned.

The discussion concentrates on the measurement curves of Figure 4 and Figure 5 in the results section, where two representative examples of dielectric measurements were selected. In the first diagram the different measuring methods were compared on the one hand and the influence of the storing condition on the other hand. It can be pointed out that applying the measuring circuit without guard ring the results of FDS and PDC are comparable qualitative and quantitative in a high accordance. Measuring with the guard ring configuration a negative tan δ can appear at the FDS and a polarity reversal at the PDC method. If these effects appear the measuring results cannot be interpreted useful. For this reason the measurements should be applied without guard ring. However using the PDC device for on-site measurements the polarity reversals can only be avoid by using an additional device, the so called phantom source. This phantom source is necessary to gain a potential separation between the ground tap of the PDC Analyzer and the earth tap of the transformer.

Comparing the practicability of PDC and FDS method we decided to apply only FDS for the further investigations due to the fact of shorter measuring duration and more comfort of the evaluation software.

In Figure 4 two similar bushings which were stored under different conditions were compared and the result was that the one without oil containment hade remarkable better results. The bushing can absorb much humidity during the storage what can lead to failures in the insulation system and result in a high operational risk. All the measurements on the other bushings indicated a high dissipation factor behavior for unprotected stored bushings. This observation leads to the conclusion that bushings should only be stored in oil containment or under vacuum in a sealed bag from aluminum according to the producer's recommendations. Another possibility instead of keeping spare bushings without applying frequent diagnostic measurement is to change the maintenance philosophy to a condition based strategy where bushings were replaced when imperfections were detected during inspection.

In the second diagram (Figure 5) the bushings of a spare transformer were measured. One of the four bushings showed a noticeable higher tan δ at 50Hz. Further measurements showed a capacitance within the tolerance level, which can be interpreted that there were no short circuits between the shielding layers. Dissecting the bushing it could be found out that the insulation system was partly dried out. Resuming these results it can be pointed out that three of the bushings were old but ok and one was not recommended to use further more.

Beside the insulation humidity the capacitance as well as the type and age of the bushing are important evaluation parameters. If an elevated capacitance is given short-circuits between field control layers is a reasonable suspicion. In dependence of the construction more than one short-circuits have to be classified as critical and the bushing should be replaced immediately.

As conclusion of our investigations following recommendations can be summarized:

- The condition based maintenance strategy is recommended for aged transformer bushings what means from an age of 30 years a visual inspection should be done yearly. Each 5 years the bushings should be assessed by the means of dielectric response measurement. If there is a suspicion of failure the diagnostic interval has to be reduced.
- The measurements should be carried out without guard ring configuration to prevent of negative dissipation factor of polarity reversal phenomena.
- The bushings should be stored according to the producer´s recommendations or within an oil containment to prevent them from humidity.

REFERENCES

[1] "IEEE Guide for Application of Power Apparatus Bushings," *IEEE Std C57. 19. 100-2012 (Revision of IEEE Std C57. 19. 100-1995),* pp. 1-42, 2013.

[2] CIGRE TF D1.01.09, "Dielectric Response Methods for Diagnostics of Power Transformers," *CIGRE Brochure,* vol. 254, pp. 1-42, 2006.

[3] C. Sumereder and M. Muhr, "Dielectric response measurements at high voltage bushings," *Condition Monitoring and Diagnosis, 2008. CMD 2008. International Conference on,* pp. 1150-1153, 2008.

[4] S. Zhang, "Analysis of some measurement issues in bushing power factor tests in the field," *Power Delivery, IEEE Transactions on,* vol. 21; 21, pp. 1350-1356, 2006.

[5] A. Küchler, F. Hüllmandel, K. Böhm and N. Koch, "Einfluss äußerer Grenzflächen auf die dielektrische Diagnose betriebsgealteter Hochspannungsdurchführungen", ETG Fachtagung Hanau, 2005, pp. 223-228.

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After finishing his studies of electrical power engineering at Graz University of Technology he worked as a project engineer at a big transformer company and as principal engineer in a utility. Then he started his academic career as assistant at the Institute of High Voltage Engineering at Graz University of Technology and finished his PhD thesis with honours. Within his postdoc employment as assistant professor he was guest lecturer at the University of Gothenburg and Kosice and he finished the postdoctoral lecturer qualification. During the winter semester 2011/12 he was the head of the Department for High Voltage Engineering at Technische Universität Berlin. Currently he is senior project engineer and lecturer at the Institute of High Voltage Engineering in Graz.

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