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온라인 및 오프라인 PD 모니터링에 관한 연구 동향

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A Research Trend on On-Line/Off-Line PD Insulation Diagnostic System

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Abstract - The paper considers the relation between on-line monitoring and diagnostics on the one hand and high-voltage (HV) withstand and partial discharge (PD) on-site testing on the other. HV testing supplies the basic data (fingerprints) for diagnostics. In case of warnings by on-line diagnostic systems, off-line withstand and PD testing delivers the best possible information about defects and enables the classification of the risk. Because alternating voltage (AC) is the most important test voltage, the AC generation on site is considered. Frequency tuned resonant (ACRF) test systems are best adapted to on-site conditions. They can be simply combined with PD measuring equipment. The available ACRF test systems and their application to electric power equipment -from cable systems to power transformers - is introduced.

1. Introduction

Monitoring and diagnostics of power apparatus and systems are applied for cost reduction by avoiding of defects during service (with consequences up to blackout), application of condition based maintenance, extension of lifetime, etc. This introduction shall demonstrate that diagnostics of electric insulation is not an isolated method, but only successful considering interactions with high-voltage (HV) testing and previous test results.

On-line monitoring has the big advantage that it indicates certain measurands of apparatus without interruption of service. The measurands might be related to volume phenomena or to weak point phenomena (e. g. PD). But in any case, they are indirect results requiring interpretation by knowledge rules. Such knowledge rules are based on basic research, but should also be related to results of previous type, routine and on-site tests. A remarkable improvement of the conclusions is reached if in case of warning by the on-line diagnostic system an off-line withstand test combined with PD measurement (this means a combination of a direct test with an indirect measurement) is added. Such an off-line, onsite test enables PD measurements in a wide range of voltages, higher and lower than the operation voltage. This means on-line diagnostics and HV testing on site must not be considered as separate or even contrary methods. They complete each other in an excellent way. The optimum interpretation of on-line monitoring and offline PD test results requires not only a knowledge rule but also information of all previous data from the test object. Modern information technology enables to establish the life cycle record from all relevant data semi-automatically or - for important and expensive equipment - even automatically. It should be mentioned that it will be helpful if the different tests are performed under comparable conditions, e. g. related to the test voltage shape. The life cycle data deliver the important information about the trend of the measurands and are the basis for a decision after the warning respectively after the subsequent on-site test.

It is good practice for nearly 100 years and a basic principle of insulation coordination [1] that the test voltage shall represent stresses in service. The horizontal standards for HV testing in test laboratories [2, 3] consider this principle by defining power frequency (45 to 65 Hz) lightning and switching impulse voltage (applicable for AC equipment). With respect to weak point detection by withstand voltage testing and PD measurement, voltages which represent power frequency are by far the most important. The application of direct or very low-frequency (VLF) voltage (Fig. 1) to AC insulation causes resistive instead of capacitance voltage distributions. Consequently the PD measuring results are much less representative than those measured at an AC voltage which is representative for power frequency. IEC Standards (e. g. [4, 5]) allow for AC on-site testing wider frequency ranges. This is considered by a frequency range 10 Hz to 500 Hz in the latest draft for the horizontal IEC Standard for HV testing on site. Using AC voltages of a certain frequency range of that overall range will deliver test results in close relation to the stresses in service (For details see III.B to III.E below.). Therefore AC voltage generation on site will be considered more in detail.

2. Experimental

Most test objects are capacitances and therefore HVAC test systems based on series resonant circuits have tremendous advantages compared with conventional test transformer. Because the capacitance C_T of the test object is fixed, there a two ways to reach resonance

- by tuning the inductance LH in such a way that f_r becomes equal to the frequency of the supply power (50/60 Hz): inductance-tuned (ACRL) system ;
- by the power supply via a frequency converter with exactly fr: frequency-tuned (ACRF) system.

In both cases the capacitive power demand is compensated by the inductance LH. The ACRL system operates at power frequency whereas the ACRL system needs a wider frequency range (e. g. 20 to 300 Hz). This certain disadvantage is more than compensated by the following series of advantages: Because of lower frequency at maximum load (20 Hz), ACRF systems have a higher equivalent test power at identical current. A reactor of tuneable inductance (ACRL) has higher losses than one of fixed inductance (ACRF), consequently the quality factor of an ACRF system is about twice of that of an ACRL system. The necessary feeding power is remarkable lower and can be supplied from a three phase system. Also the weight-to-power ration, which is an indication for the transportability, is about three to five-times better for ACRF systems than for ACRL systems. This is completed by an ACRF load range up to 10 times larger than that of ACRL system. The high robustness of ACRF systems comes from components without moving parts, whereas ACRL systems contain a reactor with a moving core and a conventional regulator transformer.

3. Results and Discussion

Quite often withstand testing of power equipment in service is not applied, because utilities are afraid that it could damage or even destroy the equipment. But when the test is performed with a well selected AC voltage amplitude (in relation to the standardized test voltage level for routine tests) and combined with a sensitive PD measurement, then this fear is not justified and the advantage of a direct test becomes evident. Because testing means classification into equipment safe for service, equipment which must stay under observation and equipment critical for service. If the HVAC withstand test results in a breakdown the equipment would have failed in service soon. The whole test should be performed as a step test (Fig. 1shows an example) and all the time be observed by PD measurement. In addition to the selection of the withstand voltage level (Uw = n . Uo; usually 1,3 < n < 2) a voltage level shall be chosen below that PD should not exist (UPD = mUo; e.g. m = 1.1 ...1.2).

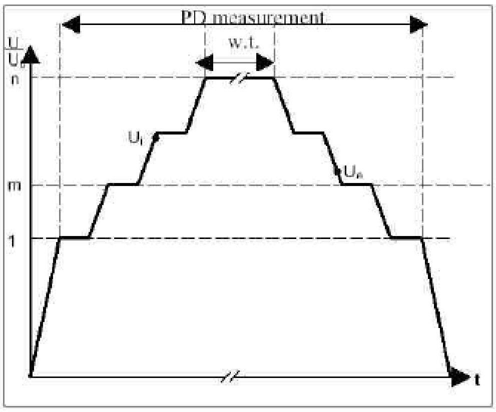

Fig. 1. Voltage-time characteristic of a combined PD and withstand test.

4. Conclusion

With respect to on-line monitoring and diagnostics, off-line testing and PD measurement is not unnecessary, but an important completion in case of a warning by the on-line diagnostic system. Off-line withstand testing in combination with PD measurement enables a classification of defects in connection with the life cycle record.

Acknowledgement

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[References]

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[3] IEEE Standard 4 - 1995: Techniques for high-voltage testing.
[4] IEC 60840:1999 and 62067:2002: Cables with extruded insulation and their accessories for rated voltages 30 to 150 kV respectively 150 up to 500 kV.
[5] IEC 62271-203:2003: HV switchgear and controlgear. Part 203: Gas insulated, metal-enclosed switchgear for rated voltages above 52 kV.