



# Technical Document

## Simultaneous Dissipation Factor and Partial Discharge Measurement on Rotating Machines – Limitations, Challenges, Solutions

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# Simultaneous Dissipation Factor and Partial Discharge Measurement on Rotating Machines – Limitations, Challenges, Solutions

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**Abstract**—Dissipation Factor (DF) and Partial Discharge (PD) measurements are widely used as non-invasive diagnostic methods on rotating machines. These tests are done after manufacturing for routine, type and acceptance tests, and on site for predictive maintenance. Each test includes a different measurement setup and therefore is done separately, one after the other. This paper deals with the possibility of performing these two measurements simultaneously. Benefits of a simultaneous measurement are reduced overall testing time and a significantly simplified test arrangement, the limitations and challenges arising while simultaneous testing are described and a reliable solution is proposed, real measurements are presented as confirmation.

**Keywords**—dissipation factor measurement; partial discharge measurement; rotating machines; simultaneous measurement

## I. INTRODUCTION

In case of simultaneous PD and DF measurement, it is necessary to take into account several circumstances. Since test arrangements differ for both methods (Figure 1 and 2).

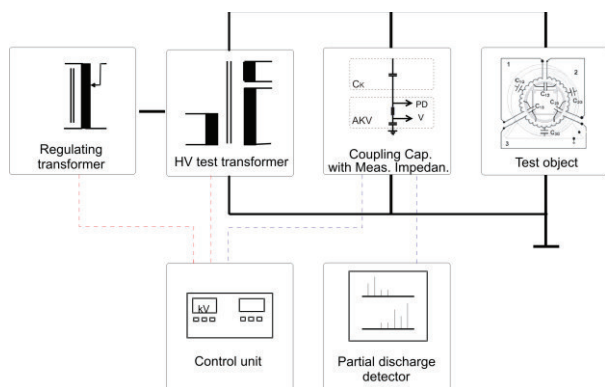


Fig. 1. PD measuring circuit

It is essential to examine and define possible influences and uncertainties. The paper shows that the combination of these two methods is feasible and practical in case appropriate equipment and procedures are used and followed. There exist two principal approaches.

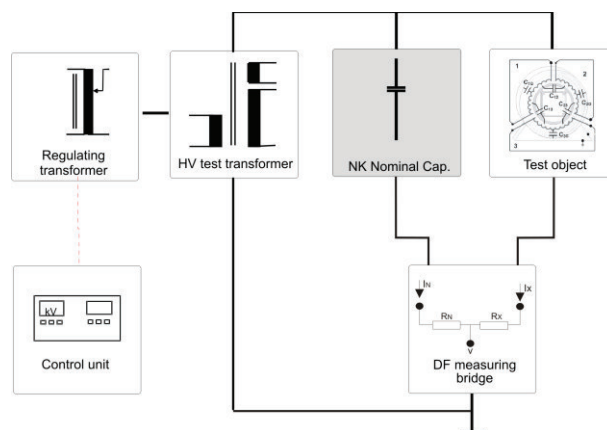


Fig. 2. DF measuring circuit

The first approach is advantageous with regard to the measurement uncertainty but shows higher complexity with regard to the test set-up and test procedure. In fact, measurements are not performed simultaneously but one after the other in a fixed measurement sequence. This approach requires a change in the connection of the DUT (device under test) and the test arrangement, by doing so, performance with regard to measurement uncertainty does not deteriorate. On the other hand, other upcoming measurement challenges have to be evaluated which are discussed in more detail within this paper.

The second approach uses one combined test set-up in order to perform PD and DF measurements simultaneously without the need of changing connection on the DUT or within the test set-up. By using this approach certain limitations and challenges with regard to the measurement uncertainty may arise which have to be evaluated and discussed in the context of rotating machines' measurement applications. The paper describes both of the possible ways and evaluates which one is more convenient for the field of application.

For DF measurement and evaluation according IEC 60250 [4], the commercial measurement device Tettex MIDAS 288x (Mobile Insulation Diagnosis & Analyzing System) is used [1]. MIDAS includes a DF measuring bridge, a 15kV power supply and a 15kV SF6 standard capacitor in one single box. PD

measurements according IEC 60270 [3] were done with Tettex DDX 9121b [2] PD detector.

This paper is focused on PD and DF measurement on rotating machines [5, 6]. Fig. 3 shows a common test circuit for DF and PD measurement at the same time. Filter at the output of power source has blocking function for PD measurement.

During DF measurement the filter and the arm including  $C_k$  and AKV introduce a systematic error as additional capacitance is added into the circuit. Hence, it is necessary either to remove this systematic error or to take it into account.

During PD measurement, the DF measuring circuit, ( $C_n$  and shunts), does not introduce any significant error.

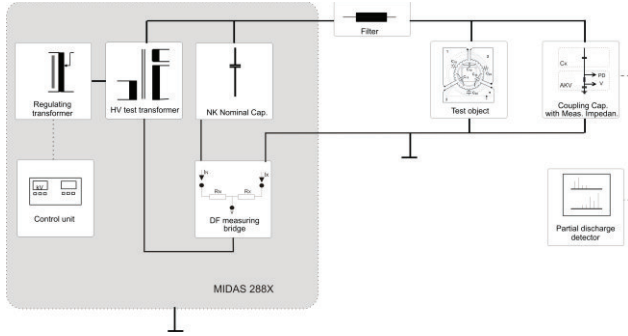


Fig. 3. Measuring circuit for simultaneous PD and DF measurement

## II. FIRST APPROACH DISCUSSION

Most commercial devices designed for DF measurement allow selection of different measuring modes and therefore changing the connections of the test circuit remotely. The first approach takes benefit of this option. Because of the limited extent of this paper, we refer to the device instruction manual [1] for further information about connection modes. Basically device has three measuring inputs – Input A, input B and HV (High Voltage) ground and the so called V-point, where measuring signal can be guarded.

Possible advantages of this solution would be that only one common connection of test set-up is used – benefitting the operation crew – time saving and avoiding possible mistakes in making connections and the error in DF measurement, caused by PD arm ( $C_k$  and AKV) is removed.

On the other hand there are several disadvantages and issues. The error of filter, which seems to be dominant (it will be shown in following chapters) remains. The over voltage protection provided by surge arrester is not directly grounded (in fact it is grounded via the V-point and then Shunt  $R_x$  which is inside the MIDAS). This can be dangerous in case of breakdown as surge arresters should be connected directly to the ground (recommended maximum lead distance of 2 cm). The inner capacitance of the long screened grounding cable will drastically affect the voltage reading. It may also create a loop for the PD signal, which goes against the recommendation of having as short ground connection as possible. The last, but not insignificant problem is that, in case of DF measurements on rotating machines, four possible measuring connections are possible. Usually the phases are measured separately against

the ground (3 connections) and then all phases together against ground. That implies that inputs A and B are needed in case of separate phases' measurement to exclude the influence of the next two phases. It means input B cannot be used for PD measurement, since it is occupied (this doesn't apply when rotating machine is in delta connection or neutral is not accessible).

A possible solution would be new AKV design – the surge arrester would be permanently grounded and AKV built into the MIDAS with relays to introduce/eliminate from the circuit. The HV filter will also be removed through a kind of relay. The presence of relays requires batteries inside the given elements which would make implementation difficult.

It can be concluded that the first approach has many difficulties for application, therefore a second approach is discussed in the following chapter.

## III. SECOND APPROACH DISCUSSION

This approach takes into account standard connection (Fig. 3 and Fig. 4). The Test object and coupling capacitor are permanently grounded. For DF measurement, the MIDAS device is connected to the ground point of DUT. This introduces two errors in case of DF measurement. One error caused by the PD arm and a second error caused by the filter. In this chapter, these two errors are calculated and evaluated.

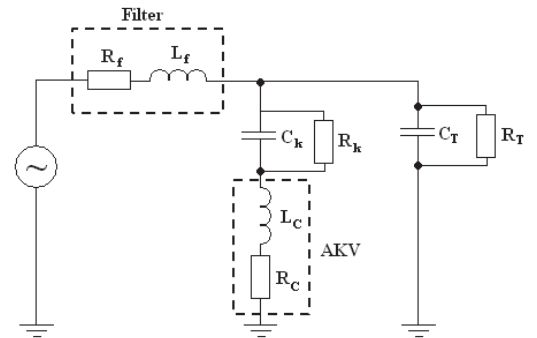


Fig. 4. Simultaneous PD and DF measurement test set-up, electrical equivalent for DF systematic error calculation

### A. Calculation of DF errors

The theoretical calculation of errors was done in the following four steps:

- Calculate the impedance  $Z$  of the complete test circuit (Fig. 4, equations 1 and 2)
- Calculate angle  $\varphi = \arctg \frac{Im(Z)}{Re(Z)} = \frac{X_C}{R}$  (Fig. 5)
- Calculate angle  $\delta = \varphi + 90^\circ$
- Calculate  $\tan \delta = DF$

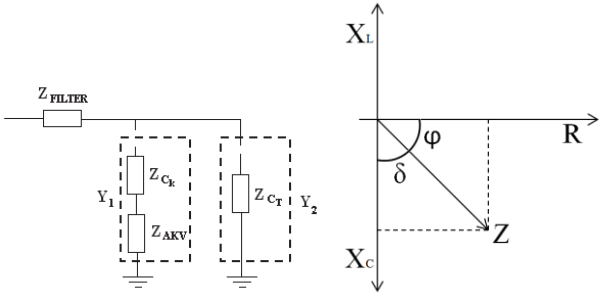


Fig. 5. Substitution diagram for circuit and vector diagram  $\tan \delta$  (DF) calculation

Complete impedance of the circuit was calculated based on Fig. 5. Formula 1 and 2 derived from this circuit.

$$Y = Y_1 + Y_2 \quad (1)$$

$$Z = Z_{\text{filter}} + \frac{1}{Y} \quad (2)$$

### B. Accuracy of measuring device MIDAS

For evaluation of introduced errors in case of DF measurement, the accuracy of MIDAS itself should be taken into account.

- Defined accuracy of MIDAS unit is  $\pm 0.5 \% \text{ rdg} \pm 0.0001$  ( $\pm 0.5 \% \text{ rdg} \pm 0.01 \%$ )
- It means if  $DF = 1 \%$  (this is typical order of DF for rotating machines), then the error is  $\pm 0.015 \%$
- So total deviation is  $\pm 0.15 \%$ . This deviation is taken into account in following chapters as a default value.

### C. Verification and behavior of mathematical model

The influence of the PD arm and of the filter is evaluated and discussed in this sub-chapter. First theoretical error calculation based on mathematical model was done and then the real measurement to verify model was performed. Measurements show that the model works with high precision and within the error of measuring equipment.

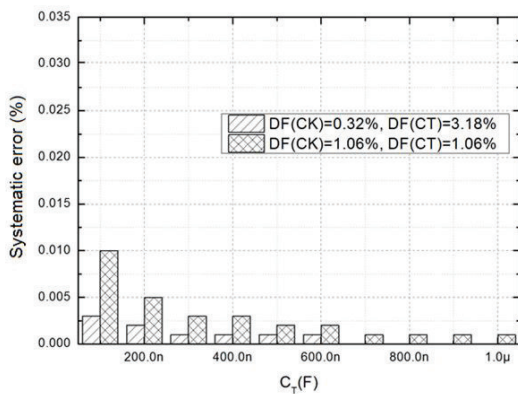


Fig. 6. Systematic Error between the DF of  $C_T$  and DF of  $C_T$  and PD arm

Fig. 6 and 7 show the error caused by PD arm and filter. Typical DF values for rotating machines were considered (order of units in percent range [7]) and typical capacitance range of  $C_T$  from 100 nF (small motors) to 1  $\mu$ F (large (hydro-) generators). PD arm contains coupling capacitor, where two different DF values were taken into account -  $DF(C_k) < DF(C_T)$  and 1:1 ratio. DF of  $C_k$  depends on  $C_k$  type. E.g.  $SF_6$  types can have very low DF (around 0.01 %) or oil standard capacitors which can have DF up to 1 %). Next part of PD arm is AKV with defined  $L_c$  and  $R_c$  values, which are fixed. The HV filter has an  $L_f = 6$  mH and its defined parasitic values which influence DF measurement were considered. Vertical axis of diagrams show deviation (error) from original DF of  $C_T$  in comparison to complex DF of complete measuring circuit (contains PD arm or PD arm and Filter).

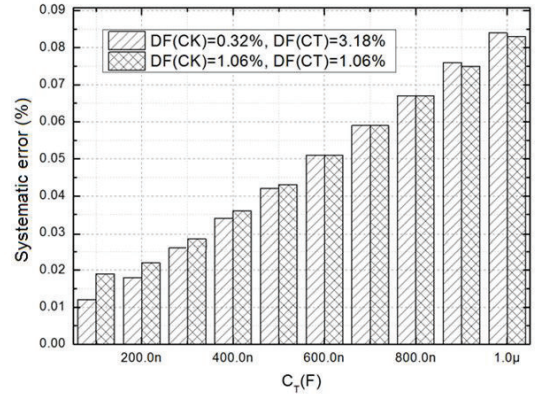


Fig. 7. Systematic error between the DF of  $C_T$  and DF of  $C_T$  with PD arm and Filter

With higher values of  $C_T$  the influence of the PD arm ( $C_k$  and AKV) decreases. This is because of the ratio between the  $C_k$  and  $C_T$ . When  $C_T$  gets bigger,  $C_k$  has lower influence. But with higher values of  $C_T$  the influence of the Filter increases. Because when the capacitance of test object is higher the impedance  $Z_{C_T}$  is smaller and hence the DF is higher - see Fig. 8.

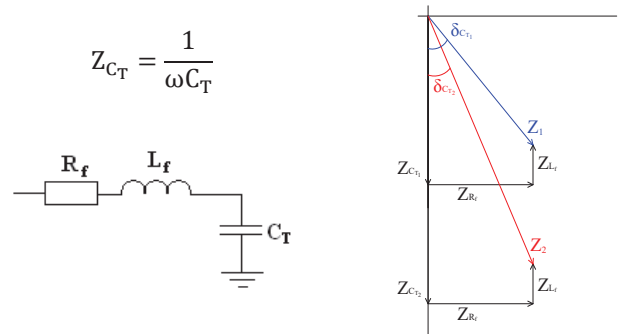


Fig. 8. Influence of  $C_T$  capacitance size to the filter error

## IV. FIELD MEASUREMENT

To verify theoretical assumption, real tests were done on the field. First measurements on nominal capacitors were performed. Primarily DF was measured separately and then simultaneously with PD. After that comparison of measured

values was done. Same procedure was done for real rotating machine on-site.

### A. Pure capacitor measurement

Three nominal capacitors were tested.  $C_T = 25$  nF, 50 nF, 260 nF. In Fig. 9 it is shown that error is acceptable until the filter error is added (Fig. 10) with  $C_T = 25$  nF. The reason is the relatively low ratio between  $C_T$  and  $C_k$  (25:1). Normally the capacitance of rotating machines is significantly higher (starting from 150 – 200 nF).

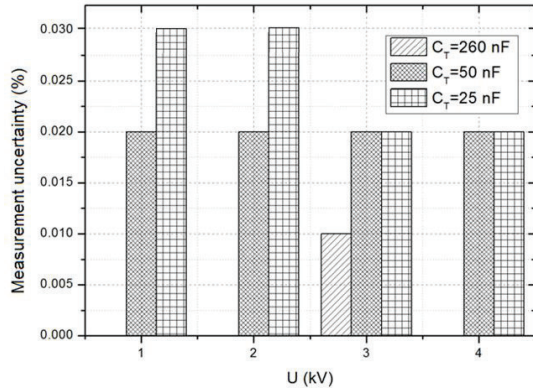


Fig. 9. Measurement uncertainty between the DF of CT and DF of CT and PD arm

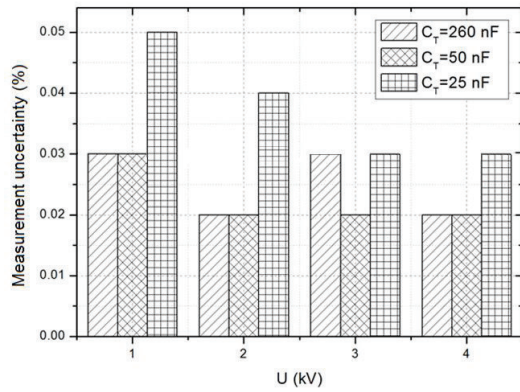


Fig. 10. Measurement uncertainty between the DF of CT and DF of CT and PD arm and Filter

### B. Measurement on real stator of rotating machine

To verify the second approach of DF and PD measurement simultaneously, a measurement on an stator winding with nominal voltage  $U_n = 5.5$  kV was performed (Table 1).

TABLE I. MEASURED DF AND CAPACITANCE VALUES WITH TEST OBJECT CAPACITANCE 193 nF

Test voltage	DF - without PD meas.	DF - with PD meas.	DF error
2.00 kV	0.84 %	0.84 %	0.00 %
3.00 kV	0.84 %	0.85 %	- 0.01 %
4.00 kV	0.89 %	0.92 %	- 0.03 %
4.49 kV	0.97 %	0.99 %	- 0.02 %

It can be seen that DF error caused by PD arm and Filter is within the error of measuring devices (0.03 %). It means that simultaneous DF and PD measurement can be done without any significant negative effect.

Another measurement was also performed on-site on a medium size rotating machine – nominal voltage  $U_n = 10.5$  kV, power  $P = 20$  MW. Maximum DF error caused by PD measurement in comparison with single DF measurement was 0.05 % slightly above the error caused by measuring device. In case of rotating machines international standards recommend that DF should not exceed  $DF = 10$  %. [7] It means that accuracy of 0.1 % of DF measuring devices is fully sufficient systematic error 0.05 % can be compensated by the measuring device or neglected.

## V. CONCLUSION

Two approaches for DF and PD measurement have been evaluated.

First approach (based on MIDAS switching modes possibility) has too many limitations and without further adjustments cannot be recommended for use.

Second approach (using the standard connection – PD arm ( $C_k$  and AKV) and test object is grounded, MIDAS is connected to the ground point of DUT. For rotating machines the error in DF measurement introduced by the PD arm is negligible. The error introduced by the HV filter, connected at the MIDAS HV output, is higher and cannot be neglected, but is not critical. In addition, this systematic error could be compensated by the DF measurement device (in this case MIDAS) by software (as e.g. test cable length is compensated) using the test circuit mathematical model presented in this paper.

The PD measurements which were done separately and simultaneously with DF measurement will be presented in additional papers.

A decrease of testing time up to 50 % can be reached by using presented solution in comparison with standard test procedure.

## REFERENCES

- [1] Haefely Test AG, "MIDAS 288x Mobile Insulation Diagnosis & Analyzing System", Operating Instructions, Version 1.9, Switzerland, p. 168, 2012
- [2] Haefely Test AG, "DDX 9121b Partial Discharge Detector ", Operating Instructions, Version 6.0, Switzerland, p. 140, 2014
- [3] IEC 60270, "High-voltage test techniques - Partial discharge measurements", 2000
- [4] IEC 60250, "Recommended methods for the determination of the permittivity and dielectric dissipation factor of electrical insulating materials at power, audio and radio frequencies including metre wavelengths", 1969
- [5] IEC 60034-27, "Off-line partial discharge measurements on the stator winding insulation of rotating electrical machines", 2006
- [6] IEC 60034-27-2, "On-line partial discharge measurements on the stator winding insulation of rotating electrical machines", 2012
- [7] IEC 60034-27-3, "Rotating Electrical Machines - Part 27-3: Dielectric Dissipation Factor Measurement On Stator Winding Insulation Of Rotating Electrical Machines", draft, 2011





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