COMBINED BROAD AND NARROW BAND MULTICHANNEL PD MEASUREMENT SYSTEM WITH HIGH SENSITIVITY FOR GIS

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Abstract

A computer controlled GIS (**G**as **I**nsulated **S**witchgear) PD (**P**artial **D**ischarge) measurement system is presented which combines UHF broad and narrow band **PD** measurements with high sensitivity, multichannel performance and near real-time response.

Each measurement channel consists of a low noise broadband sensor amplifier with automated high voltage transient protection, a full band power/envelope detector, a narrow band spectrum analyzer interface and a computerized display unit. With 0.1 to 2.0 GHz frequency range, 3 dB noise figure, 40 dB of sensor amplifier gain, full flashover and switching transient protection, twelve measurement channels, less than 0.1 second response time and a user friendly computer interface, the presented system is optimally suited for on-site commissioning tests, for laboratory testing during development and for long term monitoring of complex GIS.

This system allows the detection, localization, identification and monitoring of fault sources using a fully electrical method.

Introduction

In order to obtain the required PD measurement sensitivity [1], manufacturers of GIS are placing more and more PD sensors per GIS length [2]. Some GIS systems even allow to use some construction parts (shielding, windows, ...) as additional PD-sensors [2, 3]. Hence, about 7 to 10 sensors should preferably be monitored simultaneously during high voltage test with a typical test-section of about 10 nF.

Actually, two different PD measurement methods in the UHF frequency range are used: UHF narrow band and UHF broad band PD measurement [4, 5, 10].

UHF narrow band PD-measurement method can be characterized as follows:

+ Very high sensitivity (resonance's with high Q-factor)
+ Very insensible against external noise (allows measurement of signals near the thermal noise limit)
+ Rough localization of signal source by interpretation of PD signal spectrum is possible (the closer to the signal source, the higher the measurable frequency components of the PD signal).
+ Electrical localization with an oscilloscope is possible (full frequency range is available for measurement at the input of the spectrum analyzer).
- Only one channel can be observed simultaneously (normally only one spectrum analyzer available)
- Automation for PD monitoring is very difficult

UHF broad band PD-measurement can be characterized as follows:

+ High sensitivity, if no strong external RF noise is present.
+ Relatively simple system design (amplifier, detector, display unit).
+ Easy to implement in a PD monitoring system.
+ Parallel display of several sensors is possible (not too expensive)
- Localization with interpretation of frequency spectrum is not feasible.
- Localization by signal delay comparison method is not possible (In this circuits, the RF signal is normally not available for measurements)
- Existing UHF broad band monitoring systems present a slow display update rate and are therefore not very well suited for on site high voltage testing.
- Actually used UHF broad band PD-monitoring systems in service (known to the authors...) have cable lengths of 10 m to 30 m between PD sensor and amplifier resulting in a reduced signal to noise ratio [6].

Especially during on site commissioning tests it is very important to have a highly sensitive, flashover protected, noise immune PD measurement system with near real-time display of all measurement channels in order to localize and identify PD-sources as fast as possible [10].

These requirements imply the following specifications for a possibly 'universal' measurement system:

- Very high sensitivity (< 1 pC)
- High bandwidth (100 MHz – 2 GHz)
- Signal amplifier directly connected to the PD sensor
- Near real-time parallel display of 12 channels (<0.5 sec.)
- Full bandwidth parallel RF outputs for localization.

- For identification, it should be possible to connect the system to classical PD-measurement systems.

Measurement System

A 12 channel measurement system was realized (Fig. 1), consisting of flashover protected amplifiers connected directly to the PD sensors using a well shielded, low loss coaxial cable, a twin RF path with one output to a fast oscilloscope (for signal delay comparison method) and a multiplexed output to a spectrum analyzer for narrow band UHF PD measurements (total RF gain: 40 dB). Each channel is equipped with a low noise power detector with outputs to a 12 channel, 0.1 second response time display unit for instant overview of all signal levels.

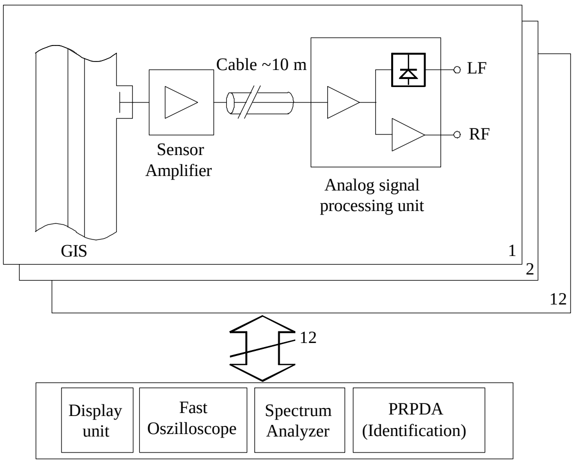


Fig. 1: Principle of realized measurement system

Sensor Amplifier

Characterization of the sensor amplifier (Fig. 2):

- Multistage circuit for transient protection (flashover, switching) at the input
- Auto-turn-off if input power > - 10 dBm
- Flat (+/- 1 dB) frequency response (0.1-2.0 GHz)
- 50Ω noise figure better than 3 dB at 1 GHz
- Gain of more than 30 dB
- Remote powered (Bias Tee and supply regulation included)

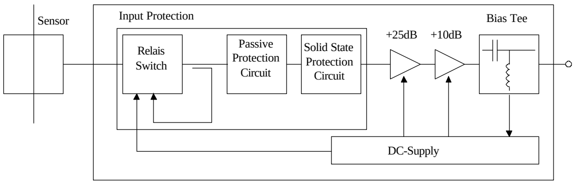


Fig. 2: Schematic of sensor amplifier

Tests have shown, that switching transients caused by disconnector switching cause more problems to the design of a protection circuit than (even higher amplitude) flashover transients during high voltage tests. An auto-turn-off circuit with additional passive protection was optimized with respect to high frequency characteristics. It is possible to use this new amplifier directly connected to a sensor in a monitoring system due to it's integrated protection circuits.

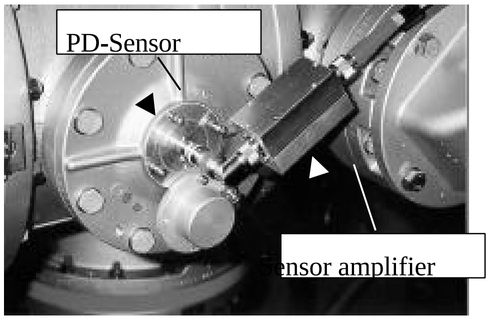


Fig. 3: Sensor amplifier connected to a PD sensor

Broad Band Power/Envelope Detector

The RF signal output of the remote powered sensor amplifier is split into 2 signal paths: A RF signal path which is amplified (10 dB) and split for multiplexed spectrum analyzer measurements and oscilloscope measurements (for PD localization), and a broad band power/envelope detector signal path (Fig. D). The broadband power/envelope detector consists of a buffer stage (40 dB), two detector diodes and a 500 kHz low pass filter-amplifier (Fig. 4).

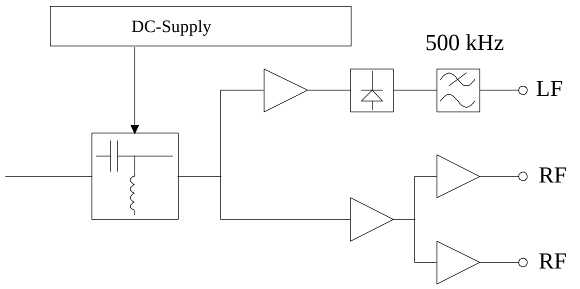


Fig. 4: Analog signal processing unit (ASPU)

Fig. 5 shows the sensitivity of the power detector as a function of frequency. The output voltage of the detector was measured with a 100 % AM modulated signal at 100 MHz, 500 MHz, 1 GHz, 1.5 GHz and 2 GHz respectively. A very good sensitivity down to – 85 dBm CW input power may be noticed over the entire frequency range [8,9].

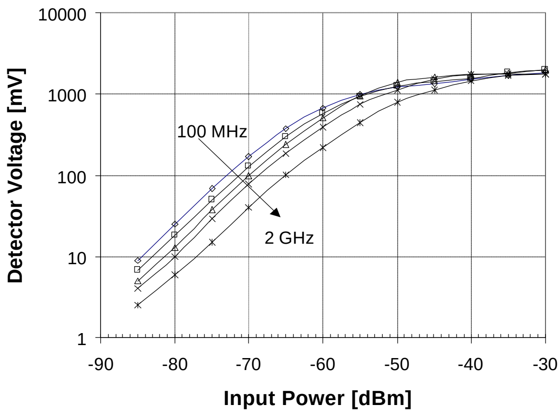


Fig. 5: Sensitivity of power detector

Display Unit

One single channel of the 12 channel display unit is shown in fig. 6. The output of the broad band envelope detector is buffered, digitized and numerically processed with a **D**igital **S**ignal **P**rocessor unit (DSP). The results of the 12 signal processor units are displayed with a Windows NT based display software on a laptop computer.

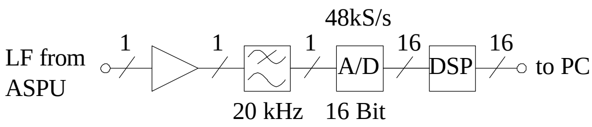


Fig. 6: Schematic of one single channel of the display unit

The display software on the laptop computer allows to set color coded reference levels individually for each channel. Three different levels are defined: Background noise level, reference level and a measurement/alarm level. In combination with the proposed sensivity check of PD sensors of GIS [1], the setting of the reference level (measured signal amplitude of an artificial PD pulse of 5 pC injected on the next sensor available) may be used (during HV testing and monitoring) as an indication of the magnitude of a real PD source (remark: UHF measurements cannot be calibrated [7]). Fig. 8 shows a part of a screenprint (3 channels) of the Windows NT based signal display. The rise and decay time of the signal display can be set, as well as different modes of maximum-hold functions. The parallel display of up to 12 sensors allows a rough but very quick overview of the PD scenery and helps to localize the PD source. Because of its standardized, computer based platform, this unit can easily be remote controlled, expanded and used as a monitoring system.

Measurements

The described system was tested with a GIS in service. The 170 kV GIS consists of an energized double busbar with 8 cable feeders and a buscoupler located in the center of Zurich, Switzerland. For PD simulation, artificial PD-pulses were injected via one

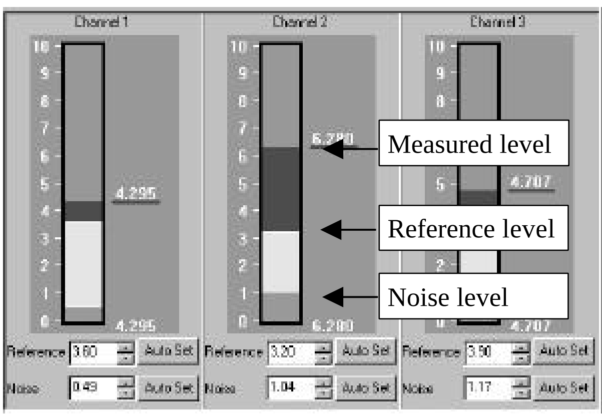


Fig. 8: Partial view of the display unit (tree of twelve channels)

of the PD sensors. The used pulse generator has a rise time (10% - 90%) of < 70 psec into a 50 Ω load at a DC operating voltage of 300 V.

For PD measurements, two types of sensors were used: Type I is a PD-sensor, Type II is an auxiliary sensor, originally not designed as PD sensor. They have both a measured capacity C_1 to center conductor of 0.15 pF. Both sensor-types have a diameter of ˜ 100 mm and are installed in earthing switch feedtrough flanges [11].

To inject a charge of 5 pC to the HV conductor, a pulse-amplitude of 33 volts was needed.

On the left hand side of Fig. 9, the RF output from the ASPU of a measured pulse in the time domain is shown, on the right hand side, the LF output from the ASPU of the power detector may be observed.

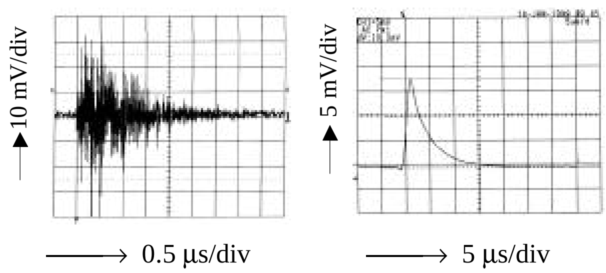


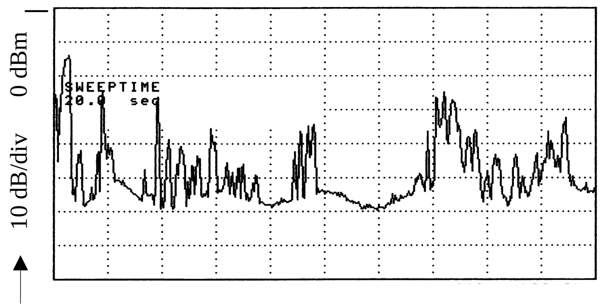
Fig. 9: Left: Output of RF path, right: Output of power detector with low pass filter

The table in Fig. 10 shows the geometrical characteristics of the sensor arrangement and the measurement results of narrow and broad band measurements. The results of the UHF-narrow band method show a very good signal to noise ratio even at very low injected charge levels. The same is valid for the UHF-broad band measurements.

The amplitude spectrum measured at sensor No. 2 has significant signal energy in the range between 1.3 GHz and 1.7 GHz (Fig. 11). The same observation was made for Type I as well as for Type II sensors. Without having a high system measurement bandwidth, these significant signal components would be lost.

	Sensor Nr.											
	1	2	3	4	5	6	7	8	9	10	11	12
Sensor Type	II	I	I	I	II	II	II	II	II	II	II	II
Location (Bus Bar or Feeder)	Fd	BB	BB	BB	BB	BB	BB	BB	Fd	BB	Fd	Fd
Physical distance to Source [m]	16.3	1.1	17.5	18.6	5.4	8.5	11.0	1.3	5.2	14.6	18.8	21.3
# of T-joints between Source	6	3	7	8	2	3	4	2	2	7	7	8
# of Disconnector between Source	3	2	2	3	0	1	2	1	1	3	3	3
# of Circuit Breaker between Source	1	0	0	0	0	0	0	0	1	0	1	1
Frequency of maximum RF response @ 15 pC injected charge [GHz]	0.61	1.70	0.56	1.63	1.75	0.71	0.51	1.66	0.90	0.15	0.11	-
SNR max [dB] @ 15 pC injected charge (Bandwidth 3 MHz)	15	40	45	40	25	23	22	32	13	10	15	-
Detected envelope voltage @ 15 pC injected charge [mV]	-	149	276	3.4	37.2	18.3	17.4	28.4	1.12	15	1.2	1.2
RF – Sensitivity [pC] (Bandw. 3 MHz)	7.5	< 0.8	< 0.8	1.5	2.3	1.5	1.5	< 0.8	9	5.3	-	-
LF – Sensitivity [pC]	> 15	< 0.8	< 0.8	11	1.1	2.8	4.1	1.5	7.5	13.5	> 15	> 15

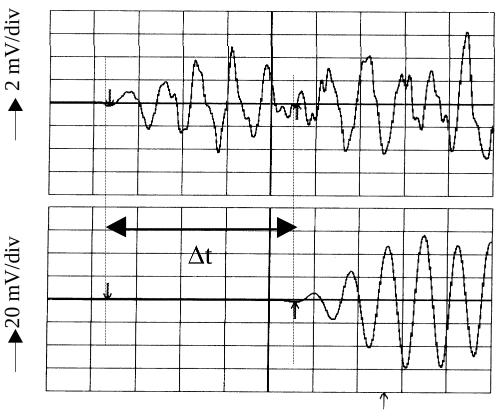
Fig. 10: Table of Measurements



100 MHz ⟶ 1.8 GHz

Fig. 11 Spectrum measured at sensor 2

It is assumed that the high signal level at sensor No. 3 can be explained by the generation of standing waves near the end of the GIS busbar. At sensor No. 12 no signal could be measured because this part of GIS was switched off (circuit breaker open) and earthed. It was generally observed, that after passing a circuit breaker, the high frequency parts of a PD signal were highly attenuated. The sensitivity and precision of an electrical localization of a PD source was tested (Fig. 12). The artificial signal source had a distance of 1.1 m to sensor No. 2 and a distance of 17.5 m to sensor No. 3. The measurements showed a maximum sensitivity of better than 0.8 pC of injected charge at sensitive sensor localizations (S/N ratio of measured signal at 0.8 pC: 6 dB) and an average sensitivity of approximately 2 pC. The stated resolution for the localization was in the order of 30 cm with an oscilloscope with a restricted bandwidth of 600 MHz.



⟶ 10 ns/div (Δt = 42 ns)

Fig. 12 Localization with signal delay comparison method

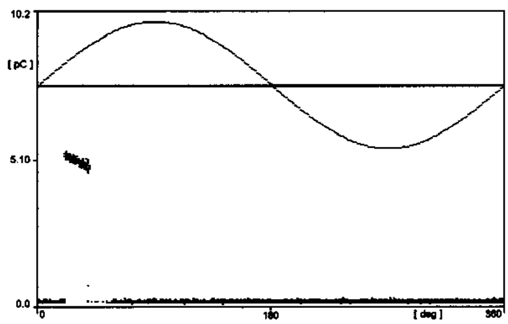


Fig. 13 Identification with conventional PD-measuring system

For identification, the down-converted output of the UHF narrow band or the output of the envelope detector can be processed with a conventional PD measuring system. In Fig. 13 the injected pulse was synchronized with the GIS power frequency (jitter due to the mechanical switching of the mercury relay).

Conclusions

A computer controlled multichannel measurement system for combined UHF broad and narrow band measurement in GIS has been realized. Due to its high bandwidth (0.1 - 2.0 GHz), 40 dB gain (RF) and 3 dB noise figure, a high sensitivity was achieved with a typical UHF sensor on site (< 0.8 pC). Due to a multistage protection circuit against flashover and switching transients, the amplifiers can directly be connected to the sensors. This solution enhances the sensitivity especially in the frequency range above 1 GHz. The combination of a high RF bandwidth and a 12 channel parallel display unit with 0.1 sec. response time makes the system ideally suited for PD source localization.

The system allows the detection, localization, identification and monitoring of PD fault sources using a pure electrical method.

References

[1] CIGRE 1998 TF 15/33.03.05 IWD 73: Sensitivity Verification for Partial Discharge Detection on GIS with the UHF and the Acoustic Method.

[2] Behrmann, G.J.; Neuhold, S., Pietsch, R.: Results of UHF measurements in a 220 kV Substation during on-site commissioning tests. 10th International Symposium on High Voltage Engineering, Montreal 1997

[3] M.D. Judd, B.F. Hampton, W.L. Brown: UHF Partial Discharge Monitoring for 132 kV GIS. 10th International Symposium on High Voltage Engineering, Montreal 1997

[4] C. Maulat, E. Fernandez, P. .Almosnino: Sensitivity of electrical Partial Discharge measuring methods on GIS with external disturbances: Experimental comparison on conventional method, UHF wide band and narrow band methods. 10th International Symposium on High Voltage Engineering, Montreal 1997

[5] A. Petit: Field Experience of Partial Discharge Monitoring with the UHF Method. Paper 5596, 9th Int. Symp. on High Voltage Engineering, Graz, 1995

[6] W. Bächthold: Lineare Elemente der Höchstfrequenztechnik, vdf verlag / Zürich 1994

[7] Sellars, A.G., MacGregor, S.J., Farish, O.: Calibrating the UHF Technique of PD Detection using a PD simulator. IEEE Trans. on Diel. and El. Ins., Vol. 2, No. 1, 1995, pp. 46-52.

[8] A.E. Bailey, Editor, 'Microwave measurements', Second edition, Institution of Electrical Engeneers, 1989, pp176 - 208

[9] R. Q. Lane, 'The determination of device noise parameters', Proc IEEE, vol. 57, pp. 1461-1462, Aug 1969

[10] W.Buesch, H..Dambach, P.Hadorn, T.Aschwanden, M.Haessig, T.Heizmann: Application of partial discharge diagnostics in GIS at on-site commissioning tests. CIGRE conference, Paris 1998

[11] Albiez, M.: Teilentladungsmessung an SF6 isolierten Schaltanlagen. ETH Zurich, Switzerland, 1992, Thesis No. 9694.