FUNDAMENTAL LIMITATIONS IN THE MEASUREMENT OF CORONA AND PARTIAL DISCHARGE

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ABSTRACT
The theoretical sensitivity of conventional partial discharge detectors is compared with that obtained from ultra wideband (UWB) (up to 1 GHz) detection systems. The comparison indicates that for relatively lossfree distributed systems, such -a-s SFe insulated bus, the UWB system is up to two orders of magnitude more sensitive. UWB detection also embodies additional advantages such as facilitating the location of discharge sites and the rejection of external electrical noise. For discharge detection in plastic-insulated cables, true UWB detection is not practical because of frequency-dependent attenuation effects, although certain gains in sensitivity can be achieved with a detector bandwidth of up to 10 MHz.

INTRODUCTION
In many high-voltage (HV) systems, partial discharges (PD) are an indication of insulation weakness which will eventually lead to catastrophic failure. For this reason, the measurement of partial discharges has become a routine procedure for acceptance testing of shielded power cables, switchgear, transformers, etc. In addition, partial discharge measurements are sometimes performed on operating equipment such as switchgear and generators to assure the integrity of such insulation systems. Since partial discharge tests are often spepified in contracts between a manufacturer and purchaser, all aspects of the measurement must be fully understood.

This paper reviews the various methods employed for partial discharge testing, especially with respect to simple distributed HV systems such as SFg bus duct and plastic-insulated concentric-neutral cable. The relative merits of a number of measurement techniques are discussed, with particular reference to the obtainable signal-to-noise ratio as compared with that obtainable in theory.

PARTIAL DISCHARGE DETECTION METHODS
A PD is a flow of electrons and ions which occurs in a gas over a small volume of the total insulation system. This short duration event emits acoustic, optical, and radio frequency energy. PDs can be detected by measuring any of these radiations [1], In this paper only the direct-coupled measurement of the radio frequency current and voltage pulses will be considered, since this method is by far the most widely employed in industrial applications.

Conventional PD Detectors
The measurement system shown in Fig. 1 is the test arrangeiaent normally employed in practical situations [2,3,4]. This configuration permits the equipment under test to be grounded in the normal fashion. The high-frequency electrical energy associated with a PD pulse flows through the coupling capacitor C_1 and detection impedance Z.

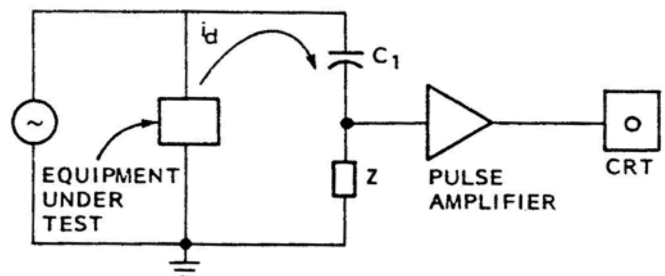


Fig. 1: Conventional PD me: Buying arrangement

The detection impedance is usually an RLC circuit having a large impedance to a certain frequency band in the PD spectruB, which causes a signal that can be amplified and displayed on an oscilloscope screen. Z is usually designed to provide a low impedance path for power frequency current.

Two forms of detection impedance have beconse popular in commercial PD detectors. One form of detector is referred to as “narrow band” since Z has a bandwidth of about 10 kHz, centered between 20 and 30 kHz. The other common detector, termed “wide band”, has a bandwidth of about 100 kHz with a center frequency between 200 and 300 kHz. In both cases, the output of the pulse amplifier (Fig. 1) is relatively easy to observe, even on older models of cathode ray tubes. The pulse output is usually displayed with respect to the power frequency voltage to aid discrimination between PD and electrical noise. Since the time constant of both detectors is long compared to the duration of a PD pulse, the conventional detectors integrate the current pulse. Thus the magnitude of the pulses must be measured in terms of charge (pC) [4]. On the other hand, one might reasonably expect that damage is roughly proportional to the number of ions and electrons involved in a PD so that this limitation is not serious.

For the measurement of PD in distributed systems, practical difficulties arise which can lead to errors in the

Interpretation of PD activity:

1. With a “narrow band” detector, two successive pulses can interfere either constructively or destructively, which can give an incorrect impression of the pulse magnitude. This can occur as a result of reflections in distributed systems or as a result of random superposition. PD pulses which are less than 50 ys apart are not uncommon [5],

2. In a lossy insulation system such as plastic-insulated power cables, the PD induced transient at one location will attenuate as it propagates. If the detector is a significant distance away from the PD site, the discharge may not be detected. Since attenuation increases with frequency, one finds recommendations in the literature that a narrow-band detector be employed [6]. In any case, standards relating to PD testing of cables insist that calibration in terms of charge be accomplished by injecting a known charge at the end of the cable remote from the detector [7].

Ultra-Wide Band Detectors

In the last few years, wide band (IGHz) real-time oscilloscopes have been introduced which permit the direct observation of low repetition rate pulses of 1 ns or less duration. In addition, amplifiers are now commercially available with similar bandwidths. Therefore, with properly designed coupling systems (discussed later), UWB (100 kHz to 1 Ghz) detection of partical discharges is possible. The UWB detection system can still be schematically shown as in Fig. 1, although in practice the capacitor C; and detection impedance Z must be implemented as part of a transmission line to obtain good frequency response.

In practical measurement applications, the UWB detection system also has certain advantages with respect to the conventional approach. The UWB detection allows more accurate observation of the true shape of a PD current pulse, rather than the integral of this pulse (the charge). With the use of two or more coupling capacitors on a cable or SF& bus duct, the sites of partial discharges can be located to within a meter or so by measuring the times of arrival of pulses at each coupler. In addition, the UWB system facilitates discrimination between PD and electrical noise [S], without isolating the ground of the equipment under test. Finally, UWB techniques have substantial sensitivity advantages in some situations.

NATURE OF PARTIAL DISCHARGE PULSES

The Most common sources of PD in cables are voids, while treeing in epoxy spacers, floating components, free-conducting particles and sharp protrusions are PD sources in SF^ bus ducts. To evaluate properly various PD detection systems, the PD pulse characteristics must be identified.

A PD consists of the flow of electrons and ions which move across a (usually) very small distance. Since the velocity of electrons in a gas is much greater than that of ions, measurement of the PD current will reveal a relatively large, short duration pulse (caused by electrons) followed by a much longer duration, lower magnitude pulse of the same polarity (caused by ions). Recent theoretical analysis of the PD current [8,9], which assumes a discharge in a small void or tree tubule, indicates that the electronic portion of a PD lasts less than 1 ns, whereas the ionic portion has a duration of about 100 ns (Fig. 2).

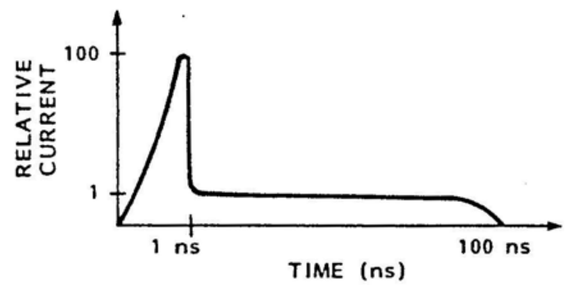


Fig. 2: Theoretical shape of a PD in a email void. The duration and magnitude depends on the void size, gas, electric field, etc. [9].

Using the UKB PD measuring system to be described later, the electronic portion of the PD current has been observed both from a sharp needle in SFg and from electrical trees growing in epoxy. In both cases, the shape is similar to that shown in Fig. 3. The rise time of the pulse is 0.3 to 0.8 ns, with a duration (full width at half the maximum magnitude - FWHM) of about 1.5 ns, which is virtually independent of when in the growth period of the tree the measurement is made.

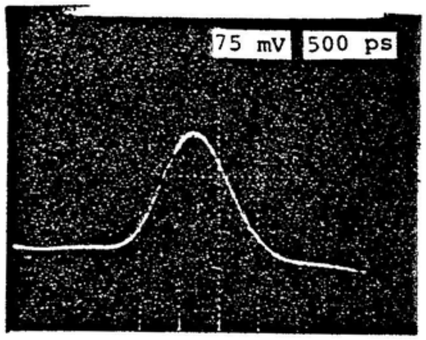
The electronic portion of the PD can be conveniently modeled as a Gaussian shape, i.e.. the current amplitude *I(t)* is given by:

$$I(t)\ I_0 \exp(-t^2/2o^2) \qquad (1)$$

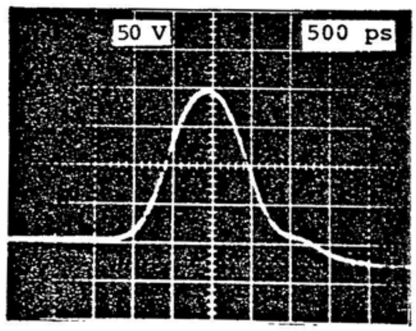
where the pulse width at half maximum is *2.36o* and I_o *is* the peak current. The voltage across the detection impedance Z is *V(t) = ZI(t).* The total charge in the electronic portion of the PD is found by integrating the current, i.e.:

$$Q = \int I(t)dt = I_o o\sqrt{2\pi} = V_o o\sqrt{2\pi}/Z,\ Z \text{ real}, \qquad (2)$$

where V_o *is* the peak voltage measured across the detection impedance Z. As long as Z is real (and hence can be removed from the integral), the charge is simply a scalar multiple of the detected PL current (or voltage), if the pulse width o is constant. Thus the sensitivity of the UWB and conventional detecter can be directly compared.



(a)



(b)

Fig, 3: Oscilloscope photographs of partial discharge currents using UWB detection. Only the electronic portion of the current is visible.
(a) PD frcn either a sharp point in gas (corona pulse) or a tree in epoxy.
(b) PD from a floating component.
All the discharge transients ha»e similar shapes; however, the floating component generates kV pulses as opposed to the mV fran the other sources.

The energy in a PD pulse is given by:

$$E = V_o^2/Z \int[cxp(-t^2/2o^2)]^2\, dt = Vo^2o\sqrt{\pi}/Z \qquad (3)$$

The total charge is two times that shown, if the ionic contribution to the PD is included.

The frequency spectrum of a single PD voltage pulse, assuming a Gaussian shape, is:

$$F(w) = V_o o\sqrt{2\pi}\, exp(-o^2o^2/2) \qquad (4)$$

Which is also Gaussian. Of course, this spectrum may be modified by attenuation or dispersion between the discharge site and the detection site.

UWB DETECTION IN A LOSSLESS SYSTEM

As outlined above, the fundaments] characTe~istics of a partial discharge pulse are now more accurately known through direct Measurements with 1 GHz bandwidth apparatus. With the knowledge of the true shape of a PD pulse, the basic tenets of information theory can be applied to analyze various detection systems. Understanding of the sensitivity liaitations with the various detection systems facilitates matching of the measurement system to the application to improve sensitivity. This is particularly important in the testing of components such as solid dielectric spacers for CIS. In this and the next section, the conventional and UWB detection systems will be compared on the basis of the maximum possible signal-to-noise ratio (p) theoretically achievable with each system.

For a lossless system, the frequency spectruia of the PD signal is preserved between the points of generation and detection. The theory of optimum detection in lossless systems, developed for radar applications [10], can be usefully employed. The optimum signal to noise ratio (S/N) under any circumstances is given when a filter with frequency characteristics matched to the signal is used for detection. For such a case, in the presence of thermal (Johnson) noise, the S/N ratio is given by:

$$o = E/S_{N^3} \qquad \textbf{(5)}$$

where E is the energy of a PD pulse and S_N is the noise power per Hz.

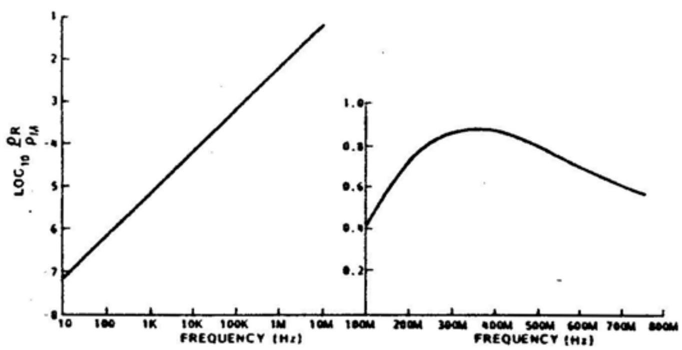


Fig. 4: The ratio of S/K for a rectangular bandpass (pR) to S/N for a matched filter p^ as a function of the high frequency limit of the rectangular bandpass filter. A l.S ns FWHH Gaussian pulse input is assumed. Note the change from logarithmic to linear frequency scale at 100 MHz.

Since a matched filter is difficult to realize, it is more convenient to model the detection filter as an idealized rectangular filter. The ratio Pfl/p^, where p^ and p^ are the S/N ratios for the rectangular and matched filters respectively, can be calculated with non-analytic formulae [10] and is shown in Fig. 4. The difference between the S/N ratios for a matched and rectangular filter is less than 1 dB for the optimum rectangular filter bandwidth, and the peak in the curve is quite broad. However, the ratio drops off rapidly for narrow bandwidths. For the 100 kHz and 10 kHz bandwidths commonly used in conventiona1 detectors, this ratio is $6.3x10^{-4}$ and $6.3xl0^{-5}$, respectively.

As an example, consider a PD pulse injected into one end of a lossless SFe bus duct, (i.e., skin effect losses are negligible). A 1 pC, 1.5 ns FWHM pulse propagating in a 60 0 characteristic impedance bus generates a peak voltage amplitude of 37 mV and an energy of $2.6xl0^{-14}$ J. If this pulse is detected at the end of the bus across a matched load of 60 n (ignoring practical considerations such as blocking the power frequency), then the minimum thermal noise at 290 K is kT or $4x10^{-21}$ W/Hz corresponding to a voltage of $9.8x10^{-10}$ V/√Hz [11]. (If the signal must be amplified, the noise in a real amplifier neglecting gain, will add 2 to 10 dB of extra noise.) Therefore the signal-to-noise ratio for the optimum case of a matched filter is

$$o_M = E/S_N = 2.6x10^{-14}/4x10^{-21} \neq 6.5 \text{ x } 10^{-6} \text{ or } 65 \text{ dB}. \quad (6)$$

With an ideal rectangular filter having a bandwidth of 350 MHz, a ~64 dB S/N is theoretically achievable. With this bandwidth, a PD of 10^{-14}C should be detectable. In contrast, from Fig. 4, a detector with a 100 kHz bandwidth would reduce the S/N ratio by 1000 to 35 dB, permitting detection of $\sim 30x10^{-14}$C. These charge sensitivities assume a 25 dB S/N ratio in the detected pulse.

The same arguments apply to simple lumped systems, although characterization is somewhat more difficult since transmission line impedances cannot be assumed, and stray capacitances become more important.

Limitations of Pulse Rise Tine in a Lossless Transmission Line

In addition to considerations of finding the bandwidth to optimize the S/N ratio, it is of interest to estimate the risetime of a detected pulse in a lossless transmission line. A PD source within a transmission line is characterized by its capacitance and the capacitance of its boundaries to the transmission line conductors which have been combined into C_2 (Fig. 5). A third capacitance, C_3, has been included to cover the case of a discharge source in a lumped element (spacer in CIS) within a transmission line; for a void within a cable, $C_3 = 0$.

During a partial discharge, the combination of C_1 and C_2 can be replaced by a current source. This current source drives the parallel combination of C_3 and Z, which has a time constant $T = C_3Z$, if Z is the real characteristic impedance of the bus. Thus for PD from a sharp protrusion in an SFg bus, the rise time of the detected signal *As* the same as the rise time of the actual discharge current. For a discharge in an epoxy spacer, C_3 might be up to 10 pF. Thus for a 60 Ω bus duct, the detected rise time is 2.2 T or 1.3 ns.

Limitation of Pulse Rise Time in a Lumped Element

Fig. 6 shows the geometrical configuration commonly employed for PD testing in small laboratory samples. This configuration differs from the transmission line case by the presence of a high-frequency return path CH, stray ground capacitance Cg, and a power supply decoupling resistor 18]. Ignoring the HV supply circuit, the combination of Ci and C; can be modelled as a current source. By using the Norton equivalent circuit, the time constant can be calculated [8].

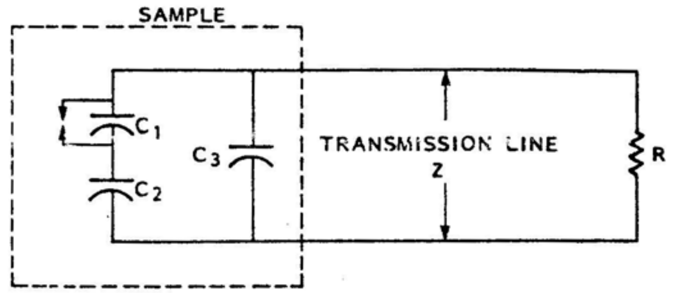


Fig. 5: Model for calculating the rise time of a partial discharge pulse for a solid dielectric sample in a transmission line. The HV pouer supply is not shown.

$$T = Z(C_s+C_4C_3/C_3+C_4) \quad (7)$$

For C_3 = 10 pF, C_s = 2 pF, C_4, = 500 pF and Z = 50 Ω, the minimum detectable rise time will be 2.2 T or 1.3 ns. Since transmission lines are not used for interconnections, response can be considerably degraded from this optimum by lead inductance.

COMPARISON OF CONVENTIONAL AND ULTRA-WIDE BAND DETECTION IN PRACTICAL SYSTEMS

The above discussion establishes the basis for calculating sensitivity of partial discharge detection systems. These methods will now be applied to three practical systems, viz, gas-insulated transmission line or switchgear (GITL or CIS), solid dielectric cable, and generator stator windings. These systems will also offer the opportunity for a brief discussion of other benefits of UWB detection, such as noise reduction techniques and discharge location.

Gas-Insulated Transmission Line and Switchgear

GITL makes an excellent high frequency transmission line as a result of the large conducting skin and lossless dielectric. The calculated attenuation of 500 kV GITL is ~3 dB/km at 1 GHz. The effects of multimode propagation, solid dielectric spacers, and contact assemblies are not known. As mentioned briefly above, the most common sources of partial discharge in such systems are floating components, treeing in solid dielectric components, free conducting particles and corona. These all generate pulses with ~l. 5 ns FWHM; however, amplitudes vary from mV (treeing and particles) to kV (floating components).

Little has been published on the high frequency propagation characteristics of GITL [12]; Ontario Hydro will be conducting extensive measurements on a 138 kV research gas-insulated substation now being commissioned. The calculated loss resulting from skin effect for 500 kV class GITL is given by exp(-2.303 ∂∫ √f/20), where ∂ is the attenuation in dB/m. HV, ∫ is the distance to the source (m), and *f* is the frequency (Hz).

For 500 kV class GITL, a’10-7 dB/^iI.n and the frequency spectrum of an (initially) Gaussian pulse emerging from the cable is given by

$$F(w) = V_o o\sqrt{2\pi} \exp(-o^2 w^2/2 - 4.9\times10^{-9} \int \sqrt{w}), \quad (8)$$

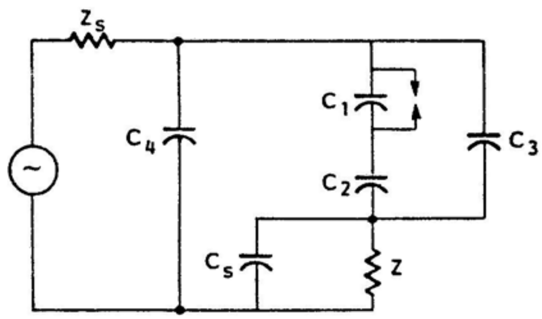


Fig. 6: Model for calculating the rise time Of a partial discharge pulse in a lumped element detection system.

which is not Gaussian for *l>0.* This frequency spectrum can be transformed into the time domain for various detection bandwidths to determine detected pulse magnitudes as a function of distance to the source and detection bandwidth. Pulse energy can be computed for a very large bandwidth so that the signal-to-noise ratio can be computed for the matched filter case. Fig. 7 shows the sensitivity as a function of distance for a number of detection bandwidths and for the matched filter case. The latter is not really practicable. since the matched filter response must vary continuously with the position of the source. For GITL, which has very low loss even for 5 km of bus, sensitivity for the optimum rectangular bandwidth for a 1.5 ns FWHM pulse of 350 MHz (Fig. 4) is very close to that of the matched filter. The 350 MHz detection bandwidth gives one to two orders greater sensitivity than the more common 10 to 100 kHz detection bandwidth. According to these calculations, an ultimate sensitivity of ~0.08 pC with 20 dB S/N ratio should be achievable, although this must be reduced by 2 to 10 dB to account for excess amplifier noise which has not been included in the calculation. Experimental ‘ configurations which facilitate such sensitivity will be discussed below.

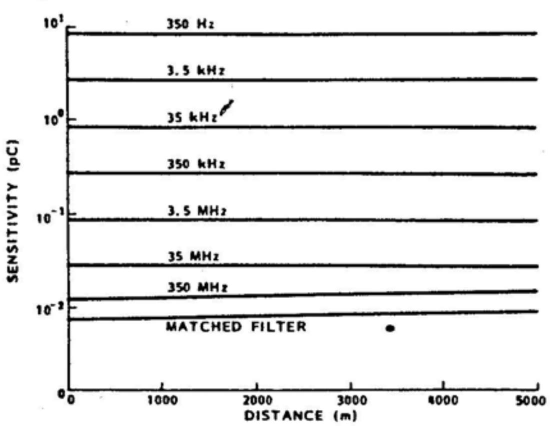


Fig. 7: Partial discharge detection sensitivity v∂ distance to the PD source as calculated for 500 kV GITL. These sensitivities are for a 20 dB S/N, assuming perfect amplifiere at 290 K. Real amplifiers will reduce the sensitivity by 2 to 10 dB.
Note that a S/Nratio of 0 db ie often acceptable when the PD is displayed on a CRT.

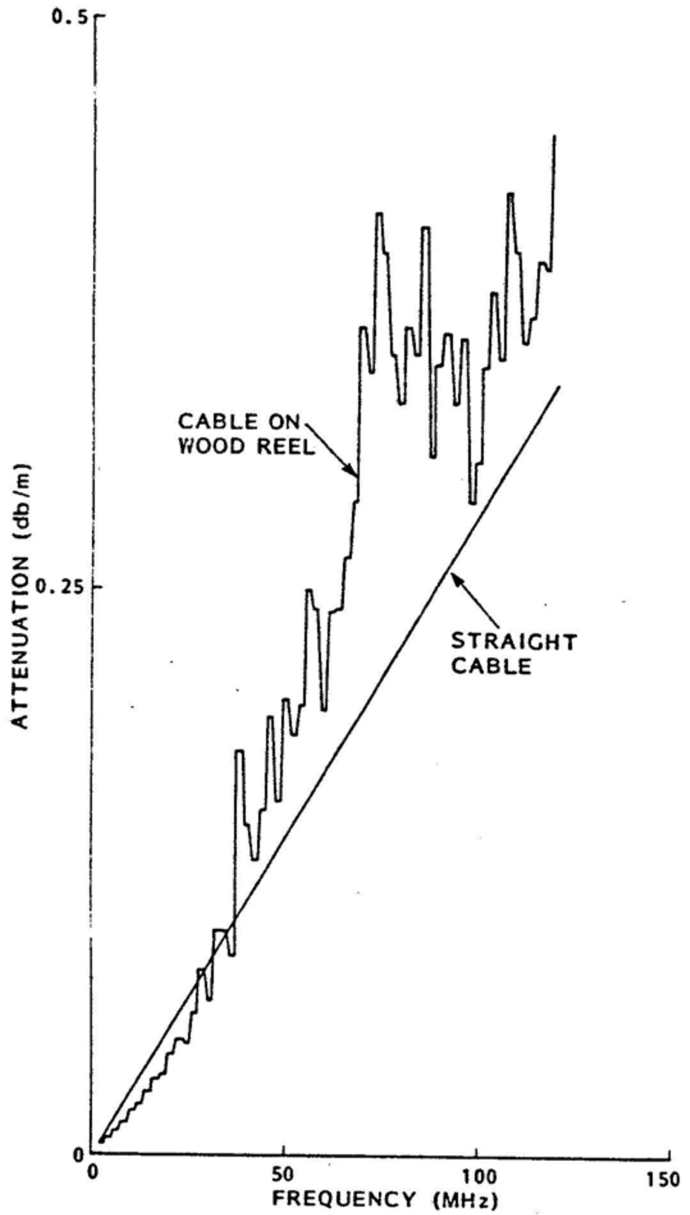


Fig. 8: Loss vs frequency for a typical 28 kV XLPE distribution cable manufactured without a copper tape ground shield. The loss for the reeled cable shows the effects of layer to layer coupling at high frequencies.

The case of GIS is both nore interesting and more complex as a result of T’s, changes in enclosure diameter, circuit breakers, etc. The propagation of partial discharge pulses in gas-insulated stations has received little attention [12]. As mentioned above, Ontario Hydro will be studying this subject using the research substation.

Partial discharge in gas-insulated systems is intolerable. Partial discharge tests during commissioning of such systems are becoming Bore common [13,14]. However, detection is of no use in a large system without Beans for location. For this reason, EPRI is sponsoring the development of a partial discharge location system based on measuring the relative tines of arrival of pulses at one or both ends of a GITL or at the terminals of GIS [15,16]. The excellent propagation characteristics of these systems are crucial to such an application. Directional couplers, which discriminate against noise entering the system by detecting the propagation direction of a pulse, can also be implemented [17].

Solid Dielectric Cable

Each reel of solid dielectric concentric-neutral cable is tested in the factory for partial discharge. The sensitivity achieved during this test is important. The construction of such cables varies in the resistivity of the semiconducting layers, the presence or absence of a copper tape ground shield and the type and loss of the dielectric. Fig. 8 shows the loss as a function of frequency for a typical 28 kV class XLPE-insulated cable manufactured without a copper tape ground shield, but with a concentric neutral wire shield. The loss curve is much smoother when the cable is off the reel than when it is on, as a result of layer-to-layer coupling at high frequencies resulting from a lack of taped ground shield. The high frequency loss recorded with a Hewlett Packard Model 4191A high frequency impedance Measuring system is much greater than that predicted by skin effect losses or the literature [18,19]. Measured dielectric losses in the XLPE are too small by an order of magnitude to e.xplain the measured attenuation which has tentatively been assigned to the displacement current which flows radially through the semiconducting layers. This aspect of the problem is still under investigation and will be reported in the near future [20].

The measured attenuation of $2.5\mathrm{x}10^{-9}$dB/Hz • m varies with frequency as one would expect of a displacement current loss and gives a frequency spectrum as a function of distance to the discharge source of

$$F(w) = V_o \partial \sqrt{2\pi} \exp(-\partial^2 w^2/2 - 4.6\mathrm{x}10^{-11} zw) \qquad (9)$$

Again, this can be transformed into the time domain as a function of bandwidth and distance to produce a sensitivity graph (Fig. 9). Here the situation is very different from that of GITL, since the losses are large. The optimum detection bandwidth varies with the position of the discharge source. If one were to pick a single detection bandwidth, it would probably be in the range of 1 to 10 MHz, far below the 350 MHz which is optimum for the initial pulse. These curves are predicated on a 20 dB S/N in the detected signal and perfect amplifiers (with noise of $9.8\mathrm{x}10^{-10}$ V√Hz at 290 K). Real amplifiers will degrade the sensitivity by 2 to 10 dB.

The accuracy of these sensitivity curves is probably poorer than that for the GITL. The attenuated pulses should be symmetrical according to the calculations. However, the measured pulses are quite asymmetrical, probably because of dispersion resulting from the frequency dependent characteristics which have been measured for the semiconducting material. For 8 ns FWHM pulses, calculations of pulse shape are close to that measured for 62 m of cable. Calculated energy attenuation is very close to that measured with a 1.5 GHz true rms voltmeter. The calculated and measured shapes for 1.5 ns FWHM pulses, however, differ substantially at 62 B length. Measurements for greater lengths have not yet been completed.

In any ease, the data indicate very real limitations to the sensitivity with which partial discharge can be detected in solid dielectric cable, and the potential increase in sensitivity which can be achieved by increasing detector bandwidth by one or two orders of magnitude beyond that now commonly in use.

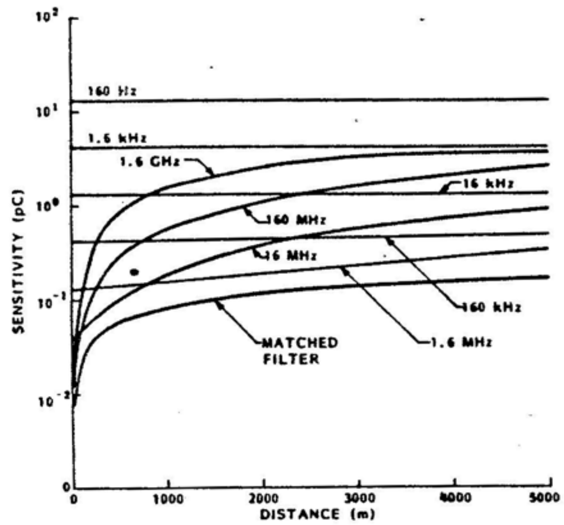


Fig. 9: Partial discharge detection sensitivity vs distance to the partial discharge source for the 28 kV distribution cable (Fig. B). These sensitivities are calculated for a 20 dB S/N.

Generator Stator Insulation

Measurements of PD in generators can be used to assess the integrity of the stator groundwall insulation. Measurements in this system are complicated by electrical noise from overhead lines, isolated phase bus, etc. In a high-voltage, high-power system such as a generator, grounds cannot be removed to facilitate the use of conventional bridge circuits. This problem has been resolved [5,17] by placing capacitive couplers near the high voltage end of the phase splits, of which there are always at least two per phase. These are arranged as pairs symmetrical with respect to the phase outputs so that noise which is introduced to the ring bus from outside the generator arrives at the two couplers simultaneously and is cancelled by a differential circuit. Partial discharge pulses originating within either of the two splits under test arrive at the two couplers at different times and are detected. This system, which has a 75 MHz bandwidth and is in routine use by Ontario Hydro and other Canadian utilities, depends on the transmission line-like character of the circuit ring bus and could not be implemented with conventional partial discharge detection technology.

Signal Coupling

Many experts in the field of partial discharge detection will argue that UWB detection is impractical, whatever the potential benefits in noise discrimination, partial discharge location, and increased sensitivity. To prove this is not the case, the following discussion of the practical aspects of signal coupling is included.

Coupling a signal from a transmission line can be accomplished in a number of ways. The use of a coaxial coupling device [21,22] offers the advantages of simplicity, good low frequency response under the correct conditions, and excellent high frequency response, but suffers the disadvantage of a large coupling loss (typically 20 dB) when implemented in a high voltage system. Because this loss comes before any amplification, it results in an equal reduction in sensitivity. This loss can be eliminated at the cost of increased complexity by using a solid dielectric coupler (Fig. 10), which nay be practical under laboratory conditions, but almost certainly not in switchgear. To provide a lower cutoff frequency of 20 MHz in a 60 Ω

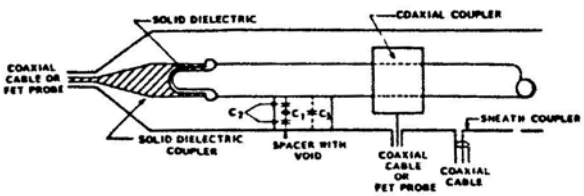


Fig. 10: Transmission line geometry and various coupling schemes.

transmission line, (which causes negligible pulse degradation) a coupling capacitance of 130 pF is required. For a laboratory system rated at < 100 kV and a researcher willing to take risks, this can be isolated with a 10 mm solid dielectric filled gap as shown in the Figure. For a transmission line with a 200 mm sheath i.d. and a 76 mm o.d. conductor and capacitor geometry as shown in Fig. 10, the necessary 130 pF can be achieved with a capacitor length of 20 cm, taking into account the hemispherical capacitor at the end and assuming a dielectric constant of 3.5. The lengths, impedance mismatches, and dielectric constants of this capacitor may cause ringing in the 500 MHz range. Assuming that such a capacitor is well designed, a partial discharge signal can be coupled directly from the transmission line, with negligible (5%) loss as a result of the 20 MHz cutoff. High frequency characteristics will be limited only by practical aspects of the capacitor and the fundamental time constants of the system discussed above.

Coupling from a transmission line can be achieved also by.providing an isolated section of sheath. To provide a 20 MHz low frequency cutoff into a 50 R load, approximately 2.5 B of sheath would be required for a typical gas-insulated transmission line or somewhat less than half that for a typical solid dielectric cable. The major disadvantage of ^this approach is the total lack of shielding for the measuring capacitor, which makes use of this approach practical only in a shielded room or for very large signals. The long coupling capacitor greatly complicates the device, since an element of such length must be treated as a transmission line rather than a lumped element. For pulses with the characteristic typical of partial discharge, a coupler of this type will probably not perform adequately.

The design of all forms of couplers can be simplified and performance improved through the use of a detecting impedance greater than 50 Ω [22]. The Tektronix Model 6201 FET probe is ideal for this purpose. It features a 100 kΩ input resistance in parallel with 3 pF at unity gain and a 900 MHz bandwidth. For the frequencies of interest, this probe becomes a capacitive divider, the division ratio of which can be held close to unity as long as the coupling capacitance is ouch greater than 3 pF. Reference [22] discusses the use of this probe with coaxial couplers. For the solid dielectric coupler discussed above. Fig. 10, the required capacitance could be reduced from 130 pF to ~15 pF, although probe resistance would have to be reduced to ~500 Ω to avoid excessive 60 Hz voltage.

In summary, coaxial dividers in coaxial transmission lines can provide >1 GHz bandwidth with a 50 ft pickup or ‘’•700 MHz bandwidth with good low frequency response using a FET probe pickup, both with ~20 dB signal loss. A solid dielectric coupling system with ~700 MHz bandwidth and essentailly no loss should be practical.

Coupling from the lumped element system is somewhat more complex to model, but allows much less room for innovation since the discharge current flows directly through the measuring impedance Z, which can be the termination of a low loss transmission line [8]. In principle, the signal magnitude can be increased by increasing Z; however, any significant increase over 50 n is likely to increase the system tine constants to the point that the signal amplitude becomes time constant limited, which defeats the purpose of increasing the measuring resistance. The largest “imperfection” in the lumped element configuration is the stray capacitance between the measuring electrode and ground. Fig. 6 [8]. This is in parallel with the measuring resistance and will normally limit the measurement bandwidth to less than is achievable with the coaxial geometry. This may not be less than the ~350 MHz required for optimal detection of a 1.5 ns FWHM Gaussian pulse. Thus, in spite of inherent limitations, the lumped element system may be adequate for partial discharge measurement, if carefully implemented [8].

CONCLUSIONS

UWB PD technology can be efficiently implemented to effect systems and applications which are impossible with conventional technology. To approach the fundamental limits to detection sensitivity in lumped element systems and low loss transmission lines, UWB technology is necessary as a result of the very narrow pulses characteristic of partial discharge and corona. The improvements in sensitivity which come with UWB technology are appreciable, especially for CIS. In many applications, such as testing of solid dielectric spacers for GIS, the presently achieved sensitivity may be less than that desirable.

One must keep in mind that the sensitivities often quoted are normally for pulses injected directly on the measuring electrodes, and may be many orders of magnitude greater than that achieved for a discharge source in the sample under test. In most cases, this sensitivity loss for sources within a sanrple is not easily calculated. One exception is a coaxial floating component (spacer insert) in GIS, where, depending on geometry, this ratio can vary from 103 to >105. Thus, order of magnitude improvements in sensitivity nay be of real benefit in many situations.

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