Detection of Low-level Electromagnetic Signal of Partial Discharge by Means of Disturbed Acquisition Discrimination

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Abstract— The article presents a new approach to the detection of a very weak electromagnetic (EM) signal, which is generated by partial discharge (PD) in a high-voltage, oil-filled power transformer. The new technique is based on the discrimination of signal acquisitions disturbed by interference; this procedure enables the desired weak signal to pass for further processing. The method was verified via an experiment, in which very short electrical pulses were injected in the transformer vessel by the antenna. The weak pulse signals were successfully detected in the presence of high level of interference.

1. INTRODUCTION

The electric energy is at the present (and in near future will be also) produced in central facilities, from which is transported after transformation into the place of consumption. The transition to the new decentralized energy sources will be rather consecutive [1]. The interface between the energetic facility and place of consumption plays an important role. Pivotal parts of these interfaces are high voltage power transformers. The security and reliability issues of energetic transformers have been intensively solved by research community [2, 3]. Critical transformer component is dielectric oil filling, which ensures isolation and cooling. The quality of oil filling is degraded due to activity of partial discharges (PD). Sudden failures in transformers isolation filling usually leads to energy delivery drop-out. It could lead to blackouts in severe cases of combined failures.

Various diagnostic methods for transformer condition determination have been developed. Each of these suffers from some disadvantages. The recent technology development and the availability of hi-tech instrumentation have opened new opportunities to employment of advanced diagnostic methods, as the radiofrequency (RF) method is [4]. RF method is based on the sensing, evaluation and source localization of the EM signal in UHF range. Therefore, it is frequently called the UHF method. Our group has developed an UHF method based diagnostic system for detection and localization of partial discharge activity, as described in [5].

One of the intensively solved aspects of UHF method is design and properties of suitable UHF sensors [10] for pulsed broadband signals and optimal design of high frequency signal processing chain [11]. The initial phase of PD activity is typical with a relatively low magnitude of its apparent charge, which could range from circa 100 pC. Such PD would generate relatively weak EM radiation. One of the often mentioned advantages of the UHF methods is that the PD radiated signals are sensed in metal transformer vessel. This will ensure efficient EM shielding and the weak PD signal could be therefore detected. However, experiments made by our group [6] have shown the presence of critical points on the vessels, which allows penetration of the outer EM disturbance [7]. One of the points was the connection of the sensing heads to the vessel. This has been solved by the installation of efficient EM shielding [8] (shown in Fig. 1(a)). It has allowed the suppression of the disturbance of remote sources. The second critical input point represents length compensative collars in the high voltage feedings encapsulation (bushing). However, more serious effect has been observed. Due to the imperfection of high voltage feedings installation on the inner isolators, a strong sparking activity is present in the bushings. Generated pulsed EM signal propagates into the vessel through the bushings and it is added to the weak PD EM signal. The above described shielding couldn't avoid this problem and the signal level of expected PD activity was still below the level of the interference.

2. DESCRIPTION OF NEW METHOD FOR LOW-LEVEL PD SIGNAL DETECTION

In order to overcome the above mentioned issue a new method for weak PD signal detection has been proposed and verified. The method exploits the multi-trigger ability of the diagnostic system (this means that the signal acquisition can be triggered by the signal threshold-crossing in any of

(a) (b) (c)

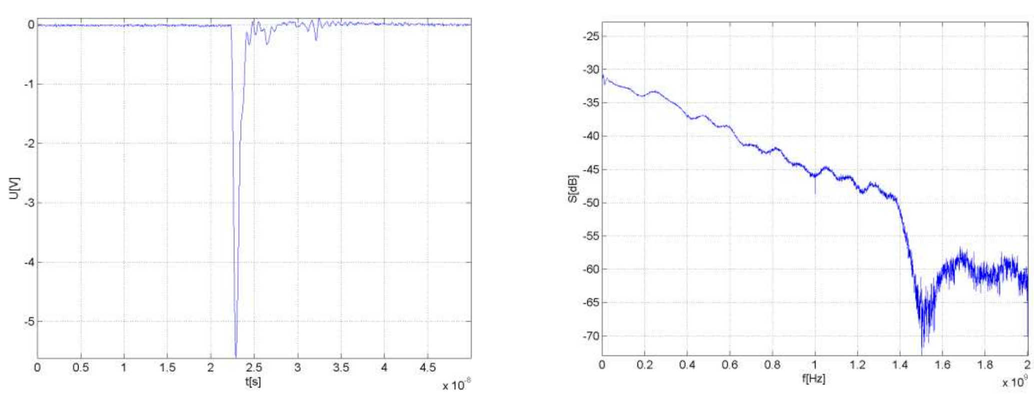
Figure 1: (a) Sensing head with EM gasket, (b) installed under the busshing collar, (c) disassembled exter. sensor.

the four channels simultaneously). One of the sensing head was removed from its vessel inlet and it was positioned near the place, where the interfering signal exits the feeding bushing (under the bushings collar, Fig. 1(b)). The signals acquisition procedure was initiated and the signal gain of sensing heads was set on suitable level. Now the acquisitions, which were recorded by the trigger from the outer head, were discriminated for further processing. Only acquisitions triggered from the vessel installed heads were stored and displayed. By this way, the outer disturbance was eliminated from the overall signal processing. Subsequently, the gain of the vessel installed heads was increased up to the level, where weak residual signals could be observed. In order to use high signal gain, the sensing heads have to be equipped with additional signal limiters, since residual strong interfering signal can occur.

After the method verification, a special purpose external sensor has been developed, which is shown in Fig. 1(c). The external sensor is based on the same components as the sensing heads. Within the transformer diagnostic procedure, the external antenna is installed in the vicinity of the transformer and senses the outer disturbing signal. In this case, only three vessel installed heads are used. Nevertheless, this is sufficient for the signal source localization. Following the successful verification, the method for PD signal detection by means of disturbed acquisition discrimination has been implemented into the control software of the system [9].

3. DETECTION OF ARTIFICIAL LOW-LEVEL SIGNAL

The diagnostic system development and detection method verification were conducted on the series of block transformer 15 kV/400 kV. The transformers have been recently put into operation and the quality of the oil filling was high. Therefore no PD activity was observed, despite of the new method utilization. In order to prove the ability of the low level EM signal detection, artificial pulses have been injected into the vessel by means of an antenna installed in the vacant inlet. The negative going pulse has been produced by avalanche transistor generator. The peak value of the pulse was -5.9 V, falling edge of the pulse was 300 ps and the FWHM (full width at the half of maximum) of the pulse was 700 ps. The pulse waveform is shown in Fig. 2(a). The radiated pulse has simulated the EM signal generated by PD in view of its waveform, time duration and spectral characteristic also. The calculated amplitude spectrum of the pulse is shown in Fig. 2(b). The



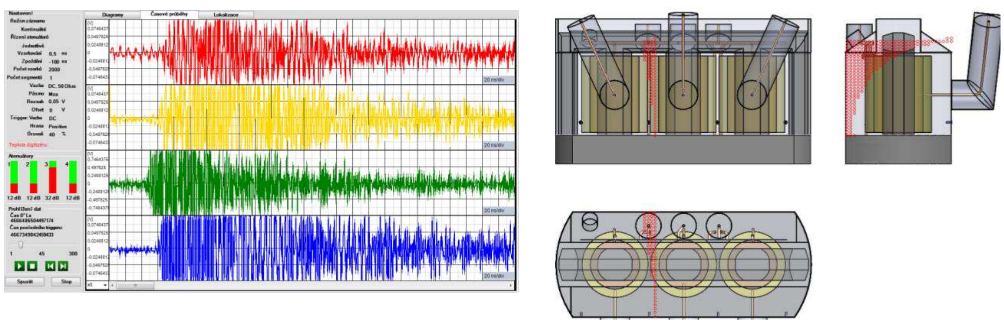
(a) (b)

Figure 2: The waveform of (a) the artificial pulse signal and (b) its amplitude spectrum.

pulse generator has been built into the shielding cover and equipped with the same antenna as the sensing heads.

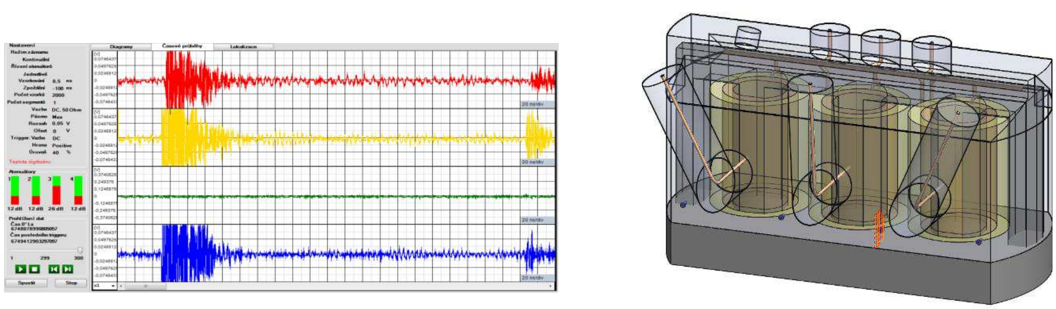
Following procedure of low level signal detection consist of two steps. In the first step, the all sensing heads (4) were installed into the inlets. The measurement and localization of the strong disturbing signal, which source is outside the vessel, was performed. The acquired waveforms of the disturbing signal are shown in Fig. 3(a) and the signal source localization is shown in Fig. 3(b). It is apparent that the signal comes from the first input feeding bushing. Therefore, the external antenna was installed close to the first input feeding bushing in the second step. The pulse transmitting head was installed into the third inlet in the transformer vessel and the diagnostic software has been switched over the mode of low-level signal detection by means of disturbed acquisition discrimination.

The transmitting head was switched on. Now the acquisitions interfered by the disturbing signal from the bushing were discriminated and only the acquisitions triggered by the signals from vessel installed heads were processed. The example of such acquisition is shown in Fig. 4(a). The third signal is missing, since this receiving channel is used for the external head signal, which is discriminated. The following signal source localization is shown in Fig. 4(b). It is obvious, that the result indicates the correct position of the transmitting head in the third inlet.



(a) (b)

Figure 3: Acquired waveforms of (a) the disturbing signal and (b) its source localization.



(a) (b)

Figure 4: Acquired waveforms of (a) the artificial pulse signal and (b) its source localization.

In order to evaluate the sensitivity of the method in view of assumed apparent charge value of PDs a simple, straightforward consideration was proceeded. The consideration assumes, that the PD represents a charge transport through certain impedance. The similar case is the charge transport through the input impedance of pulse transmitting antenna. The difference is that the electromagnetic radiation effect will be more efficient in case of PD, since the antenna reflects some portion of the signal due to non-perfect matching. If we simply consider a real character of antenna's input impedance Z_i, then we can deduce the current waveform through this impedance $i(t) = u(t)/Z_i$. The waveform will be same as in Fig. 2(a). The current is defined as the transported charge during a time interval $i(t) = dQ(t)/\mathrm{d}t$. It can be deduced from previous relations that the total charge transported through the antenna's input impedance is $Q = (1/Z_i)\int u(t)\mathrm{d}t$. This rapidly transported charge causes an electromagnetic wave radiation as in case of PD. If we apply the charge relation on the voltage waveform in Fig. 2(a), we find the charge value $Q = 94\,\mathrm{pC}$. It has to be noted, that for given pulse waveform the power of radiated wave will be proportional to 94 pC in the ideal case only, when antenna's input impedance will be real and perfectly matched. In real case, we obtain radiated wave, which power magnitude is lower and it is proportional to lower value of the charge than 94 pC. Therefore, we can estimate, that for the used antenna with known reflection coefficient, the equivalent apparent charge will be 30–50 pC. According to this result, we can conclude, that if we are able to detect above described artificial pulses in the environment with the presence of strong interference, we are able to detect the weak radiated signal of PD's with apparent charge in the order of tens pC also.

4. CONCLUSIONS

The UHF method is one of the most promising methods for transformer diagnostic in view of PD activity monitoring. Its advantage is the possibility of on-line PD detection and PD localization. However, several precautions have to be adopted. The EM signal of the PD is weak. Therefore the influence of outer, PD non-related pulse disturbance has to be taken into account. A great advantage in sensitivity improvement and interference immunity attainment is the developed method of disturbed acquisition discrimination. The method has been verified during an on-site measurement, where low-level pulsed signal, comparable to weak PD signal, has been detected and its source has been localized.

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