Usage of Antenna for Detection of Tree Falls on Overhead Lines with Covered Conductors

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DOI: 10.15598/aeee.v15i1.1894

Abstract. *The direct contact of a tree or a branch of tree with Covered Conductors (CC) overhead lines causes Partial Discharges (PD) inside the insulation. The presence of PD degrades the insulation systems and eventually destroys insulation, which may lead to power delivery interruption. The detection and diagnosis of PD is an important tool to address the problem of tree caused faults in forested terrains. The PD occurs in the impulse component of the signal, which is usually measured by Rogowski coil (current signal) or single layer inductors (voltage signal). In this paper, we introduce a possibility to detect the tree caused faults with the usage of whip antenna. The advantage of the antenna is a very low price and the possibility to install antenna under voltage. The disadvantages are sensitivity to ferromagnetic materials and impossibility to distinguish affected phase. The measurements were carried out in the real environment in forested terrain in Jeseniky Mountains. The real environment is different from a laboratory conditions due to heavy noise (e.g. corona, radio emissions). This paper provides an examination of the background noise from the antenna signal. The experimental results indicate that the antenna may be successfully used instead of the current approach.*

Keywords

Covered conductor, partial discharges, whip antenna.

1. Introduction

Usage of CC on overhead powerlines brings some advantages compared to usage of regular Aluminum Core Steel Reinforced (ACSR) conductors [1] and [2]. The most important one is higher reliability of powerline, especially in a forested terrain. The CC insulation prevents short circuit connection between phases in the case of tree or branch fall on the line. During the contact with CC internal PD appear inside its insulation. These discharges cause degradation of an insulation, so a long term contact between CC and branch is still able to cause a short circuit fault [2]. The presence of PD cannot be detected by regular protection relays because of low value of current caused by their activity [3]. Our goal is to develop a simple tool for detection of PD activity on Medium Voltage (MV) overhead lines. Technicians will be able to recognize a fall of tree or branch on the line and remove it before avoiding a serious powerline fault.

2. Background

There are many methods for PD detection [4]. PD activity creates characteristic pattern in an impulse part of time domain of a signal. This pattern consists of peaks of different amplitudes and polarities, depending on configurations of electrodes and type of dielectric [5]. Usually, current or voltage signal is examined for presence of PD pattern [6]. This can be done using common signal processing tools, machine learning algorithms etc.

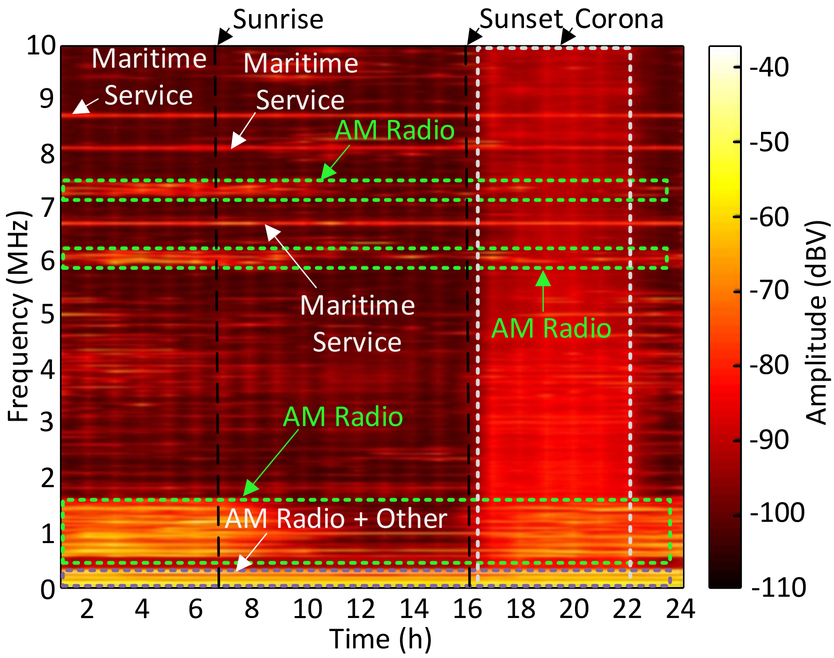


Fig. 1: Frequency spectrum of the background noise (record length 24 h).

2.1. Principle of PD Detection

In our previous work [7], Single Layer Inductors (SLI) were used to obtain voltage signals from the powerline. These inductors were winded-up on the surface of each phase and connected with measuring device through the Capacity Dividers (CD). This system provides satisfying results, but it is relatively expensive. Another disadvantage is necessity of powerline disconnection during the installation. In this paper, we suggest replacing SLI and CD with an active whip antenna. This solution is cheaper and it can be assembled on the pole without powerline disconnection.

Presence of PD activity is influencing the electromagnetic field in surrounding space of CC, which can be detected with an antenna [9] and [10]. Intensity of electric field is variating in a rhythm of PD voltage pattern.

The paper [11] presents PD measurements on 72 kV cable connectors in an unshielded laboratory. The paper also provides a summary of PD measurements applying the Ultra-High Frequency range (UHF) measurements of PD in noisy environments. The paper [12] describes a radiometric PD locator that is able to accurately locate PD sources up to 15 meters. The locator is 4 elements antenna array and it is based on ultra-high-speed antenna measurements. The detection of a transformer internal PD with mobile wideband Radio Frequency (RF) is demonstrated in the paper [13]. This approach has limited diagnostic ability, but it allows non-invasive and low cost detections of potential insulation faults in transformers. A single-arm Archimedean spiral antenna is utilized for PD measurement in [14]. Among others, the study also examines the influence of dielectric materials on the measurements. The paper [15] describes the usage of four antennas to measure electromagnetic pulses radiated by PD activity in substations and cables.

As it is shown in this paper, presence of internal partial discharges on overhead line is detectable with a simple active whip antenna.

2.2. Noise Description

Unlike laboratory environment, signals obtained from real environment are influenced by background noise [16]. Except signals from internal PD activity, any other signal is considered as noise in our experiment. Frequency band from 20 kHz to 10 MHz was examined with sampling rate 20 MS·s^{-1}. This band is normally used for many purposes like radio broadcast propagation, time signals, maritime services [17]. That is why Discrete Spectral Interference (DSI) is presented in measured raw signals. Propagation of radio waves depends on ionosphere condition [18] and [19], so the level of this DSI is variable. It is usually more significant during night, as it can be seen in Fig. 1.

High level of DSI can cover the signal from internal PD activity, especially when the source of this activity is situated in a long distance from the antenna. The most significant permanent sources of DSI on measured site are shown in the Tab. 1. Note that one of them was not identified.

Tab. 1: The most significant permanent sources of DSI.

Signal type	Number of positive peaks	Number of negative peaks	Fractal dimension (5 steps)	Fractal dimension (10 steps)	Entropy of the signal	Entropy of decomposition	Entropy of coefficients
non-fault	13	12	1.8064	1.3712	$-7,947,593$	$-156,154$	0.9268
non-fault	7	8	1.7459	1.3779	$-8,431,609$	$-13,324$	0.9543
non-fault	41	56	1.7441	1.3849	$-10,588,085$	$-33,062$	0.9560
non-fault	3	2	1.8721	1.3696	$-8,399,448$	$-249,006$	0.9118
non-fault	25	22	1.8922	1.4758	$-29,618,728$	$-5,451,075$	0.7666
fault	261	319	1.7253	1.3735	$-6,793,552$	$-261,104$	0.9042
fault	156	140	1.7143	1.3607	$-5,515,738$	$-111,561$	0.9158
fault	376	357	1.6203	1.3926	$-5,566,240$	$-187,308$	0.9162
fault	416	451	1.5741	1.3802	$-8,222,361$	$-449,030$	0.9056
fault	529	597	1.6475	1.3830	$-7,570,198$	$-291,997$	0.9219

Medium voltage lines are sources of Random Pulses Interference (RPI) [16]. This interference is caused by other types of discharge activities. The corona discharges are very often presented on the line (especially during bad weather) on measured site (Fig. 2). The corona creates typical pulse train in the time domain. The challenge is to distinguish between peaks caused by internal PD activity and peaks caused by RSI.

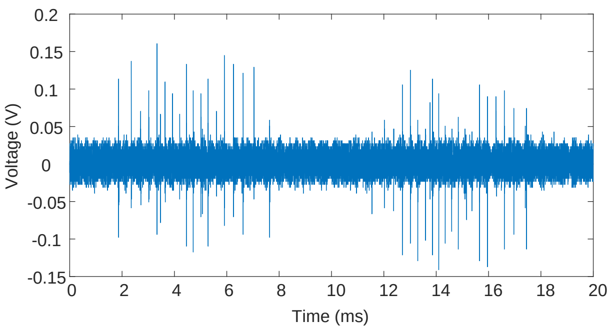


Fig. 2: Corona discharges.

Tab. 2: The most significant permanent sources of DSI.

Average amplitude (dBV)	Frequency (kHz)	Source	Location
-52	23.4	DHO38 (NATO)	Germany
-53	21.7	HWU (French Navy)	France
-60	128.95	unknown transmitter	
-63	77.5	DCF77 (time signal)	Germany
-64	279	Sasnovy (AM radio)	Belarus
-64	66.66	RBU (time signal)	Russia

3. Experiment Platform Description

The measuring platform uses Boni whip active antenna [20] as a sensor [21]. This antenna is inserted in a waterproof box, which is situated about 1 meter below the overhead line cables. We found out that presence of ferromagnetic materials in surrounding space of the antenna have negative influence on the reception and the level of background noise. That is why the antenna should be situated as far as possible from such elements. On our platform, the antenna box is attached at the end of long aluminium stick. This stick is mounted on the pole of the overhead line, as it is shown in the Fig. 3.

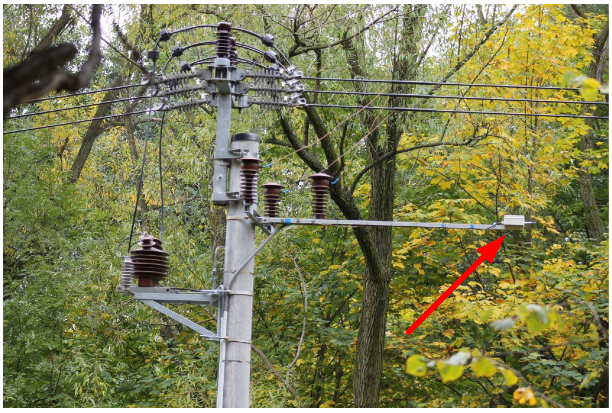


Fig. 3: Antenna mounted on the pole.

Raw signal from antenna output is sampled with 20 MS$\cdot$s^{-1} rate and stored in memory. Sampling is performed once per hour, record length is 20 ms (400,000 samples). Data acquisition process is wireless - measured data are transferred via GPRS into database for further analysis.

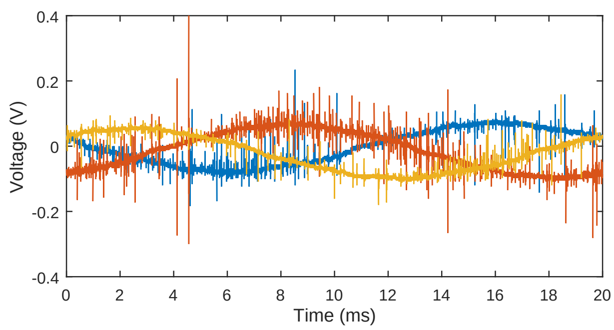
4. Evaluation

Several features were extracted from the raw signal. The literature about feature extraction is very extensive [22] and [23]. In the experiment, the hard thresholding was applied for all raw signals and the following features were extracted:

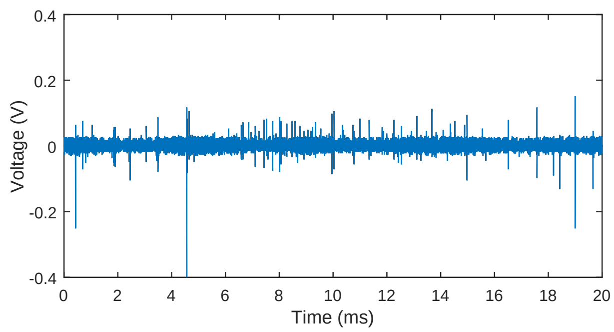
- number of positive peaks,
- number of negative peaks,
- fractal dimension (5 steps),
- fractal dimension (10 steps),
- entropy of the signal,
- entropy of decomposition,
- entropy of detail coefficients.

In total, the experimental results contain 10 signals. 5 signals with PD activity caused by direct contact of the tree with the cable and 5 signals without PD activity. All measurements were performed in real environment of forested terrain in Jeseniky Mountains.

The example of measured signal is shown in Fig. 4. The upper graph represents voltage signals from overhead line phases, measured through capacity divider. Lower graph is voltage signal from the antenna output. These signals were not synchronized during the measurements.



(a) Influence of PD activity.



(b) Influence of PD activity on antenna signal.

Fig. 4: Influence.

The results of our experiment are shown in Tab. 2. The most significant features are number of positive and negative peaks. The signals can be easily distinguished, because the fault signals contain much higher number of peaks. Another relevant feature seems to be fractal dimension (5 steps). The fractal dimension (10 steps) and other features are less relevant.

It is not possible to determinate the distance between PD activity spot and detector with one antenna only. Amplitude of PD-pattern depends on many factors. The most important one is the electric conductivity of a branch, weather conditions have also a significant influence. Figure 5 shows PD-pattern caused by green branch at the distance of 100 meters from the antenna. In the Fig. 6 is a different PD-pattern, caused by dry branch at the distance of 50 meters from the antenna. PD-pattern caused by dry branch at the distance 1000 meters is buried in the noise and cannot be detected. This is why the distance cannot be estimated from PD-pattern amplitude.

For proper location of PD activity on CC, several detectors must be installed along the overhead powerline, dividing it into sections. By comparing PD pattern amplitudes from different sections, the most affected

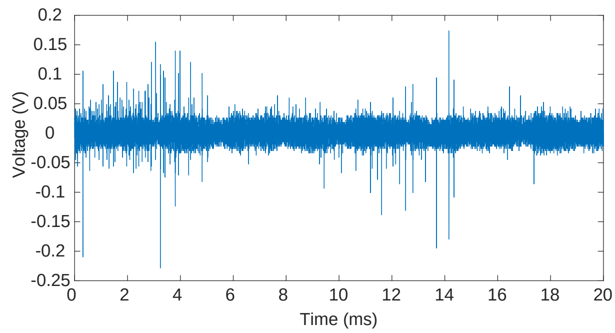


Fig. 5: Influence of green branch at the distance of 1000 meters from the antenna.

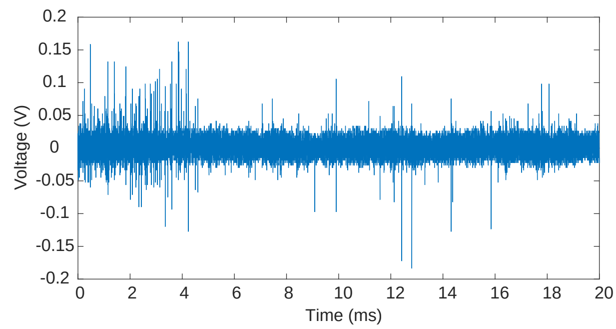


Fig. 6: Influence of dry branch at the distance of 50 meters from the antenna.

section (and approximate position of tree fall) can be determined.

5. Conclusion

Unlike artificially created PD-pattern in laboratory conditions, measurements in a real terrain are affected by background noise. The examples of the noise are corona or radio emissions. This noise may be confused with the PD-pattern caused by insulation fault. The noise cannot be completely eliminated even after noise reduction procedure (like hard thresholding). The challenge is to develop an enhanced approach to reduce the noise even more. This may include the improvements in measuring devices, denoising procedures or classification algorithms.

The tree falls were simulated in a relatively close distance (hundreds of meters) from the measuring device (antenna). The unknown behaviour for practical usage of the antenna is to detect tree faults in greater distances. The amplitude of the signal decreases with the growing distances. In our future work, we will try to determine maximal possible range of the antenna for the tree fall detection.

Acknowledgment

This research was conducted within the framework of the project LO1404: Sustainable development of ENET Centre, Students Grant Competition project reg. no. SP2015/170, SP2015/178, project LE13011 Creation of a PROGRES 3 Consortium Office to Support Cross-Border Cooperation (CZ.1.07/2.3.00/20.0075), project TACR: TH01020426.

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