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Partial Discharge Localization Based on Received Signal Strength

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Abstract— **Partial Discharge (PD) occurs when insulation containing defects or voids is subject to high voltages. If left untreated PD can degrade insulation until, eventually, catastrophic insulation failure occurs. The detection of PD current pulses, however, can allow incipient insulation faults to be identified, located and repaired prior to plant failure. Wireless technology has paved the path for PD detection and monitoring. Software Defined Radio (SDR) is a promising technology. Signals from two PD sources are received at six outdoors locations using an SDR USRP N200 which is connected to a laptop. PD sources, thereafter, are localized based on received signal strengths.**

Keywords—Partial discharge detection; SDR; Spectrum sensing; USRP N200.

I. INTRODUCTION

The failures caused due to electrical insulation are one of the reasons of unexpected disruption in power systems and associated electrical machines and power cables. In general, the power generation, transmission and distribution are stated to be the most expensive electrical assets in high voltage power systems, which are subjected to numerous electrical, thermal, environmental and mechanical stresses [1][2][3]. Among them, the partial discharge (PD) issues are a common cause leading to power system failure. PD can be stated as an electrical discharge or pulse generated in a dielectric solid surface or liquid insulation system. PD can also cause insulation degradation. Especially in high voltage (HV) electrical power systems, a number of materials such as, solid, liquid and gaseous are employed to insulate certain components or equipment. Hence the detection and localization of PD is essential [4] [5][6].

PD pulse monitoring and detection is one of the areas that also requires the use of wireless technology. PD detection and localization is a difficult task. Furthermore, it is an important area that did not receive as much attention as it should have to exploit the advantages of available SDR technology. SDR is a promising technology and has been chosen because it is a cost-effective, portable, and readily available [7].

Some of the key localization approaches that have been used in the past include time of arrival (TOA), time difference of arrival (TDOA) and angle of arrival (AOA) [8-11].

Each of the localization techniques mentioned above has its prospects and concerns. The methods are all based on the range and they estimate the location of the PD source by using a database or matrix of locations [9]. In recent time the received signal strength (RSS) approach has gained importance for indoor and outdoor localization. This RSS algorithm is preferred due to its cost-effectiveness for source localization because it requires a minimal hardware and software as it does not need the employment of an antenna array or the requirement of time synchronizations as in TOA and TDOA methods.

In physical source localization, obtaining the source location is based on the receiver locations and their measurements of the received power; a closer distance between the source and the receivers, leads to a more accurate estimation of the source location. Moreover, there is often a problem associated with the RSS algorithm that when there is an obstacle between the PD source and the receiver, the received signal strength will drop significantly, especially if the obstacle is large and/or close to the receiver or the PD source. Most used algorithms for RSS-based physical source locations are: the gradient, trilateration and centroid algorithms [9].

In this paper, an RSS-based source localization algorithm has been used to estimate the PD source location in a noisy environment.

II. RECEIVED SIGNAL STRENGTH

The primary reason for the popularity of the RSS algorithm is its ability to exploit the features of the communications systems that already exist. It implies that there is no need to install additional hardware and software, that ultimately reduces the cost and complexity of the implementation. Also, there is a relationship between the quality of the communication, and the RSS, whereas a lower received signal strength leads to a lower quality of communication between the transmitter and the receiver [9] [10].

When using the RSS for localization purposes, it proves extremely useful because it provides information about the distance between the source and the receiver that can be exploited to locate the source by converting the received power into distance [12]. Multiple locations can be added by using multiple receiver nodes that allow trilateration or even multilateration. The main issue is the accuracy of the estimated location because of the heterogeneous nature of the radio propagation environment [12]. The major challenge that is faced in PD localization is the anonymity of the propagation parameters i.e. the source transmitted power is unknown as well as the path loss index is environment dependent and can vary from node to node due to the heterogeneous nature of the propagation enviromemnt [12][13]. The following equation describes the RSS model that is based on the common path loss model:

$$R_i = R_o - 10\, n \log_{10}\left(\frac{d_i}{d}\right)$$

Where,

R_i is proportional to the received signal power (in dBm).

R_0 is the radiated power of the PD source (in dBm).

d_i is the distance between the ith receiver and the PD source.

d is a reference distance.

n is the path loss exponent (n=2 for free space propagation).

In the localization system used, the transmitted source power is unknown as well as the path loss index. As the equation above implies, the received power or equivalently the received signal strength, can be converted into distance. To overcome the problem of unknown parameters, a linear approximation is used. It is worth mentioning here that the performance of the RSS algorithm is very low when the geometric conditions are poor yielding an estimation error that becomes very large, especially at corners [14].

The algorithm executed as follows:

(i) initially assume a plausible path-loss index (e.g. n = 2, free space propagation).

(ii) Calculate the received power ratios at any two nodes to find the locus of possible source location.

(iii) establish an initial estimate of source location using intersecting loci from all measurements node pairs.

(iv) calculate an improved estimate of source location using pairs of nodes corresponding to paths with nearly equal n. If necessary, iterate to converge on a final location estimate.

In a noisy environment, the error should be less than 1 m between successive location to stop the algorithm. The main challenge is to optimize the value of the path loss exponent n for each path.

In Fig. 1 the flowchart of the algorithm is drawn:

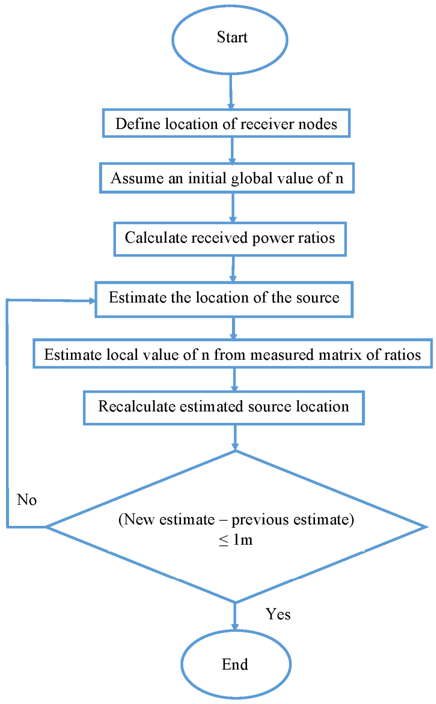

Fig. 1 Flowchart of the location algorithm.

III. THE EXPERIMENTAL SET- UP

Fig. 2 shows the experimental set-up. A PD emulator has been used as PD source. Due to a limitation in the number of receivers available, a single receiver (USRP N200 connected to a wideband biconical antenna and a laptop) has been employed to receive the PD signal at several locations and then the signal processing and the localization are performed sequentially. It is worth mentioning here that the PD emulator is a high voltage equipment and is placed inside a wooden box, for health and safety reasons [15] [16].

Fig. 2: Experimental setup.

The spectra of the PD signal and the background noise plus interference are obtained in the following scenario: Firstly, before switching the PD emulator on, the noise background spectrum should be obtained. Secondly, the D emulator is switched on and the PD spectrum is obtained.

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This scenario is repeated at every location. Fig. 3 shows the results obtained at one of the locations. It can be clearly seen that the spectra of the PD signal and noise background are spiky. Some signal processing is required to remove the spikes from the spectra. Fig. 4 shows the spectra after signal processing with a moving average filter.

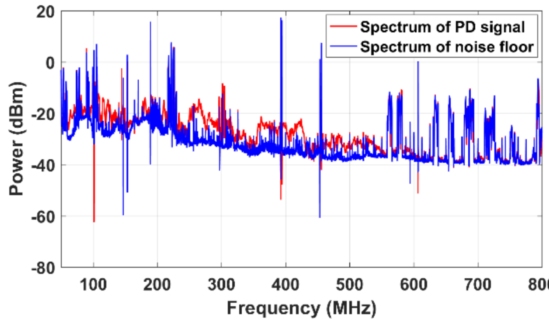

Fig 3. The measured spectra using a USRP transceiver (outdoors).

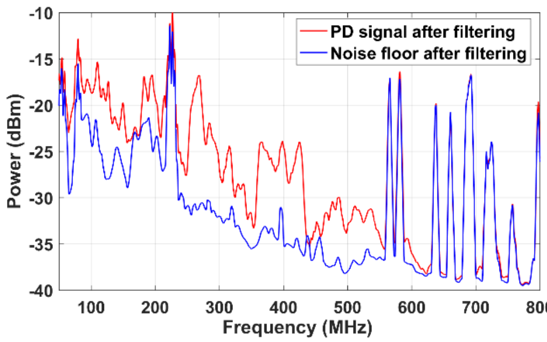

Fig 4. PD signal and noise floor after filtering.

By inspecting Fig. 4 it can be clearly seen that some very strong interference caused by TV broadcasting and mobile communications systems in the band of 500-800 MHz is present [17]. To avoid this interference, this band is removed and the new calculated PD band is 50 - 450 MHz. This will not have an important impact as most of the PD energy is at lower frequencies. Fig. 5 shows the new PD band.

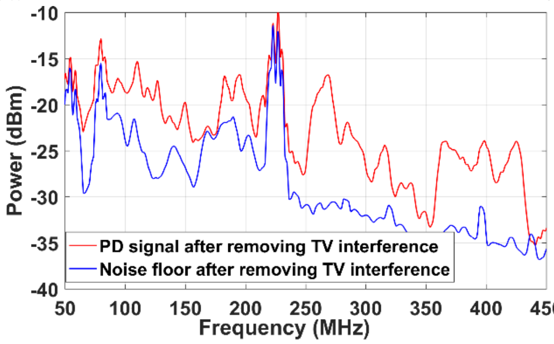

Fig 5. PD signal and background noise plus interference after removing TV interference.

After signal processing is performed, the values of the curves in dBm are converted into a linear scale (milliWatts) and then subtracted from each other at every frequency and integrated to get the average power at each location in milliWatts as shown in the Table 1. It should be noted that received signal power is not calibrated, therefore, this is only a relative estimate of received power and not an absolute value [18]. Fig. 6 shows the difference between the PD spectra and noise floor in milliWatts.

Table 1. Power values at the receiver locations

Receiver location	Relative power in milliWatts
1	14.8
2	10.4
3	14.3
4	32.0
5	2.6
6	8.1

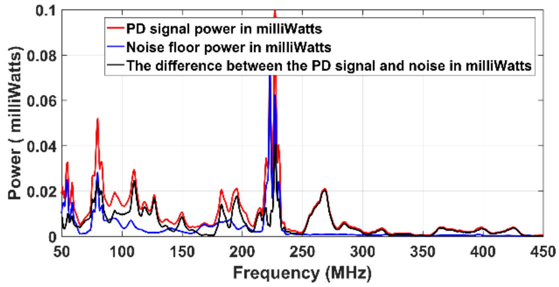

Fig 6. The difference between the PD signal and background noise plus interference.

IV. THE LOCALIZATION RESULTS

The localization algorithm proposed here is based on received signal strength, thus the power values obtained from the SDR system are entered into a MATLAB code to localize PD sources.

Fig. 7 shows the localization results. The estimated error is 1.3 meters. The proposed estimation error is less than 1 m, however the estimated error is still acceptable in this case. Table 1 contains the record of relative power values at six locations. The SDR localization system can receive the PD signal up to maximum range of 20 meters [16]. As can be seen in Table 1 and Fig. 7, the receivers closer to the PD source receive a higher signal power and based on this principle and the relative strengths of received powers at various locations, the source is localized.

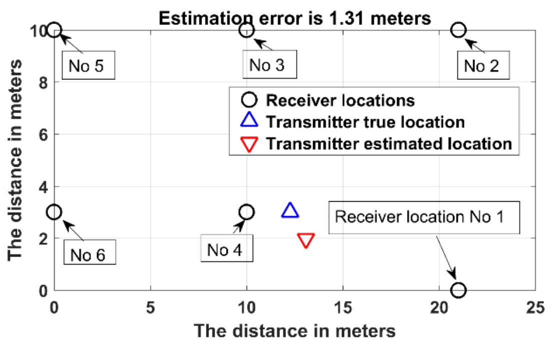

Fig. 7 PD source localization set-up and results

Comparing to previously obtained results with more conventional methods, [2], the localization accuracy of this method is very satisfactory.

V. CONCLUSION

A PD detection and localization system using the SDR technique has been demonstrated. Considering the noisy environment and the simplicity of the system, the estimation error obtained using the selected localization system is acceptable.

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