Antenna Array Layout for the Localization of Partial Discharges in Open-Air Substations

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Outline

- Introduction
- Finding the radio-frequency source
- Antenna deployment and sensitivity to measurement errors
- Experimental Study
- Conclusions

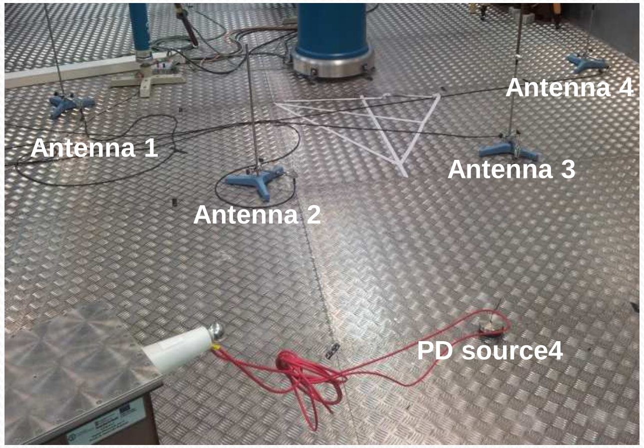
Introduction

Introduction – What are PD?

- Partial discharges (PD) are the dielectric breakdown of a gas within solid/liquid insulation systems due to highly concentrated electric fields .
- They are rapid flows of charge carriers lasting some nanoseconds.

Introduction – PD localization

- Locating the source of these discharges is of importance because it helps in identifying the piece of equipment which is prone to failure.
- PD emit energy in the radio-frequency (RF) band so they can be measured with antennas.
- PD sources can be located with an array of antennas.



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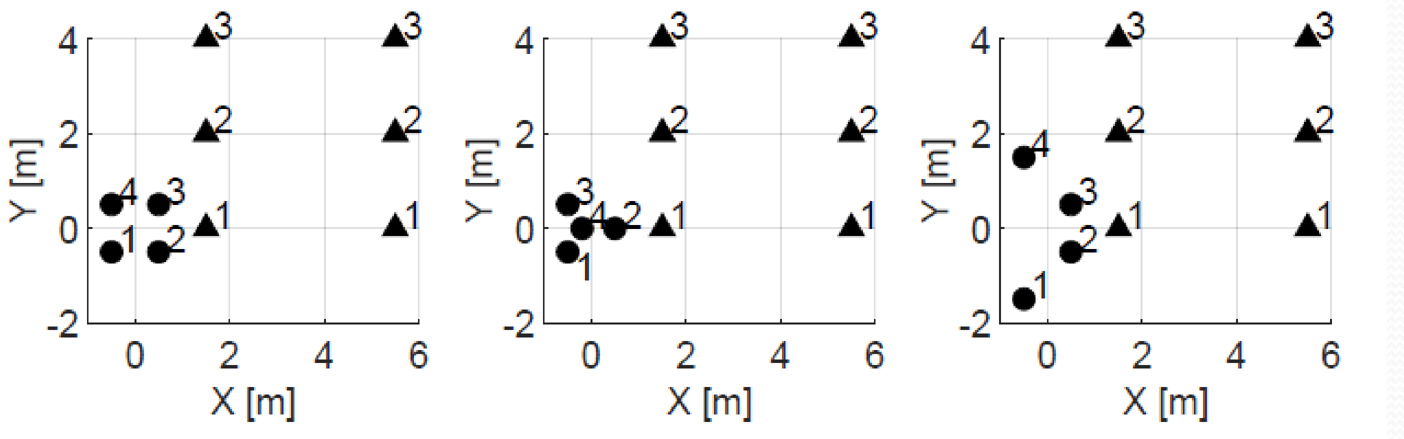
Introduction – Antennas layout

- The antennas layout affects in the accuracy of the localization.
- PD sources included inside the antennas polygon gives an accurate location.
- In our study, the PD source is placed outside the antennas polygon.



(a) Square array (b) Star array (c) Trapezoidal array

Finding the radio-frequency source

RF emission propagation

- The distance from the source to the antenna i through free space is written as:

$$D_i = c \cdot t_i = \sqrt{(x_i - x_s)^2 + (y_i - y_s)^2 + (z_i - z_s)^2} = \|\boldsymbol{P_i} - \boldsymbol{P_s}\|$$

- The absolute time of arrival (t_i) is not known so it is necessary to measure the time difference of arrival.

$$D_{ij} = c \cdot (t_i - t_j) = \|\boldsymbol{P_i} - \boldsymbol{P_s}\| - \|\boldsymbol{P_j} - \boldsymbol{P_s}\|$$

Uncertainties in the location

- There are many factors that can affect in the correct localization, $\boldsymbol{P_s}$. Some of them are:
  - The nature of the received signal
  - The position of the antennas
  - The measuring procedure

Uncertainties studied

- This work is focused on:
  - The position of the antennas

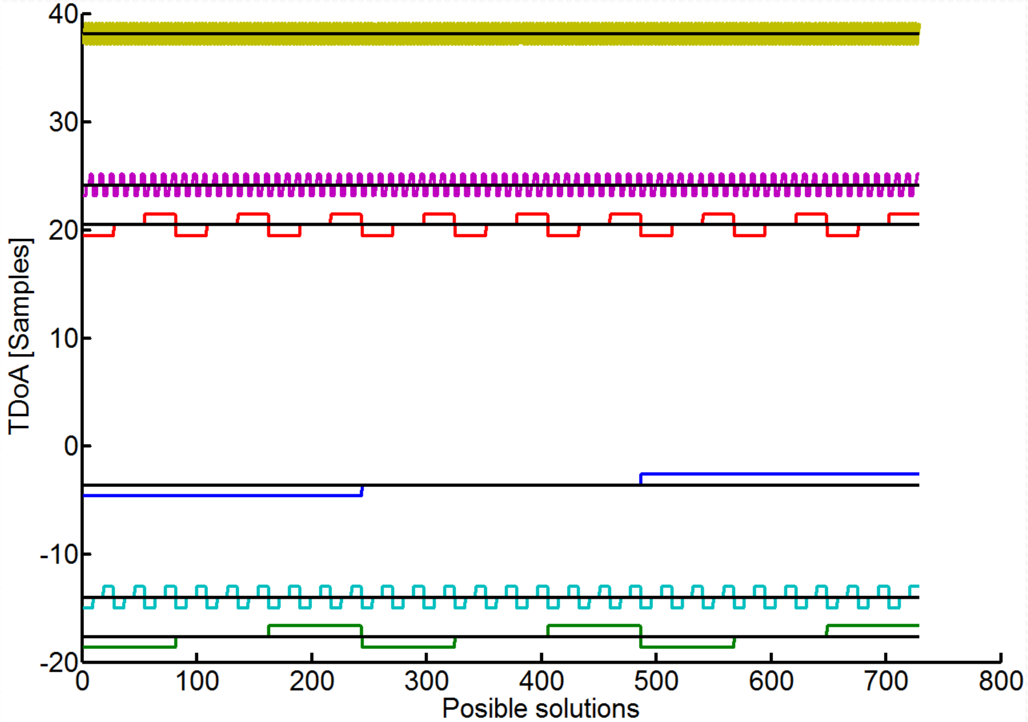
    How the antenna layout geometry, P_i, affects the location performance.
  - The measuring procedure

    Inducing an error in the $TDOA_{ij} = (t_i - t_j)$ during the simulations

Antenna deployment and sensitivity to measurement errors

Sensitivity to error

- Adding an error of one time sample in all TDOA.



$TDOA_{12}$= -3.6

$TDOA_{13}$=-17.7

$TDOA_{14}$= 20.5

$TDOA_{23}$=-14.0

$TDOA_{24}$= 24.1

$TDOA_{34}$= 38.1

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Sensitivity to error

- D'_{ij} is the distance including the error

$$D'_{ij} - \|\boldsymbol{P_i} - \boldsymbol{P'_s}\| + \|\boldsymbol{P_j} - \boldsymbol{P'_s}\| = 0$$

- Objective function (OF) to minimize

$$f(\widehat{x_s}, \widehat{y_s}, \widehat{z_s}) = \sum_{i=1}^{L-1} \sum_{j=i+1}^{L} \left(D'_{ij} - \|\boldsymbol{P_i} - \widehat{\boldsymbol{P_s}}\| + \|P_j - \widehat{\boldsymbol{P_s}}\|\right)^2$$

- Particle swarm optimization (PSO) to minimize OF

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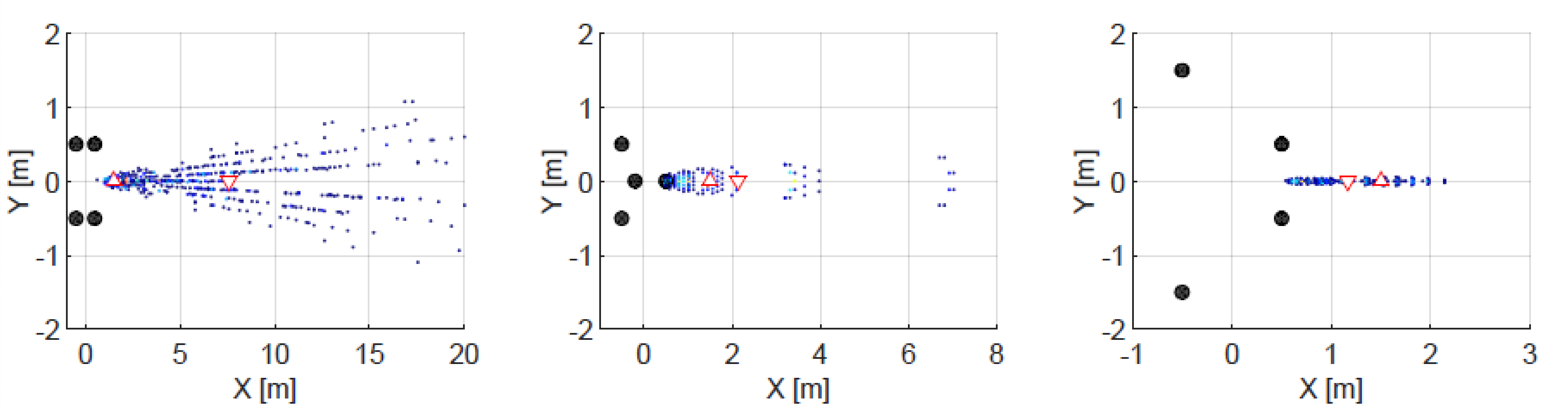
Behavior of the antenna arrays

- Statistics analysis
  - Distance of the mean value in X and Y axis to the actual position of the source
  - Standard deviation of the distance of all possible values to the actual position

Simulation results

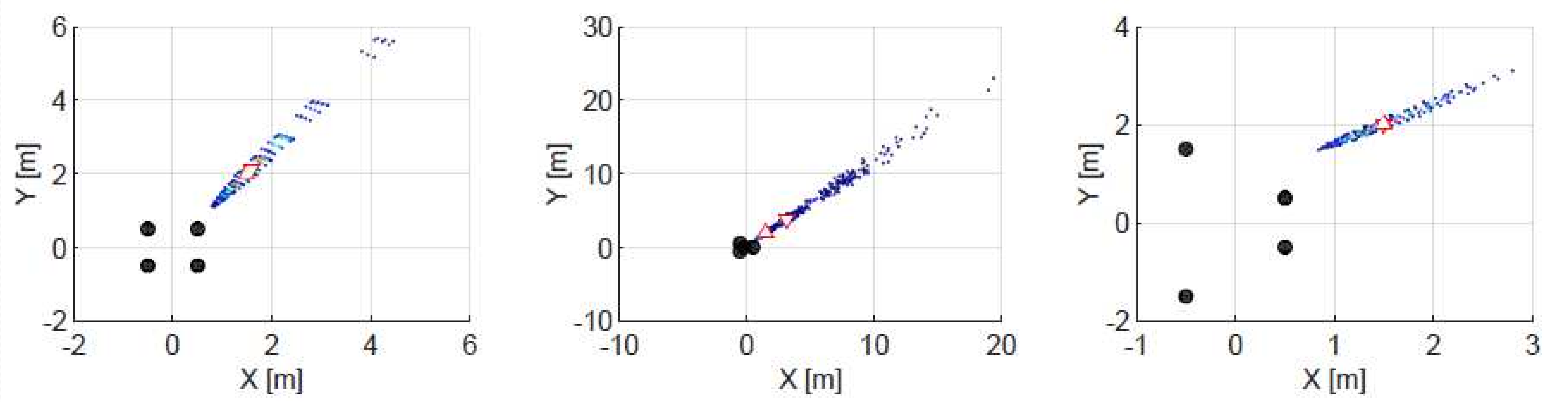
- Position 1



Mean	6.09 [m]	0.64 [m]	**0.34 [m]**
Std	10.54 [m]	6.25 [m]	**0.28 [m]**

Simulation results

- Position 2



Mean	0.15 [m]	2.49 [m]	**0.01 [m]**
Std	0.66 [m]	3.94 [m]	**0.25 [m]**

Simulation results

- The position 3 at $x = 1.5\ [m]$ and all positions at $x = 5.5\ [m]$ were also simulated but only a summary table is shown.

			Square [m]	Star [m]	Trapezoidal [m]
X=1.5 [m]	Pos 3	Mean	3.27	6.61	**1.53**
		Std	7.90	10.98	**3.10**
X=5.5 [m]	Pos 1	Mean	33.93	10.72	**1.57**
		Std	40.30	27.87	**1.67**
	Pos 2	Mean	5.39	6.04	**0.71**
		Std	11.04	13.06	**1.00**
	Pos 3	Mean	3.45	7.16	**0.23**
		Std	7.93	10.16	**1.61**

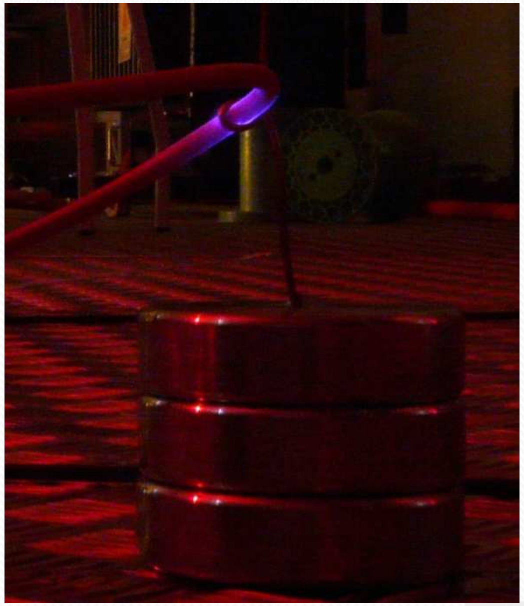
Experimental Study

Setup in laboratory

- The omnidirectional antennas are monopoles 10 cm long
- All coaxial cables have the same length
- Oscilloscope with four channels
- Sampling frequency is 5 GS/s → Sampling time Ts=200 ps
- Interpolation increase the resolution and improve the results
- Fast frame of 500 partial discharges
- The $TDOA_{ij} = (t_i - t_j)$ are calculated using a cumulative energy method with negative slope

PD source

- A copper wire is bent to form a ring around the high-voltage cable 25 kV and then, connected to ground.
- Surface partial discharges.

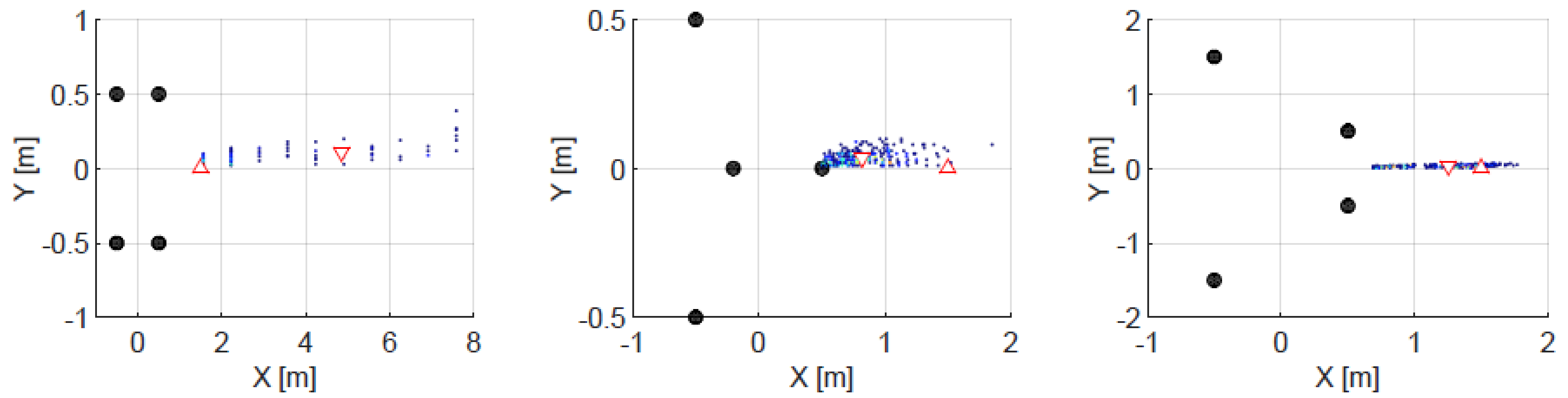


Experimental Study

- The three antenna array layouts were tested in laboratory.
- Experimental measurements were taken for positions 1 and 2 with x = 1.5 [m] due to laboratory space constraints.

Experimental Study

- Position 1



Mean	3,35 [m]	0,69 [m]	**0,27 [m]**
Std	8,54 [m]	**0,21 [m]**	0,23 [m]

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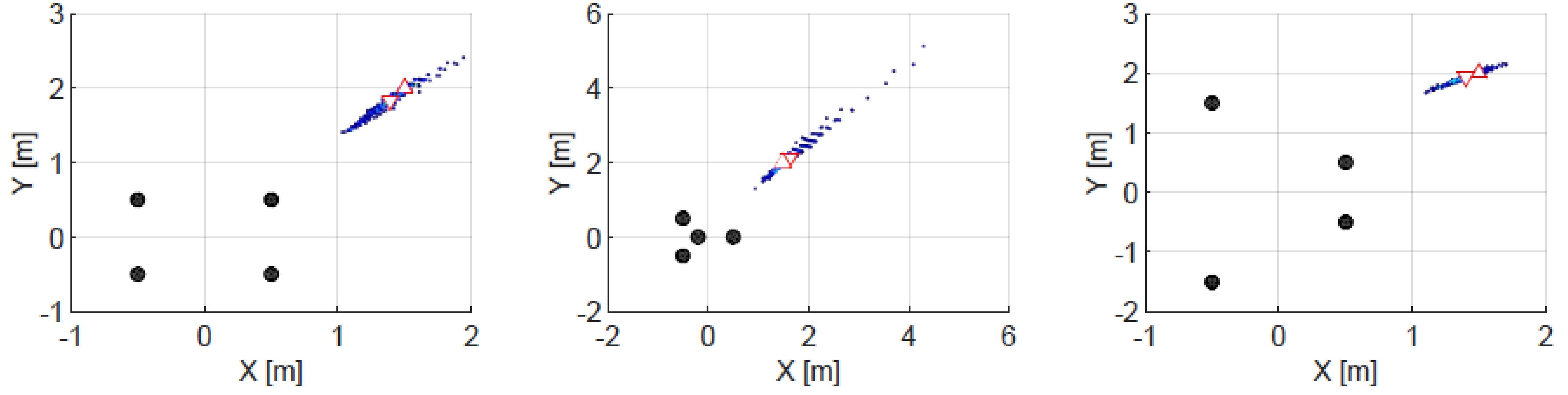
Experimental Study

- Position 2



Mean	0,25 [m]	0,35 [m]	**0,14 [m]**
Std	0.17 [m]	0,48 [m]	**0.10 [m]**

Conclusions

Conclusions

- Choosing an adequate layout of antennas can help in the localization of DP source.
- The trapezoidal configuration can reduce the dispersion of the possible solutions of the source better than the other tested configurations.
- The average value of all data in the components x and y is also closer to the actual position of the PD source.

Conclusions

- If the PD source is far from the antenna array, the performance of the trapezoidal configuration is even better which is very appropriate when measuring this type of events in open air substations.
- The study in the axis Z has been omitted because all antennas are in the same plane; at least one of the antennas have to be placed outside the horizontal plane to have sufficient resolution in height if localization is space is intended.

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