

Development of a Digital Counterpart for Internal Arc Testing

2nd International Workshop on Metrology for
Virtual Measuring Instruments (VirtMet2025)

Dec/2025

Lic. Matias A. Aguirre, INTI.



INTI

Instituto Nacional
de Tecnología Industrial



Secretaría de
Industria y Comercio
Ministerio de Economía



The internal arc failure:

A common electrical industry problem

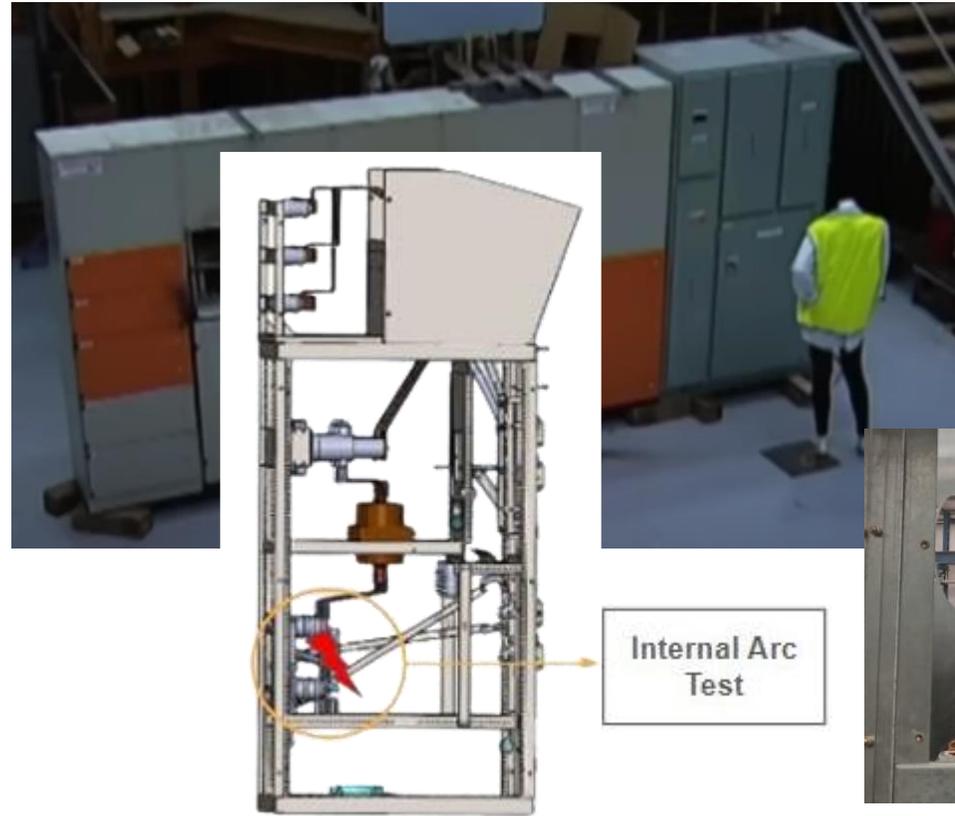


Source: Progress Switchboards. (2016). 65kA Arc Fault test [Video]. YouTube. [📺](#)

MV and HV metal-enclosed switchgear and controlgear.

The **internal arc** failure:

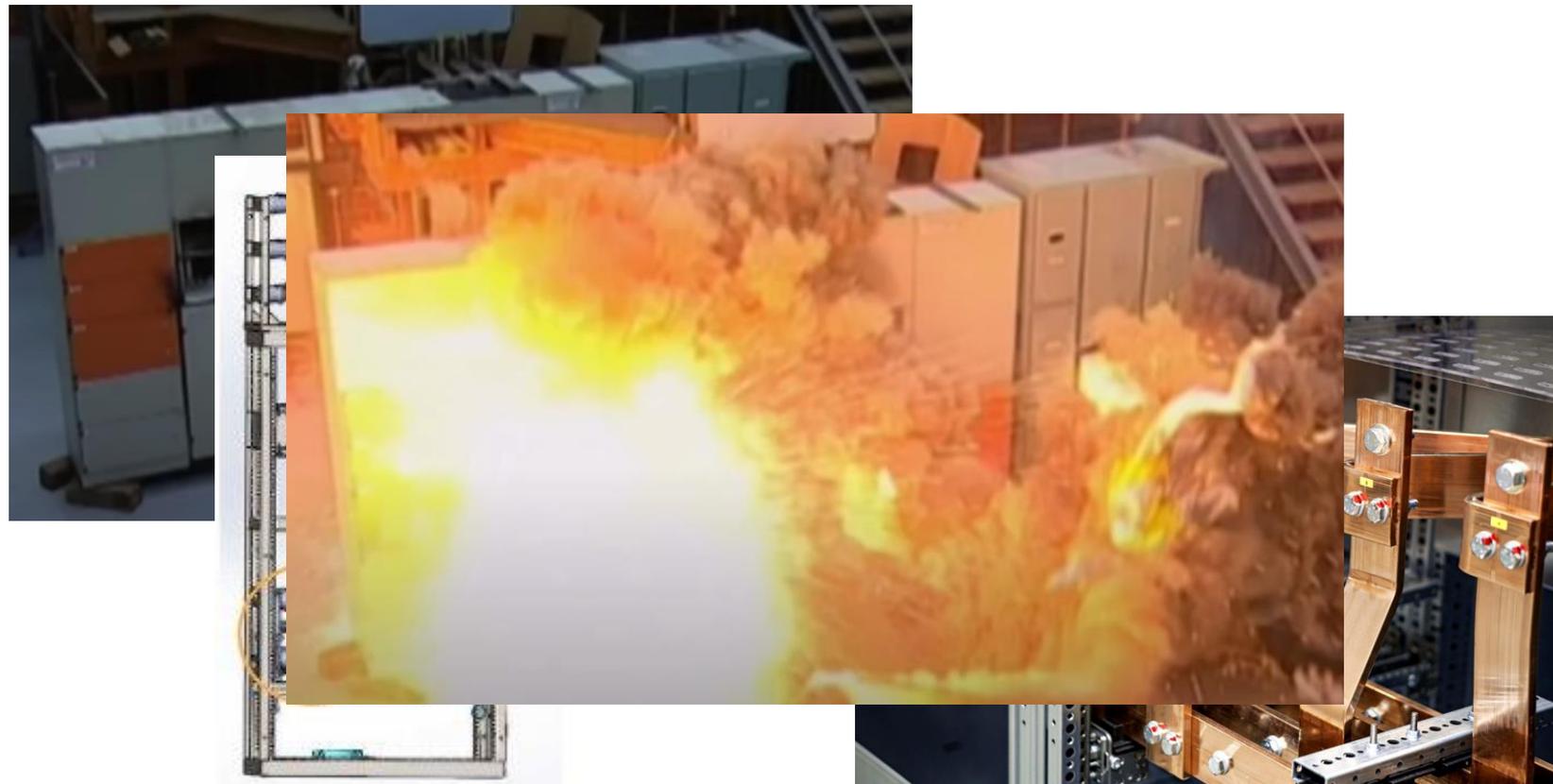
A common
electrical industry
problem



A **short circuit** between any two conductors would create an **electric arc**.

The internal arc failure:

A common
electrical industry
problem

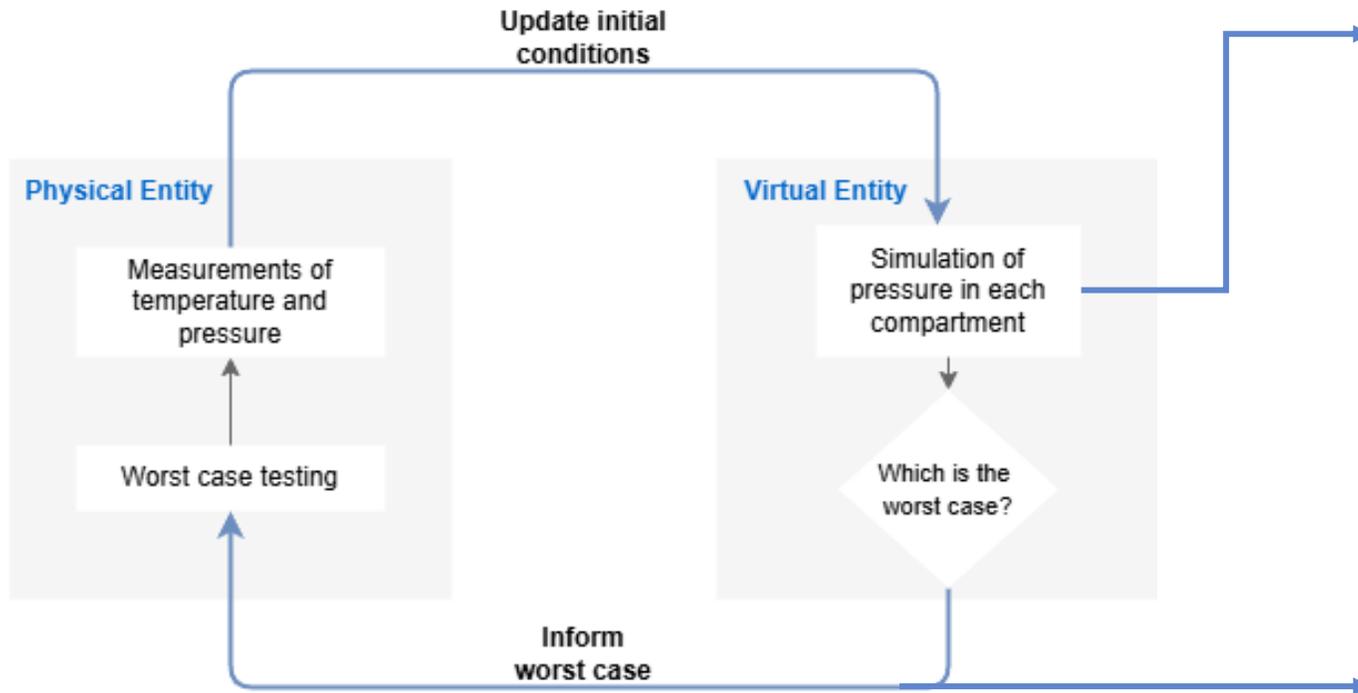


Standards **IEC 60694** and **IEC 62271-200** establish experimental type tests to verify different aspects of these metallic enclosures and their components.

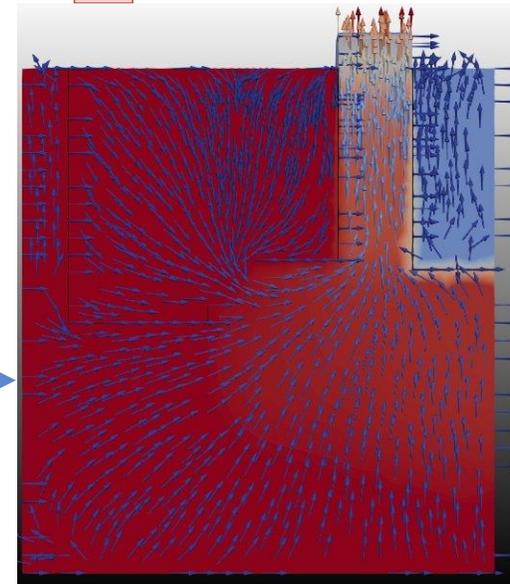
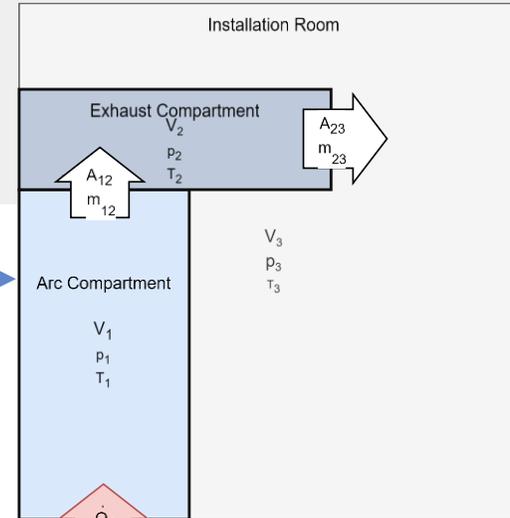
The proposed solution a digital twin for Internal Arc Test (IAT)



Proposed method for the digital twin (DT)



- From the virtual outcomes, **the worst-case overpressure** result is informed.
- The physical test is **repeated** for this case.



- Temperature and pressure measurements are used as initial conditions for a **simplified FDM model**.
- The SM calculates the **mean pressure** for each switchgear compartment.
- The data for the **worst-case** is used as initial conditions for a **FVM model** for further study.

Method 1 – Finite Difference (FDM)

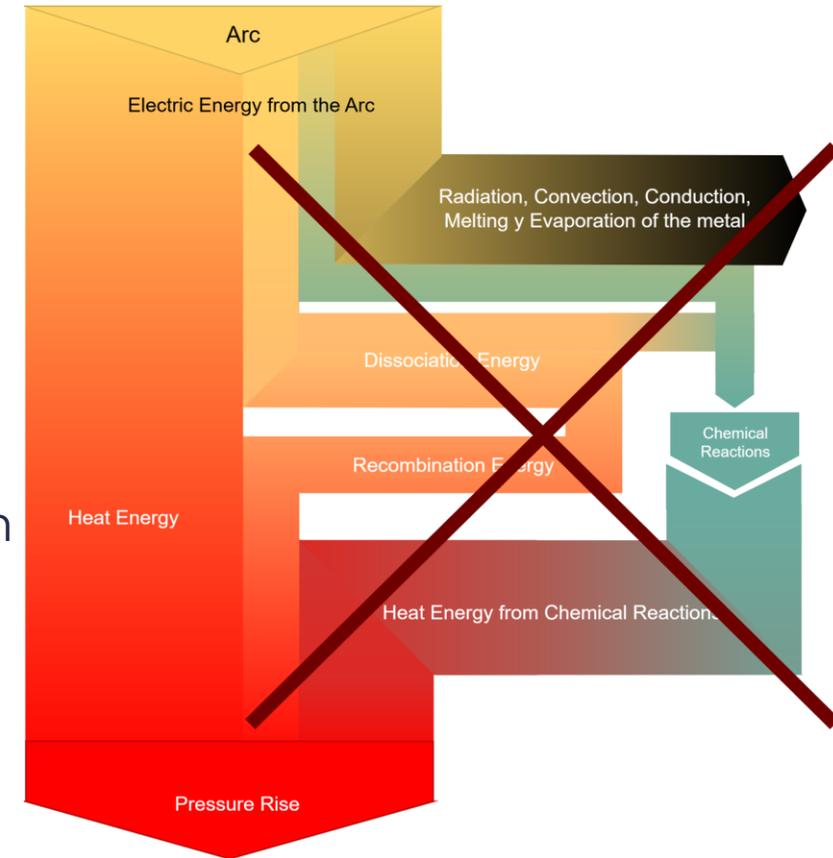


Implementation of

mass
momentum
energy } conservation eq.
+
ideal gas law

Where the energy injected is a fraction k_p of the arc electrical energy.

$$\dot{Q} = k_p (u_R i_R + u_S i_S + u_T i_T)$$



The model estimates a mean pressure rise within seconds.

This makes it feasible to propagate input-parameter uncertainties via large-sample Monte Carlo simulations (MC).

Method 2 – Finite Volume (FVM)



Discretization of

mass
 momentum
 energy

} conservation eq.

+

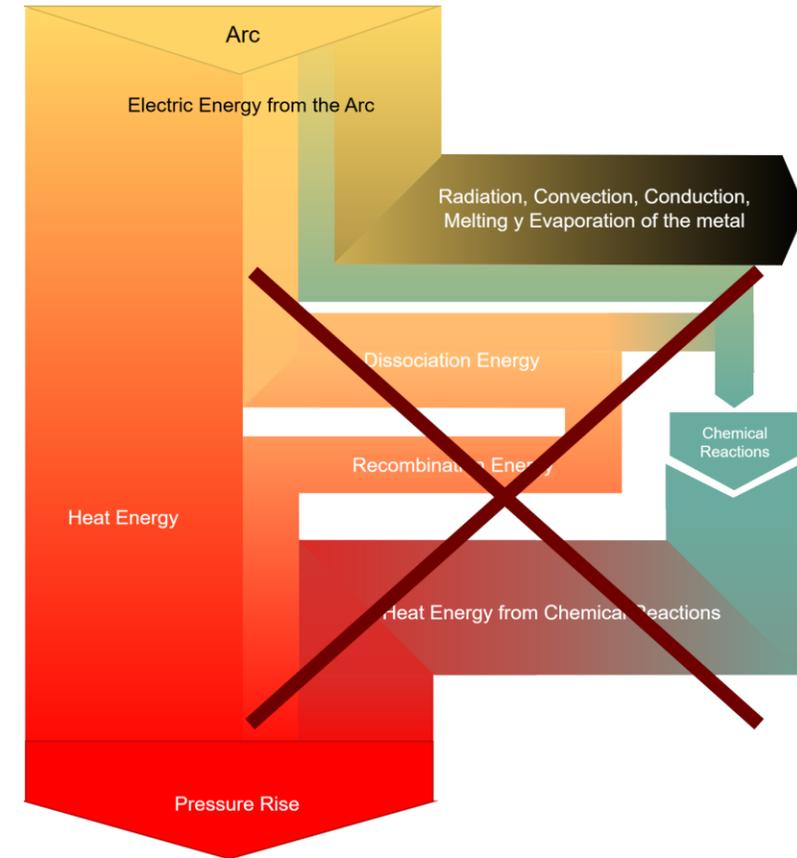
ideal gas law

+

κ - ϵ turbulence model

Where the energy injected is a fraction k_p of the arc electrical energy.

$$\dot{Q} = k_p (u_R i_R + u_S i_S + u_T i_T)$$



The model calculates a detailed pressure gradient at the cost of higher computational time.

The MC could take months, so it must be reconsidered.

Which uncertainty sources were identified and how will we obtain the uncertainty of the measurand?



Identified uncertainty sources

Source	Probability distribution	Limit of distribution	Observation
Initial gas pressure (p_i)	Normal	5 hPa	Instrument accuracy
Arc voltage (u)	Normal	1%	Instrument accuracy
Arc current (i)	Normal	1%	Instrument accuracy
Initial gas temperature (T_i)	Normal	1 K	Instrument accuracy

Table 1: Uncertainty sources from the equations used in the calculations. Normal distribution is considered with $k=2$.

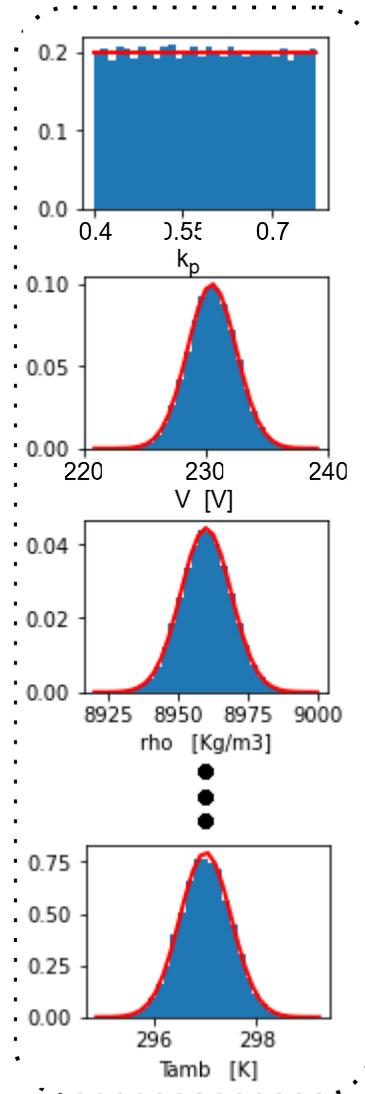
Source	Probability distribution	Limit of distribution	Observation
Dimensional	Rectangular	0,5 mm	Instrument resolution
Discharge coefficient (α)	Rectangular	0,6 – 0,75 (dimensionless)	Bibliography
Thermal transfer coefficient (k_p)	Rectangular	0,4-0,7 (dimensionless)	Bibliography

Table 2: Range of sources with rectangular probability distribution reported in the literature.

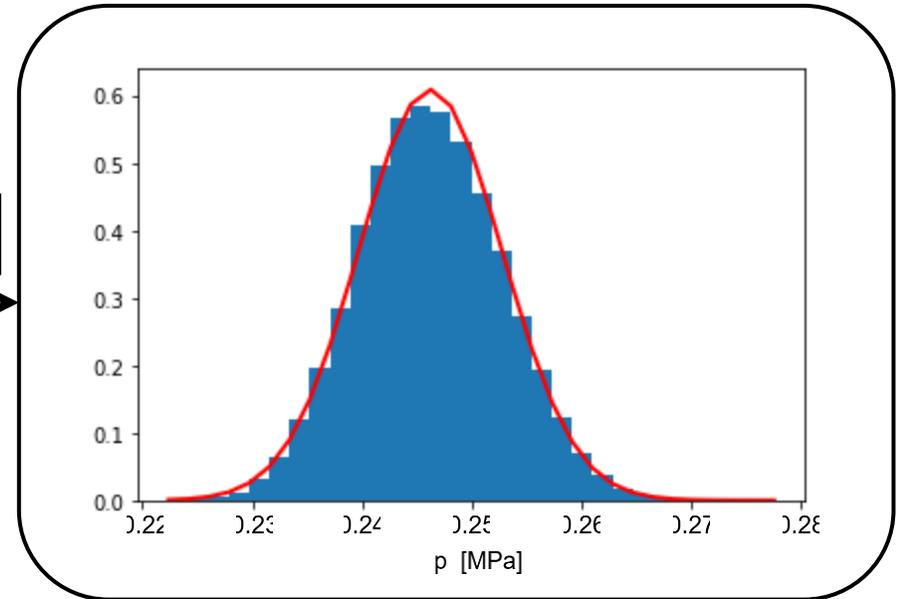
Uncertainty analysis with FDM



MC for the identified uncertainty sources

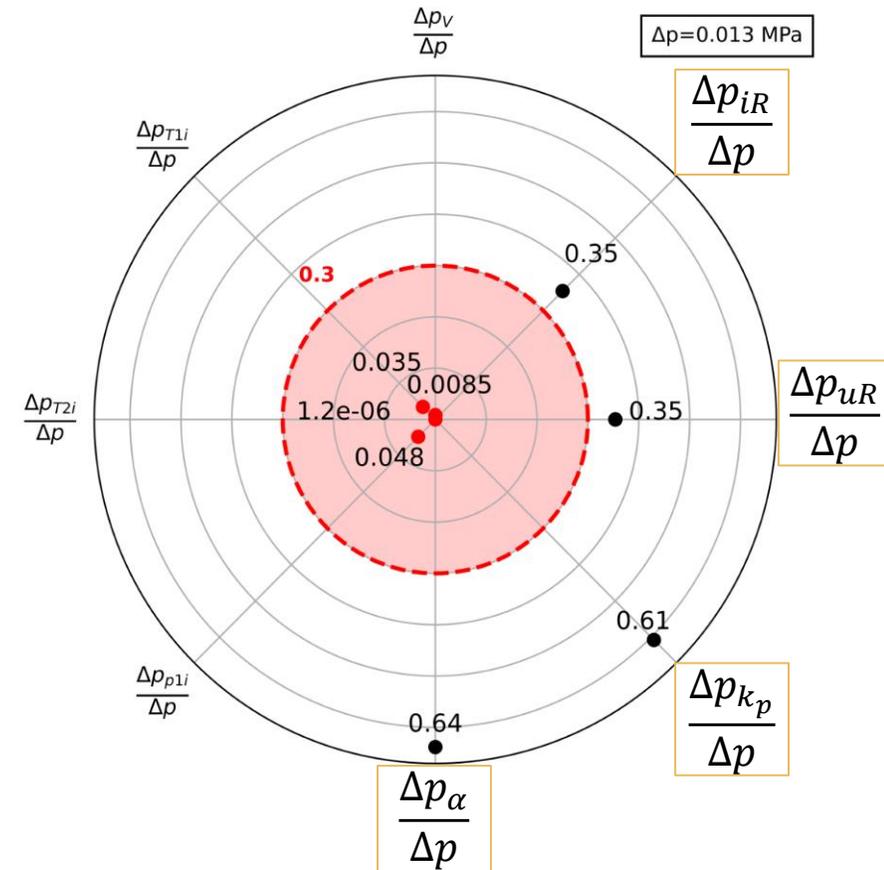
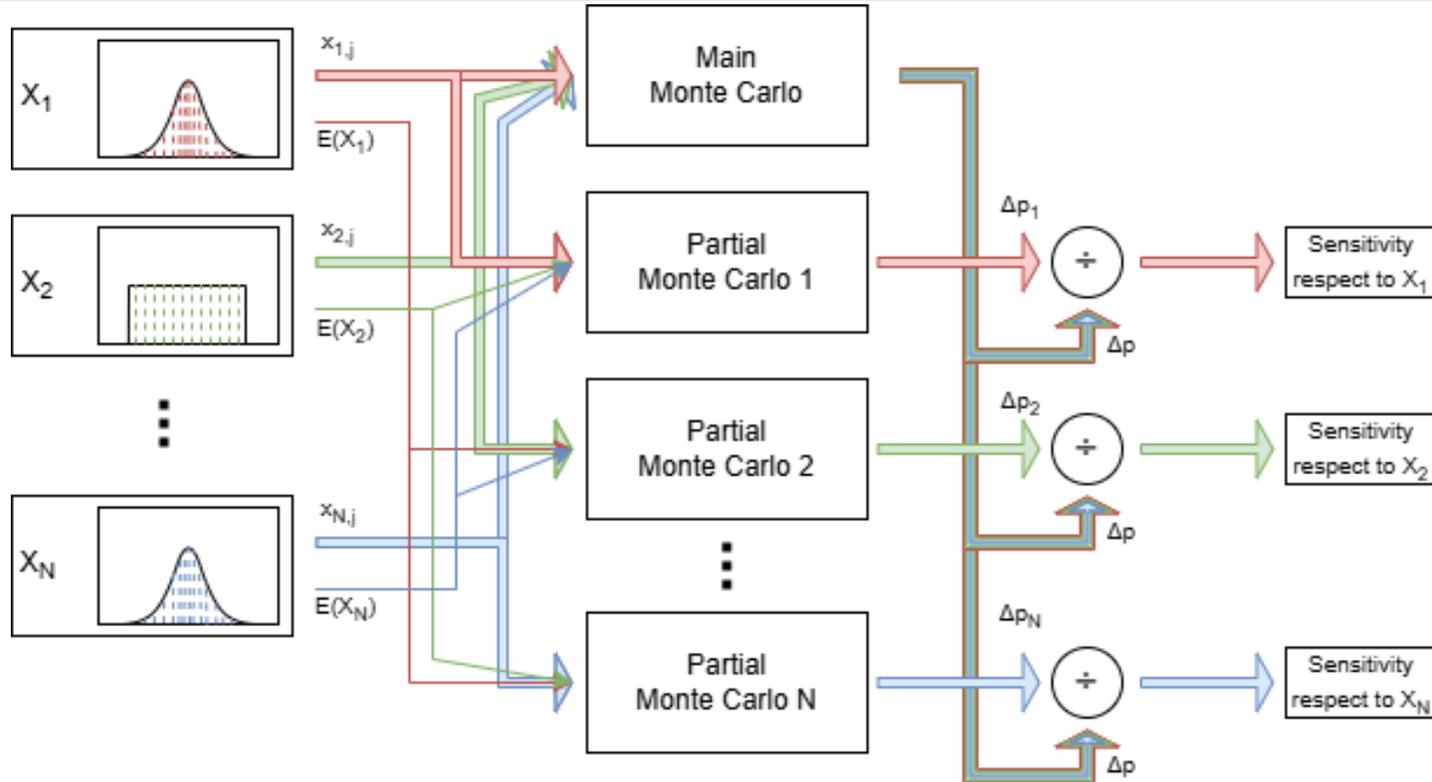


Monte Carlo Method
(10^6 elem.)



From the GUM Supl. 1, 10^6 samples are needed for a 95% confidence interval.

Uncertainty analysis with Method 1



For values lower than 30% of the total uncertainty Δp , their influence is considered negligible.

Uncertainty analysis with FVM



MC with less samples	MC with parallelization	SSPRC
Note of the 7.2 section of the GUM Supl. 1	Parallel processing with MPI	Systematic samples of the influence quantities individually propagated through the model
Use a relatively small iterations	Computing with a minimum number of iterations	Allows less iterations with similar results as MC
400 samples (48 h with 20 threads)	$3,4 \cdot 10^4$ samples for 71% confidence Interval	600 samples
Already implemented	To be implemented	Tested, to be implemented

The methods in a real case



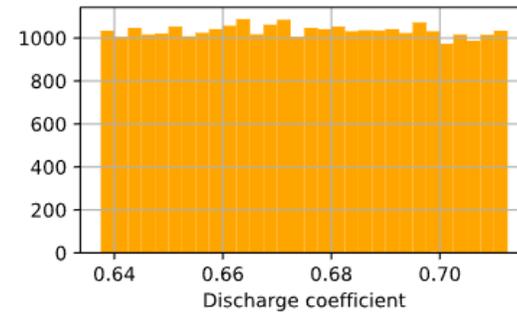
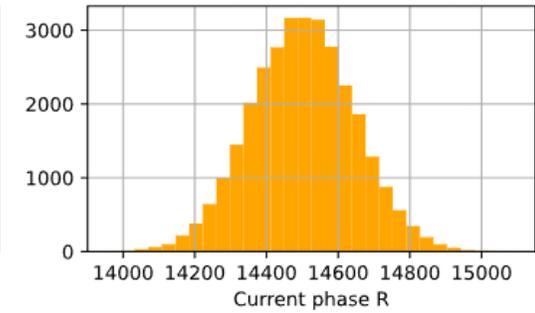
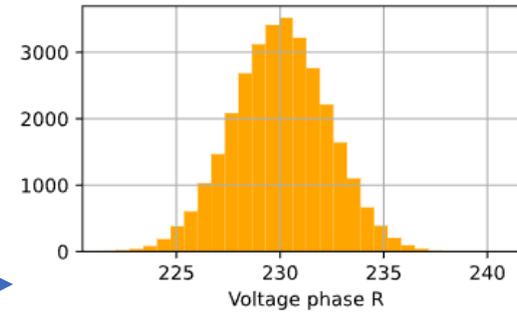
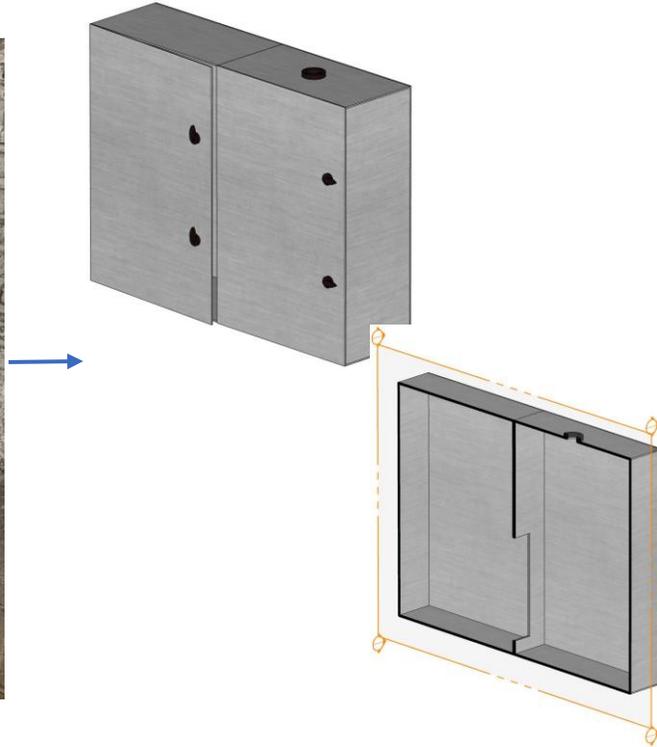
To test the method, simulations with real parameters were performed.

The methods in a real case



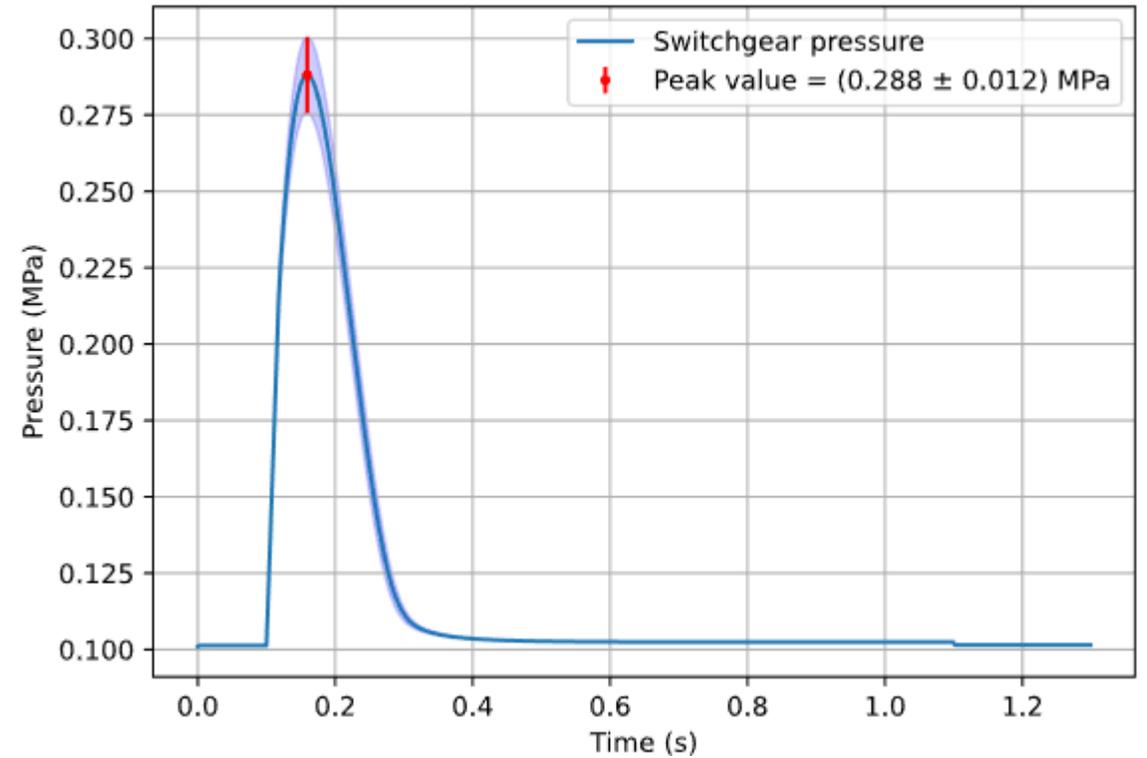
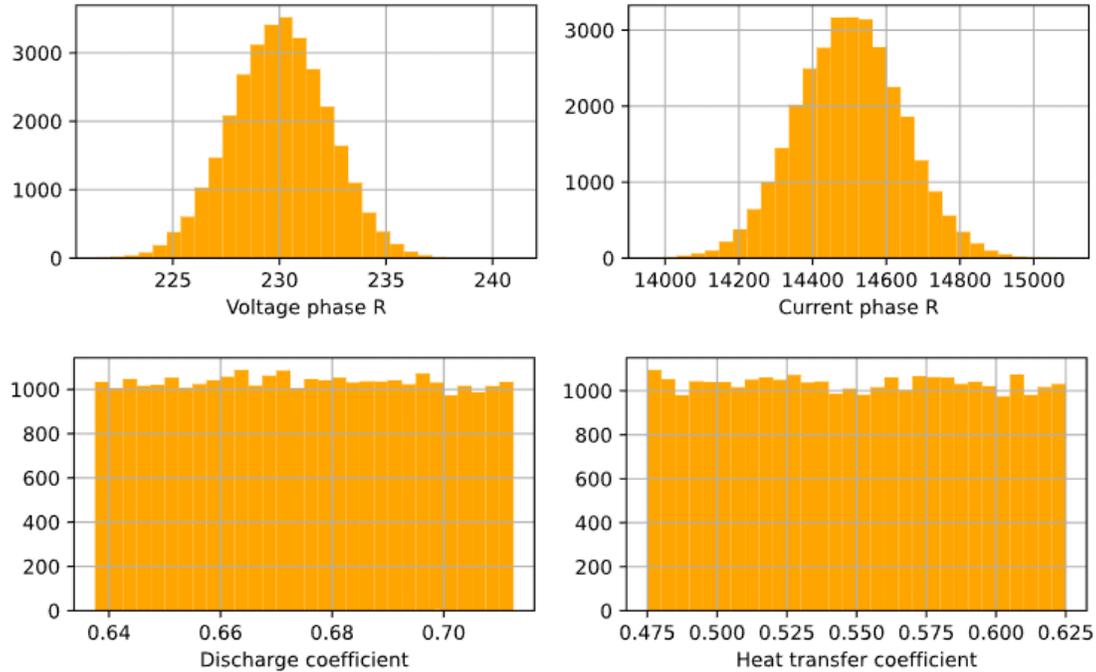
The digitalization includes a 3D modelling and discretization of the volume.

The methods in a real case



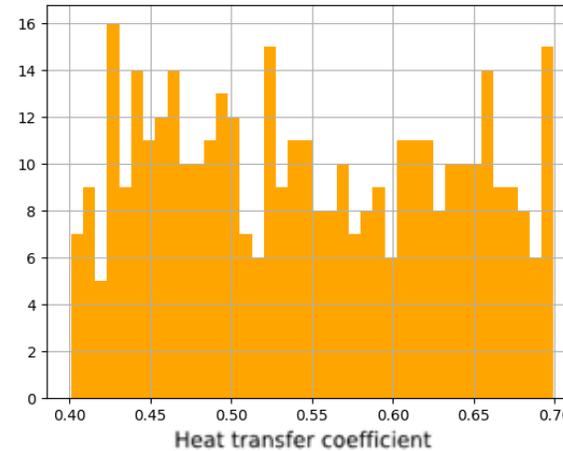
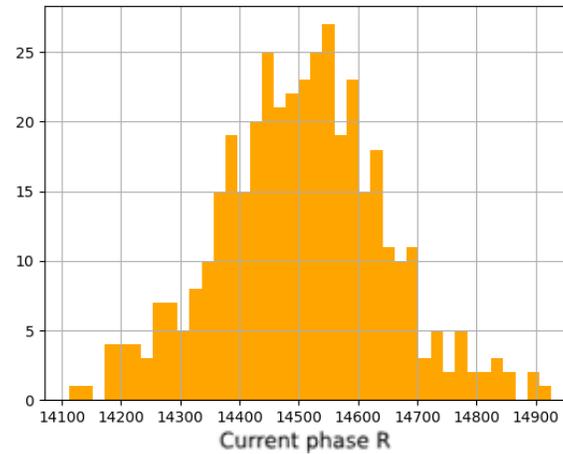
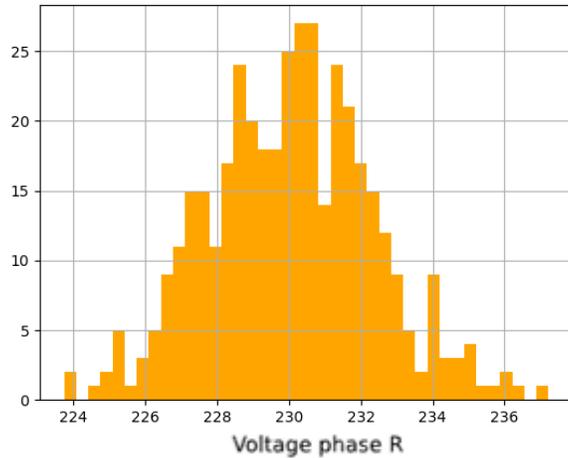
A combination of literature and common measurement uncertainties were assigned to the input parameters.

FDM in a real case



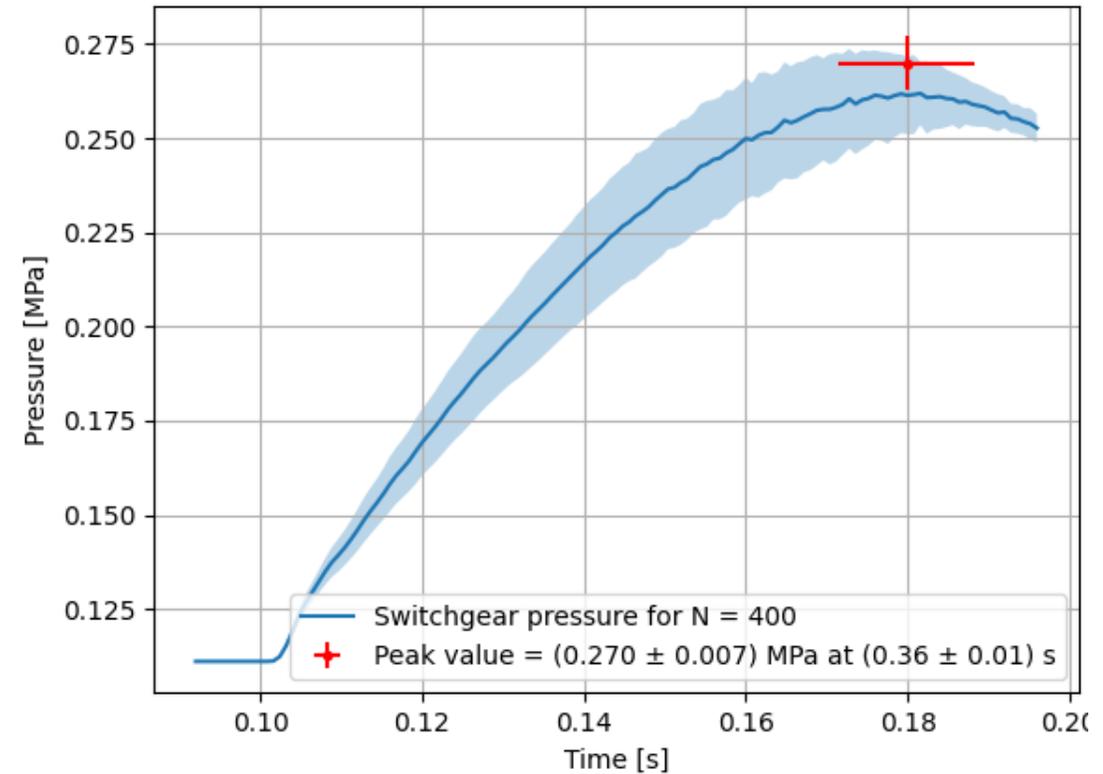
For the FDM, results were obtained within a 30 min span for the suggested samples.

FVM for a real case

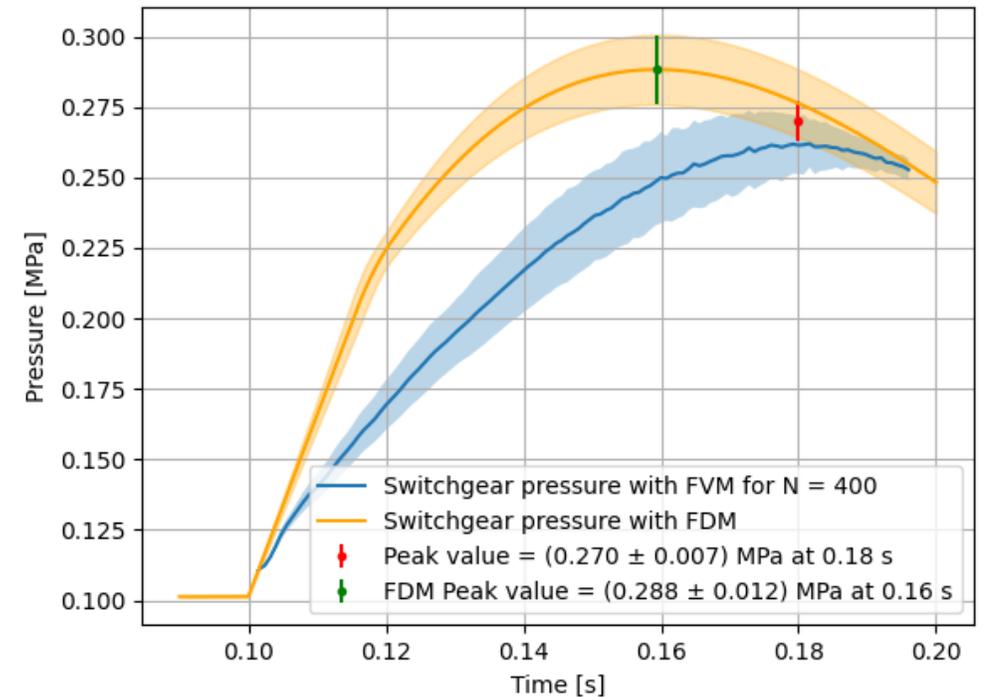
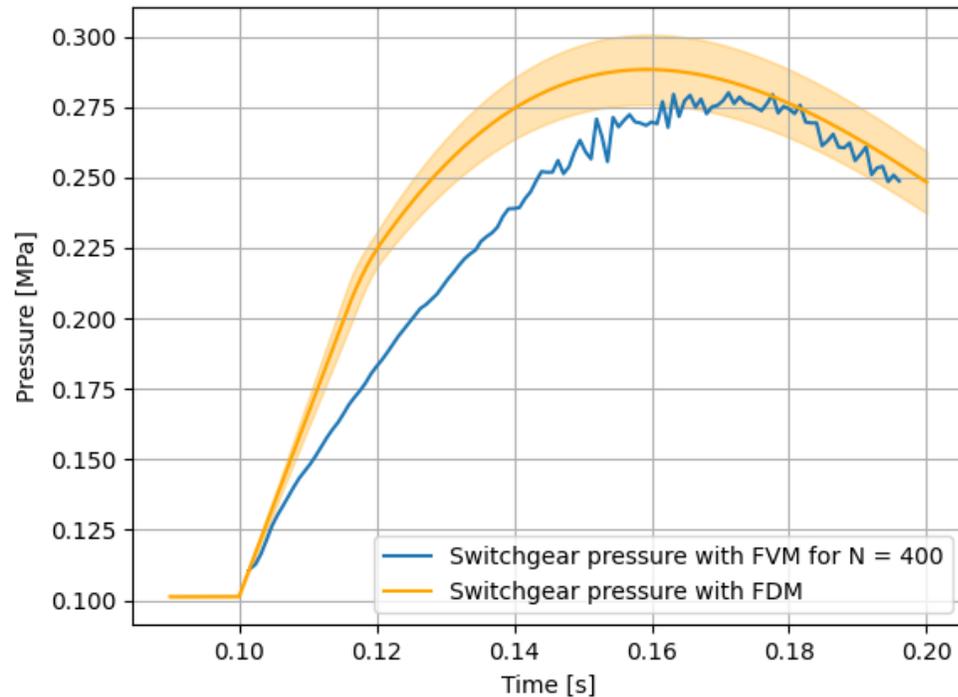


At 400 samples, the MC distributions retain some roughness attributable to limited sampling.

A strong negative correlation was observed between the peak pressure and the time at which the peak occurs ($\rho = -0.82$).



Comparison between the models



Although the FVM captures the overall trend of the pressure evolution, its comparison with the FDM results indicates that additional tuning—especially in the mesh and diffusivity terms—is still required.

Conclusion

- A. **Integration of FDM + MC was successfully made.**
- B. **Integration of FVM + MC with few elements was achieved.**
- C. **Differences with FDM highlight the need to refine the FVM mesh and diffusivity modelling.**

Further work

- A. **Validation with experimental results.**
- B. **Comparison between different uncertainty calculation methods.**



The project (22DIT01 ViDiT) has received funding from the European Partnership on Metrology, co-financed from the European Union's Horizon Europe Research and Innovation Programme and by the Participating States.

Thank you

Lic. Matias A. Aguirre

maguirre@inti.gov.ar

INSTITUTO NACIONAL DE TECNOLOGÍA INDUSTRIAL (INTI)



     | protocolo@inti.gov.ar | www.inti.gov.ar