

Minutes of Meetings

Context

Project: FELINES

PRIN 2022, grant number 20224CL7HM, Italian Ministry for Education, University, and Research and the European Union-Next Generation EU.

The research project Forecast of the Effects of Lightning IN Electrical Systems (FELINES) aims at designing a protection system capable of sensing phenomena that preliminary to a lightning event, and consequently disconnect part (or all) of the electric infrastructure under its protection. These phenomena are associated with the so-called Preliminary Breakdown (PB) pulses, localized events taking place during the first phases of the lightning inception.

Work Package 4: Coordination and Dissemination

Responsible Research Unit: UniGe

Task 4.1: Meetings organization

MoM I: 26th January 2024, DESTEC, University of Pisa

The group agrees on the actions and the responsible persons for the following topics:
Website

- Possible papers for IEEEIC 2024
- Patent
- Deliverable 1
- Research grants

After that, the meeting is aimed at drafting the project workflow. There are three main activities:

1. Build a reliable model of the precursors and perform validation with the data available to us (Vladimir Rakov et al. Negative strokes, Vernon Cooray et al. Positive (to obtain?))
2. Implement this model in the LIGHT-PESTO code to build the dataset
3. Develop the machine learning model for classification: starting from the overvoltage measurements detected by sensors on lines produced by the precursors, determine whether the subsequent return stroke will be dangerous or not

1. PBP Model

In our opinion, the model we need to implement must be consistent with the model currently implemented for the return stroke, i.e., it should be an engineering model: a formula that, given the current characteristics in the precursor channel, produces the fields that will couple with the lines.

Alessandro Formisano found several papers in the literature proposing models; in our opinion, this one could be suitable:

Sumedhe Karunaratne, Thomas C. Marshall, Maribeth Stolzenburg, and Nadeeka Karunaratna

“Modeling initial breakdown pulses of CG lightning flashes,” JGR, 2014

Essentially, it models the precursor as if it were a return stroke, i.e., as a vertical antenna, and computes the fields. The parameters of the base current (parameters of the formula), the propagation (v , $P(z')$), and the channel characteristics ($H1$ and $H2$) are chosen to minimize the difference between calculated and measured fields.

By the way, this has always been the approach followed in the literature to validate return-stroke models.

We could use this model and validate it with Rakov’s data, which are negative CG flash E-field recording (including both return stroke and PBP trains).

In this way, we would be able to characterize the current flowing in the precursor channel and then, using the formulas, compute all fields and overvoltages using the coupling model we have already implemented (Agrawal).

2. DATASET

Once we have the model of the whole event, the task is to simulate many events.

Given an event, first the PBP occurs: with the goal of exploiting sensors already installed on lines, I would measure the voltage waveform detected by sensors placed on the lines due to the PBP (exactly as we did in the lightning location work).

Then the return stroke is simulated (better to treat it as an independent event from a simulation standpoint to avoid an extremely high computational burden), and the maximum voltage — or, if preferred, the Disruptive Effect (better to choose the first since we have much less experience with the second) — is evaluated.

This forms the dataset where:

- **Features:** voltage values measured by the line sensors at each time instant
- **Target:** a binary variable indicating whether the overvoltage exceeds 1.5 CFO

Framed this way, we could reuse much of the work we already did on lightning location.

3. ML MODEL

Here my experience stops, although I imagine it is a classification problem that we should test with events where we only have PBP data.

OPEN POINTS

- Can there be a direct stroke with PBPs? If so, should we model it with electro-geometric model?
- We need to somehow link the precursor with the return stroke, i.e., enforce in the model that they are part of the same event. This should translate into a relationship between impact points and between the base currents of the two phenomena. I believe this is the most delicate point. We could start again from Rakov's data, which show how PBP and RS fields measured by a sensor at a given location look.

For the current:

- Reconstruct the precursor current with the method described above and devise a method to estimate some parameters of the return-stroke base current (we have seen that it is not possible to implement a regularization procedure because we only have data from one sensor, and at very large distances; most likely we need an approach such as LLS or the standard parameter-estimation approach that finds the best fit between measurements and calculations for a model with assigned structure).

For the impact point:

- Unfortunately, the data we have come from sensors very far from the impact point, so we cannot assume a distribution line near the sensor because we would never get a significant overvoltage.
- What it may be most delicate is obtaining the most accurate possible estimate of the precursor and return-stroke impact point positions in a reference system. Then we will place a line sufficiently close in that reference system so that the flash is potentially dangerous.

MoM II: 10th May 2024, online mode

Review Paper on PBP data and models: Genoa group is ready. We can pass it to Pisa and Naples to add the other part and get 20 pages more or less. PisaNaples part is almost ready. Many papers are appearing along the way. A "psychological" stop criterion is needed. Beginning of July paper ready. Internal review and submission by mid-July.

Patent: proposal submitted to UniGe/Unicamp/UniPi TTO (check the status of submissions). Each University will share TTO reviews with other participants

Live meeting in Genoa: week from 8-12 July, organized like in Pisa (dinner+1 working day). 11 Afternoon to 12 lunch? Venue: Savona Campus?

Models:

Griffiths (G): geometrical+ electromagnetic model that requires many input data. Fascinating but not so easy to match with K model. If we manage to do so for some cases, can we train a ANN to guess the link between G and Karunarathne (K)?

K: sensitivity analysis done, for now on the 2 cases of Rakov's dataset that we have; we asked the others (still waiting). It will be necessary to understand physically if there are parameters that are basically the same for all events (as what happens for H and v of the RS) and instead parameters that must be different from event to event (as for I_p and τ_1 of the RS)

Next stages of the project:

- Statistical characteristics of PBP
- Relation with RS
- Model of the complete phenomenon
- Effects on MTL (Ge) and PV (Camp) in terms of Overvoltage
- Simulations to setup a data set to train ML tools

Next Deliverables: UNICAMP T1.2, UNIGE T2.1 (by Sept 2024), start T2.2 (to finish by march 2025)

MoM III: 12th July 2024, Savona Campus, University of Genoa

Agenda

1. Deliverables

- T1.2: UniCamp will prepare it as a selection of our work on sensitive devices.
- T2.1: Currently being prepared by UniGe and will be completed once Rakov data are finished.

2. Griffith model

Or other physical models that can validate the k-model, which is instead postulated. Griffith does not work; there is the Syssoev model (2021). **DECIDE WHICH ONE IS WORTH PURSUING.**

3. Patents

Prepare a document explaining how it works and a couple of working cases, based on Alex's one. Possibly include the correlation plot between peaks, which they can understand since they are physicians.

4. Review paper

Almost ready. Alessandro Formisano will complete the logical flow soon. UniPi will proofread to check consistency. Submission by early August?

5. Website

It is working. Content uploaded by UniGe

6. Conferences 2025

- COMPUMAG (22–26 June 2025): 2-page digest submission by December; this may include an extended 6-page papers (IEEE Transactions on Magnetics), July 2025 (field model simulations)
- SIPDA deadline later (PBP statistics?). Proceedings on IEEE Xplore

7. Next in-person meetings

- Pisa January 2025?
- Naples June 2025
- Final meeting September 2025

8. Next stages of the project

Detailed below

PBP AND RS MODELING

PBP Model. Through MACACO and Vladimir Rakov's data, we can reconstruct the current $I(z', t)$ and, in particular, identify for each event the corresponding parameter set. Subsequently (from the full database analysis) we can identify the PDFs of the MTLK model parameters. At the moment we do not have data on the measurement location of the PBP(s). However, the current identification procedure was performed using Rakov data and the distance between sensor and return stroke (RS). Therefore, the distance error is already implicitly incorporated in the reconstructed current.

RS Model. We do not have RS current data from Rakov. We can compute it using simplified formulas (e.g., LLS) that estimate current from RS position and electric-field peak. We assume typical values for other RS variables such as front time, total charge, maximum derivative, propagation velocity, etc. The distance between sensor and RS strike point is known for Rakov data.

Correlation between PBP and RS. Rakov data provide correlation between field peaks, not current peaks. To obtain correlation between current peaks: i) Compute the PBP peak current (via MTLK model) and ii) Compute the RS peak current (via simplified formula / LLS)

LAYOUT — IDENTIFICATION PROCEDURE FOR TRAINING SET AND TEST SET

Hypothesis: RS strike point = PBP "strike" point

Training set

1. Rakov database is used. For each event identify:
 - $I(z', t)$ of the PBP (Does it make sense to consider both vertical channels? If measurements are only overvoltages and fields are far away, it might be risky.)
 - RS peak current
 - Correlation between PBP and RS peak currents
2. Different lightning–line distances are defined

3. For each event and distance, compute the overvoltage on a distribution line caused by PBP and RS and determine whether the event is damaging or not.

Test set

1. Generate a new PBP from PDFs of MTLK parameters
2. Compute RS peak from PDFs of the current-peak correlation coefficient
3. Sample a line–lightning distance
4. Compute overvoltage on a distribution line and determine if the event is damaging

The ML algorithm must determine, from the voltage induced by the PBP, whether the RS will be dangerous.

Another option: split Rakov dataset into two databases (training and test).

ADDITIONAL POINTS

1. PV application
2. k-model validation
3. Channel tortuosity
4. Another data source, possibly closer?
5. Same-distance issue
6. For each event consider multiple PBPs (as in data?)
7. Sensor effects
8. Use recurrent networks instead of treating each voltage sample independently

MoM IV: 13th February 2025, DESTEC, University of Pisa

1. Dataset

- Discussion of the **current dataset** and potential **additional test cases**.
- Agreement to consolidate available data and evaluate integration of future datasets.

2. Classification Methods

- Review of approaches for **event classification (Detected / Non-Detected)**.
- Minor methodological refinements may be required; no major conceptual changes identified.

3. Organization of deliverables (WP2 and WP3)

WP2

- **T2.2 – Sensor Network (UniGe)**: concept and preliminary design presented.

- **Deadline:** March 2025
- **T2.3 – Dataset (UniGe):** preparation and documentation.
 - **Deadline:** April 2025

WP3

- **T3.1 – Early Detection Algorithms (UniPi):** development of ML-based solutions.
 - **Deadline:** May 2025
- **T3.2 – Digital Twin of Detection System (UniPi):** modelling and validation.
 - **Deadline:** July 2025

Formal deadlines for all deliverables will be confirmed and circulated.

4. Intellectual Property

- Action item: request feedback from the TTO offices of UniPi and UniCamp.
- Possible preliminary assessment with UniGe TTO.

5. Publications

- Planned paper on **PBP statistics** (conference + journal submission).
- Paper preparation responsibilities:
 - **UniGe:** introduction and dataset preparation
 - **UniPi:** machine-learning methods and results
- Target journals under consideration:
 - IEEE Transactions on Electromagnetic Compatibility (TEM C)
 - IEEE Transactions on Power Delivery (TPWRD)
 - IEEE Access
 - Elsevier Electric Power System Research

6. Compumag 2025

- Discussion of organizational aspects and participation planning for Compumag 2025.
- Decision on presenting FELINES partial outcomes

7. Project Website

- Need to update content and ensure alignment with dissemination activities.

8. Project Report

- Short report to be prepared summarizing **published and submitted papers**.
- **WP3:** UniPi will prepare the reports once the main paper draft is available.

9. Budget and Administrative Issues

- Verification of **expenditure deadline (tentatively December 2025)** required.
- Clarification requested on limits for **dissemination expenses** and feasibility of conferences in **Summer 2026**.

10. Technical Outlook (Project Completion)

- Remaining work mainly involves:
 - Minor refinements in event classification methods
 - Inclusion of **transient voltage (TV) behavior**
 - Exploration of **experimental validation**
 - Assessment of **protection solutions for specific devices**

11. Future Developments

- Discussion on a potential “**FELINES 2.0**” follow-up initiative.

12. Next Meeting

- Proposed **in-person meeting**:
 - Pisa, January–February 2026 or
 - Genoa, January–February 2026 or
 - Workshop at external facilities (to be confirmed)

MoM V: 17th February 2026, DITEN, University of Genoa

1. Project achievements

The group reviewed the main achievements of the project and agreed on the need to consolidate results while preparing the ground for future developments.

2. Current simulation tool drawbacks (submitted paper version)

- Assumption that PBP and RS share the same coordinates (since PBP location is unknown)
- Limitations related to PBP representation within the MTLK model
- Dependence on two voltage sensors, requiring both PBP and RS induced waveforms
- Focus only on overhead distribution lines → need to address protection strategies, including:
 - Disconnection systems triggered by overvoltage prediction
 - Applications to specific loads

3. Strategic directions for FELINES 2.0

- Future PRIN call expected for Spring 2026

- Explicitly address the main drawbacks highlighted in the first proposal reviewers' report, using them as guidelines for the next proposal.
- Move the project toward experimental validation scenarios, which are essential to strengthen credibility.
- Involve a DSO or an industrial partner to significantly increase funding chances.
- If PRIN rules remain similar to 2022, keep the same research units (with the possibility of changing the PI).
- To build a clearly multidisciplinary project, consider to expand the group by including specific competences within the same units:
 - Measurement experts
 - Computer science specialists (to reinforce data-driven approaches)

4. FELINES 2.0 proposal framing according to project evaluation criteria

- Excellence → Emphasize the expertise and complementarity of the group (this is a strength point)
- Feasibility → Ensure well-structured WPs and timeline
- Impact → Clearly justify the societal and industrial relevance of the project (carefully identify the object to protect). In this context, the group agreed to further focus on applications to overhead distribution lines, specifically on predicting RS induced overvoltages from PBP induced voltage measurements on such lines, but developing protection solutions tailored for critical systems supplied by the monitored line (e.g., hospitals and microgrids).

5. Possible planning of FELINES 2.0

- WP1 – Simulation tool advancement
 - T1.1 Validate the model when PBP and RS coordinates differ, and including updates to the MTLK model
 - T1.2 Extend the model to subsequent strokes (PBP → 1st RS → 2nd RS with forecast updating) (*to be assessed*)
 - T1.3 Include voltage measurement non-idealities and assess the required number of sensors
 - T1.4 Apply data distillation / Generative AI to enlarge the dataset
- WP2 – Reduced-scale experimental campaign (in-house)
 - Involve measurement experts (former ING-INF 07) from UniPi and UniCampania
 - Develop scaled experiments based on the A. Piantini facility structure in São Paulo, Brazil
- WP3 – Real-world experimental campaign (to be procured)
Potential collaborators to be contacted:

- A. Piantini, University of São Paulo, Brazil
- Italian DSO managers
- A. Leal, New Mexico Tech, USA
- People of Thessaloniki High Voltage Lab, Greece
- C. Petrarca, UniNa
- COELMO, Naples

5. Low-term actions

- Create GitHub repository for the submitted paper data (PBP and RS induced voltage waveforms)
- Compile a list of publications acknowledging FELINES
- Re-read FELINES proposal review report
- Verify deliverables status and complete missing items
- Prepare the final document report
- Contact potential collaborators