

Unit Plan

DISCIPLINE: Theory and Practice of Learning from Data: Application of Machine Learning Algorithms to Power Systems and Electromagnetic Fields

CODE:

Professor: Martino Nicora and Rodolfo A. R. de Moura

Total hours: 60h

Credits: 4

Concentration Area: Power Systems

Year: 2026

Semester: 1st

Course Overview:

The course will provide a comprehensive introduction to machine learning algorithms and their applications in power systems and electromagnetic fields. It will address the foundational concepts of probability theory and the theoretical principles underlying widely used algorithms, including ensemble learning techniques, kernel methods, and neural networks. The course will also introduce simple code examples that students can use to practice and gain hands-on experience. For each of the methods covered, practical applications to real-world problems in electrical engineering and electromagnetic field analysis will be presented.

As far as neural networks are concerned, the course will illustrate the use of shallow and deep neural architectures to estimate lightning location, determine peak current from lightning-induced overvoltages, and predict lightning flashover on overhead distribution lines. Additionally, it will explore ensemble learning techniques and kernel methods for power system applications, including forecasting cloud-to-ground lightning, estimating photovoltaic power production, evaluating lightning effects on transmission lines, and assessing income ranges for participation in ancillary services markets.

INTERDISCIPLINARIDADES

Inter-relações desejáveis

The topics covered in the course “Theory and Practice of Learning from Data: Application of Machine Learning Algorithms to Power Systems and Electromagnetic Fields” are related to the following courses and research lines:

- **Disciplines** ⇒ Lightning Induced Voltages on Distribution Systems; *Inteligência Computacional*; *Introdução ao Machine Learning*; *Teoria Eletromagnética*.
- **Research Line** ⇒ Applied Electromagnetism (EA) – Power Systems

Objectives – By the end of the course, it is expected that the student can:

- Understand the fundamental concepts underlying machine learning techniques.
- Understand the key parameters and implement widely used machine learning algorithms, including ensemble learning, kernel methods, and neural networks.
- Know how to apply neural networks to estimate lightning location and peak current from lightning-induced overvoltages on distribution lines.
- Know how to predict lightning flashover on distribution lines using deep learning approaches based on preliminary breakdown-induced voltages.
- Utilize machine learning methods for power system applications, including forecasting cloud-to-ground lightning, estimating photovoltaic power production, and assessing lightning effects on transmission lines.
- Analyze real-world problems in power systems and electromagnetic fields using machine learning techniques, connecting theoretical knowledge with practical applications.

Unit Plan

Pedagogical Methods Employed

Place an X on the board:

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|---|---|
| ☐ Lecture on the board | ☐ Seminar |
| ☐ Lecture with the use of transparency | ☒ Research |
| ☒ Lecture using a projector | ☒ Individual work |
| ☐ Practical class | ☒ Group work |
| ☐ Text discussion | ☐ Field trip |
| ☐ Film | ☐ Others: _____ |

Course Calendar		Workload Class hours
1	Module 1: Introduction to Machine Learning Algorithms i. Artificial Intelligence and Machine Learning ii. Probability Theory: Frequentist and Bayesian Statistics iii. Algorithms: Ensemble Learning, Kernel Methods, Neural Networks	20
2	Module 2: Neural Networks for Electromagnetic Fields i. Shallow Feedforward Neural Networks for Lightning Location and Peak Current Estimation from Lightning-Induced Overvoltages on Overhead Distribution Lines ii. Deep Neural Networks for Lightning Location and Peak Current Estimation from Lightning-Induced Overvoltages on Overhead Distribution Lines iii. Deep Learning-Based Prediction of Lightning Flashover on Overhead Distribution Lines from Preliminary Breakdown-Induced Voltages	20
3	Module 3: Machine Learning Algorithms for Power Systems i. Ensemble Learning Algorithms to Estimate the Income Range for Participation in Ancillary Services Markets ii. Kernel Methods for Estimating the Lightning Disruptive Effect on Overhead Transmission Lines iii. Neural Networks for Estimating Photovoltaic Power Production iv. Recurrent Neural Networks for Forecasting Cloud-to-Ground Lightning	20
Total		60

Assessment Criteria

A1 – A 10-question test will be given to students to assess their understanding of the main theoretical principles of the presented machine learning algorithms.
A2 – Four problems (one for each section) will be assigned to students, who are required to solve them and submit their solutions at the end of the course.

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Basic Bibliography

Goodfellow, I., Bengio, Y., Courville, A., & Bengio, Y. (2016). *Deep learning* (Vol. 1, No. 2). Cambridge: MIT press.

Bishop, C. M., & Nasrabadi, N. M. (2006). *Pattern recognition and machine learning* (Vol. 4, No. 4, p. 738). New York: springer.

Murphy, K. P. (2023). *Probabilistic machine learning: Advanced topics*. MIT press.

Tom Mitchell (1997). *Machine learning*. Publisher: McGraw Hill.

Additional Bibliography

S. Barmada, S. Dodge, M. Brignone, M. Nicora, and R. Procopio, "Relating transmission line overvoltages and lightning location: a machine learning-based procedure," COMPEL, vol. 44, no. 5, pp. 769–783, 2025, doi: 10.1108/COMPEL-12-2024-0521

S. Barmada, M. Tucci, M. Brignone, M. Nicora and R. Procopio, "Neural Network Based Procedure for Lightning Localization," ICLP 2024; 37th International Conference on Lightning Protection, Dresden, Germany, 2024, pp. 938-942.

S. Dodge, M. Nicora, S. Barmada, M. Brignone, R. Procopio, and M. Tucci, "A deep learning based lightning location system," Electric Power Systems Research, vol. 242, p. 111437, 2025, doi: 10.1016/j.epsr.2025.111437.
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La Fata, A., Caprara, G., Barilli, R., & Procopio, R. (2025). A Classification Algorithm for Revenue Range Estimation in Ancillary Service Markets. *Energies*, 18(19), 5263.

La Fata, A., Moser, G., Ribeiro de Moura, R. A., & Procopio, R. (2025). Near Real-Time Photovoltaic Power Forecasting Through Recurrent Neural Network Using Timely Open-Access Data. *Energies*, 18(23), 6220.

La Fata, A., Moser, G., Procopio, R., Bernardi, M., & Fiori, E. (2024). A Gaussian process regression method to nowcast cloud-to-ground lightning from remote sensing and numerical weather modeling data. *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing*.

La Fata, A., Amato, F., Bernardi, M., D'Andrea, M., Procopio, R., & Fiori, E. (2022). Horizontal grid spacing comparison among Random Forest algorithms to nowcast Cloud-to-Ground lightning occurrence. *Stochastic Environmental Research and Risk Assessment*, 36(8), 2195-2206.

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