PhD in Information Technology and Electrical Engineering
Università degli Studi di Napoli Federico II

PhD Student: Nagananthini Ravichandran

Cycle: XXXVII

Training and Research Activities Report

Academic year: 2022-23 - PhD Year: Second

Tutor: Prof. Amedeo Andreotti

Co-Tutor: Prof. Daniela Proto

Date: October 23, 2023

Training and Research Activities Report

PhD in Information Technology and Electrical Engineering

Cycle: **Author:**

1. Information:

- **PhD student: Nagananthini Ravichandran**
- **PhD Cycle: XXXVII**
- **DR number: DR996074**
- **Date of birth: 26.11.1993**
- **Master Science degree: Master of Engineering**
- **University: Anna University, Chennai**
- **Scholarship type: UNINA**
- **Tutor: Prof. Amedeo Andreotti**
- **Co-tutor: Prof. Daniela Proto**

2. Study and training activities:

Activity	Type[1]	Hours	Credits	Date	Organizer	Certificate
Publishing Open Access IEEE Journal Articles under the Care Crui Agreement in Italy	Seminar	1	0.4	09.11.2022	IEEE Technology Centre GmbH	Yes
QUANTUM COMPLEXITY	Seminar	1	0.2	10.11.2022	SSM, UNINA	No
Data mining the output of quantum simulators - from critical behavior to algorithmic complexity	Seminar	1	0.2	11.11.2022	QSM Seminar Series, UNINA	Yes
Crash course on Data excellence – Part I	Seminar	1	0.2	14.11.2022	DIETI, UNINA	No
Analysis and control of functional brain networks	Seminar	1	0.2	09.03.2023	SSM, UNINA	No
Non-local Schrödinger operators: Some explicit results	Seminar	1	0.2	16.03.2023	SSM, UNINA	No
How to Publish Open Access Articles with IEEE under the CARE CRUI Agreement	Seminar	2	0.4	05.04.2023	IEEE	Yes
Exploring Advanced Aerial Robotics: A Journey into Cutting-Edge Projects and Neural Control	Seminar	2	0.4	29.06.2023	Prisma Lab, UNINA	No

Statistical data analysis for science and engineering research	Course	10	4	06.02.2023-16.02.2023	UNINA	No
Using Deep Learning properly	Course	10	4	10.01.2023 - 24.01.2023	UNINA	No
2023 Spring School on Transferrable Skills	PhD School	10	2	24.05.2023 - 25.05.2023	DOP, UNINA	Yes
Wave propagation along transmission lines	Course	20	4	25.09.2023 - 11.09.2023	EPFL	Ongoing

2.1. Study and training activities - credits earned

	Courses	Seminars	Research	Tutorship	Total
Bimonth 1		**2.2**	**10**	**0**	**10.6**
Bimonth 2	**8**	**0**	**6**	**0**	**10**
Bimonth 3			**10**		**10**
Bimonth 4	**2**		**8**		**10**
Bimonth 5			**10**		**10**
Bimonth 6			**10**		**10**
Total	**10**	**2.2**	**54**	**0**	**60.6**
Expected	**30 - 70**	**10 - 30**	**80 - 140**	**0 – 4.8**	

3. Research activity:

The power quality issues are fundamental and need to be addressed with precise solutions for reliable operation. Voltage sags, transients, permanent interruptions, and temporary interruptions are the issues, and lightning events are major cause factors for all these issues. Lightning-produced overvoltages (LPOV) on the phase conductors are from direct lightning events and lightning overvoltages (LIOV) are from indirect lightning events on the ground at a distance away from the power lines. These lightning overvoltages on overhead phase conductors cause insulation failures which are followed by high replacement costs and subsequent outages of grids. Thus, an accurate analytical formulation and numerical modelling of LPOV and LIOV are important. Eventually, an effective lightning protection system to improve lightning performance is of equal importance for the uninterrupted operation of the grid.

3.1 Protection Devices

The prevention of power outages due to lightning in overhead distribution lines is highly challenging. The overvoltage mitigation measures involve the selection and implementation of suitable protective measures considering their advantages, constraints, and costs. Unlike transmission lines, which can be threatened only by direct lightning, distribution lines must face the effects of direct and indirect lightning events. In this case, proper analysis of the protection device is indeed for the better lightning performance of overhead distribution lines. This study is carried out in reviewing recent literature with an overview of the lightning protection methods addressing the direct and indirect lightning events

separately. The analysis was carried out on the shield wires (SWs) which include underbuilt shield wire and overhead ground wire and line surge arresters (SAs).

3.2 Performance of the line arrester

From the analysis of the protection devices for direct and indirect lightning, it is evident that installing only SW protects the system at a relatively low cost compared to installing only SAs. However, neither the solution of installing only SWs nor that of installing only SAs provided significant protection due to the number of flashovers occurring at ungrounded/unprotected towers/poles. Although costly, combined installation of the SW and SAs has improved protection performance compared to their separate installation.

With these results, the type of arrester suitable to enhance the efficiency and reliability of surge protection systems in power distribution networks is further analysed. The following key observations are made on analysing the externally gapped line arrester (EGLA) and non-gapped line arrester (NGLA)

• The transfer voltage effect is present with both types of arresters and needs to be taken into account during the flashover rate analysis.

• In terms of discharged energy, the EGLA outperforms the NGLA, making it a better option.

• Examining the service life of the SAs using cumulative probability reveals that the transfer voltage effect significantly impacts the failure probability and reduces the arrester's overall service life. The EGLA, experiencing lower energy stress, is found to have a longer service life.

Implementing externally gapped-type arresters in practice represents a significant advancement in surge protection technology, offering improved performance and advantages compared to traditional surge arresters. Based on these findings, the externally gapped arrester is selected for further analysis, incorporating additional protection mechanisms to mitigate the transfer voltage effect and optimize its performance.

3.3 Flashover Mitigation and Optimization of Line Surge Arrester

This part of the study aims to examine the capability and effects of a specific type of arrester based on their locations (if placed at intervals).

Evaluation of flashover rates is significantly influenced by the random nature of lightning intensity and location. Traditionally, Monte Carlo simulation is employed to replicate the lightning effect using a log-normal distribution and assess the performance of the distribution line. However, when multiple protection scenarios are involved, conducting Monte Carlo simulations can be time-consuming. Moreover, in realistic scenarios with many network buses, the complexity becomes even more challenging.

To address these issues and reduce computational burdens while maintaining the integrity of the analysis, a multi-criteria methodology is utilized. By utilizing this approach, the authors effectively address the uncertainties related to lightning and provide valuable insights for optimizing the protection of distribution networks.

By employing this multi-criteria methodology and leveraging probabilistic approaches, the study offers a practical and efficient way to assess the performance of distribution lines under various protection scenarios, considering the uncertainties associated with lightning events. Since lightning performance depends on the type and the location of the protection devices operated, a proper optimization tool for the optimal location of the SAs is applied. The tool allows positioning the SAs

optimally considering the transfer effect to reduce the total installation, operation, and post-lightning maintenance cost sustained for the uninterrupted power supply of the distribution network.

4. Research products:

E. Stracqualursi, R. Araneo, N. Ravichandran, A. Andreotti and S. Celozzi, "Modeling of Conductors Catenary in Power Lines: Effects on the Surge Propagation Due to Direct and Indirect Lightning," in IEEE Transactions on Electromagnetic Compatibility, doi: 10.1109/TEMC.2023.3288029.

Ravichandran, N., Paneerselvam, B. and Ravichandran, N., 2023. GIS-based potential assessment of floating photovoltaic systems in reservoirs of Tamil Nadu in India. Clean Energy, 7(3), pp.671-689.

J. Cao, A. Andreotti, Y. Du, N. Ravichandran, and Y. Ding, "Selection of the Lateral Distance for the Assessment Area in a Monte Carlo Procedure Under Indirect Lightning for Overhead Distribution Lines," in IEEE Transactions on Electromagnetic Compatibility, DOI: 10.1109/TEMC.2023.3257361.

N. Ravichandran, A. Andreotti, M. Pagano, A. Di Pasquale, and F. Volpe, "Interconnection Topologies for Floating Photovoltaic System to Enhance the Power Output by Reducing the Mismatch Losses," 2022 IEEE PES 14th Asia-Pacific Power and Energy Engineering Conference (APPEEC), Melbourne, Australia, 2022, pp. 1-6, DOI: 10.1109/APPEEC53445.2022.10072079.

A. Andreotti et al., "Assessment of the Indirect Lightning Performance of a Distribution Line," 2023 IEEE International Conference on Environment and Electrical Engineering and 2023 IEEE Industrial and Commercial Power Systems Europe (EEEIC / I&CPS Europe), Madrid, Spain, 2023, pp. 1-6, doi: 10.1109/EEEIC/ICPSEurope57605.2023.10194859.

Arunachalam, Ramesh Kumar, Kumar Chandrasekaran, Eugen Rusu, Nagananthini Ravichandran, and Hady H. Fayek. 2023. "Economic Feasibility of a Hybrid Microgrid System for a Distributed Substation" *Sustainability* 15, no. 4: 3133. https://doi.org/10.3390/su15043133

L. D'Orazio et al., "Analysis of the application of LLPDs on a MV feeder of E-Distribuzione," 27th International Conference on Electricity Distribution (CIRED 2023), Rome, Italy, 2023, pp. 633-637, doi: 10.1049/icp.2023.0438.

Nagananthini Ravichandran, Amedeo Andreotti, Rodolfo Araneo, Jinxin Cao, Luigi D'orazio, Ya Ping Du, Daniela Proto, Erika Stracqualursi,'Improvement of the Lightning Performance of Overhead Distribution Lines: Possible Solutions," CIGRE: ICLPS-SPIDA, Suzhou, China October 9 – 13, 2023.

5. Conferences and seminars attended

N. Ravichandran, A. Andreotti, M. Pagano, A. Di Pasquale, and F. Volpe, "Interconnection Topologies for Floating Photovoltaic System to Enhance the Power Output by Reducing the Mismatch Losses," 2022 IEEE PES 14th Asia-Pacific Power and Energy Engineering Conference (APPEEC), Melbourne, Australia, 2022, pp. 1-6, DOI: 10.1109/APPEEC53445.2022.10072079. (Presented).

A. Andreotti et al., "Assessment of the Indirect Lightning Performance of a Distribution Line," 2023 IEEE International Conference on Environment and Electrical Engineering and 2023 IEEE Industrial and Commercial Power Systems Europe (EEEIC / I&CPS Europe), Madrid, Spain, 2023, pp. 1-6, doi: 10.1109/EEEIC/ICPSEurope57605.2023.10194859 (Virtually Presented).

L. D'Orazio et al., "Analysis of the application of LLPDs on a MV feeder of E-Distribuzione," 27th International Conference on Electricity Distribution (CIRED 2023), Rome, Italy, 2023, pp. 633-637, doi: 10.1049/icp.2023.0438.

Nagananthini Ravichandran, Amedeo Andreotti, Antonio Di Pasquale, Mario Pagano, Daniela Proto, Erika Stracqualursi, Rodolfo Araneo, Luigi D'orazio "Selection of Viable Distribution Line Surge Arrester for Prospective Optimal Protection" AEIT2023 International Annual Conference, Rome, Italy, October 5 – 7, 2023. (Presented)

Nagananthini Ravichandran, Amedeo Andreotti, Rodolfo Araneo, Jinxin Cao, Luigi D'orazio, Ya Ping Du, Daniela Proto, Erika Stracqualursi, 'Improvement of the Lightning Performance of Overhead Distribution Lines: Possible Solutions," CIGRE: ICLPS-SPIDA, Suzhou, China October 9 – 13, 2023.

6. Periods abroad and/or in international research institutions

Hosting Institutions: Ecole Polytechnique Fédérale de Lausanne
EPFL Professor/lecturer: Farhad Rachidi-Haeri
Dates: 11.09.2023 - 11.12.2023
Duration: Three months (1 of 3 months has been spent)
EPFL student number: 382077
EPFL doctoral program: Electrical Engineering

Research Activity Overview:

1. Statistical Analysis of the upward negative lightning current: Statistical data on lightning current parameters are important inputs used by engineers to carry out studies on insulation coordination and electromagnetic compatibility of power, telecommunication, and electronic systems. Lightning current data from instrumented towers have been recorded by several research groups under varying geographical conditions and using different measuring equipment. In this study, we analyze rise times of lightning current pulses in negative upward flashes using a measured dataset obtained on the Säntis tower between 2015 and 2021. Negative lightning or upward flashes are a type of lightning discharge that originates from tall structures, such as buildings, towers, or even the ground itself, and propagates upward towards the cloud base. Understanding the characteristics and behaviour of negative upward flashes is essential for designing effective lightning protection systems to mitigate the associated risks.
2. Analytical formulation: Considering the general case of a lossy transmission line (wire above an imperfectly conducting ground), the field-to-transmission line coupling equations can be expressed in three equivalent formulations. In the first, the forcing functions are in terms of electric and magnetic excitation field components; while in the second, only the vertical and horizontal electric field components are involved. Finally, a third equivalent formulation of coupling equations is derived in which the forcing functions are expressed in terms of magnetic excitation field components. Cooray–Rubinstein's formula evaluates the horizontal electric field above the earth's surface, at close,

intermediate, and long and is widely used nowadays to compute lightning-induced voltages in power and telecommunications lines. The objective of this research is to refine and provide a simplified approach to the Cooray-Rubinstein formula in the time domain. The focus will be on correcting the limitations and approximations of the formula, specifically addressing issues related to low frequency and electric field measurements far from the lightning channel. The aim is to develop an exact solution that overcomes these limitations and provides a more accurate representation of the induced voltage on conductors caused by lightning strikes. By refining the Cooray-Rubinstein formula, this research aims to enhance the understanding and prediction of lightning-induced effects on power systems, ultimately contributing to improved safety and reliability in electrical infrastructure.

3. Frequency Dependance of the tower grounding system:
   When analyzing the tower grounding system, the frequency-dependent nature of soil resistivity becomes important because it affects the impedance of the grounding system at different frequencies. The variation in soil resistivity with frequency can result from factors such as the moisture content, soil composition, and the presence of minerals. To incorporate the frequency-dependent behavior of soil resistivity in the tower grounding system analysis, the soil resistivity value is typically represented as a function of frequency. This can be done using models such as the Cole-Cole model or the Debye model, which describe the frequency-dependent behavior of materials. By considering the frequency-dependent nature of soil resistivity in the tower grounding system model, the analysis becomes more accurate and can capture the effects of high-frequency transients on the grounding system's performance. This information is valuable for designing and optimizing tower grounding systems to ensure effective protection against electrical faults and transient events.

7. Tutorship

NA

8. Plan for year three

For the upcoming year, the research progress will include the following:

1. Optimized Solution: The focus will be on developing an optimized tower and phase allocation model through further approaches based on decision theory criteria. This model will be compared to Monte Carlo simulations in terms of computational time. The aim is to find an efficient and effective solution for allocating towers and phases in power distribution systems.

2. Frequency Dependence of Grounding System: The research will involve implementing the frequency dependence of the grounding system to evaluate lightning overvoltages. This consideration will enhance the accuracy of the analysis by accounting for the frequency-dependent behavior of the grounding system.

3. Experimental Results and Protection Mechanisms: Experimental investigations will be conducted to evaluate and compare different protection mechanisms using the rocker lightning triggering method. The obtained results will provide insights into the effectiveness of various protection strategies for mitigating flashover events.

4. Statistical Analysis of Upward Negative Flashes: The research will involve analyzing upward negative flashes statistically. The focus will be on studying how the parameters of lightning current influence the occurrence and characteristics of these flashes. This analysis will contribute to a better understanding of upward negative flashes and their implications for power systems.

Based on these research advancements, the tentative title for the thesis will be "Flashover Mitigation and Analysis of Suitable Lightning Protection Strategy for Medium Voltage Distribution Lines – A Cost and Computation Time Effective Approach." This title reflects the focus on developing effective protection strategies while considering the cost and computational efficiency aspects of medium voltage distribution systems.