WESTERN UNVERSITY
FACULTY OF ENGINEERING

DEPARTMENT OF ELECTRICAL AND COMPUTER ENGINEERING

ECE9046/ECE9406 – MODELING TRANSMISSION LINES IN POWER SYSTEMS - COURSE OUTLINE 2023-24

DESCRIPTION: The main objectives of this course are:

1) To understand how transmission lines in power systems are modeled/simulated in a computer circuit simulation environment.
2) To understand how transmission lines are solved in the frequency domain and time domain.
3) To address complex high-frequency effects of transmission lines using the vector fitting algorithm.

PREREQUISITES: Undergraduate courses in circuit theory, linear algebra and differential equations.

ENROLLMENT RESTRICTIONS: Enrollment in this course is restricted to graduate students in Electrical and Computer Engineering, and if capacity permits to any student that has obtained special permission to enroll in this course from the course instructor as well as the Graduate Chair (or equivalent) from the student's home program.

COURSE FORMAT
Course material will be taught in class.

CONTACT HOURS: 3 lecture hours/week

TOPICS:

1) Transmission Line Per Unit Length Parameters
2) Frequency Domain Analysis of Transmission Lines.
3) Time Domain Models of Transmission Lines.
4) Developing Rational Models using Vector Fitting Algorithm
5) Solving Transmission Lines with Nonlinear Circuits (DC and Transient Responses).

SPECIFIC LEARNING OBJECTIVES:

1. Transmission-Line Per-Unit-Length Parameters

1) How the electrical per-unit-length parameters are obtained from the physical description of transmission-lines.

2) Modeling transmission lines with frequency dependent parameters to model proximity and skin effect.

2. Frequency Domain Analysis of Transmission Lines.

1) Solving Telegrapher's equations in the frequency domain for two-conductor transmission lines.

2) Solving Telegrapher's equations in the frequency domain for multi-conductor transmission lines. Eigen-decomposition or modal analysis is used to decouple and solve the system of equations. Telegrapher's equations are also solved using exponential matrix analysis approach.

3. Time-Domain Models of Transmission Lines.

1) Lumped resistive-inductive-capacitive (RLC) models (i.e. pi, T and L models) for single and multi-conductor transmission lines. Illustrate how these circuit models approximate Telegrapher's equations. How to select the number of lumped sections to approximate transmission lines

2) Deriving the method of characteristics to model lossless single and multi-conductor transmission lines.

3) Deriving Bergeron model for lossy single and multi-conductor transmission lines.

4) Deriving the universal line to model frequency dependent per-unit-length parameters for two-conductor and multi-conductor transmission lines.

5) Classification of time domain models. Passive versus non-passive models. Which models are preferred for electrically short lines, which models are preferred for electrically long lines? Models with frequency dependent per-unit-length parameters to model proximity and skin effect vs models with frequency independent per-unit-length parameters.

4. Developing Rational Models using Vector Fitting Algorithm

1) Describe how to implement the Vector Fitting and Relaxed Vector Fitting Algorithms to obtain rational function approximations of frequency-domain responses characterized by tabulated data.

2) Converting rational models into state-space ordinary differential equations.

3) Applying vector fitting to model proximity and skin effect of transmission lines and to model high frequency effects power transformers.

4) Using perturbation techniques to restore the passivity of the Vector Fitting model.

5. Solving Transmission-Lines with Nonlinear Circuits (DC and Transient Responses)

1) Transient simulations of transmission lines using numerical integration techniques (forward Euler, backward Euler, trapezoidal rule, linear multi-step methods). Accuracy of integration methods: numerical stability and local truncation error.

2) Solving DC and transient simulations of transmission lines with nonlinear loads using Newton-Raphson iterations.

REFERENCES:

[1] C. R. Paul, *Analysis of Multiconductor Transmission Lines, 2nd edition*. New York: Wiley, 2007.
[2] M. L. Crow, *Computational Methods for Electrical Power Systems, 2nd edition*. Boca Raton, FL, CRC press, 2010.
[3] J. Vlach and K. Singhal, "*Computer Methods for Circuit Analysis and Design*", Van Nostrand Reinhold, New York, 1994.
[4] B. Gustavsen and A. Semlyen, "Rational approximation of frequency domain responses by vector fitting," *IEEE Trans. Power Del.*, vol. 14, no. 3, pp. 1052–1061, Jul. 1999.
[5] A. Morched, B. Gustavsen, and M. Tartibi, "A universal model for accurate calculation of electromagnetic transients on overhead lines and underground cables," *IEEE Trans. Power Del.*, vol. 14, no. 3, pp.1032–1038, Jul. 1999.
[6] B. Gustavsen, "Wide band modeling of power transformers," *IEEE Trans. Power Del.*, vol. 19, no. 1, pp. 414–422, Jan. 2004.
[7] B. Gustavsen, "Improving the Pole Relocating Properties of Vector Fitting," *IEEE Trans. Power Del.*, vol. 21, no. 3, pp. 1587–1592, July 2006.
[8] Class notes.

EVALUATION:

The final course grade will be determined from students' performance in the assignments and a final exam. The weighting of each of these components will be as follows:

Graduate students registered in ECE9046A/ECE9406A are required to complete 4 to 5 assignments and write a final exam. Students must work alone in completing the assignments and final exam.

		Maximum Penalties*	
Component	**Value**	**English**	**Presentation**
Assignments	40%	10%	10%
Final Examination	60%	10%	10%

*In accordance with the policy of the University, the grade assigned to all written and oral work presented in English shall take into account syntax, diction, grammar and spelling. In the professional life of an engineer, the manner in which oral and written communications are presented is extremely important. An engineering student must develop these skills as an integral part of the graduate program. To encourage the student to do so, the grades assigned to all written and oral work will take into account all aspects of presentation including conciseness, organization, neatness, use of headings, and the preparation and use of tables and figures.

All work will be marked first for content after which a penalty not to exceed the maximum shown above may be applied for lack of proficiency in English and/or presentation.

CHEATING, PLAGIARISM/ACADEMIC OFFENCES

Academic integrity is an essential component of learning activities. Students must have a clear understanding of the course activities in which they are expected to work alone (and what working alone implies) and the activities in which they can collaborate or seek help; see information above and ask instructor for clarification if needed. Any unauthorized forms of help-seeking or collaboration will be considered an academic offense. University policy states that cheating is an academic offence. If you are caught cheating, there will be no second warning. Students must write their essays and assignments in their own words. Whenever students take an idea or a passage of text from another author, they must acknowledge their debt both by using quotation marks where appropriate and by proper referencing such as footnotes or citations. Plagiarism is a major academic offence. Academic offences are taken seriously and attended by academic penalties which may include expulsion from the program. Students are directed to read the appropriate policy, specifically, the definition of what constitutes a Scholastic Offence at the following website: https://www.uwo.ca/univsec/pdf/academic_policies/appeals/scholastic_discipline_grad.pdf

CONDUCT

Students are expected to follow proper etiquette to maintain an appropriate and respectful academic environment. Any student who, in the opinion of the instructor, is not appropriately participating in course activities and/or is not following the rules and responsibilities associated with the course activities, will be reported to the Associate Dean (Graduate) (after due warning has been given). On the recommendation of the Department concerned, and with the permission of the Associate Dean (Graduate), the student could be debarred from completing the assessment activities in the course as appropriate.

HEALTH/WELLNESS SERVICES

As part of a successful graduate student experience at Western, we encourage students to make their health and wellness a priority. Western provides several health and wellness related services to help you achieve optimum health and engage in healthy living while pursuing your graduate degree. Information regarding health- and wellness-related services available to students may be found at http://www.health.uwo.ca/.

Students seeking help regarding mental health concerns are advised to speak to someone they feel comfortable confiding in, such as their faculty supervisor, their program director (graduate chair), or other relevant administrators in their unit. Faculty of Engineering has a Student Wellness Counsellor. To schedule an appointment with the counsellor, contact Kristen Edwards (khunt29@uwo.ca) via confidential email and you will be contacted by our intake office within 48 hours to schedule an appointment.

Students who are in emotional/mental distress should refer to Mental Health@Western: http://www.uwo.ca/uwocom/mentalhealth/ for a complete list of options about how to obtain help.

SICKNESS

Students should immediately consult with the Instructor (for a particular course) or Associate Chair (Graduate) (for a range of courses) if they have problems that could affect their performance. The student should seek advice from the Instructor or Associate Chair (Graduate) regarding how best to deal with the problem. Failure to notify the Instructor or the Associate Chair (Graduate) immediately (or as soon as possible thereafter) will have a negative effect on any appeal. Obtaining appropriate documentation (e.g., a note from the doctor) is valuable when asking for accommodation due to illness.

Students who are not able to meet certain academic responsibilities due to medical, compassionate or other legitimate reason(s), could request for academic consideration. The Graduate Academic Accommodation Policy and Procedure details are available at: https://www.eng.uwo.ca/graduate/current-students/academic-support-and-accommodations/index.html

ACCESSIBLE EDUCATION WESTERN (AEW)

Western is committed to achieving barrier-free accessibility for all its members, including graduate students. As part of this commitment, Western provides a variety of services devoted to promoting, advocating, and accommodating persons with disabilities in their respective graduate program.

Graduate students with disabilities (for example, chronic illnesses, mental health conditions, mobility impairments) are strongly encouraged to register with Accessible Education Western (AEW): http://academicsupport.uwo.ca/accessible_education/index.html

AEW is a confidential service designed to support graduate and undergraduate students through their academic program. With the appropriate documentation, the student will work with both AEW and their graduate programs (normally their Graduate Chair and/or Course instructor) to ensure that appropriate academic accommodations to program requirements are arranged. These accommodations include individual counselling, alternative formatted literature, accessible campus transportation, learning strategy instruction, writing exams and assistive technology instruction.