ECE 632: PHOTOVOLTAIC ENERGY CONVERSION

Term	Spring 2025
Instructor	Dr. Hrilina Ghosh (h2ghosh@uwaterloo.ca)
Lecture Schedule	Mondays (11:30am – 2:20pm), EIT 3151

Course Overview:

This course provides a comprehensive foundation in photovoltaic (PV) technology, covering the fundamental principles of solar radiation, semiconductor physics and PV device operation. Students will explore advanced concepts to overcome efficiency limits, fabrication techniques, PV module assembly, power conditioning electronics and system-level integration challenges in solar energy conversion. By bridging fundamental theory with practical applications, this course equips students with the knowledge to analyze, design, and optimize PV systems for real-world deployment.

Prerequisite: Foundational knowledge of semiconductors, electronic devices, and circuits is recommended. The required concepts will be reviewed during the early sessions of the course to ensure all students are aligned with the necessary background.

Learning Outcomes:

By the end of this course, students will be able to:

- Assess the impact of solar radiation on PV performance
- Analyze the operation of solar cells by applying semiconductor physics principles
- Evaluate and optimize key parameters for efficient solar cell design
- Identify loss mechanisms and implement advanced strategies to push efficiency limits
- Apply relevant strategies to mitigate the challenges of PV module performance
- Understand the role of PV back-end electronics in delivering usable power
- Identify power quality challenges and apply remedial measures for PV system integration

Course Content and Tentative Schedule:

Week	Topics	Key Concepts
1	***Section 1:*** **Introduction to PV**	Historical evolution of PV technology, global PV capacity and industry trends; cost dynamics of PV modules and systems; dominant and emerging PV technologies; strengths, limitations and challenges in the PV industry
2	***Section 2:*** **Photons and Solar Radiation**	Review of properties of light; solar spectrum; direct, diffuse and albedo radiations; solar angles and their impact on PV performance; solar irradiance, irradiation and energy availability for PV
3	***Section 3:*** **Semiconductor Properties for PV**	Review of electronic materials; energy band theory; generation of electrons and holes; doping; carrier concentration; carrier transport mechanisms; photo-generation of carriers; bulk and surface recombination processes
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5 6	***Section 4:*** **Junctions – Core of a Solar Cell**	Formation of pn junction; energy band diagrams; junction electrostatics; biased junctions; current conduction; current – voltage characteristics; non-idealities and their impact on device performance
7 8	***Section 5:*** **Operation of PV Devices**	Operating principles of PV devices; key performance metrics; equivalent circuits; illuminated and dark I-V characteristics; parameters influencing cell design; performance limits; advanced PV concepts for improving performance
9	***Section 6:*** **PV Device Fabrication Technologies**	Bulk semiconductor fabrication; baseline technologies for crystalline silicon based solar cells; optical confinement; junction formation; metallization; thin film, multiple junctions, and hetero-junction solar cell technologies
10	***Section 7:*** **From Cells to Module**	Module design and fabrication; interconnection schemes; I-V characteristics; current and voltage mismatch effects; mitigation techniques; by-passing circuits; ageing and degradation effects; reliability testing of PV modules
11	***Section 8:*** **Power Conditioning for PV**	Components for back-end electronics; DC/DC converters (buck, boost and buck-boost); maximum power point tracking algorithms; regulators and charge controllers; inverters
12	***Section 9:*** **PV Systems and Grid Connection**	Types of PV Systems; decentralized and central grid-connected systems; connection schemes; system configurations; power quality concerns (harmonics, islanding); remedial strategies

Course Website:

A course homepage is available on LEARN. It will contain all relevant information and materials, including lecture notes, assessment information, important updates and announcements.

Supplementary Reading (Optional):

The lecture notes are quite comprehensive, and you are NOT REQUIRED to refer to any additional resources. A few references are listed below for supplementary reading (optional):

- J. Nelson, *The Physics of Solar Cells*, Imperial College Press, 2003
- M. A. Green, *Solar Cells: Operating Principles, Technology, and System Applications*, Prentice-Hall, 1982
- Luque and S. Hegedus, Eds., *Handbook of Photovoltaic Science and Engineering*. 2nd ed., Wiley, 2011

Grading Scheme:

Assessment	Weight	Remarks
Quiz 1	5%	• Held after week 4 of lectures
Quiz 2	5%	• Held after week 8 of lectures
Research Project	40%	• Due at the end of the term • Research review of any topic that addresses key challenges within the PV industry, including exploring innovative solutions and evaluating their potential for technological and commercial impact • Report should be in IEEE format • Length: At least 5 pages • Minimum of 15 relevant references • Further details will be provided as the course progresses
Final Exam	50%	• Held during regular final exam period

Territorial Acknowledgement: The University of Waterloo acknowledges that much of our work takes place on the traditional territory of the Neutral, Anishinaabeg, and Haudenosaunee peoples. Our main campus is situated on the Haldimand Tract, the land granted to the Six Nations that includes six miles on each side of the Grand River. Our active work toward reconciliation takes place across our campuses through research, learning, teaching, and community building, and is co-ordinated within the Office of Indigenous Relations.

Mental Health: At the University of Waterloo, we are dedicated to supporting your mental and emotional well-being. Our Counselling Services offer confidential support, including individual counselling, workshops, and crisis intervention. If you're struggling, please reach out for help at 519-888-4096 or visit their website for more information.

Academic integrity: In order to maintain a culture of academic integrity, members of the University of Waterloo community are expected to promote honesty, trust, fairness, respect and responsibility. [Check the Office of Academic Integrity for more information.]

Grievance: A student who believes that a decision affecting some aspect of their university life has been unfair or unreasonable may have grounds for initiating a grievance. Read Policy 70, Student Petitions and Grievances, Section 4**.** When in doubt, please be certain to contact the department's administrative assistant who will provide further assistance.

Discipline: A student is expected to know what constitutes academic integrity to avoid committing an academic offence, and to take responsibility for their actions. [Check the Office of Academic Integrity for more information.] A student who is unsure whether an action constitutes an offence, or who needs help in learning how to avoid offences (e.g., plagiarism, cheating) or about "rules" for group work/collaboration should seek guidance from the course instructor, academic advisor, or the undergraduate associate dean. For information on categories of offences and types of penalties, students should refer to Policy 71, Student Discipline. For typical penalties, check Guidelines for the Assessment of Penalties.

Appeals: A decision made or penalty imposed under Policy 70, Student Petitions and Grievances (other than a petition) or Policy 71, Student Discipline may be appealed if there is a ground. A student who believes they have a ground for an appeal should refer to Policy 72, Student Appeals.

Note for students with disabilities and disabling conditions: The University of Waterloo recognizes is obligations under the Ontario Human Rights Code to accommodate students with known or suspected disabilities and disabling conditions (e.g. medical conditions, injuries, impacts of trauma such as from violence or discrimination) to the point of undue hardship. To support this obligation, AccessAbility Services (AAS) collaborates with all academic departments and schools to facilitate academic accommodations for students with disabilities and disabling conditions without compromising the academic integrity of the curriculum. If you believe you may require academic accommodations (e.g., testing accommodations, classroom accommodations), register with AAS as early in the term as possible by completing the online application. Students already registered with AAS must activate their accommodations for each of their courses at the beginning of each term using AAS' online system. If you require assistance, contact AAS by phone (519-888-4567 ext. 35082), email (access@uwaterloo.ca) or in-person (Needles Hall North, 1st Floor, Room 1401).