Development of Renewable Energy Course for Electrical Engineering Program

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***Abstract*—With the increased penetration of renewable energy in Jordan, higher education institutes are required to equip students with the knowledge and skills to thrive in the market. In response to that, this paper presents a newly developed course in renewable energy systems (RES). The designed course contains a practical part in addition to theoretical knowledge. The laboratory embedded in this course includes state-of-the-art equipment in the field of photovoltaic modules, an off-grid system with storage and a wind turbine. The course offers a unique teaching method that bridges theoretical and practical knowledge gaps. As this course is part of an ABET-accredited program, the course learning outcomes are designed carefully to align with ABET outcomes. Upon completing this course, students show a better ability to design and implement a renewable system. An example of a small-scale off-grid photovoltaic (PV) system is demonstrated in this work. At the end of the course, all students are asked to fill out a feedback questionnaire to assess the teaching method's effectiveness and evaluate if all learning outcomes are met. The results of this pilot project are auspicious and students' overall perception was very positive.**

Keywords*—*Renewable energy awareness, education, ABET, off-grid, renewable energy systems.

I. Introduction

Jordan's total energy consumption in 2020 is over 18,500 gigawatt-hours (GWh). The distribution of electric energy consumption is illustrated in Fig. 1. The Figure shows that residential and industrial sectors dominate energy consumption with 45.8% and 22.1%, respectively. Most energy is generated by non-renewable and nonenvironmentally friendly sources such as crude oil and natural gas [1], [2]. The Jordanian government recognizes the harmful effects of these resources and sets up plans to use renewable energy sources, such as wind and solar. The Jordanian government encourages and incentivizes investors to build utility-scale wind and solar farms to achieve this goal, creating a high demand for specialized and skilled personnel in the market [3].

As a response, higher education institutes such as Princess Sumaya University for Technology (PSUT) started to develop curricula in this field to support the growing demand. In order to provide the electrical engineering students at PSUT with state-of-the-art knowledge in the renewable energy field, the university actively develops renewable energy courses, laboratories, and on-campus off-grid solar stations. This allows students to gain theoretical and hands-on experience with photovoltaic systems components such as solar cells, inverters, and batteries. In addition, the students learn about wind energy and how renewable energy is integrated into residential and commercial enterprises, as well as gain an understanding of the adverse economic and health impacts of coal-based energy generation.

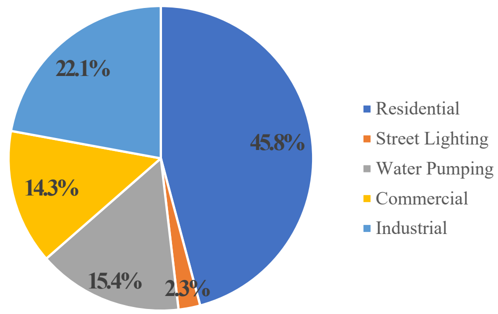

Fig. 1: The distribution of electric energy consumption in Jordan.

Program-level accreditation is increasingly becoming popular worldwide as it ensures a good quality of degree programs and graduates [4]. The Accreditation Board of Engineering and Technology (ABET) is the main accreditation body for engineering programs. More than 3709 programs in the United States and worldwide have gained ABET accreditation [5]. This paper presents the experience of the engineering school at Princess Sumaya University for Technology in developing a renewable energy laboratory that complements the theoretical part of the course. Thus, the overall course provides a unique experience to students as it combines theoretical and real-world environmental aspects of the subject matter.

The rest of the paper is organized as follows; the advanced renewable energy course is described in Section II. The course learning outcomes are discussed in Section III. Section IV presents the main results and discussion. Finally, the conclusions are drawn in Section V.

II. The advanced renewable energy course

The advanced renewable energy course is a three-credit-hour course for bachelor's students in their fifth year. The prerequisite of this course is an introductory course to renewable energy systems. The theoretical part of this course covers the following topics :

- Off-grid PV system design.

- Energy storage systems; types and design.
- Fuel cell technologies.
- Smart grid: architecture, communication and measurement technologies, including power management units (PMUs).
- Power electronics for smart grid and renewable energy systems.
- Modern distribution networks.

In addition to regular class lectures, the course contains laboratory work that accounts for 9 contact hours [6]. The Lab consists of four experiments listed in Table I. The first experiment explores the different semiconductor materials used for PV cells. Here, students identify three different types, namely, Monocrystalline (c-Si), Amorphous Silicon (a-Si) and Cadmium Telluride (CdTe), as shown in Fig. 2. This experiment aims to expose students to different types of semiconductor materials and their characteristics.

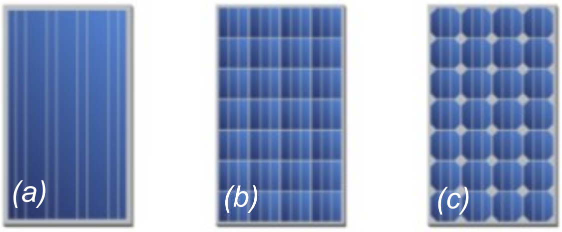

Fig. 2: PV module types : (a) Thin-film CdTe, (b) Amorphous Silicon a-Si and (c) Mono Crystalline Silicon c-Si.

The second experiment explores PV panel performance under different tilt azimuth angles. Here a compass and a protractor are used to determine the module tilt and azimuth angle. The objective here is to enable the student to understand the impact of these angles on the power produced by the module. Related topics like sun path diagram, development of shadow diagram and tracking systems are also clarified. Fig. 3 depicts the used PV modules with a movable custom-made structure. The PV module tilt angle Σ is set using a built-in protractor and the azimuth angle ϕ_C is determined using a generic compass.

In the third experiment, students are introduced to off-grid PV systems. This part is complementary to lectures dealing with off-grid systems and storage sizing. The experiment comprises two parts: the first part deals with the off-grid PV system components, where students study an existing large-scale system and examine its main parameters. On the other hand, the second part teaches students to build a small-scale off-grid PV system. Fig. 4 shows the large-scale off-grid system components. The system comprises a string of PV panels with a peak rating of 1250W mounted on the roof, a maximum power point tracking (MPPT) charge controller, a battery energy storage system (BESS), an inverter and a distribution board containing fuses and circuit breakers. The BESS is constructed using 4 lead-acid absorbent glass mat (AGM) batteries; each with a 300Ah capacity [7]. The storage system has two strings, each containing two 12V batteries

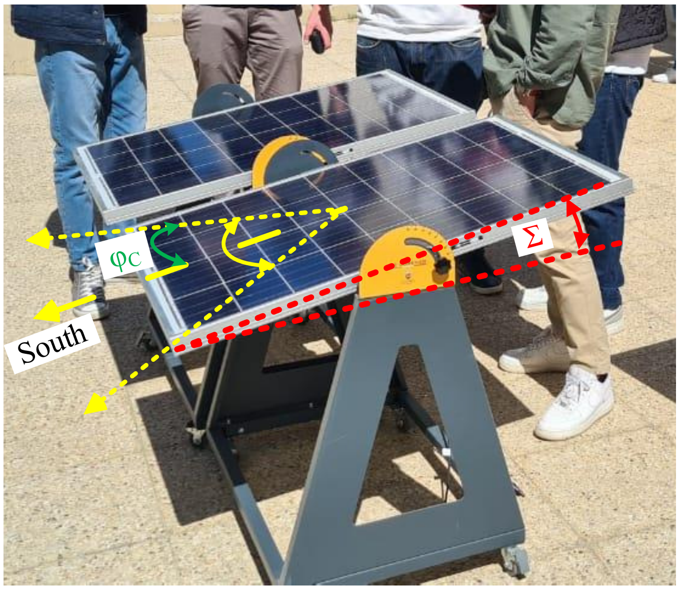

Fig. 3: PV panel performance under different tilt azimuth angles setup.

connected in series resulting in a 24V DC bus. The total system capacity is 600Ah. With an average insolation level of 5.5kWh/day in Amman [8], the system is expected to generate 2000kWh/year. This annual energy production is calculated using the peak-hours approach estimation method [9]. Fig. 5 shows a photograph of the system except for the PV panels.

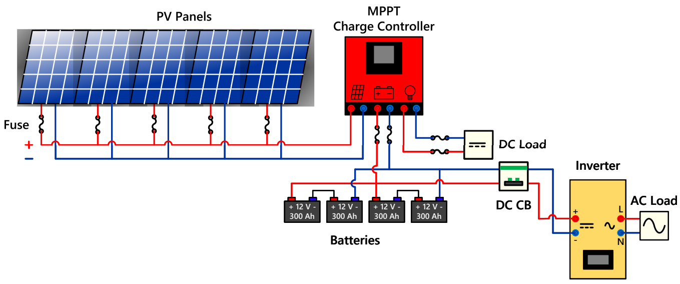

Fig. 4: The schematic diagram for the off-grid system.

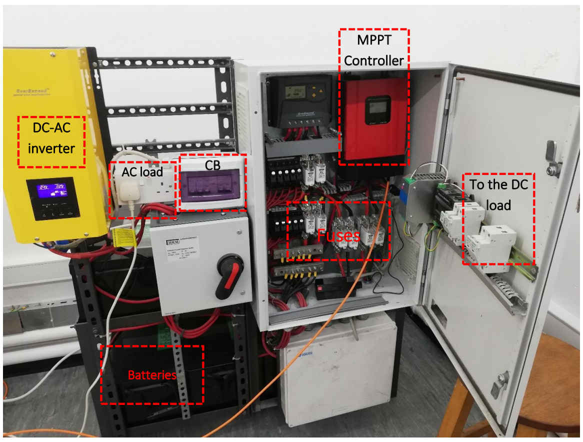

Fig. 5: A photograph of the off-grid PV system.

The last experiment deals with wind energy, particularly the characteristics of a wind turbine. The experiment introduces students to the effect of the number of blades on the turbine performance. Students can evaluate the wind turbine performance at different speeds by using two, three, and four blades turbines and measuring the power delivered to a load connected to the generator. This part of the experiment clarifies the theoretical analysis done during the course that relates the tip speed ratio to the rotor's efficiency. By increasing the number of blades, the turbine reaches the highest efficiency at a lower wind speed. The students can develop the wind turbine's power curve in the second part of this experiment. The objective here is to identify the key wind speeds: cut-in, rated and cut-out speeds and differentiate them from the idealized characteristics of the turbine. The power curve is developed by changing the wind speed and measuring the power delivered by the turbine. The power versus wind speed curve of the used turbine is depicted in Fig. 6. This setup is delivered by the De Lorenzo Group [10].

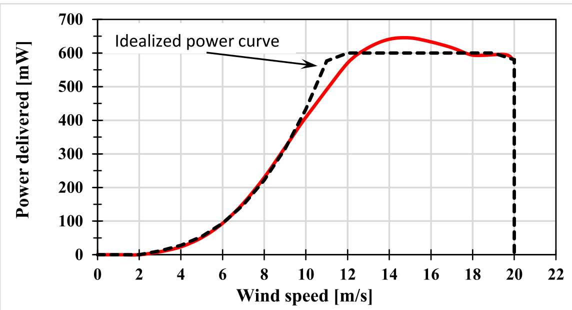

Fig. 6: Measured (solid) and idealized (dashed) power curves of the used wind turbine.

TABLE I: List of experiments.

Experiment No.	Experiment Title
1	Types of PV modules material and I-V characteristics
2	PV panel performance
3	Off-grid PV systems
4	Wind turbine characteristics

III. The course learning outcomes

Laboratories and practical classes are vital parts of the engineering learning process. Specific course learning outcomes (CLOs) are achieved by performing practical experiments. This course includes the renewable Lab to enhance the teaching process and improves students' understanding of the main topics in the field of solar and wind energy. Furthermore, skills in solving engineering problems, the ability to function effectively in a team and communication skills are also fostered during the Lab. these CLOs are achieved by dividing the class into teams and assigning a design task for each. The key learning outcomes upon completion of this course are:

CLO1 for types PV modules material and I-V characteristics:

- Identify different semiconductor materials used in the PV cells.
- Understand the impact of semiconductor material on the PV module parameters such as power rating, efficiency and temperature derate factor.

CLO2 for PV panel performance:

- Compute and measure the power delivered from a module at different tilt angles.
- Describe the impact of collector azimuth angle on the PV module performance.
- Describe the performance and applications of connecting modules in series or parallel.

CLO3 for Off-grid PV systems:

- Identify the main components used for off-grid PV systems and describe their functionality.
- Compute the required storage size considering the battery type, load demand, power availability and the site temperature.

CLO4 for wind turbine characteristics :

- Describe the design of the wind turbine and the effect of the number of blades on the turbine performance.
- Construct the wind turbine's power curve and identify the cut-in, rated and cut-out wind speeds on the constructed curve.

Since this course is part of an ABET-accredited program, the instructor is also required to assess ABET students' outcomes (2, 3, 5 and 6) [5].

IV. Results and discussion

The learning process in this course comprises two phases. The first phase targets enhancing theoretical knowledge via lectures and homework assignments. The second phase offers an opportunity to gain hands-on experience in the Lab. To demonstrate the effectiveness of this strategy, students were asked to design an off-grid PV system for a household before conducting an experiment. In this off-grid PV system, the calculation of the load demand, the design of the PV array and battery sizing using lead-acid batteries are covered. An example off-grid system built by a group of students is shown in Fig. 7. This learning process enables the students to understand the practical experiment better and compare measurements to theoretical calculations.

The aim of this work is to enable higher education institutes to develop high-tech courses in the renewable energy field. For continuous improvement purposes, a questionnaire was distributed seeking students' feedback about the course. The survey instrument is designed based on 18 items in four dimensions (The effectiveness of the learning pedagogy, Lab status equipment, educational learning outcomes and their relevance to ABET, and students' overall perception). The Likert-type scale, a 5-point scale ranging from "Strongly disagree" to "Strongly agree," was used to collect the data from the 14 undergraduate students enrolled in the course. Table II lists the items

TABLE II: The students' feedback survey questionnaire items.

Item No.	Effectiveness of the learning pedagogy	Strongly agree (%)
1	The Lab was organized in a manner that helped me understand the underlying concepts.	92.9
2	The Lab gave me the confidence to do more advanced work in the subject.	85.7
3	I believe that what I'm being asked to learn in this Lab is important for me.	85.7
4	The Lab associated with the RES course increased my knowledge in the PV and wind energy resources field.	64.3
5	The Lab complemented the material covered in the lectures.	92.9
Item No.	**Lab equipment status**	**Strongly agree (%)**
1	The equipment used in the renewable energy Lab is suitable for the learning proposes.	92.9
2	The Lab experiments were up-to-date (modern).	64.3
3	The RES Lab experiments helped me understand the practical design of PV systems.	85.7
4	After conducting the RES Lab experiments, I will be able to design a simple off-grid PV system.	64.3
Item No.	**CLOs versus ABET's student outcome**	**Strongly agree (%)**
1	The RES Lab helped me acquire and apply new knowledge in the PV and wind energy fields.	78.6
2	The RES lab enhanced my ability to function effectively on a team formed by my classmates and the instructor.	78.6
3	The RES Lab enhanced my ability to develop and conduct appropriate experiments to characterize different PV module types.	85.7
4	The RES Lab enhanced my ability to develop and conduct appropriate experiments to better understand the wind turbine characteristics.	64.3
5	The skills I learned while writing the RES Lab report helped me write an effective and concise report to communicate experimental results and conclusions.	85.7
6	After taking the RES Lab, I can follow the design procedure for designing an off-grid system introduced in the course to create an off-grid system that meets specific design requirements.	71.4
Item No.	**Students' overall perception**	**Strongly agree (%)**
1	I would highly recommend this course to other students.	92.9
2	Overall, this course met my expectations for the quality of the course.	85.7
3	The course was helpful in my progress toward my degree in Electrical Power and Energy Engineering.	92.9

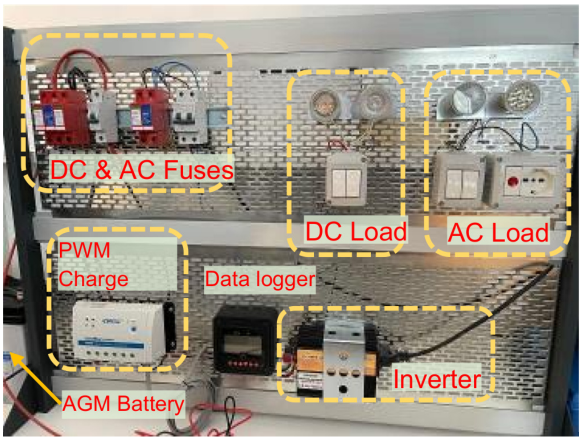

Fig. 7: A simple off-grid PV system built by a group of students.

included in the survey and the percentage of strongly-agree responses.

In the "Effectiveness of the learning pedagogy" dimension, the overwhelming majority of students find the teaching method very effective; 93% assert that the Lab complements the lectures and increases their knowledge. The overall average of the "Strongly agree" responses in this dimension is 84%.

As for the "Lab equipment status," most students believe the Lab has up-to-date apparatus suitable for learning. A 64.3% of students responded with a "Strongly agree" that they are confident replicating a simple off-grid PV system after taking this course. The overall average of this dimension's "Strongly agree" responses is 76.8%.

In the "CLOs versus ABET's student outcome" dimension, the survey reveals that most of the learning outcomes of this course are met. 98.7% of students "Strongly agree" that the Lab helps them acquire and apply new knowledge in the field of RES. A 93% of students assert that the course enhances their ability to function effectively in a team and enhances their skills in technical writing. All students either agree or strongly agree that their ability to develop and conduct experiments in the RES field has improved. The overall average of the "Strongly agree" responses in this dimension is 77.4%.

In the last dimension, "Students' overall perception," 85% of students think the course has met their expectations, and 92.9% would highly recommend this course to other students. The overall average of this dimension's "Strongly agree" responses is 90.5%.

Soliciting other input not covered by the survey, students are invited to write their comments on their course experience and potential future enhancement. Here are samples of students' written comments:

"This course was of great benefit and helped me further understand the renewable energy world and was most enjoyable because it had an integrated lab within the course, which greatly helped me understand the topics discussed during this course and I hope more courses implement the same strategy in the following years."

"I really enjoyed this course; it was accompanied by practical implementation, which our courses lack the most; it also sets you up for real work, where a lot of research and reports are written."

"The course increased my knowledge in battery types and PV systems." "It was an amazing course, honestly."

V. Conclusion

This course was held purely as an extension course in renewable energy for undergraduate students. The majority of students really enjoyed it. The development of an advanced RES course that combines theory with laboratory came as a response to the increasing awareness of clean energy needs. The teaching style used in this course, combining theoretical knowledge and practical experience, has proven to be very effective. This course's quality of teaching and learning is enhanced as students acquire various skills through observation and practical experimentation. This course achieves different learning outcomes in the field of renewable energy technology in general, PV and wind in particular. The designed course successfully conveyed the necessary knowledge of renewable energy to students. For example, the students demonstrate the ability to design and build a small-scale off-grid PV system. All students are asked to complete a feedback survey questionnaire at the end of the course to evaluate the teaching strategy's effectiveness and determine whether all learning objectives have been accomplished. The outcomes of this initiative are promising, and students generally had a very high opinion of it. The aim of this work is to enable higher education institutes develop high-tech courses in the renewable energy field. Future work will be intended to improve the teaching methodology by implementing a flipped-classroom approach [11] and upgrading the renewable energy Lab so students can access it remotely [12].

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