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Learning About Solar Power in South Sudan: An International Collaboration

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Abstract

More than 1 billion people in the world currently live in energy poverty. Solar energy has vast potential for South Sudan but there are challenges to implementing it. How can students and others such as technicians learn about the context of South Sudan and the particular engineering challenges for utilizing its abundant sunlight to provide energy? We capitalized on a unique opportunity to conduct an international collaboration between a solar power entrepreneur in South Sudan and an engineering professor in the USA to explore this topic. As part of an undergraduate independent study course, we designed two modules (introductory and advanced) on off-grid solar power for South Sudan. Meetings were held over zoom during the summer of 2020. The student brought his practical experience of owning and operating a solar energy company in South Sudan. The instructor brought her experience in developing educational materials. Each module included learning objectives, content, and exercises. Topics included Introduction to energy access in South Sudan, Principles of Electricity and Solar Energy Generation, Building blocks of a solar power system, Architecture of various solar power systems, *Solar Company*, and Design of Off-Grid PV Systems. Particular challenges for photovoltaics in South Sudan were highlighted. Finally, examples were drawn from the student's experience with designing and installing solar power systems for customers in South Sudan to demonstrate the proper integration of the various components to meet a particular power need for a customer. In this work in progress, we introduce the context of solar energy in South Sudan, and describe the course, the modules designed, and lessons learned. These modules offer an opportunity for students in the USA and elsewhere to expand their global engineering mindset by learning about the context of South Sudan which few may have the opportunity to visit. We are continuing to improve these modules and welcome feedback from others in the larger community.

Keywords: Energy Access; Renewable Energy; Off-Grid Solar Power; Electrification in South Sudan

Introduction

More than 1 billion people in the world currently live in energy poverty, i.e., they lack access to basic energy for essentials such as lighting and cooking. In South Sudan, only the country's capital, Juba, is partially supplied with grid electricity impacting less than 1% of the country's population. Solar energy has vast potential for South Sudan, but there are challenges to implementing it. How can students and others, such as technicians, learn about the context of South Sudan and the particular engineering challenges for utilizing its abundant sunlight to provide energy?

In the USA, one way that engineering faculty attempt to engage students in learning about other countries is by having them interact with the United Nations Sustainable Development Goals [1] which may lead some students to learn more about South Sudan [2]. Other programs promote collaboration between the USA and other countries, including South Sudan, via disaster relief and photovoltaic (PV) solar projects such as the solar suitcase [3] from We Care Solar [4]. Researchers have compared undergraduate civil engineering programs at the University of Juba and the University of Florida [5]. Others have described the challenges and lessons learned from implementing a US-based master's program in Kilimanjaro, Africa, including students from South Sudan [6, 7].

In this work, we capitalized on a unique opportunity to conduct an international collaboration between a solar power entrepreneur in South Sudan (*Student*) and an engineering professor in the USA to explore this topic. Having an authentic voice from an engineer in South Sudan is particularly valuable for students in the USA to recognize expertise from outside of the Global North. His experience working with solar energy technicians in Africa gives him unique insights into the knowledge that they need. *Student*'s experience living in South Sudan in Africa and the USA in North America is invaluable in addressing audiences across both continents. This collaboration offered him the opportunity to further develop his pedagogical and solar energy knowledge as he designed these modules. The instructor contributed expertise in solar energy and educational methods. This collaboration also allowed the faculty member an opportunity to develop curriculum that integrates a global component for US students to develop their global engineering mindset without travelling. The instructor's future students in the USA have an opportunity to learn about the context of South Sudan which few may have the opportunity to visit. In this work in progress, we will describe the context of South Sudan, the independent study course, the modules designed, lessons learned in doing this work, and suggest next steps.

Context

South Sudan

Officially the Republic of South Sudan, the country is located in North-Eastern Africa bordered by Sudan, Ethiopian, Kenya, Uganda, Congo, and Central African Republic. South Sudan is the world's newest independent country, having recently gained its independence from Sudan in 2011 after multiple civil wars. As of 2020, it has an estimated population of 12 million, though there has never been a complete census to determine the exact population count [8]. The Nile and its tributaries feature significantly geographically, culturally, and in livelihood. The land is a mixture of swamps, savannas, and rainforest and is landlocked. South Sudan is rich in natural resources, led by its vast agricultural potential, with 90% of its land arable with plentiful rain. Large swathes of the country is alive with wildlife making it a future potential top tourist destination. South Sudan is also rich in minerals such as gold and oil reserves, with crude oil sales currently making up more than 98% of its revenue [9]. Despite its wealth in natural resources, the economy is underdeveloped and predominantly reliant on imported goods, with more than 80% of inhabitants dependent on subsistent farming or animal husbandry as the primary source of income. The country's long periods of civil unrest dating back to the colonial era has consequentially robbed it of the prerequisite peace needed to develop the infrastructure and economy.

An example is South Sudan's current lack of infrastructure to refine, transport, and ship the oil that it produces – forcing it to rely on the existing infrastructure through the North, its former foe, to access the international market. As a result of this handicap, the landlocked state imports refined fuel for domestic consumption from neighboring countries at a high cost. A new power grid started operating in late 2019 at $ 0.25/kWh, which is too expensive for most people. The combination of expensive fuel resulting from imported costs and an economically challenged population with a gross domestic product (GDP) of $275 means that it is difficult to sustain the existing grid, let alone its expansion.

Independent study course

This work was the result of an independent study course entitled “Solar Energy Systems in South Sudan” to complete degree requirements for a BS in Electrical Engineering for Mou Riiny. Given the COVID-19 pandemic and the fact that the student was in South Sudan and the instructor in the USA, meetings were held over zoom during the summer of 2020 on a weekly basis. In fact, the current situation meant that an online course was possible since the university moved to accept such offerings in Spring 2020.

The learning objectives for this independent study were that by the end of the class, the student will

- Prepare and deliver a presentation about solar energy systems in South Sudan, including identifying technical and contextual criteria
- Design and revise a course module on solar energy systems in South Sudan for fourth-year engineering students, including presentation of content, class activities, sample data, and analysis
- Design and revise a course module on solar energy systems in South Sudan for second-year engineering students, including presentation of content, class activities, sample data, and analysis
- Prepare convincing documentation with evidence of achieving specific ABET outcomes required for all EE electives

The deliverables included:

1. Module 1: Introduction
2. Module 2: Advanced
3. Video introducing Mou Riiny, SunGate Solar, and Off-grid solar in South Sudan
4. PowerPoint Presentation about the modules and the course with narration
5. Documentation of achieving ABET outcomes

The instructor assessed the student’s achievement of the objectives using the deliverables and provided written feedback to the student. Once the student successfully completed all deliverables, the current Electrical Engineering chair approved this independent study course as an EE elective used in fulfillment of graduation requirements for the BS in EE. .

The student brought his practical experience of owning and operating SunGate Solar [10], a solar energy company in South Sudan. The instructor brought her experience in developing educational materials.

Student

Mou Riiny was born in South Sudan during the country’s 1983 – 2005 civil war, escaping to the refugee camp in Kenya as a result. There, he relocated to the United States, where he graduated from high school at the Governor's Academy in the Boston area and pursued his degree in Electrical Engineering from the University of San Diego. While at the University, Mou Riiny and three of his classmates did their senior design project on solar power that attracted immense attention from the University and the Institute of Electrical and Electronics Engineers (IEEE). In 2011, Mr. Riiny returned to be with his family in South Sudan, where he worked for a non-profit organization to lead a program building schools and installing solar power in the rural communities within the region. In 2013, with seed funding from IEEE and clean energy investors, he founded SunGate Solar [10], which is headquartered in the South – Western city of Wau and has more than 30 employees with offices across the country, making it the largest solar power company in South Sudan. Mr. Riiny is married and lives with his wife and two sons in Wau.

Instructor and University

The University of San Diego is a private Roman Catholic university with a School of Engineering that offers undergraduate degrees in Electrical, Mechanical, Industrial and Systems, and Integrated Engineering along with Computer Science. Programs are ABET accredited and the focus is on undergraduate students with typical class sizes of about 20 students.

Dr. Susan Lord, the instructor for this independent study course has over 25 years of teaching experience at the university level and is currently a Professor of Integrated Engineering at the University of San Diego. She holds BS, MS, and PhD degrees in Electrical Engineering (EE) and was the Chair of Electrical Engineering at this institution for about 10 years, including while Mou Riiny was an undergraduate student. The instructor's teaching interests include electronics, materials science, and optoelectronics. She developed an Optoelectronic Materials and Devices elective course [11] and recently developed a broad introduction to electrical engineering for non-EE students [12, 13]. Thus, she has experience teaching about the fundamentals of solar cell operation but more at the device than system level. She is very interested in using evidence-based practices such as learning objectives, active learning, and inclusive pedagogies. She is currently developing an elective course on Photovoltaic Solar Energy to be taught in Spring 2022. She hopes to use the modules developed in this independent study in her second-year introduction to EE course and the PV Solar Energy elective for third and fourth-year undergraduate students. The instructor is a White woman who was born and raised in the USA and has traveled to Africa as a tourist but has not been to South Sudan. She is currently in a department that is actively working to help students see engineering as a sociotechnical endeavor [14, 15] so the opportunity to approach solar energy from the specific context of South Sudan fits well with the goals of the department.

Modules

As we worked through various iterations of the modules, we identified the intended audience for Module 1 as university engineering students and solar power technicians. We expected that they would have little or no prior knowledge of solar power and wanted to gain a basic understanding of its application off of the grid, especially in South Sudan. The audience for Module 2 is advanced engineering students and experienced solar power technicians and we expected that they would have already completed Module 1.

The student aggregated the content of these modules from different sources, including his education, training, and experience working in the Off-Grid solar power business in South Sudan. Information for further reading is available in the references at the end of each module. For some unfamiliar terminology and acronyms, we included definitions in an Appendix.

Each section of the modules includes learning objectives, content, and exercises for practicing application of the material presented. Particular challenges for photovoltaics in South Sudan were highlighted. For example, measurements at Standard Test Conditions (STC) can be misleading in such extreme temperature environments. Choosing among different battery chemistries for energy storage must consider the specific environmental conditions. Where appropriate, students are asked to compare the context in South Sudan to their own. For example, when doing a load assessment example from South Sudan, they also are asked to do a similar calculation for their own house or dormitory.

Module 1: Solar Power in South Sudan: Principles and Applications of Off-Grid Solar Energy (Introduction)

Module 1, divided into six sections, covers introductory topics that are necessary to understand the context of solar power technology and the environment. This module begins with an introduction to South Sudan, energy access, and solar energy prospects in the country. Section two outlines the Principles of Electricity & Solar Energy Generation, which is designed to acquaint both the non-technical and technical readers of the fundamental principles of electricity as well as the physics of how electricity is generated by a solar power module [16] was found to be a useful reference for this section. This is followed by Section 3 on the building Blocks of a Solar Power System, which is necessary for understanding the basic elements of Solar Power systems. Solar modules, charge controllers, inverters, and energy storage batteries were introduced. One of the section exercises is included here as Example 1.

Example 1: Module 1, Section 3 exercise questions and answers

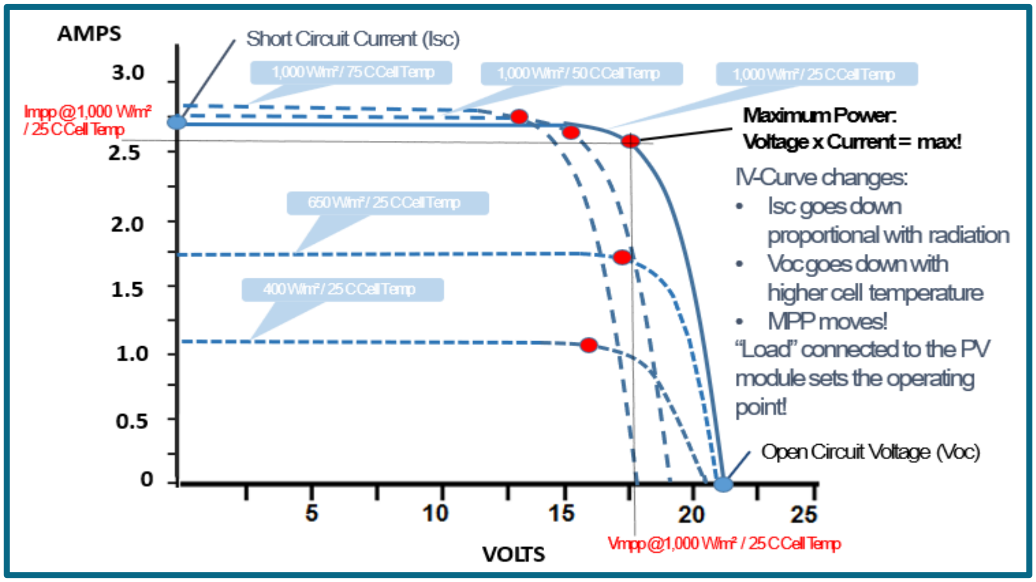

Figure 1: I-V Curve and temperature effects on voltage [13]

1. If you need a 175 W solar power output from your array, how would you design it to account for the effects of heat and other losses in South Sudan, assuming losses of 30%?
   Answer: Assume 175 W is only 70% of what you need, find the 100% by dividing 175 by 70% (175/0.7) = 250 W.

2. Identify Vmax, and Imax at STC in Figure 1. Use them to calculate Pmax.
   Answer: Vmax = 17.5 V, Imax = 2.6 A. Pmax is therefore 17.5 Volts x 2.6 Amps = 45.5 Watts

The fourth section is on the various architectures of a PV system, in which two of the key concepts, the Grid-Tied and Off-Grid PV system configuration methods, are introduced. Section 5 describes what *Solar Company* does currently, especially how it is sustainably addressing the various energy access needs in South Sudan and the technical and environmental challenges it considers to design, install, and maintain solar power systems. This module ends with Section 6 on the Design of PV Systems. Readers are led through the steps required to design simple Off-Grid solar power systems, including the load assessment and calculation of energy requirements for a customer, the relevant geographical data, and other essential design parameters for a real-world scenario. Example 2 shows part of the sizing exercise from Section 6.

Module 2: Principles and Applications of Off-Grid Solar Energy (Advanced)

Module 2 explores some of the more advanced topics of Off-Grid Solar Power. It begins with a case study of the utility of discarded solar batteries in South Sudan to consider one of the leading environmental concerns arising from the pervasive use of solar energy, particularly in South Sudan. Section 1 covers the differences between Grid-Tied and Off-Grid System Architectures. In Section 2, the rationale behind PV Parallel Stacking and Three Phase system configurations are explained in detail. This allows the reader to evaluate and qualify the criteria for choosing a Parallel Stacking and Three-phase system design. Readers are also able to extricate a Parallel Stacked & Three-phased system from other solar power system designs. Section 3 expounds on the concept of AC-Coupling, which explains the difference between AC and DC-Coupled Systems and specifies the conditions that necessitate an AC-Coupled system design. Similar to Module 1, Section 4 focuses on the design of advanced Off-Grid PV systems, where the readers are able to perform necessary calculations to design an advanced Off-Grid PV solar energy system, given a customer's requirements. After going through the design process, one is able to utilize key sizing variables to modify a solar power system design. Section 5 concludes with a discussion of issues related to the installation and maintenance of solar energy systems in South Sudan, including shading, tilt, orientation, and transportation.

Example 2: Module 1, Section 6 exercise questions and answers

Appliance	*Calculation*	*Total Energy per day (W-hrs)*
TV	120 W x 8 hrs	960
LIGHT BULBS	240 W x 9 hrs	2160
FRIDGE	240 W x 7.5 hrs	1800
LAPTOPS	180 W x 9 hrs	1620
PRINTER	100 W x 2 hrs	200
MISC	200 W x 2 hrs	400
	Total	7,140

1. Calculate total energy consumption by multiplying connected loads with the stated usage hours
   Answer: We estimate the energy consumption of the house as 7,140 Watts-hours per day.

EXERCISE: USAGE TIME AND ENERGY

1. Determine the total energy used if all the loads in this example were used for an additional hour.
   Answer: 8,220 Watt-hours, a 15% increase of energy consumption.

Lessons Learned

Student (Mou Riiny)

Throughout the course, I identified several complex engineering challenges relevant to the Photovoltaics Industry and practice, particularly in South Sudan. These include the need for a multidisciplinary knowledge of various components that make up solar power systems. First is the need to know the physics of a solar cell, how it functions, and its performance criteria. Second is the requisite knowledge of the converters, such as the charge controller and inverters: their engineering, performance parameters, different technologies, and suitability in various applications. Thirdly is the necessity to acquire knowledge of the different battery chemistries used for the storage of renewable energy and which is most appropriate to specific environmental conditions such as South Sudan. The fourth identified problem is the proper integration of the various components to meet a particular power need. Throughout the course, I broke down the various problems presented by these components and their integration and, using engineering, science, and mathematics, clearly solved for the selection criteria and use of each one. In the end, I was able to demonstrate the solution to these problems by assessing, sizing components, and designing a solar power system to be used in a real-world scenario.

In addition to the engineering lessons, I was able to learn different technical and professional skills and techniques in the application of Off-Grid solar power systems in remote areas. During this course, I was able to master the use of software called PVGIS [17], used for estimating solar power irradiation and its fluctuation throughout the year. In Module 1, I incorporated an example for South Sudan and surrounding regions. The course also offered me the opportunity to learn more about the engineering of electronics used in solar power conversion technology. Through this course, I learned several indispensable communication and organizational skills. I am now able to prepare a large and complex professional document that addresses disparate audiences, such as engineering students, technicians, and policymakers. I now fully appreciate the need and value of getting feedback and incorporating it to improve my work. Not only will I use these skills for the rest of my life, but I intend to pass them on by teaching others.

Instructor (Susan Lord)

As the instructor in this independent study course implemented during the COVID-19 pandemic and across continents, I learned a lot about such long-distance collaborations. As with other international research collaborations I had been involved in, a big challenge was including identifying a suitable time for both of us. The 11 hour time zone difference meant that we had to schedule at a time that was early for me and after work for him. I also learned about being patient with technological challenges such as dropped Zoom calls, insufficient video bandwidth, and sharing large files.

I appreciated learning more deeply about the unique context of South Sudan including the resources and cultural wealth of the county, strategies for pay as you go for customers with little income, impact of high temperatures on bandgap and solar cell efficiency, differences in design of solar energy systems for residential and office installations, and challenges of installation in a place where floods can happen half the year. As we worked through multiple drafts of the modules, I was approaching this from two perspectives-1) as the instructor trying to support this student in demonstrating his learning and 2) as an instructor who wants to use these modules with other students. Thus the importance of having carefully constructed learning objectives as well as exercises and answers to questions to support student learning was emphasized for me. I needed to ask questions and not assume that I understood the context. Personally, I struggled with how best to present information about South Sudan to an audience of mostly White students in the USA to avoid perpetuating stereotypes.

Summary and Next Steps

We successfully developed two modules on solar energy in South Sudan: one as an introduction and one including more advanced topics. These modules were reviewed by a solar energy technician and a student at the University of San Diego. The feedback from these reviews was used to improve the modules. These modules were the major deliverables for an independent study, which served as an EE elective to satisfy BS degree requirements for the student.

The next phase of the study and documentation will include testing these modules with engineering students at the University of San Diego and other students at a university in South Sudan and incorporating their feedback. The instructor plans to use parts of these modules in her engineering classes in Spring 2022. We plan to have Mou Riiny present part of this material to the class either via Zoom or in-person if he is able to visit the USA. Having the videos is also helpful as a backup in case the in-person or online is not possible.

The modules will also be used to train technicians at SunGate Solar as well as others who are interested in solar energy applications. Over the next two to three years, we hope to expand on these modules, adding further experience from the field as well as new innovations in the industry. We hope this collaboration will not only assist in the education of students and technicians of solar power but also policymakers who may want to get gain an in-depth understanding of the pros and cons of solar energy at a national level. We welcome feedback and partnerships with others.

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