Development of Educational Tools for Electrical Microgrids

Roxana Melendez-Norona, PhD[1], Maria M. Larrondo- Petrie, PhD[2]
[1]*Florida Atlantic University, United States, rmelendez40@gmail.com*
[2]*Florida Atlantic University, United States, petrie@fau.edu*

Abstract*– The U.S. National Science Foundation is currently supporting projects for workforce development and research in cybersecurity, state estimation and optimization smart electrical grids, based on simulations that may use real data. P ower systems administrators and customers are constantly seeking more resilient, secure and reliable power system. Electrical Microgrids represent a relevant portion of a smart power grid, where the microgrid may operate in grid-connected or islanded mode. Academic, Industrial and Government sectors are constantly considering the application of new tools concerning the study and analysis of microgrid design and operation, motivating the creation of modern tools for such purposes. This paper focuses on the proposed future design of tools for a Massively Open Online Courses (MOOCS) on Microgrid/State Estimation, Microgrid/Optimization and Microgrid/Cybersecurity. Thus, students, instructors and representatives from industry and government may be able to count on a resource to learn and expand their knowledge on microgrids. This paper presents the main ideas associated with the future design of MOOCS for the electrical microgrids field of research.

***Keywords*-- microgrid, cybersecurity, state estimation, optimization, MOOCS.**

I. INTRODUCTION

Sustainability is a term highlighted as one of the key words to describe concerns regarding quality of life in planet earth and to point out those limitations in natural resources and moreover the sense of the commitment with future generations. The appropriate design, implementation and resilient operation of microgrids represent an important element in a sustainable scenario.

Microgrids play a vital role in the world's efforts to make our planet sustainable [1][2][3]. The study and analysis of Electrical Microgrids performance is of extreme importance. State Estimation, Optimization and Cybersecurity are part of the most suitable aspects to explore as part of microgrids structure. The vulnerability of energy grids is evident with attacks and failures due to increased demand caused by climate change. In order for the grid system to be resilient there has to be a hybrid combination of solutions and microgrids represent one of these solutions.

A microgrid is a local energy grid able to operate in islanded (disconnected from the main utility electrical system) or grid connected modes and includes a control system for power management [4]. Some characteristics to mention about Microgrids are shown in Fig. 1. The detailed description of these characteristics must be included in Massively Open Online Courses (MOOCS) and online courses.

Fig. 1 Electrical Microgrids main characteristics.

II. WORKFORCE DEVELOPMENT FOR FUTURE SMART ENERGY SYSTEMS

The need for continuous training in smart energy systems is manifested in the development of courses funded by the US National Science Foundation. The CyberTraining Project: Data-Centric Security and Resilience of Cyber-Physical Energy Infrastructures [28] took place in the year of 2021. This cybertraining supported students and professionals to obtain mentored, hands-on training combining expertise across electrical engineering, communication, data science, and science and technology studies. The participants had the opportunity to develop multi-disciplinary skill sets needed for the data-centric power and energy industry. Participants strengthened career competitiveness as future cyberinfrastructure professionals. The cybertraining project was divided into two stages: a general training and a goal oriented project individually assessed by an instructor.

Next the main areas included in the general training [28] are presented:

- Artificial Intelligence and Data Analytics
- Communication and Network Security
- Sensor Networks and Internet of Things (IoT)
- Real-Time Learning and Microgrid Optimization
- Multi-Level Decision-Making Process of Intelligent Systems

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The training took place during a two week window of time. The main addressed topics are detailed as follows:

- Background of electric power systems, renewable energy, electrical demand and renewable energy prediction. Renewable energy generation prediction using data-driven techniques. Time series prediction techniques and Artificial Intelligence technologies were analyzed.
- Tutorial on basics of communication and network security, common vulnerabilities, and security attacks in smart grids. Communication and security designs, security attack generation, security setting, and data collection.
- Renewable power generation, with emphasis on modeling, conversion, and the impacts on the smart grid. Matlab based hands-on laboratory where participants studied some codes with the aim of modeling a variety of environmental conditions.
- Introduction to machine learning, neural networks, and deep learning concepts and models. Practical section with applications of programming by using Python for object detection and classification.
- Basics on Internet of Things (IoT) including background in sensors and actuators, architectures and basics of programming. Development of the laboratory focused on the creation of IoT applications.
- Basics of microgrids, its principal elements and algorithms for optimization of power flow in these systems. The module used Artificial Intelligence (AI) methods.
- Characteristics of a wide-area monitoring system (WAMS) for power systems. Study of the phasor measurement unit (PMU) and its relevance for smart grid state estimation. This section included a project associated with the creation of state estimation models for smart grids.
- Data-centric network science and graph signal processing, applied to smart grids, with the analysis of energy data.
- Introduction to attack and defense design and analytics for smart grids using deep learning methods, for cybersecurity studies.

After the general training a project oriented to design of Matlab algorithms for microgrid optimization using the Q-learning deep learning technique was developed. The Matlab code included the following actions and results:

- Generation of data related to power production from the photovoltaic array in the system and data associated with electrical load demand. Data was generated for a time window of 15 minutes, for 24 hours per day.
- Random creation of cost and price parameters for photovoltaic source, diesel generator, batteries, etc.
- Definition of battery initial state of charge and minimum and maximum battery and diesel generator capacities.
- Definition of gamma, alpha and epsilon values for the Q-learning method (discount factor and learning rate). The optimization method was based on exploitation of two different actions during the microgrid operation. The first action oriented to not use the diesel generator, using the power provided by the renewable energy source and batteries to cover the electrical load. The second action was based on the utilization of the diesel generator for not enough production from the photovoltaic array.
- The state of the system was defined by the value of different variables such as renewable energy generation, load demand, maximum and minimum capacities of batteries and the maximum power that the diesel generator was able to provide to the system.
- Creation of the for-loops for the different scenarios or actions. The calculation of cost in the system's operation was introduced as part of these loops.
- Calculation of Q-values for 200 different iterations.
- Decision making process to compare Q values related to action 1 and action 2 and decide which value was larger. Therefore, selecting the powers scheduled to be delivered by the different sources in the microgrid.

The academic, industry and government sectors are constantly considering the application of new tools concerning the study and analysis of microgrids design and operation, motivating the creation of modern tools such as Massively Open Online Courses (MOOCS). Thus, the main idea that has been conceived in this paper is the presentation of a general proposal for the future design of a MOOC for the study of Microgrid Cybersecurity, State Estimation and Optimization. The majority of existing online courses cover from definition of microgrids up to the detailed analysis of the operation for these electrical systems. In [31] the program is presented in 2.5 hours sessions over the course of four days, addressing the generalities regarding microgrid definition and applications. Principal studied aspects are economic issues and financial methodologies, advantages and disadvantages of microgrids, microgrid configuration, drivers for developing microgrids, history of microgrid development, using renewable and alternative energy systems in microgrid applications, integrating microgrids with energy storage and fuel cells, microgrids in context with central and distributed electrical generation and transmission systems, types of microgrid applications, making a business case for deploying microgrids. On the other hand [32] offers a course that is perhaps one of the most extensive trainings in the field of microgrids, which also includes a certification, after 4 days of instruction which comprises microgrid aspects such as reliability, optimization and cybersecurity. Particular details considered to a certain degree are introduction to microgrids, microgrid operation and control energy management systems in microgrids through the analysis of different types of load fault tolerance in microgrids, cost benefits, hybrid microgrids, stability assessment and protection, pulse width modulation techniques in microgrids, applications of energy storage systems in microgrids, voltage source converters, effect of electric vehicle charging and operation of storage units in islanded mode. The training also explores virtual synchronous generator effect in islanded microgrid, power quality in islanded mode, master and slave control, frequency restoration, peak shaving, demand response in microgrids, voltage harmonic reduction, optimal dispatch in microgrid Energy Management System (EMS), monitoring devices for EMS, load dispatch in EMS, battery energy storage effect in EMS, centralized and decentralized EMS and microgrid central controller (MGCC). Finally the course reviews further points namely communicating with neighbours, synchronization through consensus objective, data transfer limit between neighbours, human machine interface (HMI), real-time control effect in EMS, optimization in EMS, weather forecasting, electricity market in EMS, time synchronization, reliability and cyber security of microgrid EMS.

Microgrids hands-on experience is offered in [33], with 40 hours of intensive education, where the content includes from introduction to microgrid systems up to high-level microgrid system sizing and feasibility analysis. [34] is an online course related to microgrid operation and advantages of these systems. However, there is still an existing necessity for the development of additional free access online tools that may include software applications.

In this paper Section III is dedicated to explain the generalities of the main technological tools utilized in the design of the MOOC. Section IV shows the proposed content of the MOOC. The methodology for future development of the MOOC is introduced in Section V. Section VI includes a general overview regarding microgrid characteristics as mentioned in Fig. 1, plus a brief introduction about cybersecurity, state estimation and optimization in microgrids.

III. Tools for the future design of Massively Open Online Course in Microgrids

The content of the MOOC will utilize several technological tools for the development of examples and practical problems associated with the study of Cybersecurity, State Estimation and Optimization for microgrids. The courses will represent next generation MOOCS centered on artificial intelligence tools for simulations.

- *Python:* this is an object-oriented programming language [5]. Thousands of applications in Engineering are based on Python, with the purpose of data analysis and building websites.
- *Machine learning:* it is based on the use of data and algorithms to imitate human behaviour [6].
- *Deep learning:* it is focused on techniques for teaching computers to learn by example [7].
- *Jupyter Notebook:* web application for creating and sharing computational documents [25].
- *PHP:* a general purpose scripting language for web development [26].
- *Data Analytics: science centered on data analysis to make conclusions about given information [27].*
- *Matlab: software used in the engineering field for calculations and simulations [8].*

IV. Content for the MOOC

The content related to the MOOC comprehends three main items. The first component is represented by the syllabus, the second item is linked to the course content and the third element covers the simulation results by using Python and Matlab.

For the syllabus it is relevant to include the following information:

a) *Course Title*- Cybersecurity, State Estimation and Optimization in Electrical Microgrids.

b) *Course Modality*- online MOOC

c) *Course description*- the course covers the general analysis and some software applications associated with electrical microgrids Cybersecurity, State Estimation and Optimization. Simulations using Matlab and Python will be studied as part of the MOOC.

d) *Content*- the modules are organized as follows:

Electrical Microgrid, definitions
Electrical Microgrid, characteristics
Cybersecurity in Electrical Microgrids
State Estimation in Electrical Microgrids
Optimization in Electrical Microgrids.

e) *Learning Outcomes*- at the end of the course students should be able to:

-Describe the definition of an electrical microgrid.
-Identify and delineate the major characteristics of a microgrid.
-Outline the principal cybersecurity risks and possible mitigation actions.
-Identify and use appropriate techniques utilized for microgrid state estimation.
-Outline various methods used for microgrid optimization.
-Run Matlab and Python simulations pertaining to microgrid Cybersecurity, State Estimation and Optimization.

f) *Course access and navigation*- the online MOOC should be available for different types of learners (university undergraduate and graduate students, college students, representatives from industry and government, among others).

Evaluation method- the learning outcomes will be evaluated based on quizzes, exams and projects.

V. Methodology for future development of MOOCs

The MOOC will be developed within two years. The main motivation lies in the recent opportunity provided by the National Science Foundation through the e-fellows program

[30]. Additionally, one of the authors of this paper participated as part of the NSF CyberTraining Project focused on Data-Centric Security and Resilience of Cyber-Physical Energy Infrastructures (2021-2022) [28]. The author encountered the necessity of continuing with the development of interactive tools for the examination of microgrids. The first year of the MOOC design process will be devoted to training in programming in Python and PHP, data analytics (DA) and machine learning (ML), deep learning (DL), refining training in Matlab, and literature review in State Estimation, Optimization and Cybersecurity issues in Microgrids. Furthermore, the identification of datasets will be part of the design process. Research will continue the second year with a focus on the design of the MOOC.

The free access Massively Open Online Courses (MOOCS) will be taken by students, instructors and professionals who manifest interest in the study of microgrid operation and the role that these microgrids play for secure and optimal performance of energy grids. The courses will become an advanced tool for application in the continuous process of research carried out by universities and utility companies.

VI. Microgrid characteristics and introduction in Cybersecurity, State Estimation and Optimization in Microgrids

The MOOC will include the definition of the main characteristics of a microgrid as presented in Fig. 1.

A. Distributed Generation:

Traditional microgrids often feature a mix of renewable energy and conventional sources [22]. The renewable power sources are most known to be photovoltaic or wind and to a lesser extent fuel cells. On the side of conventional sources, diesel generators or microturbines are primarily used as backup power sources whenever primary sources are not present or insufficient.

An example of Matlab simulated model was created as a result of P hD research (Fig. 2), where photovoltaic power production typical pattern for a photovoltaic residential roof mounted equipment is displayed. The bell-shaped curve is a consequence of the fluctuation in solar radiation values for a typical summer day.

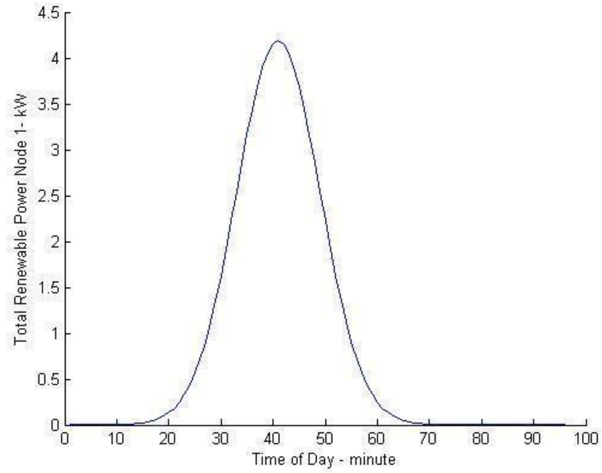

Fig. 2 Example of power production for a photovoltaic array in a microgrid [29].

Additional options for distributed generation on the side of renewable energies are wind power and fuel cells. Fuel cells have become an additional alternative in terms of power technology for implementation as part of microgrids. Hydrogen as a fuel has enormous potential to be explored, in the scenario of sustainability. Academia, industry and government are in the search of better ways to use hydrogen in fuel cells, with the aim of providing electrical energy for local consumption. Fuel cells (Fig. 3) are devices using fuel (i.e., hydrogen) as primary input and oxygen as secondary resource.

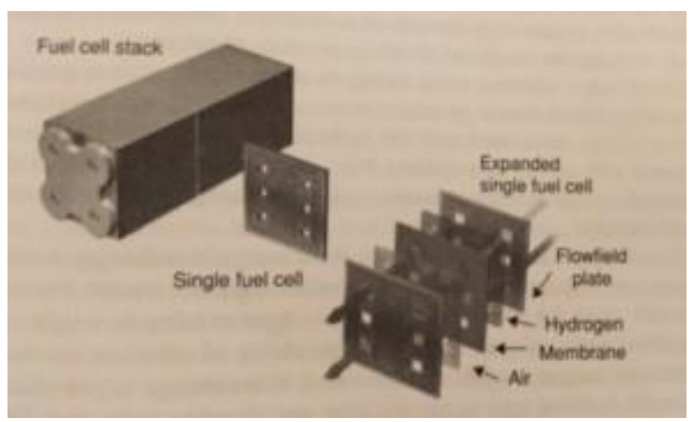

Fig. 3 Example of fuel cell structure [9].

Wind turbines are a very well-known alternative for power production in microgrids. These sources convert the kinetic energy from the wind into mechanical power, by movement of turbine blades and then a conversion to electrical energy takes place due to the presence of an electrical generator.

Other power sources installed as part of a microgrid are small hydropower, diesel generators and microturbines.

B. Demand Side Management:
Traditional microgrids load demand modelling imply the operation of industrial, commercial, residential or combination of these types of customers. Demand side Management allocates the users according to power production schedules and the classification of total electrical demand into essential and non-essential. Essential or critical loads are considered relevant as they need to continue working during the 99% of time, while non-essential or non-critical loads require power at least 95% of the time [10].

C. Power Management Control:

Control systems for traditional microgrids are in general classified into centralized (Fig. 4) and decentralized [19][20] schemes (Fig. 5). Research work has shown the benefits of operating the microgrid with the support of an energy or a power management system [18][21].

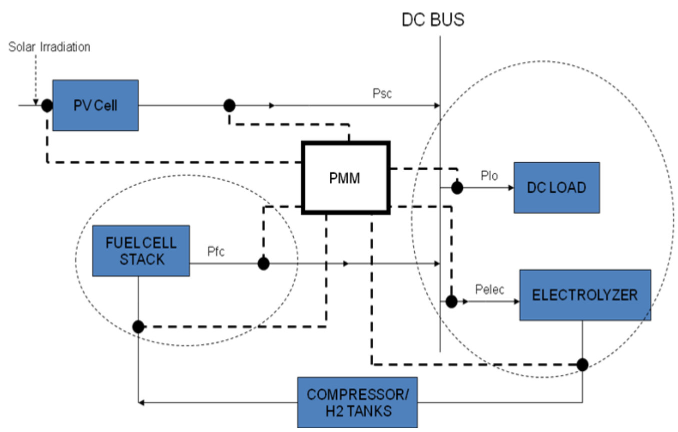

Fig. 4 Example of centralized power management system for microgrids.

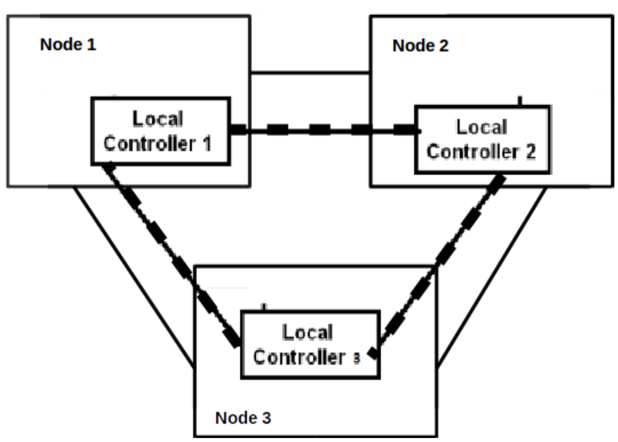

Fig. 5 Example of decentralized power management system for microgrids.

D. Topology:

The topology of any electrical system defines the system configuration, with generation equipment, loads, storage devices, power distribution lines, control elements, etc. In general, microgrids present a variety of topologies, involving several buses and different types of loads and distributed generation, control centers and the point of common connection to the utility company in grid connected systems. Some topologies count with an AC bus collecting overall generation and consumption points, in what is known as a radial configuration. An alternative topology allows the interconnection of the same elements by using a closed loop or forming a ring. A different topology is represented by star topology [11][23].

E. Stand Alone or Grid Connected Operation:

Micrograds are often connected to the utility company at the point of common coupling (PCC). While the PCC is active, the rules for performance in terms of voltage and frequency are dictated by the utility company for every period of time. A different situation is related to isolated performance where microgrid policies establish the corresponding nominal values for electrical parameters. An example of a stand alone system is shown in [12].

F. Stability:

Power systems stability conditions are by standard defined in direct relation to voltage and frequency parameters. Microgrids as power systems are not the exception to this rule. As a consequence, is of high relevance to establish conditions intended to assure a safe and reliable operation, especially in the presence of sudden changes in load or generation. Stability translates into maintaining frequency and voltage within nominal values. In the study of power systems and microgrids some tools such as the well-known P-f curves (active power versus frequency, Fig. 6) and Q-V characteristics (reactive power versus voltage) are extensively used in the heart of control applications.

Fig. 6 Example of P-f curve for stability analysis.

F. Cybersecurity:

Microgrid infrastructure may be seen as a combination of Information Technology and Equipment [13]. The importance of microgrids as part of the smart power system makes them become a target for cybersecurity attacks. Abrupt disconnection from the smart grid, failure in equipment (i.e., breakers, power transformers, relays, etc), and the technical problems with the control and telecommunication elements are among the multiple issues that a microgrid faces in a cyber secure scenario. Microgrids must become more and more resilient to cyberattacks. The data managed through microgrid operation needs to meet three main conditions: Availability, Integrity and Confidentiality [14]. The proposed MOOC will cover the main aspects concerning the risk from a cybersecurity point of view, classification of cyber attacks together with focal cyber defense mitigation actions.

H. State Estimation:

State Estimation is associated with the process of visualizing the different operating microgrid states. The goal of state estimation exercise is the acquisition of the data pertaining to voltage and angles of the different buses in the electrical system. Numerous state estimation algorithms are centered on the employment of Phasor Measurement Units (PMU) [15]. The proposed MOOC shall investigate the importance plus the main ruling methods for state estimation in microgrids.

I. Optimization:

The optimization of power flow in microgrids is a well-known material of analysis in the area of power systems [16][17][24]. In many cases microgrids optimal performance is oriented either towards obtaining a minimal value for operational cost or a maximum revenue/profit. Constraints are often presented in terms of power sources maximum and minimum capacities, maximum, energy cost parameters ($ per kWh) power balance and power losses, among others. The MOOC will cover principal optimization techniques and examples of optimization simulated with the use of Matlab.

VII. CONCLUSIONS AND FUTURE WORK

The evolving field of microgrid operation requires the creation of free online MOOCS that present the foremost aspects on Cybersecurity, State Estimation and Optimization for electrical microgrids. These MOOCS must employ real data for simulation purposes, using machine learning, deep learning and in general artificial intelligence methods. Moreover, there is an urgency in pursuing additional simulations linked to microgrid cyber secure and optimal performance. This paper presented the main features for the future design of the MOOCS and the invitation is open to students and professionals that would like to collaborate with this project.

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