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Massive Open Online Course in Electrical Microgrids Cybersecurity, State Estimation and Optimization utilizing Open Science Datasets

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Abstract*– Smart Grids represent one of the most important sustainable electrical power systems. Microgrids are vital components of the smart grid, supplying energy to different types of customers in both stand alone or grid connected modes. Therefore, the study of microgrids is of extreme relevance. Massive Open Online Courses (MOOCs) have become a useful alternative for millions of students and professionals that wish to learn about a specific topic. In this scenario the design of a MOOC to study aspects of a microgrid such as Cybersecurity, State Estimation and Optimization represents a step towards the modernization of the education associated with electrical systems. This paper describes the main aspects in the design process of a MOOC in Cybersecurity, State Estimation and Optimization for Electrical Microgrids. The process of design has been supported by the eFellows program administered by the American Society for Engineering Education (ASEE) and funded by the US National Science Foundation (NSF); and the Latin American and Caribbean Consortium of Engineering Institutions (LACCEI). The MOOC includes practical online laboratories using engineering software, such as MATLAB, Python and Google Colaboratory, utilizing real datasets for solar radiation, electrical demand, voltage, current, among other variables. The real datasets, provided by the Ministry of Mines and Energy of the Dominican Republic, have been placed in Open Science Framework's repository, granting free access to other researchers, professors and students.

Keywords—MOOC, microgrids, cybersecurity, state estimation, optimization, online laboratories, open science.

I. Introduction

Electrical microgrids are a fundamental building block of electrical power systems. The US Department of Energy has expressed that multiple efforts will be made with the aim of making microgrids an important element as part of the electricity delivery system, increasing its resilience and reliability [1].

Massive Online Open Courses (MOOCs) represent a powerful tool for learning purposes. MOOCs are courses offered with the aim of covering specific topics for students and professionals in different fields of study. Since electrical microgrids have become one of the most important components of smart grids, the study of these systems is of extreme relevance. Consequently, the design of a MOOC to cover the basis of cybersecurity, state estimation and optimization in electrical microgrids constitutes a good step towards offering a mechanism of study and analysis for academics and for industry capacity building. This paper goes further, applying artificial intelligence methods of deep learning to analyze cybersecurity; Q learning technique [2] of reinforcement learning methods to study optimization; and the Least Square Method to study state estimation using real datasets. This paper presents details of the design process of the MOOC, the general content and the different laboratories included as part of the MOOC. Also, the general strategy to commercialize the MOOC is explained.

II. Content of the Mooc

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 [3] 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 this general training are:

- 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

There is still a need to offer additional free access MOOCs that can cover the aspects associated with electrical microgrids.

A. Content of the MOOC

A.1 Learning Outcomes and Course Objectives

The MOOC related to Cybersecurity, State Estimation and Optimization in electrical microgrids includes the following learning outcomes:

- Simulate, analyze and adapt algorithms related to Cybersecurity, State Estimation and Optimization in Microgrids, by designing and writing Python [4] and MATLAB [5] codes.
- Analyze a power management model for community microgrids.

The objectives of the MOOC are presented below:

- Describe the fundamental components and characteristics of electrical microgrids.
- Analyze the features related to cybersecurity, state estimation and optimization for microgrids.
- Explain the basics of community microgrids.
- Simulate algorithms in Python and MATLAB related to microgrids.
- Simulate power management control algorithm for community microgrids.
- 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.

A.2 Modules

The MOOC designed by engineers for undergraduate and graduate engineering students is divided into several modules:

- Introduction to Electrical Microgrids
- Cybersecurity
- State Estimation
- Optimization
- Community Microgrids

The theory is presented in the different modules and students interact with assignments and simulations associated with Cybersecurity, Optimization and State Estimation. Algorithms are created based on scenarios for stand-alone microgrids. Real datasets associated with the electrical power system of the Dominican Republic will be available to course takers via the Open Science Framework repository [6].

A.2.1 Introduction to Electrical Microgrids Module

The first module of the MOOC, Introduction to Electrical Microgrids (Fig. 1), covers the following aspects:

- Electrical microgrid definitions,
- Microgrid components and characteristics,
- Microgrid distributed generation,
- Microgrid demand side management,
- Microgrid power management control,
- Microgrid topology,
- Stand alone or grid connected operation,
- Stability,
- Objective functions and constraints, and
- Introduction to planning and design for microgrids.

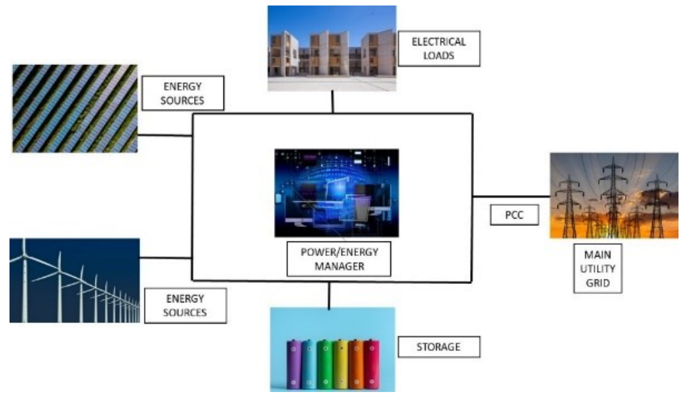

Figure 1. General microgrid structure

A.2.2 Cybersecurity in Microgrids Module

The second module is devoted to the study of cybersecurity in microgrids, presenting the main definitions of cybersecurity and requirements. Finally, the module presents a unit that covers algorithms for detection of cyberattacks in microgrids using tools such as MATLAB, Python and Google Colaboratory [7] and also methods for artificial intelligence.

A.2.3 State Estimation in Microgrids Module

The module devoted to state estimation covers the general description of the state estimation process for electrical networks, including a simulation in MATLAB showing the example of calculation of voltages and phase angles for a microgrid with two buses (one bus for generation and the other bus for electrical consumption).

A.2.4 Optimization in Microgrids Module

Optimization is one of the most important topics to analyze for electrical microgrids. The module lists the main optimization techniques applied in engineering, with a simulation in MATLAB describing the optimal power flow for an islanded microgrid using the reinforcement learning Q-learning method.

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A.2.5 Community Microgrids Modules

MOOC module five covers the detailed description of community microgrids, defining the basis for the design of a decentralized power management model for community microgrids (PMMC). Module six presents the mathematical model of the PMMC and the PMMC algorithm in MATLAB.

III. Laboratories included in the MOOC

This section presents in general the different types of laboratories included in the MOOC.

A. Cybersecurity in Electrical Microgrids

The design of algorithms that may be able to detect cyberattacks in electrical microgrids has been included as part of the MOOC.

The first algorithm was developed using the MATLAB engineering tool. The algorithm associated with cybersecurity has been implemented using the MATLAB tools and libraries for Artificial Intelligence (AI). Most AI areas use Machine Learning and Deep Learning. Deep Learning [8] is an area that incorporates Machine Learning, where several layers are implemented in a network in order to process information and infer patterns. The Machine Learning (ML) philosophy is based on providing to the ML algorithm the test data and the answers and once trained the algorithm will decipher the rules that relate the data and the corresponding results. Real datasets associated with the operation of the electrical power system in Dominican Republic were used for the cybersecurity simulations. Some data points were modified to model an attack condition in the electrical system. MATLAB classification learner tool was utilized to run the simulation. The classifier will train the network. The predictors are the electrical line current for each phase (A, B, C, see Fig. 2) the electrical line voltage for each phase and the energy consumption in kiloWatts hours (kWh). At the end the MATLAB tool classifies test data into one of two scenarios defined as attack and normal operation.

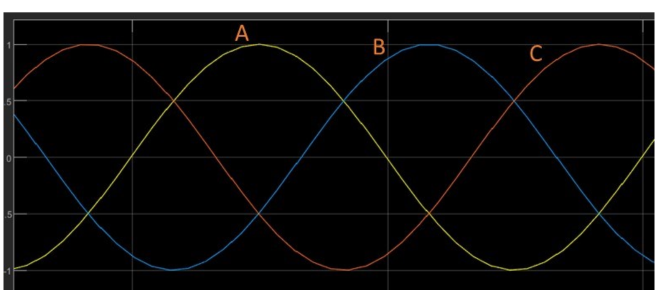

Figure 2. Diagram for phase voltages A, B,C

The MATLAB classifier tool has been employed. Fig. 3 includes the classification learner results when currents in phase C and phase A from the Dominican Republic electrical power system are used as predictors. The program immediately recognizes the two categories: attack and non-attack to the network. A total of 191 sets of variables were used for training. A total of 20 scenarios were defined for the testing phase. Some sets of data were modified by applying a 5% or 10% difference in comparison with the original data (voltage decreased by 5% or 10%, current increased by 5% or 10%), with the aim of simulating an attack condition. After the training phase, the MATLAB tool was fed with the test data and as a result, the classifier provides the output with the labels Attack and Normal Operation for the electrical system. The model was trained using a decision tree with a resulting accuracy of 97.9%.

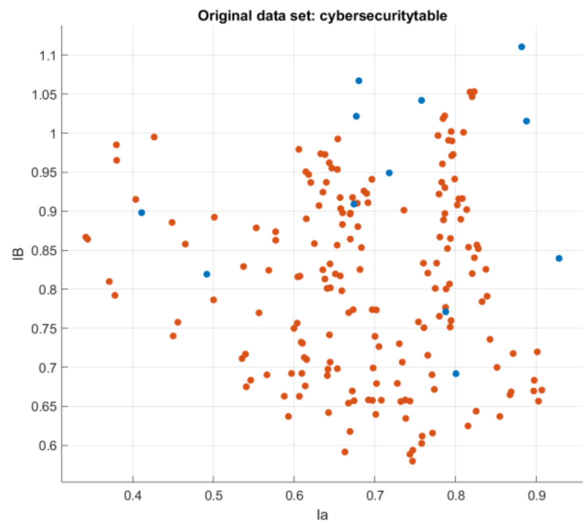

Figure 3. Classification of attacks (blue) and non-attacks (red) in MATLAB.

The second algorithm was developed in Python using Google Colaboratory. The algorithm is based on the injection of false data to the normal operation of the microgrid. False voltage data was introduced as part of 10,000 total data points, using deep learning techniques that implement neural networks. The algorithm was developed in Google Colaboratory. A total of 10,000 data points were used for the training (70% of the total data points) and testing (30% of the total data points) phases. The data points generation process was based on the values of line voltage for a portion of the Dominican Republic electrical system. The minimum and maximum values for voltage and demand were taken and the values were generated using a uniform distribution. After this the false data was inserted by modifying the voltage values by a percentage. The neural network implemented had one input layer for main variables, two hidden layers, each one with 14 neurons and one output layer. The output layer was associated with the sigmoid function as the activation function to allow the output of the network to be transformed into a probability of attack or non-attack.

The neural network was trained for 200 epochs. 70% of the 10,000 points were used for training and 30% for testing. In the training phase the resultant accuracy for the 200th epoch was 95%. Two sets of new values for voltage and electrical demand were used for prediction purposes. The first set of values was known to be an attack, the algorithm predicted that it was an attack (with 99% probability). The second set of values known to be a non-attack was predicted correctly to be a non-attack (with a probability of being an attack of 2%). The plot of the loss (Fig. 4) and accuracy (Fig. 5) are developed, to show how the loss and accuracy change per epoch in the process of calculation.

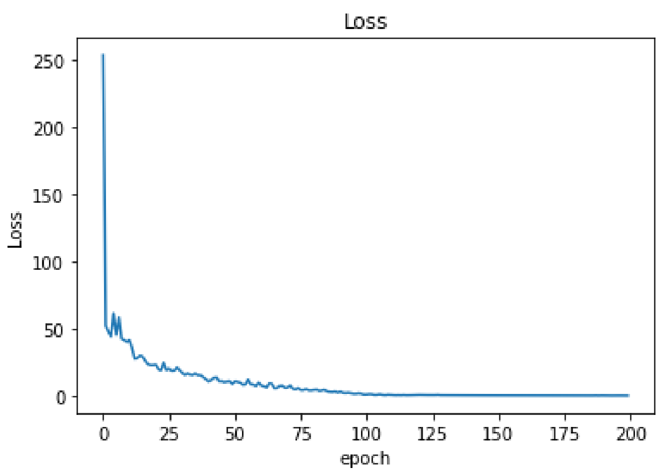

Figure 4. Loss versus epoch

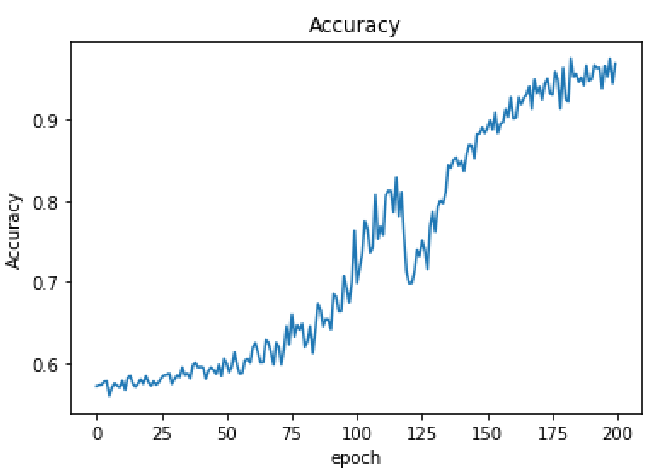

Figure 5. Accuracy versus epoch

The confusion matrix (Fig. 6) displays the performance of the classification model. The matrix includes 1,963 true negative values (predicted non attacks that are in fact non-attacks), 1,019 true positives (predicted attacks that are in fact attacks) and 18 false positive values (predicted attack that are in fact non-attacks).

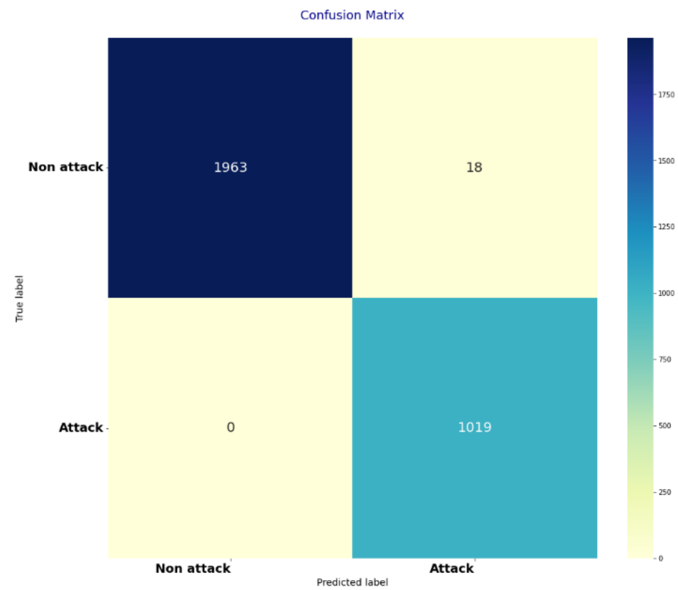

Figure 6. Confusion Matrix

B. *State Estimation in Electrical Microgrids*

State estimation is a critical process for any power system since the resulting parameters of the estimation will allow the network manager to obtain a description of the state of the network in terms of its electrical variables. Voltage and phase angles are among the main parameters to calculate as part of the estimation method. Traditionally state estimation has been supported by the SCADA (supervisory, control and data acquisition) system, where the quantification of the different electrical variables takes place. Sensor transducers, hardware elements and software applications play a vital role to obtain the measurements of distinct numeric data associated with voltage, current, active power, etc. The state estimator is the computational procedure that is implemented to obtain the estimate of the state of the microgrid. This estimator takes into consideration some measurements (i.e., active power, reactive power, voltage and current) and the objective is to find the voltage phasors (magnitude and phase) at all buses. Usually, one bus is selected as reference (voltage phase at this bus denoted as zero). The weighted-least square (WLS) method is a very well known method utilized for state estimation. Here the state variables such as voltage and phase angles are calculated through the minimization of the square of the error for all measurements.

The goal of the simulation is to estimate the state variables, where the least square function method is utilized for traditional state estimation. The microgrid system (Fig. 7) includes two buses, bus1 with generation and bus 2 where electrical load is connected. Applying the least square method with the function lscov from MATLAB it is possible to calculate the vector of estimated values. The presence of phasor measurement units [9] in the topology of the network facilitates the collection of data needed for the computational method.

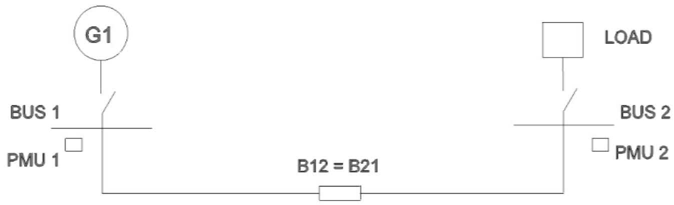

Figure 7. Configuration of microgrid for simulation

The goal of this simulation is to obtain the values for system voltage magnitude and phases. Results are produced in terms of voltages and phases in per unit. Voltage in buses 1 and 2 and phase in bus 2 are calculated. An example of the results for the standard error for the voltage at bus 2 is shown (Fig. 8), where the standard error is small, indicating a good estimation for the electrical system.

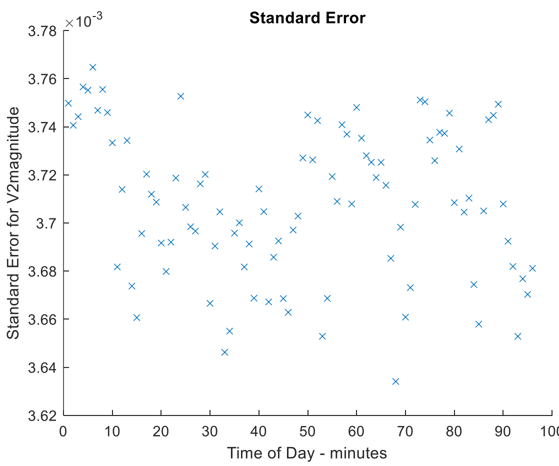

Figure 8. Standard error for voltage at bus 2

C. *Optimization in Electrical Microgrids*

The algorithm for microgrid optimization using the Q-learning reinforcement learning technique was developed in MATLAB for the purpose of simulating the electrical microgrid optimal performance. The goal is to optimize the power flow in the network using the Q-learning technique. The microgrid configuration includes an islanded mode of operation, with a photovoltaic array as a renewable power source and a diesel generator as the conventional power supplier. The battery storage is available as well as a dumping load. Cost per kW, battery capacity, size of diesel generator, learning rate, among others can be mentioned as the parameters that might be modified to test the algorithm. Real datasets associated with solar radiation [10] and electrical demand [11]. where utilized. The analysis was developed for a time window of 1 hour, for a total of 24 hours per day. Some of the content of the algorithm in MATLAB includes the following aspects and settings of initial values:

- Definition of battery initial state of charge (50%) and minimum and maximum battery and diesel generator capacities (50%, 2kW and 4kW respectively).
- Definition of discount factor and learning rate (0.8). The optimization method was based on exploitation of action 1 (using the renewable source as a main mechanism for providing energy to the electrical load) and action 2 (using diesel generator to cover renewable energy deficit).
- State of the system was defined by the value of renewable energy generation, load demand, maximum and minimum capacities of batteries and 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. The cost takes into consideration several variables such as power provided by photovoltaic subsystem, power provided by batteries, amount of dumped load, amount of failed load and unitary cost indexes, among others.
- Calculation of Q-values for 200 different iterations.
- Decision making process to compare Q values related to action 1 and action 2 selecting the larger Q value to determine the power scheduled to be delivered by the different sources in the microgrid.

The goal for the simulation is to optimize the power flow in the microgrid using the Q-learning technique. Results indicate that Q value decreases as the increase in cost of power produced by diesel generator and decrease in the learning rate. However, the convergence of the Q-value demonstrates success in the optimized operation of the microgrid, as displayed in Fig. 9.

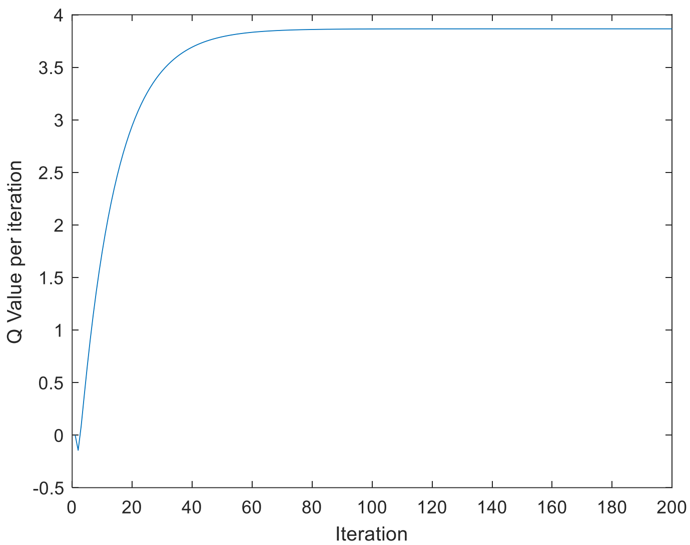

Fig. 9 Q-values results from simulations

IV. Strategy to Commercialize the MOOC

The design of the MOOC has been supported by the eFellows program [12] administered by the American Society for Engineering Education (ASEE) and funded by the US National Science Foundation (NSF). The design process has been developed during a two-year time window.

One of the authors of this paper encountered the necessity of continuing with the development of interactive tools for the examination of microgrids. The first year of the MOOC design process was 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 real datasets was part of the design process. Research has continued the second year with a focus on the design of the MOOC.

The free access MOOC 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 other companies. The MOOC will be offered with two options, certificate and non-certificate.

V. Conclusions

Electrical microgrids are part of intelligent power systems or smart grids and the study of these network is relevant in a scenario of sustainability. At the same time Massive open Online Courses (MOOCs) offer the flexibility and tools for the learning process of many students and professional around the globe. This paper presented the general description of a MOOC in Electrical Microgrids Cybersecurity, Optimization and State Estimation. Simulations in MATLAB, Python and Google Colaboratory are included as part of the MOOC. These simulations include real datasets for solar radiation, electrical demand, voltage and current. The MOOC will be offered to students and professional interested in learning the characteristics and properties of electrical microgrids and how to detect cyberattacks, optimize power flow and perform estimation of the main electrical variables. Initially the MOOC will be offered as a free educational online course.

Acknowledgment

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These real-data laboratories could not be possible without the collaboration of engineer Eduardo Sagredo in the Ministry of Mines and Energy of the Dominican Republic who shared the real data points associated with the electrical system of the Dominican Republic.

The Latin American and Caribbean Consortium of Engineering Institutions (LACCEI) supported this research through mentorship from Dr Maria Larrondo-Petrie. Also, the real dataset associated with the Dominican Republic electrical power system will be shared to the public via Open Science database.

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