Resiliency Analysis for the Development of Microgrid Architecture against Climate-Driven Events in the Dominican Republic's Electric Systems

QUARTERLY TECHNICAL REPORT

(15/01/23 -15/06/2023)

USAID
FROM THE AMERICAN PEOPLE

PUCMM
Pontificia Universidad Católica Madre y Maestra

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1. Ongoing Research

1.1. Energy Resilience Indices Literature Review

One of the last objectives for the research was to conduct a review of frameworks for assessing energy resilience in power distribution networks. There is a growing body of literature on quantitative assessments of resilience that propose relevant indicators to guide not only resilience enhancement but also cost-benefit studies prior to investment planning. Our goal was to find state-of-the-art resilience frameworks to use in our resilience analysis.

Power System Engineers are familiar with IEEE standard reliability indices: System Average Interruption Frequency Index (SAIFI) and System Average Interruption Duration Index (SAIDI). (See Figure 1). Reliability metrics are useful means of assessing the impact of recurrent events that have available historical records, and for which maintenance actions can be taken. However, major hazards, such as severe weather events, are typically excluded from these metrics. To capture the impact of more severe events, researchers have proposed extending some of these metrics, including the Storm Average Interruption Frequency Index (STAIFI) and the Storm Average Interruption Duration Index (STAIDI). Nevertheless, it has been demonstrated that these two metrics are not suitable for evaluating power system resilience because they tend to show large deviations that can even exceed the thresholds.

1.1.1 Taxonomy of resilience evaluation methods and metrics

State-of-the-art resilience frameworks for power distribution networks could be classified, evaluated, and compared using the taxonomy in figure 18. The type of analysis will vary depending on the objective and the state of grid conditions under the event. Numerous resilience features are inherent in the performance curve depicted in Figure 19, also known as the Resilience Trapezoid. This is because constructing such a graph involves considering all the factors that come into play during a catastrophic contingency.

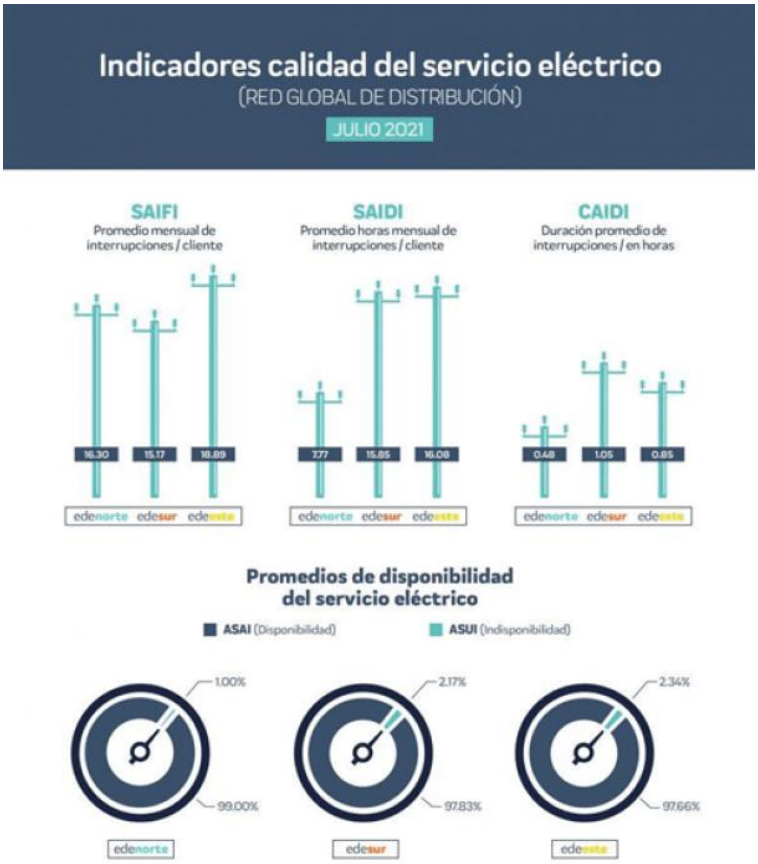


Figure 1 - IEEE standard reliability indices in the Dominican Republic Distribution Energy Utilities (JUL 2021)

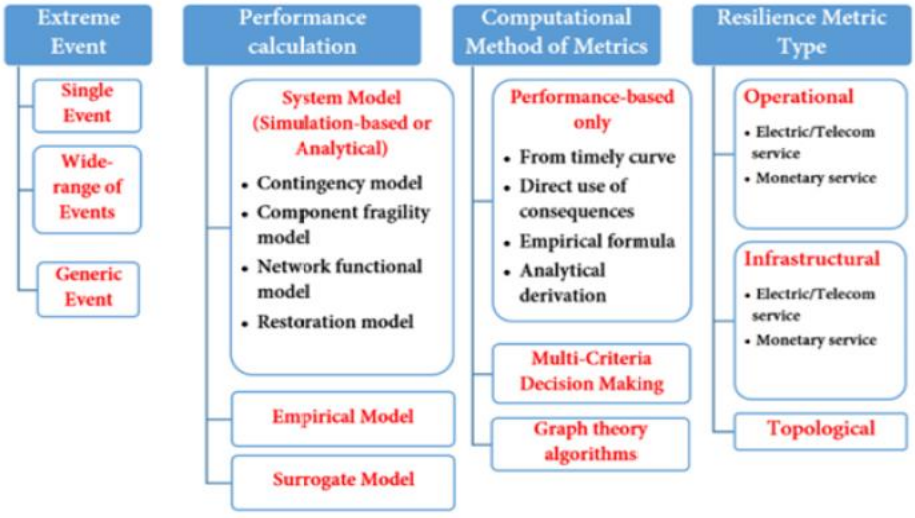


Figure 2 - Classification for resilience evaluation frameworks

The vertical axis and horizontal axes represent the grid functionality and the time, respectively. The grid is under normal conditions, QN, before an extreme weather event occurs at time tE. An extreme weather event occurs at time tE and causes the grid functionality to degrade, until it stops at time tD, when the grid is considered at its worst condition Q(tD). This state will remain constant if no restoring actions are carried out, shown in Figure 3 (below) as the degraded state.

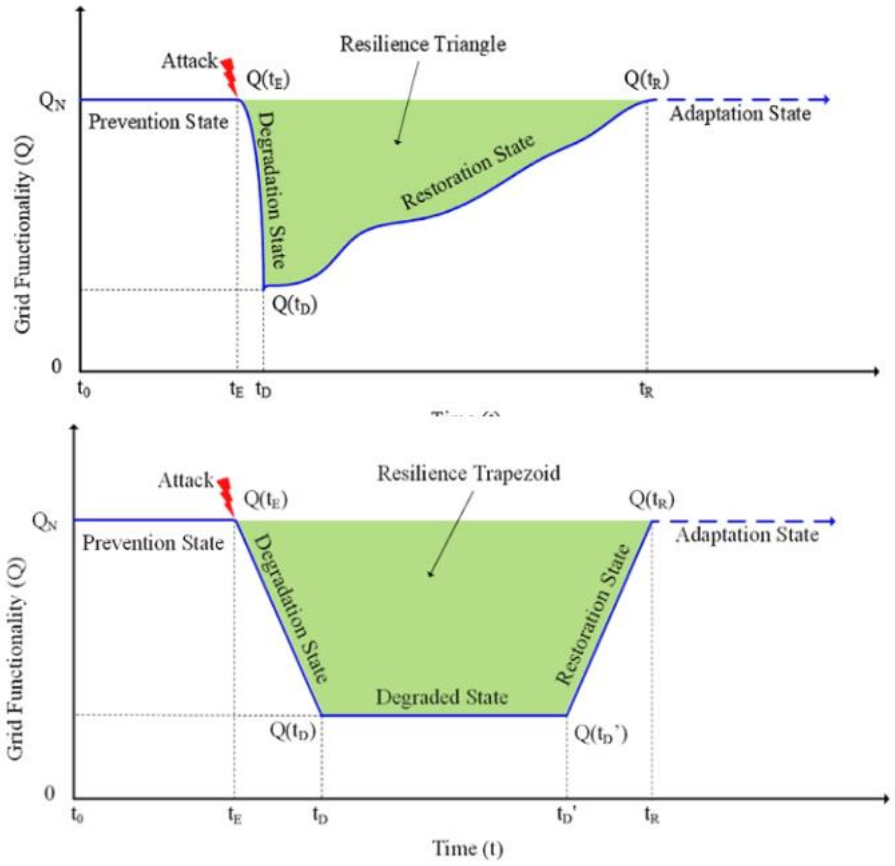


Figure 3 - – (a) The resilience triangle (b) the resilience trapezoid

1.1.2 Grid resilience indices

Resilience metrics come in many different forms, but they can generally be grouped into one of two categories: attribute-based and performance-based metrics. Attribute-based metrics generally try to answer the question “What makes my system more/less resilient?” and can be used to provide a baseline understanding of the system’s current resilience,

relative to other systems. While Performance-based metrics are generally quantitative approaches for answering the question “How resilient is my system?” These methods are used to interpret quantitative data that describe infrastructure outputs in the event of specified disruptions and formulate metrics of infrastructure resilience.

Various methodologies for quantifying the resilience index have been proposed by researchers in the field using the Resilience Trapezoid. You can refer to this blog for an in-depth exploration and to understand the open issues and challenges around the topic.

1.2. Fault detection algorithm

The use of the COM communication interface for the interaction between OPENDSS phasor domain software and SIMULINK time domain software was explored, using the advantages of both to obtain a dynamic that allows exploring interesting scenarios of dynamic variability and reconfiguration of power networks. distribution against faults in the lines. The capacity of OPENDSS to perform power flows is used, as well as the interesting variety of SIMULINK tools for analysis and optimization of scenarios and decision making.

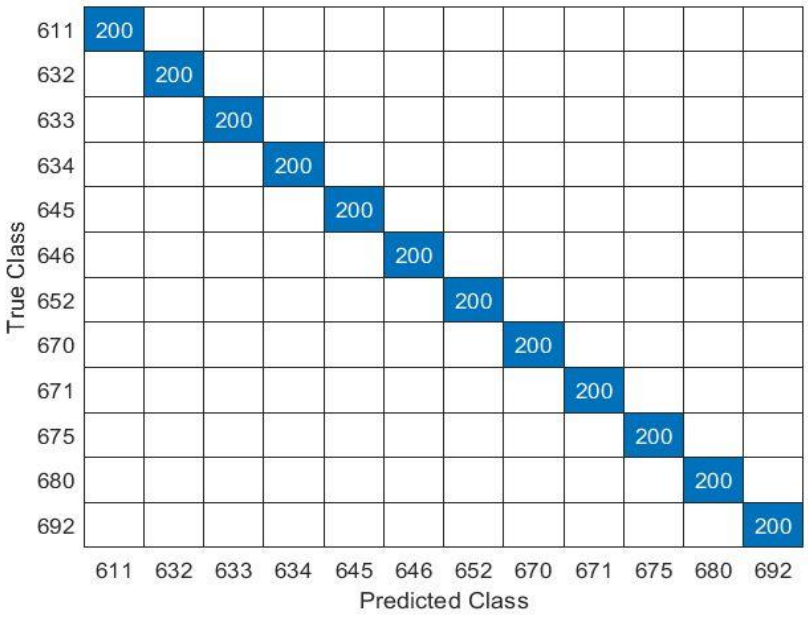


Figure 4 - Results of prediction algorithm with 100% accuracy under the proposed constraints.

Matlab/Simulink® was used to train a Decision Tree algorithm using the statistical learning toolbox. In this simplified case, a single tree was able to classify the different cases presented by the solution of the power flows provided by OpenDSS®. Two types of faults were simulated in each bus of the IEEE 13 Buses reference model. Phasor Measurement Units were simulated, and the magnitudes and phases of voltages/currents were the information used as predictors for locating the faults. This work will be expanded to be used in the proposed segmentation in a Networked Microgrid configuration of the selected study circuit of this project.

1.3. Distribution Network Segmentation into Minigrids – Proof of Concept detection algorithm

One of the main objectives of the research is the study of simulation scenarios of MG formation (segmentation) in the local distribution network (Santiago de los Caballeros), proposing possible control strategies and an overall vision of resiliency standards and practices to the regional utility company (EDENORTE)

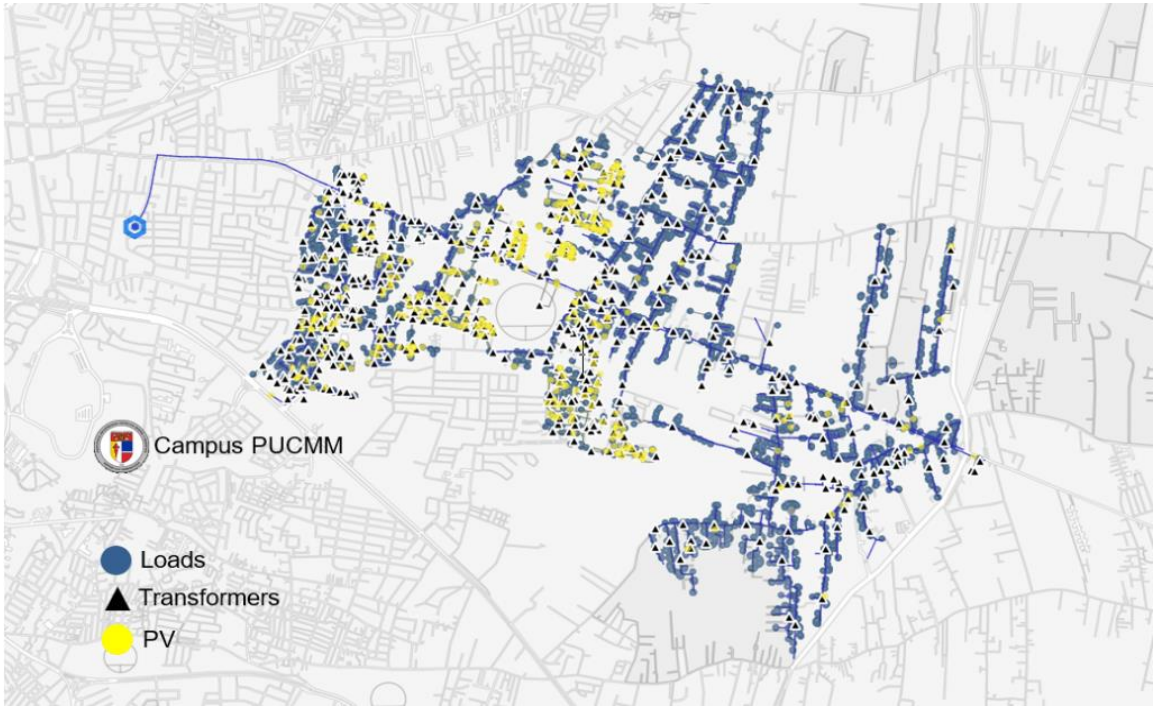


Figure 5 - Villa Olga 101 Feeder, Santiago. Source: Created by the author in QGIS

The team used the analyzed distribution circuit (VOLG101) (See this blog and Figure 5) up to the entire High Voltage Feeder from the CANABACOA HV substation, including in the simulation the other distribution circuits from the VILLA OLGA distribution substation, as well as other HV loads (Hospitals and Industries) that are considered critical for the city of Santiago. All the elements of the distribution circuit chosen VOLG101 were simplified and modeled in OPENDSS by grouping the loads and transformers based on proximity and topology.

This simplified model was interconnected in a single line diagram to the HV loads and interconnected microgrids were proposed to be formed within the VOLG101. For this, the N-1 criterion was used to end up with a set of proposed new connections in a meshed network with the capacity to feed the interconnected microgrids from different sources. (See Figure 19).

The entire feeder was modeled in OPENDSS and snapshot power flow simulations were conducted to validate the proposed simplification (See Fig 6)

```
//FLUJO DE POTENCIA

new circuit.CANA_VOLG basekV=69 pu=1.00 angle=0 frequency=60 phases=3

redirect LINEAS_CANA_VOLG.dss
redirect TRANSFORMADORES_CANA_VOLG.dss
redirect CARGASBT_CANA_VOLG.dss
redirect MONITORES_FALLAS_CANA_VOLG.dss

set voltagebases = [69, 12.47, 0.240]
calcvoltagebases

solve mode = daily number = 1

show voltages ll
show currents


!plot voltages
//set emergvminpu=0.85
//set normvminpu=0.9
//plot circuit voltage

!plot profile
//Set normvmaxpu=1.10
//set normvminpu=0.90
//plot profile phases = primary
//plot profile phases = all
```

Figure 6 - Villa Olga 101 Power Flow Simulation in OpenDSS

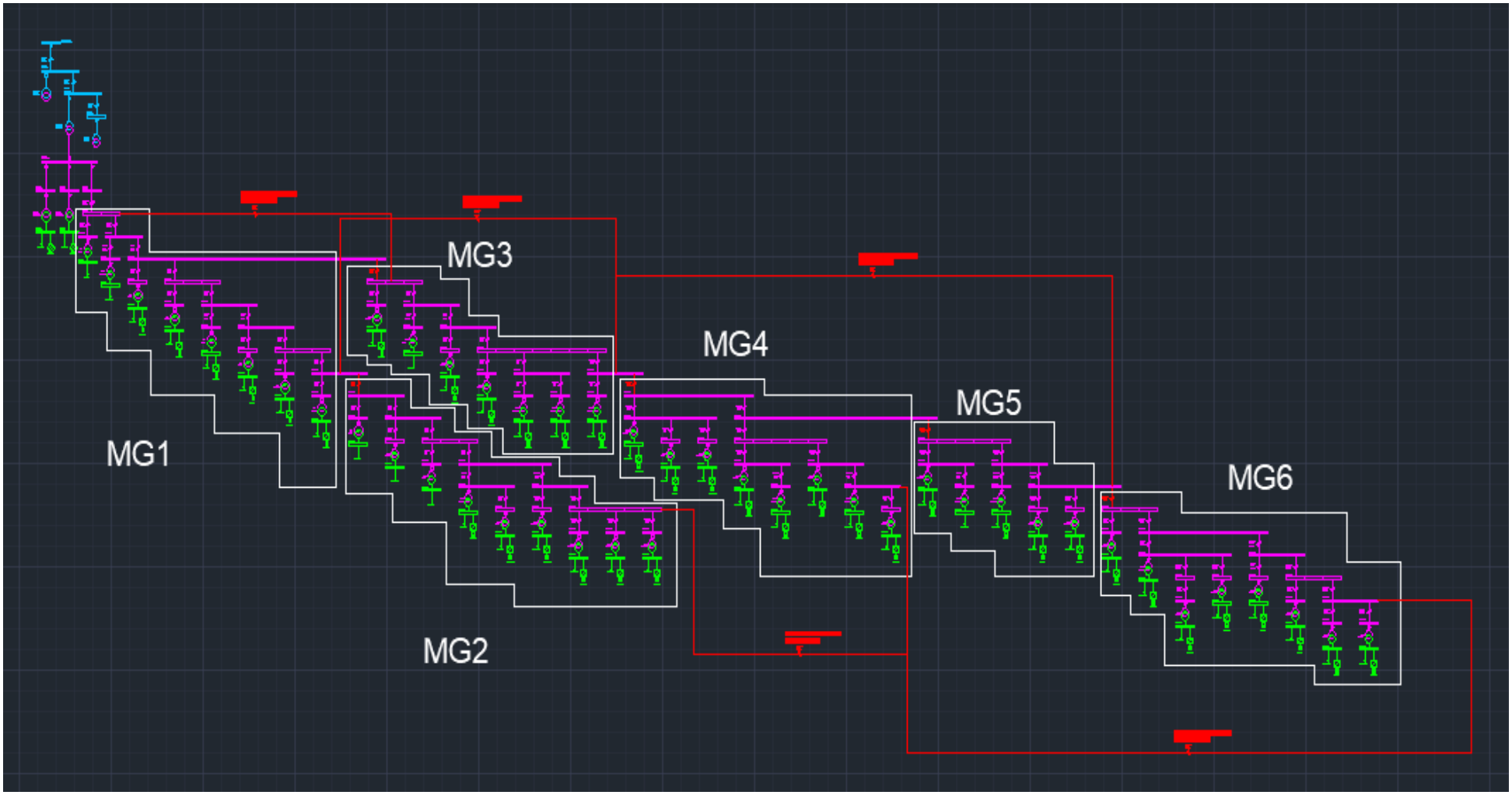


Figure 7 - OPENDSS model of networked microgrids topology proposed.

The resulting mesh topology that will be used in the simulations of the proposed resiliency scheme is shown in the following figure. The modifications proposed to this circuit focus on the enhancement of fault handling and the continuity of service for critical loads.

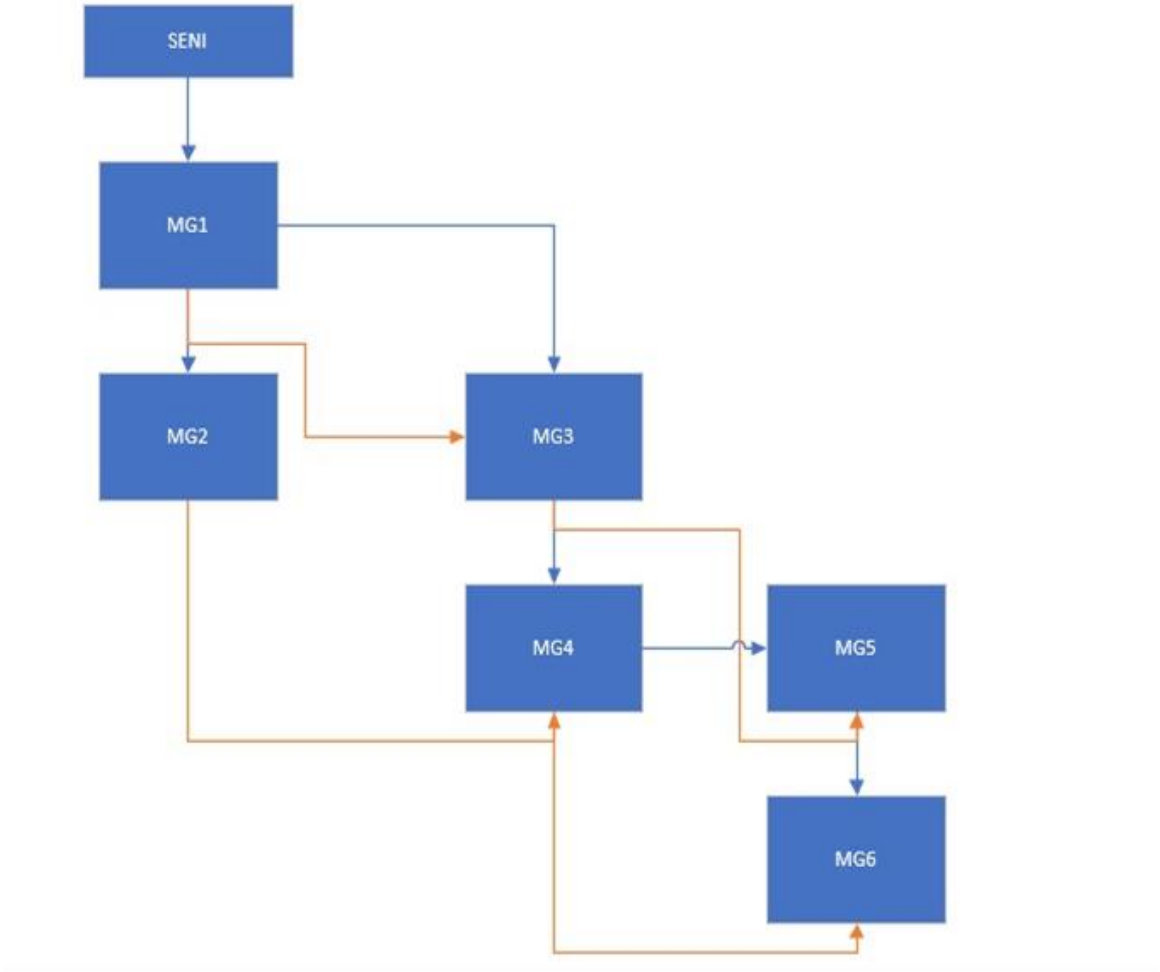


Figure 8 - VOLG 101 Microg

1.4. Ongoing equipment testing and installation.

1.4.1. Taraz Inverter and PWM generation

Initial validation of Taraz Inverter's units was done using the internal microcontroller unit of the PE LAB power electronics system. The development environment for this microcontroller is the ST32CUBEIDE and it is based on the STM32H7455 dual core microprocessor. The reference firmware from TARAZ was programmed in the microcontroller and the initial configuration of the units was completed. For this process, the internal inductors of the inverter were used as the load and sinusoidal PWM generation was done using the internal timers of the microcontrollers. The proposed control for this validation is an open-loop control of the output voltage/frequency. In Fig 6.the initial configuration of the PE LAB system is shown.

2. Project Events

2.1. Applications of real-time simulation in electrical power systems.

The MG Research Group received representatives from OPAL-RT, one of the world leaders in the development of PC/FPGA-based real-time simulators, Hardware-in-the-Loop (HIL) testing equipment and Rapid Control Prototyping (RCP) systems. We organized several talks tailored for different publics (industry, academia, and alumni) in both university campuses (Santiago and Santo Domingo) with the overall topic of *Applications of real-time simulation in electrical power systems.*

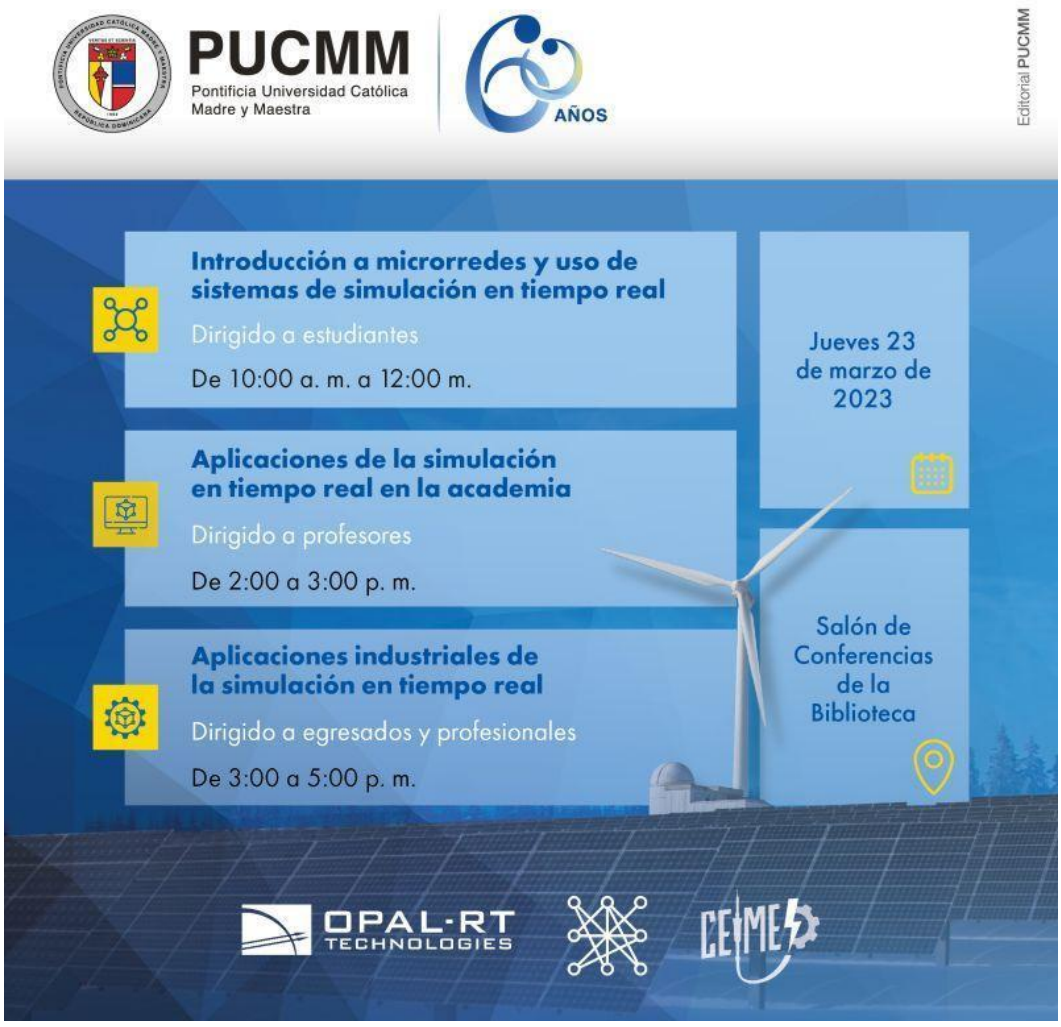


Figure 9 – Talks: *Applications of real-time simulation in electrical power systems.*

2.2. Technical Visit to the Consorcio Energético Punta Cana-Macao (CEPM)

As part of our outreaching efforts the MG Research Group visited CEPM, a leading energy group in the electricity sector in the Dominican Republic that generates, transmits, distributes, and markets energy, and that promotes technological innovation and the development of research projects and initiatives within its business strategy with the aim of improving the efficiency of its processes and increase the safety of its operations. The goal was to promote technical and intellectual cooperation in the design of joint research proposals that are in line with the strategic objectives of the microgrid research, exchanging good practices and methodologies; as well as studies, surveys, and material from the sector, to identify possible areas of collaboration.

Figure 10 – MG Research team at CEPM, Punta Cana

2.3. Dominican Week of Science and Technology 2023

The MG Research group presented several ongoing works in the XVIII International Congress of Scientific Research (XVII CIC) 2023. The event held keynote and special conferences, poster exhibitions, courses, seminars, and workshops, carried out in face-to-face, virtual and hybrid modalities at the Technological Universities of Santiago (UTESA) and Open University for Adults (UAPA).

URL: [AGENDA - XVIII Congreso Internacional De Investigación Científica (XVII CIC) 2023]

Presented works (Spanish)

1. Detección automática de fallos en sistemas de transmisión de potencia eléctrica mediante el uso de técnicas de aprendizaje de máquina y esquemas de cosimulación.
2. Plataforma de Datos Abiertos para el Análisis Espacial de la Resiliencia Energética y Comunitaria
3. Sistema de gestión inteligente para la integración de generación distribuida y vehículos eléctricos basado en algoritmos de inteligencia de enjambre
4. Validación de esquemas de protección de sistemas de potencia eléctricos en circuitos con alta penetración de generación distribuid

2.4 Office of Naval Research Global visit

The MG Research group received a visit from Profesor Arturo Ayon, Director del U.S. Office of Naval Research Global (ONRG) and Dr. James Lyke, from the Air Force Research Laboratory. During the visit Dr. Ayon presented a escription and discussion of the grants for research projects provided by the World Office of Naval Research and awarded to scientists in Latin America

Figure 11 – MG Research team at CEPM, Punta Cana

3. Major equipment purchased.

Since the previous report all equipment has arrived at PUCMM and installed or pending testing.

4. Outreach and Collaboration

4.1. Non-Governmental Agencies

4.1.1. Energy Modelling Platform Latin America

PI De Jesús participated of the EMP-LAC 2023 program, a 3-week hybrid program taught at the University of Costa Rica in the ONSSET software. OnSSET is a GIS-based optimization tool that has been developed to support electrification planning and decision-making for the achievement of energy access goals in currently unserved locations. During the training the research team got to interact with a wide range of professionals working on resiliency and energy access, providing avenues to capacity building in the near future.

URL: [Final Presentation EMPLAC]

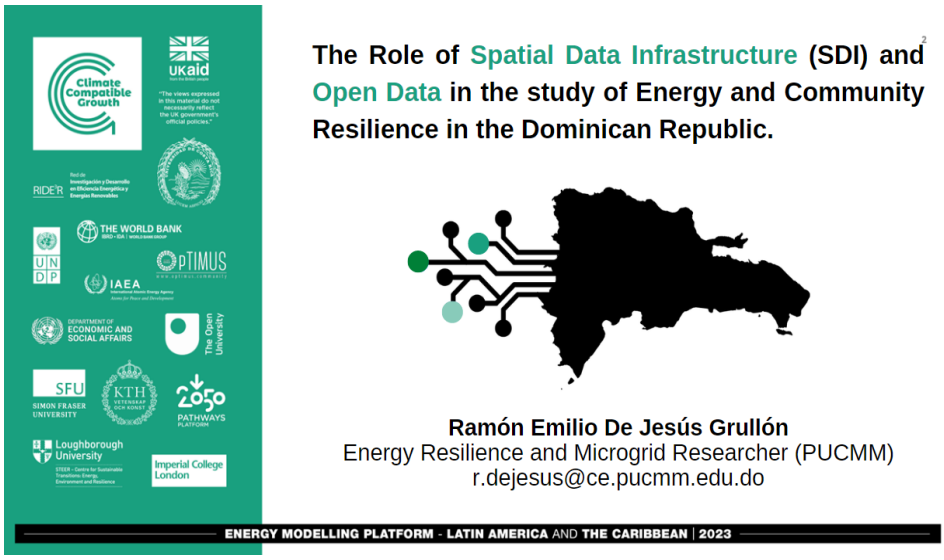


Figure 11– Final presentation for EMPLAC 2023

4.1.2. USAID - PEER Project success story article *"Researching for energy solutions."*

USAID´s social media and multimedia team reach out to the MG research group to write a story about the context, objectives, highlights and potential developments of the MG research project.

Figure 12– MG Research group Juan Pichardo (RA), Rafael Batista (CI), Ramón De Jesús (PI) and Abraham Espinal (CI) (above from left to right) (Santiago, Dominican Republic)

URL: https://www.usaid.gov/dominican-republic/news/investigando-sobre-resiliencia-energetica

4.1.3. Foro de Energía Sostenible (FES 2023) – Panel: Energy Storage: Resilience and Energy Independence in the DR

PI De Jesús was invited to moderate the panel "Energy Storage: Resilience and Energy Independence in the DR" in the Sustainable Energy Forum (FES) (@forodeenergiasostenible) a platform to promote the energy sector in the Dominican Republic, in which productive connections are established and they receive the most up-to-date information about energy efficiency, financing, technology, regulation, responsibility social, climate change, among other topics of interest.

Figure 13 - Panel - Energy Storage: Resilience and Energy Independence in the DR

4.1.4. United States Energy Association: Improving Cybersecurity and Digitization for the Energy Sector in the Caribbean and Latin America

The United States Energy Association (USEA), in collaboration with the United States Agency for International Development (USAID), invited PI DE Jesús and RA Juan Pichardo to participate in the free online course "Improving Cybersecurity and Digitization for the Energy Sector in the Caribbean and Latin America.

The course consists of 15 lessons, lasting approximately 50 minutes each, for a total of 15 hours of self-paced instruction, in which experts from around the world discuss cybersecurity and its important role in the energy sector. During the course, the USEA will host three live, online virtual sessions with an expert who will answer your questions

and work with you to develop an action plan to implement cybersecurity best practices in your organization. Upon completion of this course and submission of action plans, participants will receive an Institute of Electrical and Electronics Engineers (IEEE) certification.

5. Technical Research Presentations

5.1. Presentation to CEPM

A technical presentation of results was given to CEPM. The main goal of the presentation was to showcase the tools we have been building and using, providing insights on how CEPM can use them in their internal processes, and the possibilities to use them for more in depth analysis. Professionals from various directions were present (innovation, losses, projects, information technology and communications).

URL – Technical Presentation to CEPM

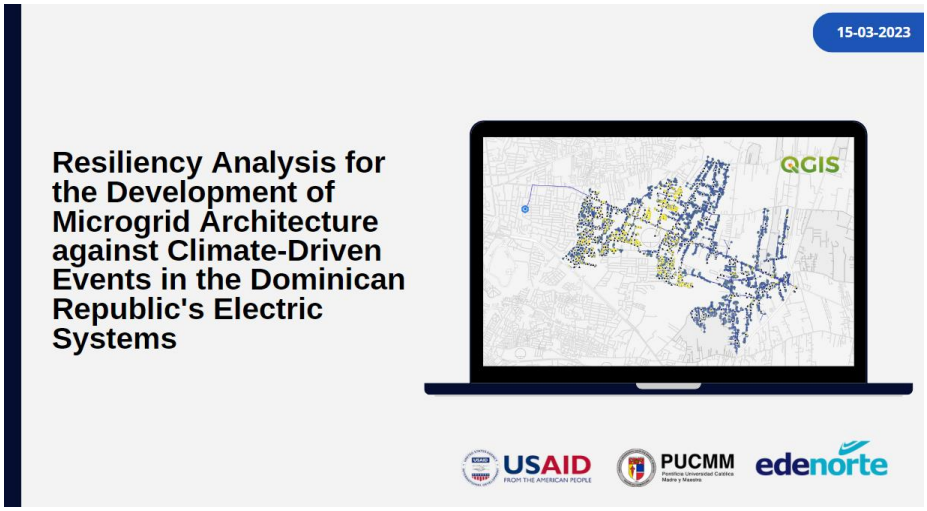


Fig. 14– Presentation of research project to CEPM

5.2. Presentation to EDENORTE

A technical presentation was given to EDENORTE´s Network maintenance management on the tools being use and developed regarding energy resiliency studies.

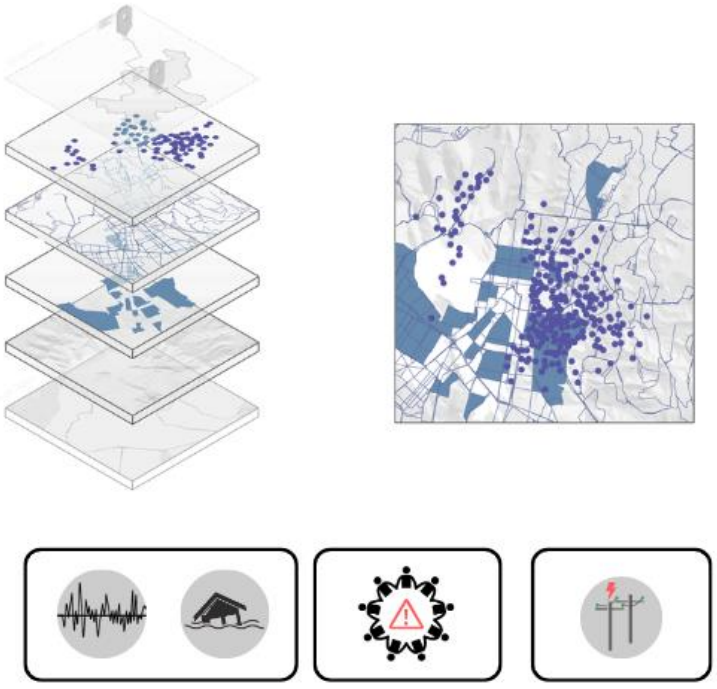


Fig. 15– Mapping Energy Resilience using QGIS - Presentation to EDENORTE

6. Potential Development Impacts

6.1 Collaboration agreement between CEPM and PUCMM

An interinstitutional collaboration agreement between CEPM and PUCMM is being explored by both PARTIES. The main objectives in the agreement are:

- Promote technical and intellectual cooperation in the design of joint research proposals that are in line with the strategic objectives of the PARTIES, exchanging good practices and methodologies; as well as studies from the energy sector, in order to identify possible areas of interest.
- Carry out joint financing efforts through national and international organizations for projects of mutual interest to strengthen the energy sector.
- Develop training programs, internships or professional practices for students and collaborators of THE PARTIES.
- Encourage the participation of THE PARTIES in knowledge fairs, symposiums, conferences and workshops to be held both at the PUCMM headquarters and at the CEPM headquarters.

- Coordinate the development and research paths for end-of-degree projects, so that students develop activities focused on solving problems of interest that are identified by THE PARTIES.
- Coordinate jointly so that the achievements achieved as a result of this agreement are disseminated, giving credit to THE PARTIES, in each of the activities they carry out, such seminars, press releases, advertising, among others related to the scope of this agreement.

6.2 Young Leaders of the Americas Initiative (YLAI) Fellowship Program

CI Abraham is participating in the U.S. Department of State's Young Leaders of the Americas Initiative (YLAI) Fellowship Program empowers emerging entrepreneurs from the Western Hemisphere to enable the full economic potential of the region's citizens. YLAI promotes U.S. business models, increases trade, encourages job creation, and builds lasting and sustainable networks of young entrepreneurs and business and social leaders across Latin America, the Caribbean, Canada, and the United States.

URL: https://www.credential.net/af5ccb94-a7bc-4177-88b3-88d944586ad2#gs.wdy92x

7. Challenges

The last challenge of the project is to be able to organize the results in a clear, concise, and compelling manner, to bring together a story of 3 years of exploration and discovery into Energy Resilience and Microgrids. This involves presenting the data and our arguments in a way that is understandable to a wide range of audiences, including experts in the field and non-experts, with the goal of achieving what should be the main objective of any research project, capacity building.

8. Future Plans

8.1. Research paper in scientific journal

The MG Research is currently writing a research paper called: *Modeling and Simulation of Distribution Networks with High Renewable Penetration in Open-Source Software - QGIS and OpenDSS,* which will be submitted to Engineering, an international open-access journal.

URL: **Manuscript for the paper**

8.2. Additional Funding for research

MESCYT announced the 2022 Call for the National Fund for Scientific and Technological Innovation and Development (FONDOCYT), In this FONDOCYT call, proposals for basic and applied research, Research and Development and innovation (R+D+i) or Technology Transfer will be accepted.

The team will present two proposals:

1. **Design of machine learning models for fraud detection in electrical power systems**

The reduction of operating losses in electrical distribution systems is a critical activity to guarantee the financial sustainability of distribution companies. In particular, non-technical losses (i.e. theft, fraud, billing and measurement errors) are a significant burden in developing countries such as the Dominican Republic, requiring subsidies that make the sector deficit. For this reason, proposing techniques that make it possible to detect

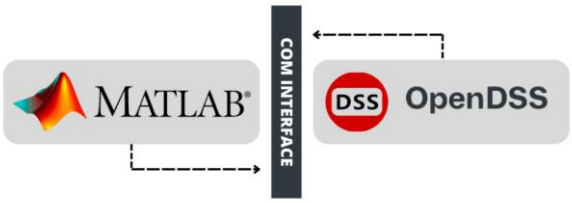
possible fraud with greater precision, is aligned with the Comprehensive Loss Reduction Plans agreed in the Electricity Pact and with the objectives set forth in the National Development Strategy. This project consists of the creation of machine learning models that allow the detection of abnormal patterns in the totalizer database of the EDENORTE distributor. For this, sequential analysis and typical load profiles will be used to identify deviations that indicate the distribution transformer is outside the expected parameters. As an additional element, the design of a power electronics system for disconnection and remote measurement at the transformer level is proposed, which using edge computing principles, allows obtaining phasor measurements and pre-processing the data to be acquired.

2. **Inspection and analysis of in-situ photovoltaic modules in photovoltaic generators using hyperspectral imaging and machine learning algorithms.**

The inspection, analysis and tests necessary to verify the correct operation of photovoltaic modules in large-scale generation plants require a visual inspection, either with field equipment or with the use of unmanned aerial platforms, the latter being the most common. due to the large surfaces of these plants. This inspection is a process that requires a systemic and objective approach, which is why it is necessary to have inspection teams trained with specialized tools; however, issues such as fatigue and repeatability in the execution of this process are important challenges. This raises an important need in the automation and standardization of inspection processes in solar parks, with computer vision systems and the integration of aerial images being a viable solution for this problem. The use of hyperspectral images in the near-infrared spectrum for the detection of anomalies would present an innovative method that would even allow the analysis of additional parameters to the traditional thermographic analysis, in addition to adding machine learning and computer vision techniques to automate this process. This requires the creation of specialized models and the use of adequate preprocessing algorithms that allow the detection of faults in photovoltaic panels. This project proposes the design of a computer vision model based on machine learning to monitor solar panels using hyperspectral aerial images. It is part of a university collaboration network to compare the results with the use of thermographic images.

9. Additional information

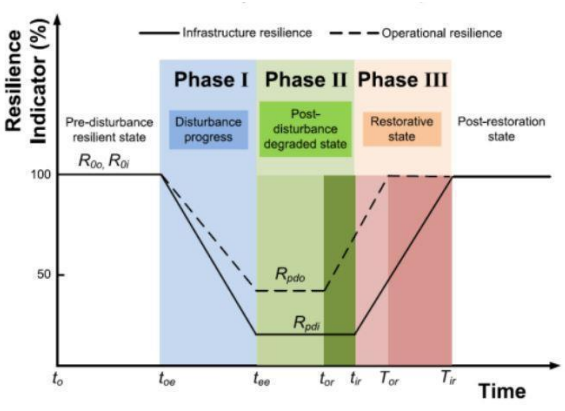
9.1. Research blog



Blog Entry 10 (Feb, 2023) | Implementation of MATLAB-OpenDSS COM Interface for Distribution Network Analysis

In this blog, our research assistant shows how the MATLAB-OpenDSS COM Interface has been broadly used to take advantage of the resources of a versatile and accurate high-level programming language like MATLAB Coding and a fast and easy electrical network simulator like ESRI's OpendDSS, showing how it offers a great simplification and improvement when it comes to advanced functionality and automation.

URL: https://microgrid.pucmm.edu.do/implementation-of-matlab-opendss-com-interface-for-distribution-network-analysis/



Blog Entry 11 (MAR, 2023) | Frameworks for Assessing Energy Resilience in Power Distribution Networks.

In this one the story is #energyresilience frameworks and indices, a key part of the equation of our current research. A lot of voices on industry and academia are certain microgrids enhance resilience, however some challenges are ahead in order to prove it.

URL: **https://microgrid.pucmm.edu.do/frameworks-for-assessing-energy-resilience-in-power-distribution-networks/**

9.2. Research assistant

SUMMARY OF COMPLETED TASKS (JAN-APR 2023)

Date submitted	Completed tasks
Feb-2023	Construction of single-line diagram for VOLG-101 circuit
May-2023	Translation of the VOLG-101 single-line diagram into OpenDSS

TASKS DETAILS:

Construction of single-line diagram for VOLG-101 circuit: To draw a single-line diagram of the circuit VOLG-101 using EDENORTE's QGIS data. Additionally, reducing the number of buses by grouping near-by transformers.

> **Objective:** The single-line diagram will be used as a tool for enabling OpenDSS simulation of the circuit (VOLG-101).

Translation of the VOLG-101 single-line diagram into OpenDSS: Translate the drawing made earlier into different OpenDSS scripts, and run a power flow simulation of the simplified circuit.

Objective: VOLG-101's OpenDSS scripts enable the implementation of the fault detection algorithm mentioned earlier in the document to the circuit.

9.3. References

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[2] “Presidential Policy Directive — Critical Infrastructure Security and Resilience | whitehouse.gov.” https://obamawhitehouse.archives.gov/the-press-office/2013/02/12/presidential-policy-directive-critical-infrastructure-security-and-resil (accessed Mar. 27, 2023).

[3] C. Ji, Y. Wei, and H. V. Poor, “Resilience of Energy Infrastructure and Services: Modeling, Data Analytics, and Metrics,” *Proceedings of the IEEE*, vol. 105, no. 7, pp. 1354–1366, Jul. 2017, doi: 10.1109/JPROC.2017.2698262.

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