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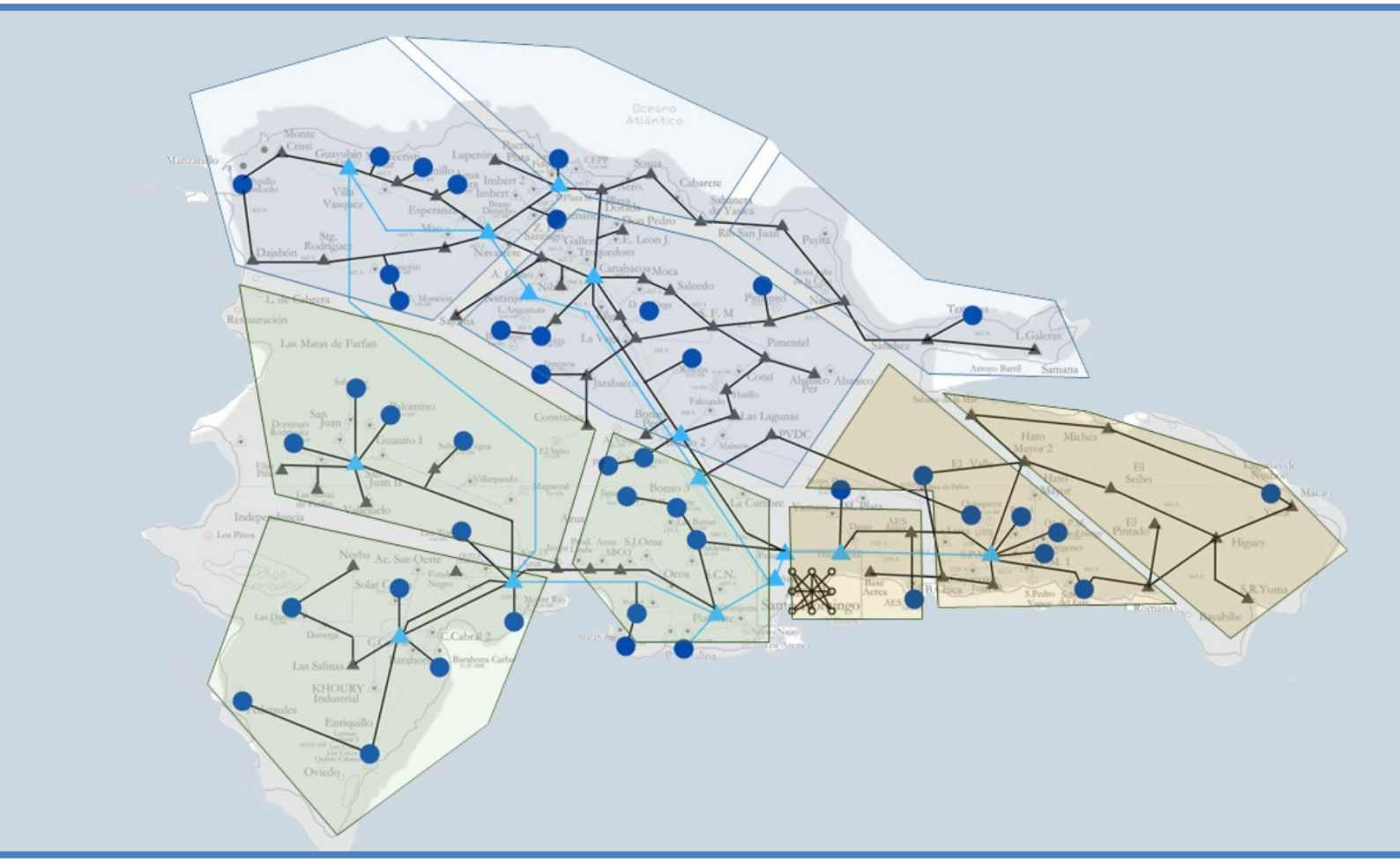

MICROGRID RESEARCH GROUP - PUCMM

RESILIENCY ANALYSIS FOR THE DEVELOPMENT OF MICROGRID ARCHITECTURE AGAINST CLIMATE-DRIVEN EVENTS IN THE DOMINICAN REPUBLIC'S ELECTRIC SYSTEMS

PARTNERSHIPS FOR ENHANCED ENGAGEMENT IN RESEARCH (PEER) PROGRAM - CYCLE 9

FINAL REPORT (15/04/2021 – 15/09/2023)

FOREWORD

This report is based upon work supported by the Partnerships for Enhanced Engagement in Research (PEER) Program, which is funded by the United States Agency for International Development (USAID) and implemented by National Academy of Sciences (NAS) under parent award number AID-OAA-A-11-00012. Any opinions, findings, conclusions, or recommendations expressed in this report are solely those of the authors and do not necessarily reflect the views of USAID or NAS.

This research was led by P.I Ramón Emilio De Jesús-Grullón, C.I Rafael Batista, and C.I Abraham Espinal, researchers from the Microgrid Research Group at the Pontificia Universidad Católica Madre y Maestra (PUCMM), Santiago de los Caballeros, Dominican Republic.

ACKNOWLEDGMENTS

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EXECUTIVE SUMMARY

OVERVIEW

The rapid growth of **grid resiliency research** worldwide is enabling unprecedented opportunities for global collaboration to expand scientific knowledge and to improve the quality of life and well-being of citizens facing the dangers of climate change. This research project is building upon, and expanding on, the knowledge from our partners and academia in this key technology area with the goal of transforming the scientific findings into tools that can generate further education and employment, necessary elements underpinning the economy and improvement of the quality of life in our society.

Recent severe power outages caused by increasingly frequent climate-driven events have highlighted the urgency to improve grid resilience worldwide. Traditionally, the power industry has focused on methods that aim to restore loads by servicing the affected infrastructure and a gradual service restoration after a general blackout. However, when the distribution system is severely damaged traditional approaches cannot guarantee that energy will be supplied to much needed critical loads. Here is **where microgrids (MGs) have emerged as a tool due to the potential to recover in an effective quick manner**, providing an alternative approach to the resilience dilemma. The new paradigm presented by active MG integration to the grid required a robust modelling process and hardware testing, this research tackled both. Using the latest **real-time hardware-in-the-loop (HIL)** simulation platforms allowed for accurate representation of device integration and modeling. To the best of our knowledge, the PHIL testbed built at the Pontificia Universidad Católica Madre y Maestra (PUCMM), campus Santiago, is the first one developed in the country.

Capacity building on this topic is essential to obtain, improve and retain the skills, knowledge, tools, and resources needed to bootstrap the industry in the region and the country.

The testbed not only serves as an educational tool to promote training and learning in this key technology area, but also as a **benchmark for government agencies, communities, and industry looking to integrate Renewable Energy Sources (RES) and resilience into their decision-making process and policies**, and as a test platform for device agnostic energy storage and electric vehicle integration into the energy grid.

OBJECTIVES

The main goal of this research is to create a **hardware-in-the-loop laboratory testbed** in the PUCMM-Santiago campus, where scenario modelling and control techniques related to the improvement of resilience through microgrid formation are evaluated. The laboratory allows for the integration of real-time simulation (us/ns) with physical systems representative of the scenarios that are studied, forming a microgrid laboratory that will be used both for **research and teaching.**

Additionally, simulation strategies based on the integration of **open-source software tools** such as **OpenDSS®** (Open Distribution System Simulator) with open-source Geographic Information System **(QGIS),** are tested for the rapid modeling of real large-scale electrical distribution circuits with distributed renewable generation, with data provided by the regional energy utility (EDENORTE).

Finally, we identified the required steps the Dominican Republic's electrical system stakeholders should considered for **improving the resilience** of the electrical grid under extreme weather events, as well as other identified vulnerabilities.

METHODOLOGY

To effectively perform an analysis on the impact of Distributed Energy Resources (DERs) in the Medium Voltage (MV) and Low Voltage (LV) networks, utilities must first have in place the data necessary to build detailed models of the Distribution Network (DN) components, as well as advanced simulation tools that allow for comprehensive analysis to evaluate system performance and identify potential issues.

Distribution Network Modelling: The project takes advantage of open-source platforms (QGIS and OpenDSS) for the rapid modeling of large-scale electrical distribution circuits with distributed renewable generation. The implementation is based on the adaptation of a tool called QGIS2OpenDSS, which creates OpenDSS distribution network models directly from an open-source geographic information system, QGIS. The plugin's capabilities are demonstrated using a real distribution feeder with more than 60% penetration of renewable generation based on photovoltaic systems. These simulations are carried out using real data from a circuit provided by a Distribution Network Operator (DNO) in the Dominican Republic.

Real-Time Simulation (RTS): RTS of the electric power system are the reproduction of output (voltage/currents) waveforms, representative of the behavior of the real power system being modeled. Our Microgrid Testbed uses the Opal OP5700 Real Time Simulation System paired with RT-LAB to edit, compile, load, execute and analyze models that are fully integrated with MATLAB/Simulink®. This complete simulation system contains a powerful target computer, a high-end reconfigurable FPGA, signal conditioning for up to 256 I/O lines, and 16 high-speed fiber-optic SFP ports, which allows for Hardware-in-the-Loop (HIL) and Power Hardware-in-the-Loop (PHIL) testing for the development, validation, and integration of microgrid control and protection systems.

KEY FINDINGS

The Digitalization Curve

- EDENORTE´s network topology is well maintained using GIS. However, the underlying base maps are not georeferenced, which hinders the ability to integrate this data into another services.

- During the process of exploring the tools and processes used by energy distribution companies in the DR to conduct their network studies, the research team discovered how far behind these institutions are on their digitalization curve and how valuable these tools would be to, for example, study distribution losses, which continue to be one of the most important burdens in the sector.

The Value of Resilience

- After reviewing the worldwide effort to define and measure resilience the team found a range of different methods and frameworks, most of which estimate the avoided costs of power interruptions or propose indicators to guide cost-benefit studies prior to investment planning. However, many of these methods have been applied in academic analyses, but few have been used to directly inform state regulatory or policy decision-making.

Policies to Support Microgrid Development

- Our research showed that there is an increasing number of countries that are supporting microgrid development. In fact, our neighbors in Puerto Rico have enacted microgrid-specific legislation to provide greater certainty to developers, utilities, and state regulators. Broadly speaking, these policies take aim at common barriers to microgrid deployment, including challenges to interconnecting with the larger grid and uncertainty around how microgrids will be compensated for services they provide to a utility.

CONSIDERATIONS FOR DOMINICAN REPUBLIC´S GOVERNMENT INSTITUTIONS

NATIONAL ENERGY COMISSION (CNE), SUPERINTENDENCE OF ELECTRICITY (SIE) MINISTRY OF ENERGY AND MINES (MEM-RD)

INCLUDE MICROGRID REGULATORY FRAMEWORKS IN THE NATIONAL ENERGY PLAN UPDATES

- Study the regulatory frameworks around microgrid development worldwide, looking at case studies for success and challenges faced by other countries in implementing and regulating microgrids
- Establish partnerships between the government and research institutions for joint R&D initiatives on energy resilience and microgrids. This will leverage the strengths of each sector and accelerate innovation.

INTEGRATE THE DISTRIBUTED ENERGY RESOURCES CUSTOMER ADOPTION MODEL (DER-CAM) INTO THE SOFTWARE STACK AT THE CNE

- The software is strongly recommended by most US Energy Agencies when addressing the need for resilience and microgrids, as can be seen in Policy Paper: *Energy Resilience Solutions for the Puerto Rico Grid*, which the U.S Department of Energy (DOE) wrote after hurricane Irma y Maria destroyed Puerto Rico´s energy infrastructure.

CONDUCT STUDIES ON THE INTEGRATION OF AC COUPLED BATTERY ENERGY STORAGE SYSTEMS (BESS) TO PROVIDE ANCILLARY SERVICES TO THE GRID

Regulatory Framework:

- **Clear Regulatory Policies:** Define clear regulatory and tariff structures for the provision of ancillary services. This will provide incentives to investors and stakeholders.

Technology Neutrality in Policies:

- Frame policies in a way that they are neutral to specific technologies.
- Ensure subsidies, incentives, or support mechanisms are not biased towards one specific technology but rather promote desired outcomes.

EDENORTE (AND OTHER EDES)

INCORPORATE MODELING AND SIMULATION SOFTWARE IN DISTRIBUTION PLANNING

Addressing the shortfall in digitization, particularly in the use of modeling and simulation software for distribution planning, is crucial for energy distribution utilities in the age of data. To catch up with the digitization curve, utilities in the DR must embrace a comprehensive strategy that integrates modern software tools, infrastructure upgrades, and continuous skill development.

- Adopt software solutions that cater specifically to the modeling and simulation of renewable energy sources' integration into distribution circuits. Programs such as OpenDSS, GridLABD, or PSS®SINCAL are valuable tools in this domain.
- Ensure the chosen software is scalable and can accommodate the growing complexity of the grid with increased renewable penetration.

GEOREFERENCING AND GIS INTEGRATION FOR IMPROVED EFFICIENCY

EDENORTE´s network topology (including substations, transmission lines, transformers, and other assets) is well maintained using GIS. However the underlying base maps are not georeferenced, which hinders the ability to integrate this data into another sevices.

Georeference Existing Base Maps:

- Engage GIS specialists to georeference existing base maps using known coordinate systems. This process involves linking points on the digital map to known real-world geographic coordinates.
- Utilize control points, or benchmarks, that have known geographic locations to ensure accuracy during georeferencing.

Adopt Standard Coordinate Systems:

- Choose a widely recognized coordinate system (e.g., WGS 84 or UTM) based on the region and the type of projects. This ensures compatibility when integrating with external data or services.

GIS FOR VEGETATION MANAGEMENT AND IDENTIFICATION OF NON-STANDARD INFRASTRUCTURE

49.5% of the interruptions reported in EDENORTE correspond to unknown causes and only 2% to trees on lines. Now, according to the literature reviewed on outages in the utility industry, tree-related outages commonly comprise 20% to 50% of all unplanned distribution outages. So, a large percentage of unknown faults can find their origin in this cause

Comprehensive Database Creation:

- Utilize GIS to create a comprehensive database of vegetation near all energy infrastructure. Ensure this database includes species information, growth rates, and potential hazards to the grid.

Enhanced Spatial Analysis:

- Use spatial analysis to predict areas of rapid vegetation growth based on historical data. This can guide proactive trimming and maintenance activities, ensuring potential hazards are addressed before they become critical.

Optimized Work Routes:

- Leverage GIS to create optimized routes for maintenance crews, minimizing travel time and ensuring urgent areas are addressed promptly.

INTEGRATE HARDWARE-IN-THE-LOOP (HIL) SIMULATIONS FOR NETWORK STUDIES

Integrating Hardware-in-the-Loop (PHIL) simulations can be crucial for energy utilities, especially as they seek to modernize and incorporate new technologies and systems. HIL simulations allow real-world hardware to be tested and validated against a real-time simulation environment, ensuring that new devices and systems are integrated effectively into the existing infrastructure.

EDENORTE can use the capabilities for:

- **Test Grid Modernization Equipment:** Before deploying new grid equipment, such as advanced transformers, breakers, or controllers, validate their operations through HIL simulations to ensure compatibility and performance.

- **Real-time Testing for Grid Emergencies:** Use HIL simulations to recreate potential grid emergency scenarios, such as a sudden drop in renewable energy generation or a major grid component failure. This can guide utilities in developing effective response strategies.

INVEST IN DIGITIZATION AND THE APPLICATION MACHINE LEARNING (ML) ALGORITHMS FOR MASSIVE ANALYSIS OF ENERGY BALANCE DATA FROM AREA METERS (TOTALIZERS) TO REDUCE ENERGY LOSSES

- **Invest in Tehcnology and Data Science :** Manage energy loss through data insights coming from an energy balance system using micro measurements and telemetry to administer, analyze, manage and monitor energy loss control in the basic management

units of the EDE, such as transformers, in an integrated Wide Area Network (WAN).

- **Work on the Association (client – transformer – circuit) in Geographic Information Systems (GIS):** Lack of maintenance of the circuit association field of supplies (customers), currently affect all the data of the intelligence tools acquired for monitoring and loss control.

THE COORDINATION BODY (OC)

Back in 2020, the OC published a SENI Island Operation report, for the Superintendency of Electricity (SIE) and the Energy Ministry (MEM-RD) agents, with the objective of analyzing the isolated operation of each of the SENI areas, based on the potential occurrence of an atmospheric phenomenon, and with the aim of evaluating, for example, partial system restore / black start scenarios.

- Repeat the study considerering the hypothetical scenario of having **BESS with AC-coupled systems**, that allow for ancilliary services from such systems.
- Repeat the study considering the hypothetical scensario of having stand alone BESS in critical subestations, those that link two or more transmission lines, through power switches that connect or disconnect the networks in conditions of failure or maintenance, for example:

DOMINICAN ELECTRICAL TRANSMISSION COMPANY (ETED)

The development of new energy generation projects, especially renewable energy, has been limited by the capacity of transmission networks to transport it to the largest points of consumption. This currently represents one of the main drawbacks when planning the development of new projects and to mark the route to follow in terms of diversification of the generation matrix.

According to the Transmission Expansion Plan (2021-2035), the budget that ETED needs to execute its expansion in the short and medium term to improve energy transmission capacity, regardless of the source of origin, totals an investment of around **800 MM USD** between now and 2030.

ETED issued no objections between 2020-2022 for the interconnection of 5,150 new megawatts, of which 3,562 correspond to renewable energy projects. In fact, 17 large renewable energy plants are under construction (September 2023); with 14 coming into operation by the end of the year. While another dozen projects are in prospective studies for the following years.

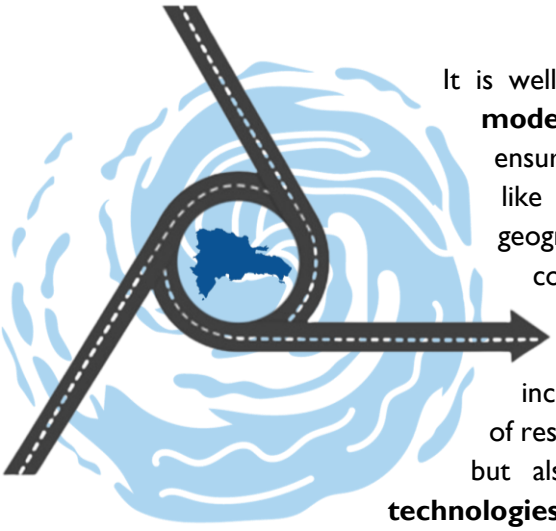
- **Developed Public Private Partnerships:** Prioritize these alliances for the design, construction, maintenance and financing of the needs of high voltage lines and substations close to areas with high wind and solar resources.
- **Update renewable penetration forecasts:** It is necessary to review and continue the expansion plans that contemplate and/or update the renewable penetration forecasts proposed by the International Renewable Energy Agency (IRENA) in 2016 for the country in the next 20 years.

MINISTRY OF ECONOMY, PLANNING, AND DEVELOPMENT (MEPYD)

INCLUDE THE DECENTRALIZATION AND THE FORMATION OF FLEXIBLE ELECTRICAL MARKETS AS A TOOL TO ADD VALUE IN THE NEXT EDITION OF THE MULTI ANNUAL PUBLIC POLICY PLAN

- **Develop Clear Indicators for Decentralization and Flexibility**
- **Capacity Building for Cooperatives:** Foster knowledge exchange programs with successful cooperatives from other countries.
- **Financial Incentives and Support:** Allocate budgetary provisions or financial incentives for cooperatives adopting innovative and green technologies

CONCLUSION



It is well known that a reliable electrical grid is the **backbone of modern society**. It plays a key role in all economic activity and ensures the wellbeing of its citizens. This is especially true for nations like the Dominican Republic, which faces the challengse of geographic isolation and the need for self-sufficiency. Given this context, it is important that the managers, policy makers and regulators of our nation's energy infrastructure explore the technological tools and innovations that allow not only to increase our ability to plan, make decisions and increase the level of resilience of our infrastructure in the face of these types of events, but also have **the technical knowledge to integrate the technologies that will make it possible.**

Drawing on Nassim Nicholas Taleb's ideas about ***'Black Swans'*** (*a metaphor that describes an event that comes as a surprise, has a devastating effect and is often inappropriately rationalized in retrospect*), we argue that to be prepared for the new realities of climate change, the dominican state should priortize a **vision towards resilience** in infraestructure. When talking about resilience in infrastructure, it's important to recognize that we're talking about **systems,** and one way to think of a system is to see it as groups of relationships. A city is a system of relationships between people, businesses, institutions, and infrastructure. So, when a city that has been devastated by a hurricane recovers, no one really care if the power grids, buildings, and bridges are rebuilt in exactly the same way. What matters is whether **the key relationships within the city system remain intact**. *Can the essential people and institutions that made up that system be recovered? Can residents remain in their neighborhoods or are they forced to leave because basic services (**energy, water, communication**) have been affected? Can shops and factories reopen, or are contracts and supply lines broken beyond repair?*

Increased demand for **reliability and resilience** in the shadow of climate change**,** combined with falling Battery Energy Storage Systems (BESS) costs, and the affordability of solar PV, are driving microgrid development across the world. Grasping and understanding these trends is essential for trackling the regulatory barriers and policy needs of microgrids, but even more important, pivotal to support the vision towards the energy transition and it´s 3D´s: **Digitalization, Decarbonization and Decentralization.**

This report is organized as follows:

- **Section 1**: Summary of key activities, impacts and outcomes (timeline)
- **Section 2:** Project Events
- **Section 3:** Research Team
- **Section 4:** Educational Impacts
- **Section 5:** Research Outputs
- **Section 6:** Professional Development
- **Section 7**: Outreach, Collaborations and Development Impacts
- **Section 8**: Open Data Initiative
- **Section 9:** Future Plans
- **Section 10:** Considerations for the Dominican Republic´s Energy Institutions

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