Quality Control Plan for Puerto Rico Electrical and Power Restoration Project

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Abstract *— A year ago Puerto Rico was dark for more than 9 months. After Hurricane Maria struck, federal, local and private corporations were forced to update their strategies due to the intensity of the Category 4 storm. This led Puerto Ricans to learn the importance of planning in our island. The electric power system demonstrated its inefficiency when receiving the impact of such a phenomenon. Deficiencies that were identified, such as the weakness of the electric system and the lack of materials, forced the creation of a Quality Control Plan. There were countless companies providing support in the restoration of the electrical system. Lord Electric Company was committed to the electrical restoration for 6 months, working more than 12 hours a day and 7 days a week. The development and implementation of this Quality Control Plan remained true to Lord Electrical Company's commitment. The philosophy of "Do it right the first time" was the focus of the plan to successfully provide electricity service to thousands of families in Puerto Rico, adhering to the electrical quality standards.*

Key Terms *— Do It Right the First Time, Electric Power System, Hurricane Maria, Quality Control Plan.*

INTRODUCTION

Puerto Ricans will remember September 20, 2017, as the date on which Hurricane Maria unleashed all its forces to the Island of Enchantment. Puerto Rico was hit by the most powerful and catastrophic hurricane of its recent history. In less than 8 hours, the hurricane caused damages unseen by Puerto Ricans in the last 80 years. Hurricane Maria's center crossed the Island from the southwest to the northeast as a Category 4. The driving reasons for this investigation are the destruction of 80% of the electrical infrastructure of Puerto Rico and the complete halt of electrical generation.

In this investigation you will find the historical context that was met by the passing of Hurricane Maria in Puerto Rico, the effects of the electric service provided by and the measures implemented by Lord Electric Company for the restoration of the electrical system. The purpose of this project is to present the Quality Control Plan developed by the Lord Electric Company after Puerto Rico was declared to be in state of emergency.

EFFECTS OF HURRICANE MARIA IN PUERTO RICO

Hurricane María, Category 4 on the Saffir-Simpson scale, with sustained winds of 155 MPH crossed the southeast coast of Puerto Rico near Yabucoa around 6:15 am on September 20, 2017 (Figure 1). Maria is the strongest hurricane to hit Puerto Rico, since Category 5 Hurricane San Felipe Segundo in 1928. Just before Maria made landfall in Puerto Rico, the eye wall replacement cycle underwent a change in which a new eye developed around the initial one. Once completed, the intensity of hurricane Maria decreased from Category 5 to Category 4 and the eye wall that resulted was approximately three times the diameter of the initial one (Figure 2), from 9 nautical miles to about 28 nautical miles (Figure 3). The eye's increase spread the hurricane force winds out over a larger area [1]. As a result, large part of Puerto Rico experienced the strongest winds. Once Maria's eye reached land, the extreme winds were able to get measured just until the winds destroyed the WSR-88D radar in Puerto Rico. This radar is one of the most powerful and advanced weather surveillance Doppler radars in the world (Figure 4).

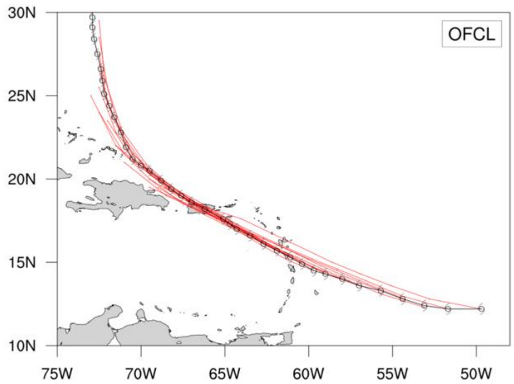

Figure 1
Official Track Forecasts for Maria

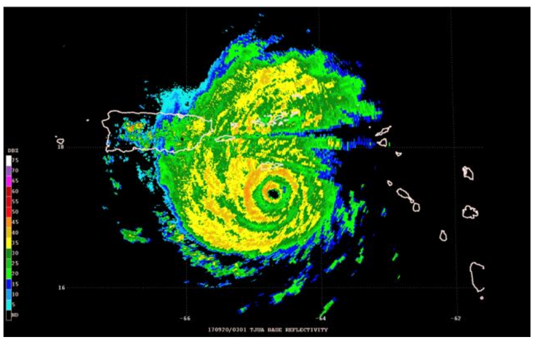

Figure 2
Beginning of an Eyewall Replacement

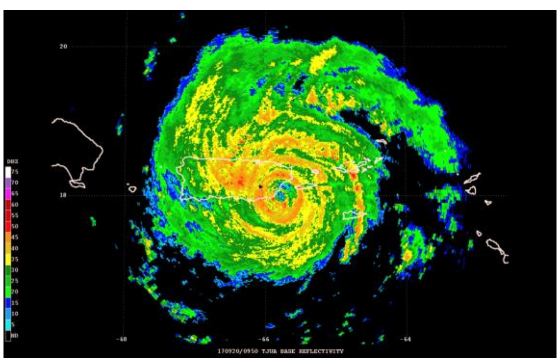

Figure 3
After of an Eyewall Replacement

Figure 4
WSR-88D Radar after its Destruction

Surge, Rainfall and Floods

The maximum water levels were being monitored by the United States Geological Survey (USGS) and the National Ocean Service (NOS), which managed to measure maximum water levels of 1 foot to 9 feet on the Island, before the sensors logged off. The combined effects of rain, swell and tide produced maximum flood levels of 6 to 9 feet above ground level along the coasts of the Humacao, Naguabo and Ceiba municipalities in Puerto Rico (Figure 5). Hurricane Maria crossed the Island with sustained winds and torrential rains, causing the overflow of the rivers Grande de Loíza; Grande de Manatí and Grande de Arecibo; La Plata, between Comerío and Bayamón; Cibuco, in Corozal; Espíritu Santo in Rio Grande; and others in Guayama, Las Piedras and Puerto Nuevo. Floods in almost 78 municipalities caused widespread anguish and devastation. The discharge of the rivers in many parts of the island reached record levels. Severe floods and mudslides affected the Island and all of its infrastructure.

Figure 5
Storm Surge Inundation (feet above ground level)

Damage Statistics

Winds, rain and floods devastated Puerto Rico. The combined destructive power of the wave of storms and the action of the waves caused extensive damage to the flora, fauna and infrastructure of Puerto Rico. The National Oceanic Atmospheric Administration (NOAA) estimate the damages in Puerto Rico in 90 billion dollars, with a 90% confidence range of +/- $65 to $115 billion, which makes María the third most expensive hurricane in the United States history. The Department of

Housing in Puerto Rico and the Federal Agency for Emergency Management (FEMA) reported the destruction of between 25,000 and 30,000 homes (Figure 6) [2].

María affected 80% of Puerto Rico's utility poles and all transmission lines. This situation caused power loss for the 3.4 million residents of the island. The day after the hurricane struck, only seven hospitals throughout the Island were operational, as they were equipped with emergency generators. Since 92.7% of telecommunications towers were damaged, all 78 municipalities were cut off from communication. The Luis Muñoz Marín International Airport also suffered serious damages. Only one of its tracking radars remained in operation. Landing and take-off flights were restricted for 11 days. The ports were closed due to the destructive weather effects, causing a delay in the arrival logistics of the aid sent to the Island. By the end of 2017, almost half of the residents of Puerto Rico still had no electricity. In January 2018, electricity had been restored in approximately 65% of the island. Eight months after Hurricane Maria, the Puerto Rico Electric Power Authority (PREPA) announced that it had reached 99.04% electrical generation capacity.

Figure 6
Effects of Maria in Morovis

ELECTRIC POWER SYSTEM IN PUERTO RICO

Electricity was implemented in Puerto Rico with the first private electric power system installed by Don José Ramón Figueroa in the year 1893, in the municipality of Villalba. After this important event for the Island, two 120-volt generators were installed on a hydraulic turbine in Utuado in 1897, with the goal of providing power service to their clients. Drawing on the success of the hydraulic turbine system, the government created the Law of Service of Irrigation of the South Coast in 1908. The law was created to develop systems for providing necessary water and reaching its maximum agricultural potential for the public development of electricity. As part of the irrigation system, in 1915 three reservoirs were built in Patillas, Guayama and in Juana Díaz. From 1893 to 1915 all electricity in Puerto Rico was produced by private companies. The production and distribution of electricity began in 1915 with the government's hydroelectric power plants, the Carite Hydroelectric Power Plant # 1 and # 2. Each year the electrical system made great advances, 1915 was also the year that electrical lighting systems were installed in San Juan and Mayagüez. All installed systems had a limited capacity, providing electric service to the main streets of the town.

The explosive growth of the demand for electric power brought about the creation of the first independent governmental agency, called "Autoridad de Fuentes Fluviales" (AFF). Created under law 83, on May 2, 1941, its purpose was promoting the hydroelectric development and administering the South Coast Irrigation System. The AFF acquired the Puerto Rico Railway Light & Power, which operated in the north and the Mayagüez Light, Power & Ice, with the goal of centralizing power services and gaining more strength. Unfortunately, due to the exploitation of agricultural resources, in 1946 the hydroelectric resources had reached their maximum capacity, causing the electrical system to overcharge. Generation deficiency led to the acquisition of the 30,000-kilowatt Sea Power floating plant, which stabilizes the delivery of electricity. The population was still increasing, so the AFF signed a contract with the United States Rural Electrification Administration to grant them a loan for the construction of the power lines in the rural area of the Island. The use of Fossil fueled power began in 1950. During the decade of the seventies, the AFF experienced the last stage of expansion in its generating system. At that time, crude oil by-products produced 98% of the electricity consumed by the Island, compared to only 2% hydroelectric power generation. In 1979 through Law no. 57, the AFF changed its name to the Puerto Rico Electric Power Authority (PREPA,) because the hydroelectric power generation was no longer the main energy source to supply the electricity in Puerto Rico [3].

Type of Energy System

In Puerto Rico the fossil fuel power generation is the predominant energy source. In the twenty-first century the private generation of energy has increased on the Island. This however has not translated a change in the production model, 98% of generation in Puerto Rico depends on fossil fuels. In the Island, oil dominates production with 47.6%, natural gas has seized 33.7% and coal is the third most used resource with 16.8%. The island is affected in numerous ways by the metric tons of carbon dioxide produced by the power plants, causing environmental damage. PREPA has become a facilitating entity for the development and safe integration of energy from renewable sources. Although this is the alternative recommended by environmental experts, it is not yet developed on the Island. The goal is approximately 20% renewable generation in 2035 [4]. Prior to hurricanes Irma a Maria, PREPA had executed more than 60 large-scale renewable energy contracts. Unfortunately, many of these contracts were affected by the passage of Hurricane Maria, delaying the implementation of renewable energy alternatives.

Distribution and Transmission Systems

PREPA's electrical system is composed of two phases of power generation, transmission and distribution, responsible for distributing power to 1,449,211 customers. PREPA generates approximately 2/3 of its electricity and purchases the rest from third parties. PREPA's energy generation is mainly concentrated in four main power plants: Central San Juan, Central Costa Sur, Central Palo Seco and Central Aguirre. The capacity of these power plants is 5,839 MW, distributed amongst the plants owned by PREPA (81.7%), the fossil-fueled private plants (16.03%) and the industrial-scale renewables (2.27%).

The PREPA transmission system has the main lines to distribute power. This consists of 2,478 miles of transmission lines that carry power from generation stations to 334 transmission and sub transmission stations. The high voltage lines operate at 230KV, 115KV and the sub transmission lines at 38KV. The backbone of the transmission system consists of 230 kV overhead lines that form three loops around the island [5]. The transmission network crosses from south to north, the 230-kV network is connected to an extensive 115-kV network system that supplies power throughout the island. The distribution lines total around 31,446 air miles and 1,723 underground miles in urban areas. The circuits of the distribution lines work with voltages ranging from 4kV to 13kV [6]. Part of this distribution system is made up of 293 substations around the Island.

Energetic System after the Hurricane Maria

Hurricane Maria caused the total collapse of the transmission and distribution systems. The strong winds, torrential rains and landslides exceeded the structural capacity of the electric power system. 200 transmission system towers and approximately 50,000 distribution poles (Figure 7) were affected. The main challenge of repairing the electrical grid in Puerto Rico was the restitution of the transmission and distribution lines. The entire island was dark, the repair process was slow due to a shortage in both materials and personnel to rebuild the power grid. Due to the lack of logistics, the assignments became affected causing it to take more than 8 months in the restoration of the power grid for the 78 municipalities.

Figure 7
Damaged Poles in Barceloneta

THE CRISIS GENERATES JOBS

After Hurricane Maria, all the electric power brigades were performing assessments to corroborate the damages that had occurred. Because of the magnitude of the damage, PREPA needed support to repair the electricity network. Puerto Rico was assisted by federal agencies to reset the island. The U.S Army Corps of Engineers (USACE) provided support to PREPA and was responsible for hiring companies to advance the stabilization of the electricity system. PREPA and the USACE's greatest challenge was to satisfy the great demand for power, especially in the north of the island, while generation occurs mostly in the south. PREPA and USACE reported that electric service would take months to be reestablished. The repair of the electrical system was carried out in four phases, according to the USACE:

- First phase: provide energy and temporary generation to critical places.
- Second phase: ensure adequate generation in power plants.
- Third phase: restore and repair the transmission lines.
- Fourth phase: restore and repair the distribution lines.

The USACE granted $400 million in contracts to companies in the electrical sector to support the restoration of electric service, one of the hired companies was Lord Electric Company. During the repair of the electrical system, the biggest obstacle was the logistics involved in transporting equipment, materials and specialists into the Island. Due to the urgent need to reestablish the electrical system, many materials had to be reused since they were not arriving to the Island. The lack of new materials forces the USACE to request a Quality Plan from the subcontracted agencies. Lord Electric's Quality Control Plan was based on electrical quality standards.

QUALITY CONTROL PLAN

Lord Electric Company developed the Quality Control Plan in accordance with its general philosophy of the Quality Program, based on the Total Quality approach: "Do it right the first time" or "DRIFT" [7]. Training and planning took priority over detection and correction of electrical systems. Procedures were developed to ensure compliance with electrical quality standards, contract requirements and good construction practices. This Plan, together with the USACE Quality Control Program Plan and the Contract Documents, served as the quality standard for Lord Electric Company and his subcontractors. All personnel assigned to work with Lord Electric Company complied with the procedures and requirements of this Quality Control Plan.

Process Control Procedures

Lord Electric Company guaranteed that this project was carried out under controlled conditions and planned and inspected installation processes. The Project Manager (PM) and Quality Control Manager (QCM) prepares Construction Work Plans (CWP) for each phase of the project. Each Construction Work Plans includes instructions, descriptions of the methods used to carry out the work, and personnel training, so that the work met the quality requirements. The Construction Work Plan defined how the work of the overall project should be carried out and approved. When carrying out the construction process plan, meetings with key personnel, subcontractors and suppliers were arranged. The tool used to determine the quality assurance was the PDCA (Plan-do-check-act) model [8] (Figure 8) which stands for:

- Plan - Establish objectives and procedures required to deliver the desired results.
- Do - Implement the procedure developed.
- Check - Monitor and evaluate the implemented procedure by testing the results against the predetermined objectives.
- Act - Apply actions necessary for improvement, if the results require changes.

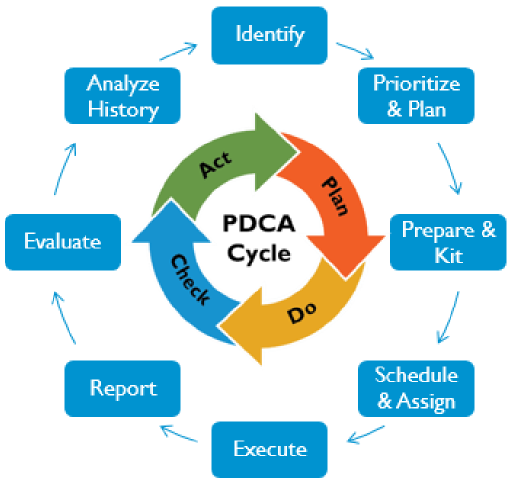

Figure 8
PDCA Cycle

Planning Stage

Before starting an activity, the Quality Control Manager performed the following procedures:

- Reviewed the contract requirements
- Verified that all materials that were to be used had been sent, approved, tested and delivered.
- Verified that all procedures, calculations and other requirements were submitted and approved.
- Held a pre-construction meeting with the field staff.
- Checked the inspection and test form for this activity.
- Conducted a site inspection.

Inspection

The inspection was carried out during all phases of the project to ensure that the work performed was in accordance with the contract requirements and quality specifications. Items that required inspection or testing were identified through the appropriate means. Checklists or inspection guidelines were provided for the different construction activities. The Quality Control (QC) staff were required to document these inspections in the Surveillance Report. This procedure specified the methods that were used to identify, perform, document and track quality surveillance activities. The inspections were carried out internally to verify the quality of the work in progress and which tasks were carried out in accordance with the requirements of the project.

The work had to comply with the PREPA quality standards, otherwise Lord Quality Control Manager would issue a nonconformity report and would begin a corrective action process. The main objective was to quickly identify the facts that can somehow affect the quality of the project. Provisions and corrections could be made by the Quality Control Manager at this stage without major complications in meeting the project's requirements. Progress inspections were performed daily, or as required by its progress, on each definable feature of the project:

- Initial assessment of damages that occurred in the distribution line.
- Analyze the best route to start working according to the materials available.
- Verify the materials available for use and their condition.
- Perform the installation methods in accordance to quality and safety standards.
- Perform pre-commission and start-up testing on equipment.
- Perform the energization.
- Inspect after the energization.

The Quality Control Manager will perform inspections at the completion of each activity along with the Owner or a representative. Lord Electric Company monitoring complements the formal quality control audits and is also used to verify the proper completion of the specified corrective actions, if necessary.

Non-conformance Controls

This procedure describes the process for identification, documentation, evaluation, segregation and disposition of nonconforming items identified during the Puerto Rico Electrical and Power Restoration Project. This procedure establishes the mechanisms for processing non-conformances works as per Quality Control Plan. If non-conformance is identified by an inspection, there is a systematic method to control, correct and ensure that project quality is not adversely impacted by the event. Non-conformance is any work that does not meet project specifications or Lord Quality System requirements.

Identification of the Non-conforming Condition

The worker identifying the non-conforming condition documents the description and signs the Non-conformance Report "NCR". The NCR is forwarded to the Contractor Quality Control Manager for processing. The Contractor takes immediate corrective action once notified. Such notice, when delivered to the Contractor at the work site, was deemed enough. If the Contractor fails or refuses to comply promptly, the Contracting Officer is to issue an order to stop all or part of the work until satisfactory corrective action has been taken.

Disposition Implementation and NCR Closure

When the Quality Control Manager receives a Nonconformance Report, he assesses the effect of the reported non-conformance. The Quality Control Manager would assign a disposition of either:

- Replacing: The non-conformance can be brought into conformance with the original specification requirements by replacing the nonconforming product or material with a conforming product or material.
- Repair: The nonconformance can be brought into conformance with the original requirements.

Every QCM is responsible of any repair and replacement to comply with every construction standard.

Initiation and Issuance of Corrective Action Requests (CARs)

Conditions adverse to quality would be processed in accordance with the following paragraphs. Significant conditions adverse to quality or repetitive violation of quality requirements would be documented on a Corrective Action Request (CAR) form. The requirement that was violated would be listed in the space provided and the adverse condition clearly and concisely described. Recommendations for correcting the condition is also to be detailed in the space provided on the CAR form. After completion of this information, the CAR form is to be forwarded to the Contractor Quality Control Manager.

The CAR would be reviewed by the Contractor Quality Control Manager to determine that the adverse condition is clearly described and valid. If the condition is valid, a unique number was assigned to the CAR and then the number were logged into a CAR log. A required response date to the CAR was also established. The normal response time was ten working days, but this time was adjusted (increased or decreased) depending upon the criticality and complexity of the adverse condition. The CAR was then forwarded to the responsible organization for resolution of the adverse condition.

Corrective Action Response

The following processes were used to implement the Corrective Action. They included, among others, the following:

- Investigate the root cause of the breach and determine the corrective action necessary to avoid repetition.
- Analyze the processes, work operations, customer complaints and non-conformance reports to detect and avoid potential problems.
- Apply controls to ensure that the corrective action is implemented and is adequate to solve the problem.
- Document, review, and report results for effectiveness.

The responsible organization received the CAR, investigated the adverse condition, and determined what actions were required to resolve the condition. Based upon the results of the investigation, the responsible organization determined the following:

- The cause of the adverse condition.
- The extent of the condition.
- The actions that are to be taken, along with a schedule for the actions, to resolve or correct the adverse condition.

The responsible organization would respond to the CAR, addressing each of the above points by the response date specified by the Contractor Quality Control Manager. If the responsible organization was unable to respond by the date specified, they could request, in writing, an extension to the response date. The response was evaluated by the Contractor QCM and, if acceptable, is approved. If not deemed acceptable, an amended response was requested from the responsible organization.

Corrective Action Verification and Closure

Upon completion of the actions specified by the responsible organization in the approved CAR response, the Contractor Quality Control Manager or his designee would verify that the corrective actions were properly implemented. This verification would take the form of document reviews, surveillance, or audit as appropriate. Upon satisfactory completion of this verification, the CAR shall be signed off and closed.

Electrical Transmission and Distribution Lines Acceptance Procedure

The acceptance procedure for the power distribution lines will be carried out after the line is certified by the QCM. This standardized procedure established the process for turning the completed lines over back to the Puerto Rico Electric Power Authority (PREPA):

- Completed construction and repair work as described in the assessment report.
- Contractor quality control inspection shall be completed, and accepted, prior to proceeding with further procedure steps.
- Contact with PREPA's personnel was made and inspection of line segment was requested.
- PREPA completed inspection and delivered inspection report.
- Any deficient items noted in the inspection report were corrected prior to proceeding with energization of the line.
- In coordination with Customer and PREPA, all grounds, locks, tags and flags were removed from completed system.
- Upon final signatures, Contractor released custody and control back to PREPA.

Case of Study

The work on the electrical lines that was carried out required a visual inspection of the distribution and sub-transmission circuits for each energization. To avoid electrical risks, Occupational Safety and Health Administration (OSHA) measures were applied when all the segments energized by the circuit breaker were closed and in the high voltage line opening.

During the inspections, any conditions that may represent a danger at the time of activation, were detected such as:

- Sunken or fallen conductors
- Not grounded circuit
- Portable / temporary land
- Active work in the circuit that will be energized.

If any conditions mentioned above were the case of the working site, the cancellation of work orders would be the procedure taken to prevent and avoid any risk.

The Surveillance Report (Figure 9) is the backup documentation that supports daily inspections. This detailed individual report was made for each electrical line that was worked on and to which all the PREPA standards were applied to individually. If any disagreement occurred, it was also detailed in the report to carry out the corrective action 10 days before the non-conformance report was emitted. This report was made by Surveillance Personnel and approved by the Quality Control Manager.

SURVEILLANCE REPORT				ID A0006-8801-04
Location: Morovis	**Subcontractor/Activity: Repair**	**Date 12/31/17**	**Completed Work** ☒ Yes ☐ No	**Report No. PR-06**
W.O Number: 1483	**Substation: Arecibo, Manati**	**Feeder 8801-04**		**Voltage 8.32kV**

Inspection Checklist, Specification, Or Drawing Used As Reference:

- Section 26. Part 2.1 – "Patrones de Construcción Aérea", Salvaging of materials.
- Section 4.16/8.32 Spacer Cable S2, 366mcm ACSR - "Patrones de Construcción Aérea", CP-B1, M1-2.
- Section 26. Part 2.1 – Wood Pole, T-1 "Patrones de Construcción Aérea"
- Section 26. Part 2.1 – Concrete Pole, T-1, AC-M-2, "Patrones de Construcción Aérea"

RESULTS: Follow-up Required ☐ Satisfactory ☒

Description Of Item/Work Inspected/Observed:

- It was verified that the auxiliary bar and open breaker was open
- Test grounds installed
- Clearing of Work Areas,
- Straightening/Removal of Broken Poles
- Salvaging of Materials if Possible
- Three (3) metal pole where straightened
- One (1) guy wire was installed
- Safety grounds were removed from conductors.
- Feeder 04 can be energized Urb. Barahona to Urb. Valle San Luis, 1,000 residences.

Observations/Deficiency:

- No deficiency was observed or found.

Person Notified Of Deficiency N/A (Name) N/A (Title)

Recommended Corrective Action:

- N/A

Corrective Actions Implemented/Accepted:

- N/A

Project Manager / 31/Dec/17 — Surveillance Personnel/Date

Zuleika Pérez Lorenzo/ 31/Dec/17 — Site Quality Manger/Date

Figure 9
Surveillance Report

The Surveillance Report in Figure 10 was carried out on December 31, 2017. The extensive work, over the span of over two weeks, on the electrical lines of Morovis and the completion of the inspections that were carried out by professionals, concluded with the goal of energizing more than 1,000 customers on New Year's Eve. After the approval of the quality standards required by PREPA, USACE and subcontractors, power was back up after 8:00pm.

CONCLUSION

The evident climate changes demand that Puerto Rico have a quality plan that addresses environmental resources. That is one of the reasons that Hurricane Maria arrived with such high intensity. As time passes, the atmospheric systems will be stronger. Because of this, it is imperative to establish island-wide Emergency Plans, including a detailed Quality Control Plans for private companies as well as the governmental agencies of the Commonwealth of Puerto Rico. The development of such plans must include all the basic services, such as Electrical Services, Water Services, Communications, Health Services, debris disposition, among others. In the Puerto Rico Electric Restoration Project, Lord Electric Company supported the quality control plan and procedures established and required by USACE and PREPA, guaranteeing the safety and general quality of the project. Lord is committed to a policy of "zero defects" as the standard for management. The purpose of the Quality Control Plan is to ensure that all work meets or exceeds the requirements. Non-conforming work has a cost for both our clients and the company. Satisfying customer requirements is necessary for giving a positive attitude towards non-conformity or the prevention of defects, based on the firm belief that things can be done right the first time.

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