Identifying Problems in Puerto Rico's Electrical System due to Distributed Generation

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Abstract *— The rapid evolution of distributed generation (DG) technologies has revolutionized the landscape of power generation, distribution, and consumption. The concept of distributed generation and feeder cluster studies has gained significant attention as a promising approach to enhance the resilience, efficiency, and sustainability of power systems. This paper presents a comprehensive review of distributed generation cluster studies, aiming to provide insights into their input to the electric system, problems, and a clearer view on how to solve these issues due to these photovoltaic system projects. Several platforms were used to accomplish this methodology which had specific ratings and characteristics. As found in the studies, many feeders had electricity ratings violations regarding Puerto Rico's electrical standards. The proposed mitigations to solve these issues should improve the electrical service.*

Key Terms *— Distributed Generation, feeders, mitigations, violations.*

INTRODUCTION

Since Hurricane María hit Puerto Rico, the electrical system was down for nearly 11 months. This event made people choose a better and reliable source of backup power during outages. Photovoltaic (PV) systems, which convert sunlight directly into electricity, offer numerous benefits that span environmental and economic dimensions. However, with a poor electrical grid and poor planning, it will lead to problems in the system.

This project is based on finding the impact which distributed generation causes to Puerto Rico's electrical grid. Distributed generation are renewable projects and, in this case, photovoltaics that once generate all the energy from the sun to its full capacity, start to flow backwards to the grid and there's when one of many problems arrives. To study many of these projects to determine which is impacting the system negatively, they are divided into feeders which are the electric ramifications that provide electricity to homes. Performing the studies will identify the problems to mitigate and further correct those violations while also determining who caused the violation.

CAUSES OF VIOLATIONS

An electrical feeder is a fundamental component of an electrical distribution system that carries electrical power from a substation or primary distribution network to individual customers or loads. It serves as an intermediary link between the distribution network and the end-users, delivering electricity to homes, businesses, industrial facilities, and other consumer premises. When the feeder exceeds 15% of DG penetration, it's when a cluster study must be conducted.

Feeder to study

To identify an electrical feeder that exceeds a 15% penetration of DG involves the following steps:

- **Data Collection:** Gather relevant data on the electrical feeder, including information on the total load demand, existing distributed generation capacity, and locations of DG installations. This data may be obtained from utility records, smart meters, customer surveys, or distributed energy resource (DER) databases.
- **Calculate Distributed Generation Penetration**: Calculate the percentage of distributed generation penetration on the feeder. This can be done by dividing the total capacity of distributed generation connected to the feeder by the total load demand on the feeder and multiplying by 100.

$$Penetration\ (\%) = \left(\frac{Total\ DG\ Capacity}{Total\ Load\ Demand}\right) x100 \quad (1)$$

- **Assess Load Variability:** Evaluate the variability of the load demand on the feeder. Fluctuations in load demand can impact the integration of distributed generation and may require additional measures to maintain system stability.

Exceeding the Capacity of the Transformer

Exceeding the capacity of a distribution transformer occurs when the demand for electrical power from the transformer surpasses its rated capacity. This violation can have several consequences, both immediate and long-term, which affect the reliability, efficiency, and safety of the electrical distribution system. Transformers with open-delta connection must have 87.5% of its capacity in use to catalog it as a transformer that reached it maximum load capacity [1]. Distribution electrical transformers are manufactured with different connection types and capacities depending on the location where are going to be installed. The capacities of these distribution transformers are in kVA units and strictly related to volts and load amperes, as shown in Table 1.

Table 1
Distribution Transformer's Ratings

kVA	Rated Line-to-Line Voltage							
	208	220	240	380	400	416	480	600
3	8.33	7.87	7.22	4.56	4.33	4.16	3.61	2.89
6	16.7	15.7	14.4	9.12	8.66	8.33	7.22	5.78
9	25	23.6	21.7	13.7	13	12.5	10.8	8.66
15	41.6	39.4	36.1	22.8	21.7	20.8	18	14.4
30	83.3	78.7	72.2	45.6	43.3	41.6	36.1	28.9
45	125	118	108	68.3	65	62.5	54.1	43.3
75	208	197	180	114	108	104	90.2	72.2
112.5	312	295	271	171	162	156	135	108
150	416	394	361	228	217	208	180	144
225	625	590	541	342	325	312	271	217
300	833	787	722	455	433	416	361	289
500	1388	1312	1203	760	722	694	601	481
750	2082	1968	1804	1140	1083	1041	902	722
1000	2776	2624	2406	1519	1443	1388	1203	962

Voltage and Current

Voltage and current violations in Puerto Rico due to (DG) can arise from various factors, including the rapid deployment of renewable energy systems, such as solar photovoltaic (PV) installations, without adequate planning, grid integration measures, or regulatory oversight. Some common issues leading to voltage and current violations include:

- **Voltage Rise**: Excessive penetration of rooftop solar PV systems in certain areas can lead to voltage rise beyond acceptable limits. During periods of high solar generation, when the local demand is low, voltage levels may increase due to reverse power flow from the PV systems back into the distribution grid. This can cause overvoltage conditions, posing risks to equipment and affecting the operation of sensitive loads.
- **Voltage Fluctuations**: Variability in solar PV output, caused by factors such as cloud cover or shading, can result in rapid fluctuations in voltage levels on distribution feeders. These voltage fluctuations may lead to voltage flicker or instability, impacting the quality of power supply and affecting the performance of connected devices.
- **Voltage Imbalance**: Distributed generation, particularly from single-phase rooftop solar PV installations, can contribute to unbalanced voltage conditions on three-phase distribution feeders. Voltage imbalances can lead to uneven distribution of power across phases, causing increased losses, reduced efficiency, and potential overheating of equipment.
- **Current Overloading**: In areas with high concentrations of distributed generation, distribution feeders may experience increased current loading beyond their rated capacity. This can result in overloading of conductors, transformers, and other distribution equipment, leading to elevated temperatures, voltage drop, and reduced system reliability.
- **Protection Coordination Issues**: The integration of distributed generation can present challenges in coordination between protective devices, such as fuses and circuit breakers, on distribution feeders. In the event of a fault or abnormal condition, improper coordination can lead to delayed fault clearing, extended outages, and compromised safety of the distribution system.

METHODOLOGY

After determining which feeder will be studied taking into consideration its voltage, demand, ratings, DGs and its penetration percentage level a study was made.

Preparation of Circuit Model

A digital model is done in all its parts representing the reality of what is on the field regarding the feeder in study. The amount of DG projects, its capacity, quantities of transformers, number of conductors and its ratings, the distance in electrical miles of the feeder, must coincide with what really exists. The cluster study basically means that all DG projects from the same electrical feeder will be evaluated at the same time.

Violations and Mitigations

Once a feeder is studied, there will probably be violations as the ones mentioned earlier. These violations don't mean that are caused by DG projects, they could also be triggered by substation misbehavior, load transfers, disconnected lines due to atmospheric events, and many more activities that engage the electrical system to failure. This is why the study is performed with the DG turned off and then turned on, to determine if it's caused by the photovoltaic systems connected to the electrical feeder. Once a violation is found in the simulation, the projects involved in it will be taken into consideration to determine whose fault it is. When the problem is found, a mitigation to this violation is also determined to properly correct the issue and gain back the best electric quality service to the customers.

RESULTS

A total of 546 feeders were studied in all its parts in which only 226 had violations due to DGs. The boxes to check to determine if it had violations due to DGs was if it needed a distribution transformer upgrade, if the primary system needed an upgrade triggered by voltage violations, and if it was triggered by thermal overload. 206 of these feeders were identified to be violating the distribution transformer upgrade, 35 by voltage violations and 5 by overloads. These studies demonstrate that from the studied feeders that had violations due to DG projects, some of them had one or more violations at the same time.

Only 41% of these feeders have violations due to DGs, meaning that photovoltaic systems also contribute a negative impact to the reliability of the electrical system. Most of these violations were related to DG projects exceeding the maximum capacity of the distribution transformer in which are interconnected. Nonetheless, the violations found in every cluster study must be confirmed in the field by performing a validation assessment. With the completion of these studies, a better overview on the electrical system is shown. Every feeder, including the ones that didn't have any type of violations regarding DGs, are analyzed and recommendations are given about how much more generation is accepted between each of them to achieve a the planned hosting capacity.

REFERENCES

[1] PR Energy Board, PREB. (2019, July 5). *Regulations to interconnect generators with the electrical distribution system of the Electric Power Authority and participate in the Net Metering Programs.* [letter]. Available: https://energia.pr.gov/wp-content/uploads/sites/7/2019/07/20190705-OIPC.pdf