Interconnection of a 13.2 kV Primary Distribution Feeder to Reduce Loading at Substation 5004

George M. Muniz Alvarado
Master in Engineering Management
Dr. Hector J. Cruzado
Graduate School
Polytechnic University of Puerto Rico

Abstract *– This project evaluated and implemented a primary feeder interconnection at 13.2 kV to reduce the electrical loading of Substation 5004 Ramblas in Ponce, Puerto Rico. Operational studies indicated that the substation was operating at approximately 96% of its nominal capacity, exceeding recommended operating limits and increasing the risk of transformer degradation and service interruptions. A feeder interconnection was designed to transfer part of the load to an adjacent distribution feeder with available capacity. Load flow simulations and distribution design validation were performed using PoleForeman and ArcGIS system data to verify the feasibility of the proposed configuration. The results demonstrated a reduction of approximately 4 MVA of load, equivalent to a 19% decrease in transformer loading, lowering the operating level from 96% to approximately 77%. The project also enabled the interconnection of a new 1 MVA commercial load while maintaining acceptable operating margins. The final design complied with distribution engineering standards, operational requirements, and system resilience considerations. The project was implemented within the existing right-of-way, avoiding legal acquisition processes and remaining within the established project budget of $500,000, with a final cost of $474,743.88. The feeder interconnection improved distribution system reliability, enhanced load management capability, and extended the operational life of the substation transformer.*

Key Terms - *Distribution Substation, Distribution System Reliability, Load Management, Primary Feeder Interconnection*

INTRODUCTION

The electric power distribution system in Puerto Rico has faced increasing operational challenges resulting from load growth, aging infrastructure, and the integration of new residential and commercial developments. These conditions have required continuous evaluation of existing substations and primary distribution feeders to ensure system reliability, service continuity, and compliance with operational standards. Distribution engineering activities have therefore focused on identifying capacity limitations and implementing technically feasible solutions to support sustainable system operation.

In the municipality of Ponce, Substation 5004 Ramblas served a highly commercialized area with significant electrical demand. Internal operational studies indicated that the substation was operating at approximately 91% of its nominal capacity of 23 MVA, exceeding the recommended operating threshold of 75% established by the equipment manufacturer. Sustained operation at this loading level increased the risk of accelerated transformer aging, reduced equipment service life, and compromised system reliability, particularly during peak demand periods and adverse weather conditions.

In addition to the existing loading conditions, multiple new service requests from hotels, residential developments, and commercial centers were identified within the service area of Substation 5004. The available infrastructure was unable to support these additional loads without further increasing the risk of service interruptions. As a result, the redistribution of electrical load through system reconfiguration was identified as a necessary measure to improve operational margins while allowing future system expansion.

The objective of this project was to reduce the electrical loading of Substation 5004 by implementing a primary feeder interconnection operating at 13.2 kV that redistributed load to an adjacent distribution feeder with available capacity. This approach was intended to improve load balance, enhance distribution system reliability, extend transformer service life, and ensure compliance with applicable distribution design standards while maintaining operational feasibility.

LITERATURE REVIEW

The planning and operation of electric power distribution systems have been widely studied due to their critical role in ensuring system reliability, service continuity, and efficient energy delivery [1]. Distribution substations and primary feeders are particularly sensitive to load growth, aging infrastructure, and the integration of new residential, commercial, and industrial developments. Several studies have emphasized that sustained operation near or above rated capacity significantly increases the risk of equipment degradation, thermal stress, and premature transformer failure [2].

Load balancing through feeder reconfiguration and substation interconnection has been identified as an effective strategy to mitigate overload conditions in urban and semi-urban distribution networks [3]. Previous research demonstrated that transferring load from heavily loaded substations to adjacent substations with available capacity improves voltage regulation, reduces system losses, and enhances overall system resilience [4]. These interconnections allow utilities to redistribute demand during peak load periods and emergency conditions without requiring immediate capital investment in new substations or transformer upgrades.

The importance of maintaining transformer loading below recommended operational thresholds has been extensively documented in industry standards and manufacturer guidelines. Distribution transformers are commonly recommended to operate below 75% to 80% of their nominal capacity to preserve insulation life and ensure long-term reliability [5]. Studies have shown that continuous operation beyond these limits accelerates insulation aging and increases the probability of catastrophic failure, particularly in regions exposed to high ambient temperatures and severe weather events [6].

In islanded power systems such as Puerto Rico's electrical grid, distribution reliability presents additional challenges due to limited redundancy and high exposure to extreme weather events. Post-event analyses following major hurricanes have highlighted the vulnerability of overloaded substations and undersized feeders to prolonged outages [7]. As a result, modern distribution planning increasingly incorporates system redundancy, feeder interconnections, and contingency analysis to improve system resilience and recovery capability [8].

Simulation tools and load flow analysis have been widely used in distribution engineering studies to evaluate proposed system modifications. These tools allow engineers to assess feeder loading, voltage profiles, and transformer utilization under various operating scenarios [9]. Validated simulation results are essential to ensure that proposed interconnections do not introduce new overloads or voltage violations elsewhere in the system [10].

METHODOLOGY

The methodology for this project was based on a systematic evaluation of the electrical load conditions at Substation 5004 and the feasibility of reducing transformer loading through the interconnection of primary distribution feeders. The study followed standard distribution engineering practices and utility design guidelines to ensure technical accuracy and operational reliability.

Initially, historical load data and operational reports for Substation 5004 were reviewed to determine peak demand levels, transformer utilization, and feeder loading conditions. This data was used to identify periods of maximum stress on the substation transformer and to confirm that the existing operating conditions exceeded recommended loading thresholds. The analysis focused on normal operating scenarios as well as peak demand conditions to capture worst-case system performance.

Following the load assessment, nearby substations and adjacent primary feeders were evaluated to identify available capacity for load transfer. Feeder characteristics such as voltage level, conductor size, length, and protection schemes were reviewed to ensure compatibility with the proposed interconnection. Special consideration was given to maintaining coordination with existing protection devices and minimizing potential impacts on system reliability. The physical location of the feeder interconnection is illustrated in Figure 1.

Figure 1. Location of the interconnection between Feeder 5004-7 and Feeder 5808-02.

A proposed interconnection between primary distribution feeders operating at 13.2 kV was then developed to allow partial load transfer from Substation 5004 to an adjacent feeder with sufficient available capacity. Load flow simulations were performed to evaluate the impact of the interconnection on feeder loading, voltage profiles, and transformer utilization under normal and peak operating conditions. These simulations ensured that the proposed configuration did not introduce new overloads or voltage violations elsewhere in the distribution system. The feeder interconnection design developed in PoleForeman is shown in Figure 2.

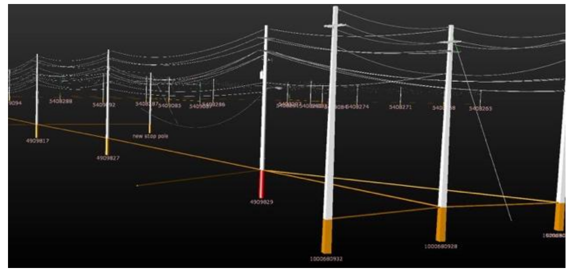

Figure 2. Three-dimensional model of the feeder interconnection developed using PoleForeman.

Compliance with applicable distribution design standards and utility operational requirements was verified throughout the analysis. This included evaluating system performance under contingency scenarios and ensuring that the interconnection supported operational flexibility during maintenance activities or emergency conditions. The methodology also considered system resilience requirements, particularly in relation to extreme weather events common to the region.

The results of the analysis were documented to support engineering decision-making and to provide a technical basis for the recommended interconnection. This structured approach ensured that the proposed solution was technically feasible, cost-effective, and aligned with long-term system planning objectives.

RESULTS

The evaluation of the feeder interconnection demonstrated that the proposed configuration effectively reduced transformer loading at Substation 5004. Prior to the interconnection, the substation operated at approximately 96% of its nominal capacity. After the load transfer, transformer loading decreased to approximately 77%, representing a reduction of about 4 MVA or 19% of the total load. The reduction in transformer loading is illustrated in Figure 3.

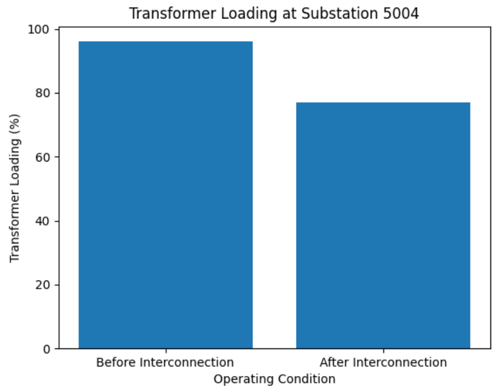

Figure 3. Transformer loading reduction at Substation 5004 after feeder interconnection.

Simulation results obtained using PoleForeman confirmed that the load transfer did not introduce overload conditions or voltage violations in adjacent feeders. System performance remained within acceptable operational limits under normal loading conditions. The redistribution of load provided sufficient operational margin to maintain reliable service and support future load growth. The structural validation of the interconnection is shown in Figure 4.

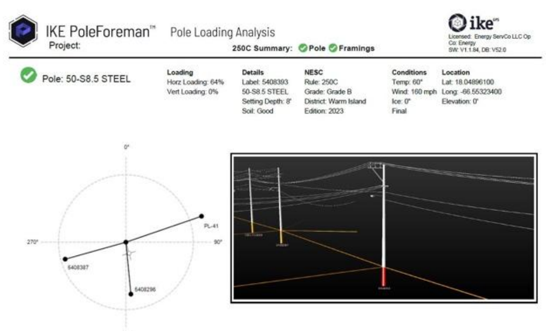

Figure 4. Pole loading analysis results for the interconnection structure obtained using PoleForeman.

The interconnection also enabled the successful connection of a new 1 MVA commercial project without exceeding recommended operating thresholds. From a project implementation perspective, the distribution line required for the feeder interconnection was constructed within an existing utility right-of-way, eliminating the need for legal acquisition of additional easements.

Financially, the project remained within the established budget constraints. The total project cost was $474,743.88, which was below the maximum allocated budget of $500,000. These results confirmed the technical, operational, and economic feasibility of the feeder interconnection.

Conclusions

The feeder interconnection implemented to relieve loading at Substation 5004 proved to be an effective distribution engineering solution for improving system reliability and operational performance. The redistribution of electrical load reduced transformer utilization from near-critical operating levels to acceptable margins, thereby decreasing the risk of equipment failure and extending transformer service life.

The project demonstrated that feeder interconnections can serve as a cost-effective alternative to substation upgrades when adjacent feeder capacity is available. The use of simulation tools and system data validation ensured that the proposed configuration met distribution design standards and operational requirements without introducing new system constraints.

In addition to improving load management, the interconnection supported future system expansion by enabling the connection of new commercial load while maintaining reliability. The project also demonstrated the importance of planning infrastructure improvements within existing rights-of-way to avoid legal delays and reduce implementation costs.

Overall, the project confirmed that proper distribution system planning, load analysis, and feeder interconnection strategies contribute significantly to system reliability, transformer life extension, and long-term distribution network sustainability.

References

[1] J. J. Grainger and W. D. Stevenson, Power System Analysis, New York, NY, USA: McGraw-Hill, 1994.

[2] IEEE Power & Energy Society, IEEE Guide for Loading Mineral-Oil-Immersed Transformers, IEEE Std C57.91-2011, 2012.

[3] T. Gönen, Electric Power Distribution Engineering, 3rd ed., Boca Raton, FL, USA: CRC Press, 2014.

[4] A. R. Bergen and V. Vittal, Power Systems Analysis, 2nd ed., Upper Saddle River, NJ, USA: Prentice Hall, 2000.

[5] IEEE Standards Association, IEEE Standard for Requirements for Liquid-Immersed Distribution, Power, and Regulating Transformers, IEEE Std C57.12.00-2015, 2016.

[6] M. Arshad and S. M. Islam, "Significance of thermal aging on transformer insulation life," IEEE Transactions on Dielectrics and Electrical Insulation, vol. 22, no. 2, pp. 1080–1086, 2015.

[7] U.S. Department of Energy, "Puerto Rico Grid Resilience and Reliability Study," Washington, DC, USA, 2018.

[8] National Renewable Energy Laboratory, "Enhancing Distribution System Resilience," Golden, CO, USA, 2020.

[9] H. Saadat, Power System Analysis, 3rd ed., New York, NY, USA: PSA Publishing, 2011.

[10] IEEE Power & Energy Society, Distribution System Analysis Subcommittee Report, IEEE PES, 2019.