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GOVERNMENT OF PUERTO RICO
PUBLIC SERVICE REGULATORY BOARD
ENERGY BUREAU

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| **IN RE: Deployment of Electric Vehicle Charging Infrastructure** | **CASE NO.** NEPR-MI-2021-0013<br>**SUBJECT:** **CAMBIO Filing of Electric Vehicle Integration Analysis** |

Honorable President Avilés and Energy Bureau Commissioners:

CAMBIO submits to the Energy Bureau and other interested stakeholders the attached distribution system modeling study (and summary in Spanish) analyzing the integration of electric vehicles into Puerto Rico's grid. The study builds off of previous grid modeling work presented by CAMBIO before this Energy Bureau that investigated the feasibility of achieving 75% distributed renewable energy by 2035. This analysis looks at the impact of increasing penetrations of electric vehicle chargers (at 10, 20, 30, and 40% of sites along the studied feeders) on feeder performance, modeling line losses, voltage violations and thermal violations, and comparing the current distribution system vs. a distribution system that has integrated 75% distributed renewable energy resources.

The study finds that a decentralized grid is much better able to handle increased penetrations of electric vehicle charging infrastructure than the current centralized grid. The decentralized grid therefore requires significantly less investment in distribution system upgrades. Specifically,

- With 40% penetration of electric vehicle chargers, the current grid suffers a 171% increase in line losses, 282% increase in voltage violations and 389% increase in thermal violations. The grid with 75% distributed renewable energy only suffers a 119% increase in line losses, 121% increase in voltage violations and 142% increase in thermal violations.
- The cost of distribution system mitigations needed to integrate 40% electric vehicle penetration to the grid with 75% distributed renewable energy is less than the cost of integrating only 10% electric vehicle penetration to the current grid.

We urge the Energy Bureau to take into account this analysis when considering the deployment of electric vehicle charging infrastructure in this proceeding. As the Bureau has recognized, it is important that the deployment of electric vehicle charging infrastructure be coordinated in a way that recognizes the impacts on the distribution system and that encourages energy efficiency, demand shifting and other measures to lessen the impact on the grid and to ensure that vehicle charging is maximized during times of peak renewable energy production.[1] The results of this analysis show the benefits of coordinating electric vehicle charging infrastructure with the overall decentralization of the grid and transition to high penetrations of distributed energy resources. We urge the Energy Bureau to require LUMA and PREPA to coordinate the use of available FEMA funds to prioritize the decentralization of the grid and the widespread deployment of rooftop solar and storage. This will not only increase the resiliency of the system, saving lives during future outages and extreme weather events, but also increase the grid's ability to handle the growth of electric vehicles in Puerto Rico.

We are available to answer any questions that the Bureau may have about the attached study.

Sincerely,

| | |
|---|---|
| Ingrid M. Vila Biaggi | Cathy Kunkel |
| President | Energy analyst |

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[1] Case No. NEPR-MI-2021-0013, Resolution and Order, November 18, 2021.

**Ingrid M. Vila Biaggi, M.S., P.E. presidenta**

**Cathy Kunkel, analista energía**

**Agustín A. Irizarry Rivera, Ph. D., P.E. consultor**

enero 2022

# Estudio de integración de vehículos eléctricos en Puerto Rico

CAMBIO desarrolló un estudio de modelaje del sistema de distribución de la red eléctrica de Puerto Rico, evaluando el impacto de una penetración significativa de vehículos eléctricos en la red actual versus una red descentralizada, como propone Queremos Sol.

Este estudio complementa los estudios del modelaje del sistema eléctrico publicados por CAMBIO en marzo de 2021 que analizaron y validaron la viabilidad de la propuesta Queremos Sol. Queremos Sol propone la transición hacia 75% energía renovable distribuida en 15 años, basado en la energía solar en techos. Esto incluye equipar a todos los hogares en el país con un sistema básico de energía solar con baterías para que todos puedan tener acceso a la resiliencia energética. Los estudios del modelaje de 2021 demostraron que esta transición es viable con mejoras modestas en el sistema de distribución y conllevaría ahorros significativos en el costo de combustible sin menoscabar la confiabilidad o calidad de potencia de la red. [1]

La sostenibilidad energética de Puerto Rico depende no solamente de una transformación del sistema eléctrico, sino también del sistema de transportación. Esto implica ampliar y mejorar las opciones y el uso del transporte público, así como integrar los vehículos eléctricos. Esto permite reducir el uso de combustibles fósiles y por consiguiente reducir las emisiones relacionadas a la utilización de vehículos a base de sistemas de combustión. Se estima que cada vehículo emite anualmente 4.6 toneladas métricas de $CO_2$. [2] En el caso de Puerto Rico, el Departamento de Transportación y Obras Públicas (DTOP) informó que para el 2019 habían 2.8 millones de vehículos registrados, lo que implica una generación de aproximadamente 13 millones de toneladas métricas de $CO_2$ anualmente.[3] Una transición a vehículos eléctricos con capacidad de recarga por medios renovables implicaría una reducción importante en emisiones de gases de invernadero y otros contaminantes producto de la combustión fósil.

El estudio actual evalúa la integración de vehículos eléctricos, lo que tendrá impactos en el sistema eléctrico al aumentar la demanda energética y cambiar los patrones del uso eléctrico. El estudio evalúa el impacto en la red actual, de generación centralizada y a base de combustibles

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[1] CAMBIO, Estudio de Integración de Recurso Solar Distribuido, marzo 2021.
[2] Environmental Protection Agency, Greenhouse Gas Emissions from Typical Passenger Vehicles, marzo 2018.
[3] Departamento de Transportación y Obras Públicas de Puerto Rico, SHSP Plan Estratégico de Seguridad Vial 2019-2023, 2019.

fósiles, así como en una red descentralizada con el 75% de su generación descentralizada y a base de energía renovable en techos y almacenamiento, como propone Queremos Sol. Debido a la fragilidad y falta de confiabilidad de la red eléctrica actual, es importante analizar y planificar bien el impacto de penetraciones más altas provenientes de cargadores de vehículos eléctricos.

El estudio de modelaje realizado evalúa la integración de cargadores eléctricos en 10% hasta 40% de los hogares y concluye que un sistema eléctrico descentralizado y basado en la energía renovable en techos, como propone Queremos Sol, resulta mucho más resiliente para integrar cargadores de vehículos eléctricos. En específico los resultados del estudio nos permiten derivar las siguientes conclusiones: [4]

- El integrar cargadores de vehículos eléctricos en el 20% de los hogares y negocios de Puerto Rico a la red actual requiere una inversión aproximada de $250 millones. En comparación, integrar cargadores de vehículos eléctricos en el 20% de los hogares y negocios de Puerto Rico en una red con 75% de energía distribuida no requiere inversión alguna.
- El integrar cargadores de vehículos eléctricos en el 40% de los hogares y negocios a la red actual requiere una inversión aproximada de $440 millones. En comparación, integrar esta misma cantidad a la red con 75% de energía distribuida requiere solamente $41 millones en mejoras, o diez veces menos. Estas mejoras se concentrarían en las líneas de bajo voltaje (4.16 kV) y en las líneas rurales y largas.
- El costo de mejoras necesarias a la red para integrar cargadores de vehículos eléctricos en el 40% de los hogares y negocios de Puerto Rico en una red con 75% de energía renovable distribuida es menor que el costo de las mejoras para integrar 10% de cargadores de vehículos eléctricos a la red centralizada y dependiente de combustibles fósiles que tenemos hoy.

El costo de las mejoras necesarias al sistema de distribución para integrar cargadores de vehículos eléctricos es significativamente más bajo con una red de distribución que ya integra una alta penetración de energía solar en techos.

En este reporte, presentamos un trasfondo sobre el crecimiento reciente de vehículos eléctricos en Puerto Rico y proyecciones sobre posibles aumentos en la integración de vehículos eléctricos y su impacto en la red. Además, presentamos un resumen de la metodología, resultados y conclusiones del modelaje de la integración de vehículos eléctricos a la red eléctrica.

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[4] Los costos podrían variar hasta un 30%, por la incertidumbre y variabilidad entre los alimentadores individuales.

# I. Trasfondo: Vehículos eléctricos en Puerto Rico

Aunque los vehículos eléctricos en este momento representan una fracción pequeña del total de vehículos que transitan por las calles de Puerto Rico, el número de vehículos eléctricos está aumentando rápidamente. El Grupo Unido de Importadores de Autos reporta que las ventas de autos híbridos o eléctricos en los primeros cuatro meses del año 2022 fue 45% más alto en comparación con el mismo periodo del año 2021.[5] La misma entidad reporta que en abril de 2022, los vehículos híbridos o eléctricos representaron más de 3.1% de la demanda de vehículos nuevos en el país.[6]

Actualmente, Puerto Rico no cuenta con metas de política pública para el despliegue de vehículos eléctricos. Sin embargo, el gobierno federal ha establecido mediante orden ejecutiva una meta para que, al 2030, el 50% de los vehículos vendidos sean de cero emisiones.[7] Estados como Nueva York y California han incorporado metas más agresivas que disponen que el 100% de los vehículos vendidos sean de cero emisiones para el año 2035.[8]

En los próximos cinco años, Puerto Rico recibirá más de $13.6 millones de fondos federales (de los cuales ya se ha recibido $4.9 millones) para establecer 15 estaciones públicas de carga en tres carreteras de la isla.[9]

El despliegue de infraestructura para cargar vehículos eléctricos debe coordinarse para minimizar el impacto en la red eléctrica. La ubicación de cargadores tiene implicaciones en cuanto a dónde y cuándo las personas van a cargar sus vehículos. Si se ofrecen más opciones para cargar vehículos durante las horas de trabajo, por ejemplo, esto significaría que más personas cargarían sus vehículos durante las horas pico del sol, maximizando el uso directo de la energía solar para los vehículos eléctricos.

Estimamos que una penetración de 20% de vehículos eléctricos para el año 2035 aumentaría en 7% el consumo eléctrico ese año. Una penetración de 40% representaría un aumento de 13%. Este aumento en demanda, además de tener implicaciones en los recursos de generación, podría sobrecargar las líneas de distribución, creando la necesidad de mejoras para poder integrar más

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[5] El Nuevo Día, “Detallan el plan para la construcción de la red de recarga de vehículos eléctricos en Puerto Rico,” 2 de agosto de 2022.

[6] El Nuevo Dia, “Crece la venta de autos híbridos y eléctricos en Puerto Rico: ¿se sostendrá?”, 4 de junio de 2022. (Nota: el 3.1% no incluye autos de marca Tesla).

[7] The White House, “Fact Sheet: President Biden Announces Steps to Drive American Leadership Forward on Clean Cars,” August 5, 2021.

[8] California Office of the Governor, “Governor Newsom Announces California Will Phase Out Gasoline-Powered Cars & Drastically Reduce Demand for Fossil Fuel in California’s Fight Against Climate Change,” September 23, 2020; Autoweek, “New York Will Ban Sale of Gas-Engined Cars by 2035,” September 15, 2021.

[9] El Nuevo Dia, “El gobierno de Biden aprueba el plan de Puerto Rico para constuir infraestructura de carga para vehículos eléctricos,” 14 de septiembre de 2022; The White House, “President Biden’s Bipartisan Infrastructure Law is Delivering in Puerto Rico,” November 2022.

lugares de carga. Esta situación puede representar un reto en Puerto Rico, dados los problemas de fluctuaciones de voltaje que ya aquejan la red eléctrica.

El Negociado de Energía inició en 2021 un procedimiento regulatorio relacionado con el despliegue de cargadores eléctricos, con la intención de planificar la interconexión de infraestructura de cargadores eléctricos a la red. Hasta el momento, el caso ha incluido una discusión de diseños tarifarios que incentivarían el uso de cargadores fuera de las horas pico de demanda eléctrica, y el Negociado ha impuesto una fecha límite de 30 de septiembre de 2023 para que LUMA cree una tarifa especial para los clientes residenciales con cargadores de vehículos eléctricos. El Negociado también ha ordenado a LUMA conocer mejor las necesidades de las comunidades de bajos recursos con relación a la transportación para integrarlas en su planificación. El caso no ha profundizado las mejoras a la red de distribución que deben priorizarse para integrar cargadores eléctricos.[10]

En las próximas secciones, presentamos un resumen de la metodología y resultados del “Análisis de Integración de Vehículos Eléctricos”, desarrollado en coordinación con WildKat Engineering, el cual arroja luz sobre el impacto de altas penetraciones de vehículos eléctricos en el sistema de distribución. Los resultados del estudio pueden contribuir a definir la política pública y las acciones necesarias para asegurar una integración confiable, costoefectiva y sostenible de vehículos eléctricos en Puerto Rico.

## II. Metodología

En este estudio, utilizamos 27 alimentadores de distribución que son representativos de los circuitos de distribución eléctrica en Puerto Rico. Estos 27 alimentadores (circuitos) de distribución son representativos de: circuitos cortos (< 5 millas), largos (> 20 millas) y medianos (entre 5 y 20 millas) e incorporan los diversos voltajes de distribución utilizados en Puerto Rico (4.16, 7.2, 8.32 y 13.2 kV entre línea viva y línea viva).

Por ejemplo, la Figura 1 muestra el detalle de ubicación del alimentador número 1203-02, Saint Just 03, en Carolina. Este alimentador tiene 9.6 millas de largo y discurre por una zona urbana, con demanda principalmente comercial. El alimentador opera a 4.16 kV nominales. Los colores indican la cantidad de fases en el alimentador de distribución y los puntos muestran la ubicación de los transformadores. El diámetro (grueso) del punto indica la capacidad del transformador.

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[10] Caso NEPR-MI-2021-0013. Vea la Resolución y Orden de 13 de enero de 2023.

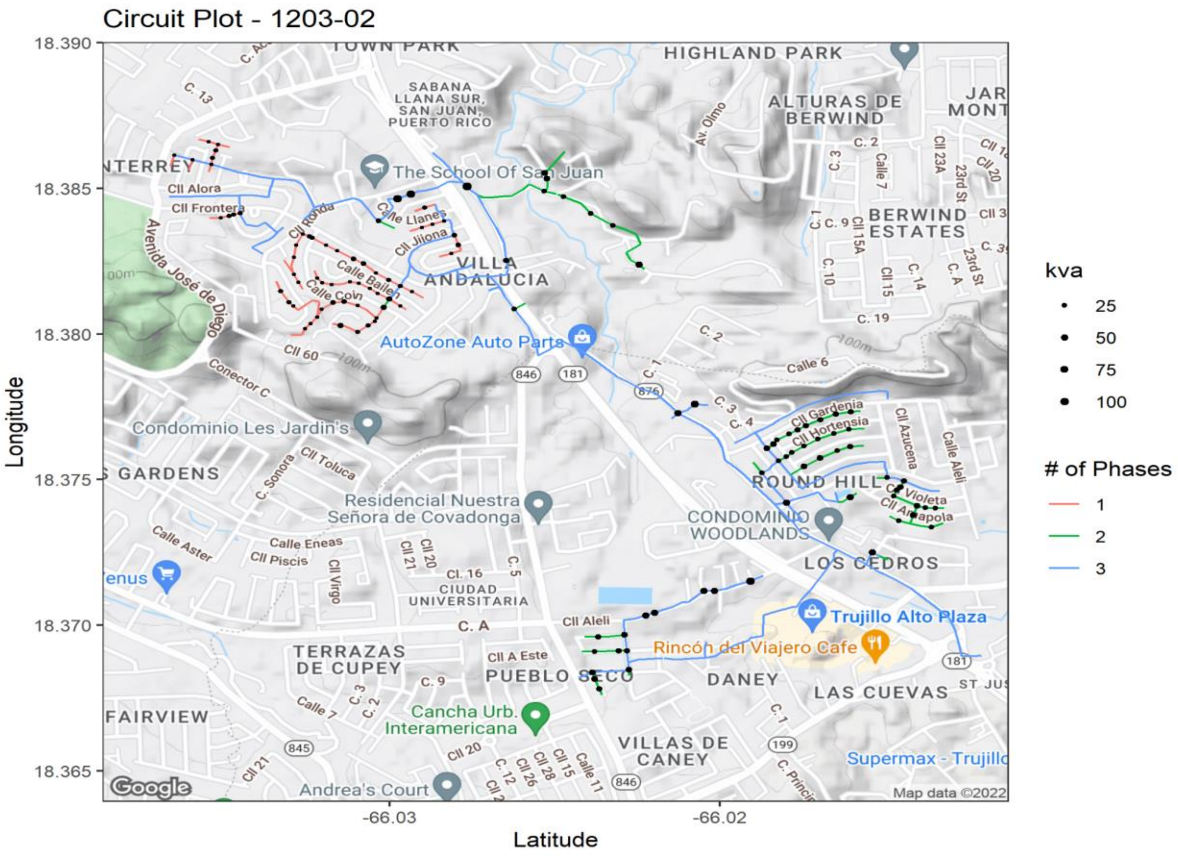

*Figura 1. Alimentador número 1203-02, Saint Just 03, en Carolina. Este alimentador tiene 9.6 millas de largo y discurre por una zona urbana, con demanda principalmente comercial. El alimentador opera a 4.16 kV nominales.*

El informe completo muestra la ubicación y características de cada uno de los 27 alimentadores modelados.

Además, los alimentadores se seleccionaron para asegurar representatividad geográfica y de zonas (rural y urbana) de Puerto Rico, como muestra el mapa de la Figura 2. Estos alimentadores representan el 2.5% del total de líneas de distribución del país. La Tabla 1, a continuación, contiene información de cada circuito modelado.

| Número de identificación | Nombre | Región | Voltaje (kV) |
|---|---|---|---|
| 8202-03 | Adjuntas 03 | Arecibo | 8.32 |
| 8405-02 | Manatí Urbano 02 | Arecibo | 13.2 |
| 7701-01 | Hatillo 01 | Arecibo | 4.16 |
| 1704-01 | Sierra Linda 01 | Bayamón | 4.16 |
| 1806-01 | Levittown 01 | Bayamón | 13.2 |
| 9103-04 | Santa Ana 04 | Bayamón | 8.32 |
| 2501-02 | Vieques 02 | Vieques | 4.16 |
| 2602-03 | Humacao 03 | Caguas | 8.32 |
| 3007-03 | Gautier Benítez 03 | Caguas | 8.32 |
| 3014-04 | Río Caña 04 | Caguas | 4.16 |
| 3201-04 | Juncos 04 | Caguas | 4.16 |
| 3205-09 | Juncos 2 09 | Caguas | 13.2 |
| 3801-02 | Culebra 02 | Culebra | 4.16 |
| 2402-02 | Loíza Valley 02 | Carolina | 13.2 |
| 1203-02 | Saint Just 03 | Carolina | 4.16 |
| 2201-04 | Luquillo 04 | Carolina | 8.32 |
| 6002-04 | McKinley 04 | Mayagüez | 4.16 |
| 6702-04 | Boquerón 04 | Mayagüez | 7.2 |
| 7011-02 | T Bone 02 | Mayagüez | 13.2 |
| 4301-03 | Maunabo 03 | Ponce ES | 4.16 |
| 3501-03 | Aibonito 03 | Ponce ES | 8.32 |
| 4003-03 | Jobos 03 | Ponce ES | 13.2 |
| 5005-05 | Pámpanos 05 | Ponce OE | 4.16 |
| 5016-03 | Villa del Carmen 03 | Ponce OE | 13.2 |
| 1525-01 | Las Lomas 01 | San Juan | 4.16 |
| 1529-11 | San Patricio 11 | San Juan | 4.16 |
| 1403-01 | Chardón 01 | San Juan | 13.2 |

*Tabla 1. Número de identificación, nombre, región y voltaje nominal de los circuitos de distribución modelados en el estudio.*

*Figura 2. Los 27 circuitos de distribución eléctrica modelados en el estudio en relación con su ubicación en Puerto Rico, Vieques y Culebra.*

Los datos utilizados para desarrollar los modelos provienen del trabajo realizado en el "Estudio de integración del recurso solar distribuido", desarrollado por CAMBIO en el 2021[11] y que partió de datos provistos, en origen, por la Autoridad de Energía Eléctrica. Sin embargo, los datos utilizados en el modelaje se calcularon de manera independiente. Los modelos desarrollados siguen fielmente los estándares de la industria eléctrica.

Para comparar la red actual, centralizada y dependiente de combustibles fósiles, con una red descentralizada a base de recursos renovables en techos, como propone Queremos Sol, se utilizó un modelo en que se añadieron sistemas fotovoltaicos residenciales de 2.7 kW de energía solar con 12.6 kWh de baterías, y sistemas fotovoltaicos comerciales para lograr 75% del consumo eléctrico en el año 2035.[12] Estas instalaciones fotovoltaicas se modelaron en las líneas de distribución conectadas a la red usando los transformadores existentes. La cantidad de sistemas fotovoltaicos con baterías en cada transformador depende de la cantidad de residencias y comercios conectados al transformador. Se utilizaron perfiles de energía solar de las diferentes regiones de la isla para modelar la generación de estos sistemas fotovoltaicos.

Tanto para la red actual centralizada y la red descentralizada con energía distribuida, se modelaron cuatro escenarios de penetraciones de vehículos eléctricos: 10%, 20%, 30% y 40%.

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[11] www.cambiopr.org/solmastechos

[12] Este modelo se utilizó en el "Estudio de integración de recurso solar distribuido" publicado por CAMBIO en 2021. Los sistemas fotovoltaicos suplen el 75% del consumo energético antes de que se añadan los cargadores para vehículos eléctricos.

¿Qué significa esto? 40% de penetración significa que en el 40% de todos los puntos de demanda de electricidad de un circuito de distribución se añade una estación de carga de vehículo eléctrico. Es decir, en el 40% de las residencias del circuito de distribución se añade una estación de carga de vehículo eléctrico. ¿Cómo se seleccionan los lugares en los que se añade el cargador de vehículo eléctrico? Los lugares se seleccionan al azar, pero siempre conectados a un transformador en uso. ¿Cuánta energía consumen estos cargadores de vehículos eléctricos? Se usa un perfil de consumo energético basado en el desempeño actual de cargadores eléctricos observados en otros estudios. Fuera del consumo de los cargadores, se utilizó el mismo consumo energético para el año 2035 que se modeló en los estudios anteriores de 2021.

Se modeló el desempeño de cada línea de distribución utilizando la herramienta OpenDSS[13] bajo los siguientes nueve (9) escenarios:

| **Escenario** | **Penetración de Vehículos Eléctricos** | **Penetración de Energía Renovable Distribuida**[14] |
|---|---|---|
| **caso base** | 0% | Actual |
| **EV10** | 10% | Actual |
| **EV20** | 20% | Actual |
| **EV30** | 30% | Actual |
| **EV40** | 40% | Actual |
| **PVEV10** | 10% | 75% |
| **PVEV20** | 20% | 75% |
| **PVEV30** | 30% | 75% |
| **PVEV40** | 40% | 75% |

*Tabla 2. Los nueve escenarios modelados*

El primer escenario, sin vehículos eléctricos y sin una penetración alta de energía renovable distribuida, provee un punto de referencia ("baseline") sobre el desempeño del sistema actual.

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[13] OpenDSS es un software de calidad industrial, capaz de modelar en detalle el comportamiento de los alimentadores de distribución, incluyendo desbalance en las fases.

[14] Enfatizamos que "75%" significa que los sistemas fotovoltaicos suplen 75% de la energía que se consume en Puerto Rico antes de añadir los cargadores de vehículos eléctricos.

En todos los escenarios, se evaluaron con OpenDSS unas métricas que indican la capacidad del sistema para manejar ese nivel de penetración de vehículos eléctricos. Estas métricas incluyen: violaciones del voltaje (las horas en el año en que el voltaje del alimentador se encuentra fuera de sus límites de diseño), violaciones térmicas (cuando la corriente se encuentra fuera de los límites de diseño del alimentador), y las pérdidas eléctricas (la cantidad de electricidad, en kilovatio-horas, que se pierden en el alimentador).

Después de evaluar el desempeño de los 27 alimentadores representativos, se extrapolaron los resultados a todo el sistema de distribución de la isla y se estimó el costo de las mitigaciones (mejoras) necesarias para atender las violaciones producidas por la introducción de vehículos eléctricos.

## III. Resultados

El modelaje revela que una red de distribución con una alta penetración (75%) de energía renovable distribuida **puede incorporar más vehículos eléctricos sin requerir mejoras al sistema** en comparación con una red con generación centralizada. La razón es que los sistemas distribuidos que producen energía cerca de donde se consume apoyan también el voltaje del alimentador y esto mitiga la necesidad de actualizar la línea.

Las siguientes gráficas demuestran que, en los 27 alimentadores analizados, un alimentador con 75% energía renovable sufre menos pérdida de energía, violaciones de voltaje y violaciones térmicas ante una mayor integración de vehículos eléctricos. Específicamente, las gráficas comparan el aumento en pérdidas, violaciones de voltaje y violaciones térmicas cuando se añade 40% de vehículos eléctricos a los 27 alimentadores, bajo los escenarios de la red actual versus la red distribuida:

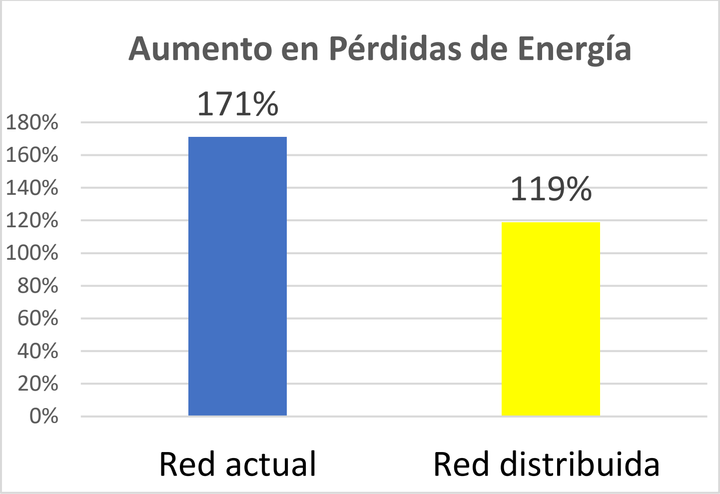

*Figura 3. El aumento en pérdidas de energía cuando se añade 40% de vehículos eléctricos a los 27 alimentadores, bajo los escenarios de la red actual versus la red distribuida.*

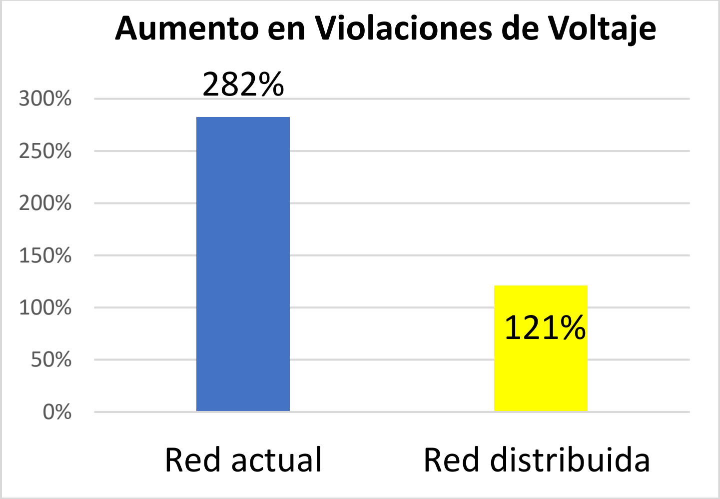

*Figura 4. El aumento en violaciones de voltaje cuando se añade 40% de vehículos eléctricos a los 27 alimentadores, bajo los escenarios de la red actual versus la red distribuida.*

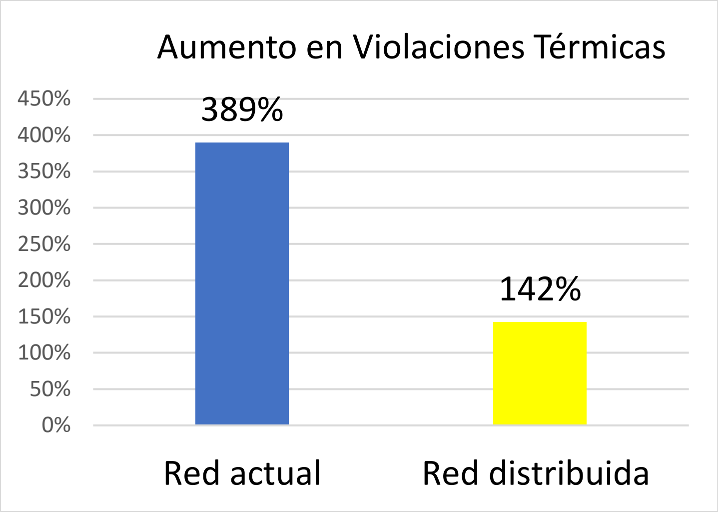

*Figura 5. El aumento en violaciones térmicas cuando se añade 40% de vehículos eléctricos a los 27 alimentadores, bajo los escenarios de la red actual versus la red distribuida.*

## IV. Conclusión

La extrapolación de estos resultados a toda la isla permite las siguientes conclusiones[15]:

- Integrar cargadores de vehículos eléctricos en el 20% de los hogares y negocios de Puerto Rico a la red actual requiere una inversión aproximada de $250 millones. En comparación, integrar cargadores de vehículos eléctricos en el 20% de los hogares y negocios de Puerto Rico en una red con 75% de energía distribuida no requiere inversión alguna.
- Integrar cargadores de vehículos eléctricos en el 40% de los hogares y negocios a la red actual requiere una inversión aproximada de $440 millones. En comparación, integrar esta misma cantidad a la red con 75% de energía distribuida requiere solamente $41 millones en mejoras, o diez veces menos. Estas mejoras se concentrarían en las líneas de bajo voltaje (4.16 kV) y en las líneas rurales y largas.
- El costo de mejoras necesarias a la red para integrar cargadores de vehículos eléctricos en el 40% de los hogares y negocios de Puerto Rico en una red con 75% de energía renovable distribuida es menor que el costo de las mejoras para integrar 10% de cargadores de vehículos eléctricos a la red centralizada y dependiente de combustibles fósiles que tenemos hoy.

Una red energizada con sistemas solares fotovoltaicos en techos y baterías puede integrar cargadores de vehículos eléctricos en el 40% de los hogares y negocios a un costo 10 veces menor que lo que representa integrarlos a la red eléctrica fósil y centralizada.

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[15] Los costos podrían variar hasta un 30%, por la incertidumbre y variabilidad entre los alimentadores individuales.

El estudio de modelaje que se presenta aquí demuestra un beneficio importante de una red eléctrica distribuida: esta ofrece un mejor desempeño al añadir cargadores de vehículos eléctricos. Este resultado tiene implicaciones importantes para las transiciones de los sistemas eléctricos y de transporte de Puerto Rico. La falta de confiabilidad del sistema eléctrico ya representa una barrera para el despliegue de vehículos eléctricos en Puerto Rico, dado que las personas que no tienen sus propios sistemas fotovoltaicos no quieren encontrarse sin luz y sin transportación durante los apagones frecuentes. La coalición Queremos Sol propone una transición justa hacia la energía solar en techos, utilizando los fondos federales disponibles para alcanzar 75% de energía renovable distribuida en 15 años, una transición que conllevaría beneficios en términos de resiliencia, asequibilidad y más independencia del mercado de los combustibles fósiles.

*Title:* ***Final Report for EV Integration Analysis***

*Synopsis:* *Final Report on results of the subject analysis.*

*Document ID:* *WKE_042022_CMB_RP-01_Rev4*

*Date:* *2023-01-13*

*Prepared For:* *Cambio*

*Prepared By:* *Wildkat Engineering LLC.*

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*Hays, KS 75067*

WILDKAT
ENGINEERING, LLC.

CAMBIO

Filantropía
Puerto Rico

# Contents

### Table I-1 – Revision History

| Date | Revision No. | Description |
|---|---|---|
| 04/01/2022 | 00 | Initial Revision for Review |
| 04/27/2022 | 01 | Progress Review Version |
| 09/10/2022 | 02 | Final Draft |
| 09/14/2022 | 03 | Revised Final Draft |
| 11/10/2022 | 04 | Revised per Client Comments |

# I. Executive Summary

Wildkat Engineering (WKE), in collaboration with Cambio PR (Cambio), has performed a comparative analysis of the impacts of various penetrations of electric vehicle (EV) charging on the “as-is” Puerto Rican distribution system versus a forward year version of the distribution system that incorporates a high level of solar & storage penetration.

The analysis was based on previous work performed on behalf of Cambio, where the majority of the Puerto Rican distribution grid was studied. The analysis was extended and refined to include the addition EV charging stations at of as much as 40% of the existing load locations . The analysis modeled a select group of feeders that are representative of the various stratifications of demand, length and operating voltage across the island. The selected feeders were purposely distributed across the entirety of the main island and two coastal islands.

The results are encouraging in that there is a significant improvement in the operational performance of the distribution network when EV penetration is offset with a high penetration of solar and storage. Highlights of the results include:

- Reductions in system losses of approximately 1.5% at high EV penetration when solar and storage is included versus the base case (no solar or storage) scenario;
- Reductions in annual voltage violation hours of between 2 and 4% depending on how the feeders are stratified;
- Reductions in thermal violation miles of between 0.1 and 0.2 miles per feeder depending on how the feeders are stratified;
- Significant reductions in the requisite infrastructure improvement costs necessary to support high levels of EV penetration.

These tangible improvements are likely accompanied by more intangible improvements, such as:

- Greater overall reliability of the system under most reasonable operating conditions;
- Decreases in greenhouse gas emissions associated with serving the islands; and
- The ability to forestall investments in T&D and generation infrastructure.

While these intangible improvements are not quantified herein, they reflect the results of the earlier system analyses.

# II. Introduction

This report describes the basis of the data used in the analysis, the processes employed and the results and attendant metrics associated with the analysis. This analysis is heavily reliant on previous analysis performed collaboratively by a consortium of Cambio, Telos Energy, the Energy Futures Group and EE Plus. This analysis established the differential impacts of various levels of solar/storage penetration on distribution and transmission systems, along with the dispatch and security of the Puerto Rican generation fleet. A selected number of the circuits analyzed as part of the previous effort were analyzed for this effort, and based on operating and demographic characteristics, were used to extrapolate results.

The analysis was based on the most aggressive level of PV and storage deployment previously considered, 75% PV/storage penetration. Multiple modifications were made to better understand the impacts of EV in the absence of DER deployment. These modifications include:

1. Direct use of USGS Puerto Rico solar irradiance data with 30-minute granularity
2. Modelling of EV charging based on synthesized, real-world, historical data for both residential and commercial charging, with 10-minute granularity.
3. Regional variation of residential load profiles for both commercial and residential loads.
4. Use of direct PV and BESS storage models within OpenDss, rather than load shape driven generation and loads for better granularity and control of devices.

The following sections describe the assumptions, procedures and processes used to perform the analyses.

# III. Assumptions

There are several groups of basic assumptions that are incorporated into the subject analysis. Broadly these are:

- Source model data
- PV and storage model assumptions
- EV model assumptions
- Charging model assumptions
- Performance Criteria

The specifics of these assumptions are defined in the subsequent sections. For the most part these are replicated from the earlier analysis or improved based on greater model granularity.

## A. Source Model Data

As noted above, WKE used previously developed models as the basis for the analysis. However, because the analysis is considerably more complicated, WKE will used a smaller subset of feeders, capturing each voltage level in each major region. The circuits used are:

- 8202-03, Adjuntas Feeder 03, 8.2 kV in the Arecibo region
- 8405-02, Manati Urbano Feeder 02, 13.2 kV in the Arecibo region
- 7701-01, Hatillo Feeder 01, 4.16 kV in the Arecibo region
- 1704-01, Sierra Linda Feeder 01, 4.16 kV in the Bayamon region
- 1806-01, Levittown Feeder 01, 13.2 kV in the Bayamon region
- 9103-04, Santa Ana Feeder 04, 8.32 kV in the Bayamon region
- 2501-02, Vieques Feeder 02, 4.16 kV on Vieques
- 2602-03, Humacao Feeder 03, 8.32 kV in the Caguas region
- 3007-03, Gautier Benitez Feeder 03, 8.32 kV in the Caguas region
- 3014-04, Rio Caña Feeder 04, 4.16 kV in the Caguas region
- 3201-04, Juncos Feeder 04, 4.16 kV in the Caguas region
- 3205-09, Juncos 2 Feeder 09, 13.2 kV in the Caguas region
- 3801-02, Culebra Feeder 02, 4.16 kV on Culebra
- 2402-02, Loiza Valley Feeder 02, 13.2 kV in the Carolina region
- 1203-02, Saint Just Feeder 03, 4.16 kV in the Carolina region
- 2201-04, Luquillo Feeder 04, 8.32 kV in the Carolina region
- 6002-04, McKinley Feeder 04, 4.16 kV in the Mayaguez region
- 6702-04, Boqueron Feeder 04, 7.2 kV in the Mayaguez region
- 7011-02, T Bone Feeder 02, 13.2 kV in the Mayaguez region
- 4301-03, Muanabo Feeder 03, 4.16 kV in the Ponce ES region
- 3501-03, Aibonito Feeder 03, 8.32 kV in the Ponce ES region
- 4003-03, Jobos Feeder 03, 13.2 kV in the Ponce ES region

- 5005-05, Pampanos Feeder 05, 4.16 kV in the Ponce OE region
- 5016-03, Villa Del Carmen Feeder 03, 13.2 kV in the Ponce OE region
- 1525-01, Las Lomas Feeder 01, 4.16 kV in the San Juan region
- 1529-11, San Patricio Feeder 11, 4.16 kV in the San Juan region
- 1403-01, Chardon Feeder 01, 13.2 kV in the San Juan region

The relative location of the feeders listed above are shown in below. The operating voltage is as noted in the legend.

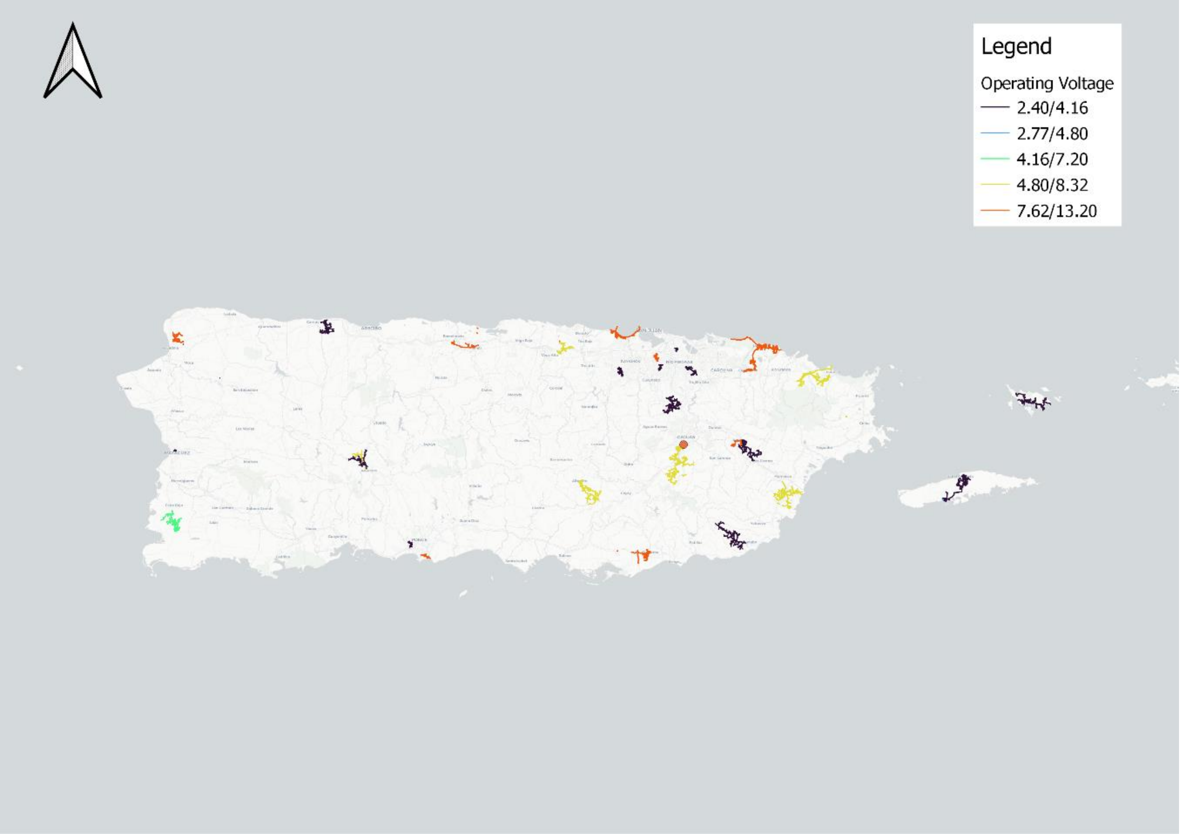

**Figure III-1: Analyzed Circuits**

## B. PV / Storage Characteristics

The characteristics of the individual PV/BESS installations was comparable to the previous analysis, with a few modest changes to better control the interaction between the PV/storage system and the EV charging system. The basic system parameters are a 2.7 kW PV system and a 12.6 kWh storage system. The OpenDSS model of PV systems permit the use of several PV module and inverter characteristics as part of the analysis. Module characteristics include the Maximum Power Point

($P_{mpp}$) value of the PV module under consideration, along with the relationship between temperature and $P_{mpp}$. Because no particular module was defined as part of the previous analysis, WKE has used the most popular residential scale modules for the residential model and a larger module for commercial installations. The modules used are:

- Jinko Solar JKM410M-72HL-V 380 W mono-facial - Residential
- Canada Solar HiKu-CS3N-400-W mono-facial - Commercial

The module information was aggregated to meet the system parameters (e.g. 2.7 kW) described above. A DC/AC ratio 1.20 was assumed. As per the previous analysis, the amount of commercial solar was enough to equal 75% of the total feeder demand. It should be noted that the 75% demand value is based on feeder demand prior to the introduction of EV load. All residential locations allocated residential system based on the size of the upstream transformer.

## C. Feeder Load Profiles

OpenDSS uses hourly load profiles to allocate load along the length of the feeder. Because EV charging typically exhibits at least two distinct modalities (Weekday and Weekend), WKE has utilized an 8760 hour load profile for each feeder. This approach captured both the weekday and weekend modalities, along with any seasonality in the load profile. An example load profile is shown in Figure III-2 below. The peak weekday and peak weekend data are based on the coincident peak days from the 2035 forecast. The individual feeder loads were scaled based on the ratio of the feeder connected kVA to the total connected kVA in the district.

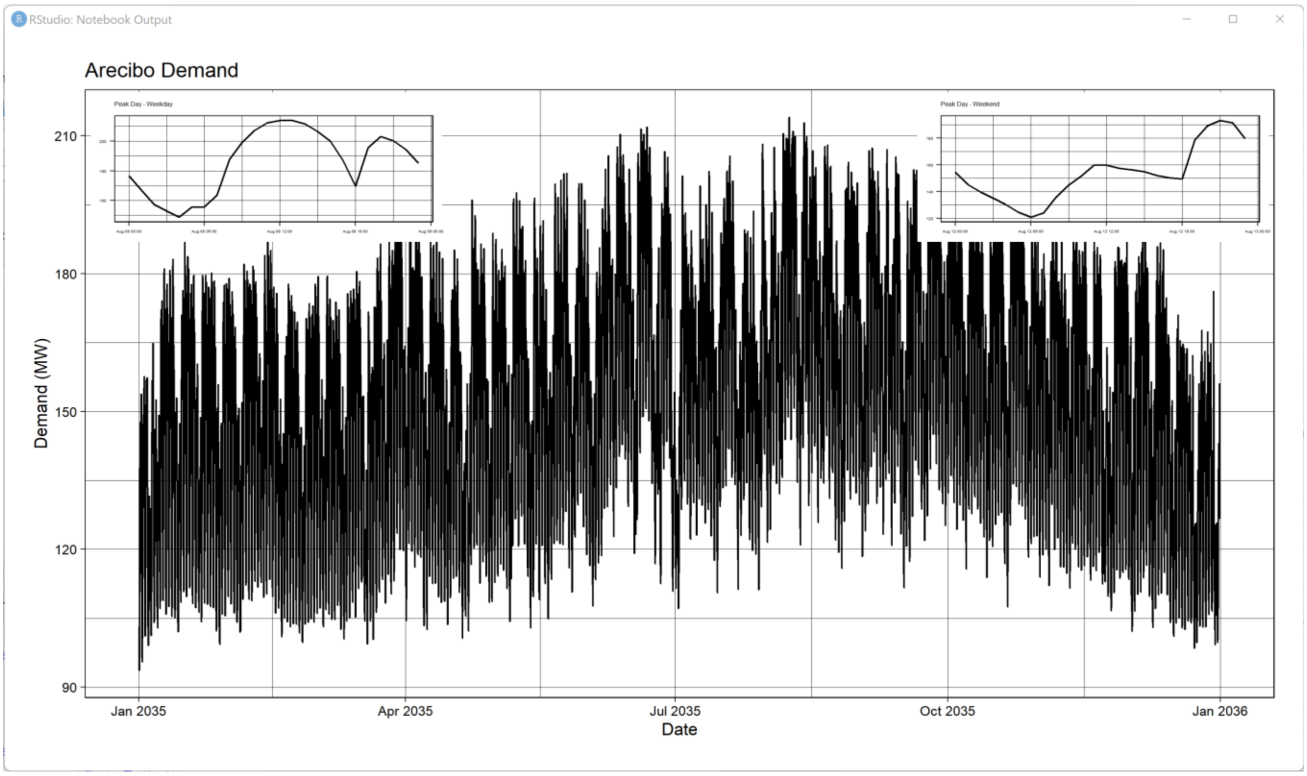

**Figure III-2: Arecibo Region Demand Profile**

## D. Incident Energy Profiles

The incident solar energy (irradiance) profiles are based on 2018 30-minute interval data collected across all regions within Puerto Rico. The profiles used for each feeder are based on the administrative region in which they reside. The correlation is as shown below:

- Adjuntas – Adjuntas
- Manati Urbano – Manati
- Hatillo – Hatillo
- Levittown – Toa Baja
- Santa Ana – Dorado
- Humacao – Humacao
- Gautier Benitez – Caguas
- Rio Cana – Caguas
- Juncos – Juncos
- Juncos 2 – Juncos
- Saint Just - Trujillo Alto

- Luquillo – Luquillo
- McKinley – Mayguez
- Boqueron – Cabo Rojo
- T Bone – Aguadilla
- Muanabo – Muanabo
- Aibonito – Aibonito
- Jobos – Guayama
- Pampanos – Ponce
- Villa Del Carmen – Ponce
- Chardon – San Juan
- Las Lomas – San Juan
- San Patricio – San Juan

An example of an irradiance energy distribution for a subject region shown in Figure III-3 below. Because the PV models are also temperature dependent, the temperature profiles have also been captured. A similar example of the temperature distributions is shown in Figure III-4 below.

## E. Charging profiles

The hourly demands for existing loads have already been determined from the previous study. The demand associated with EV charging was overlayed on top of the feeder demand profiles as recommended in (J. Quirós-Tortós, 2015). Multiple charging profiles were randomly distributed among the residential and commercial nodes during the analytical process. The charging profiles were stratified based on the day of the week, but as the reference source found only minor seasonal variations, there was no variation based on month. The demand data for the various sectors and charger types were synthesized from charging event data from (Electric Power Research Institute, 2018) (UK Department of Transport, 2018) (Lee, ACN-Data: Analysis and Applications of an Open EV Charging Dataset, 2019) (Muratori, 2017). An example of a residential Level 2 Charging profile is shown in Figure III-5 below.

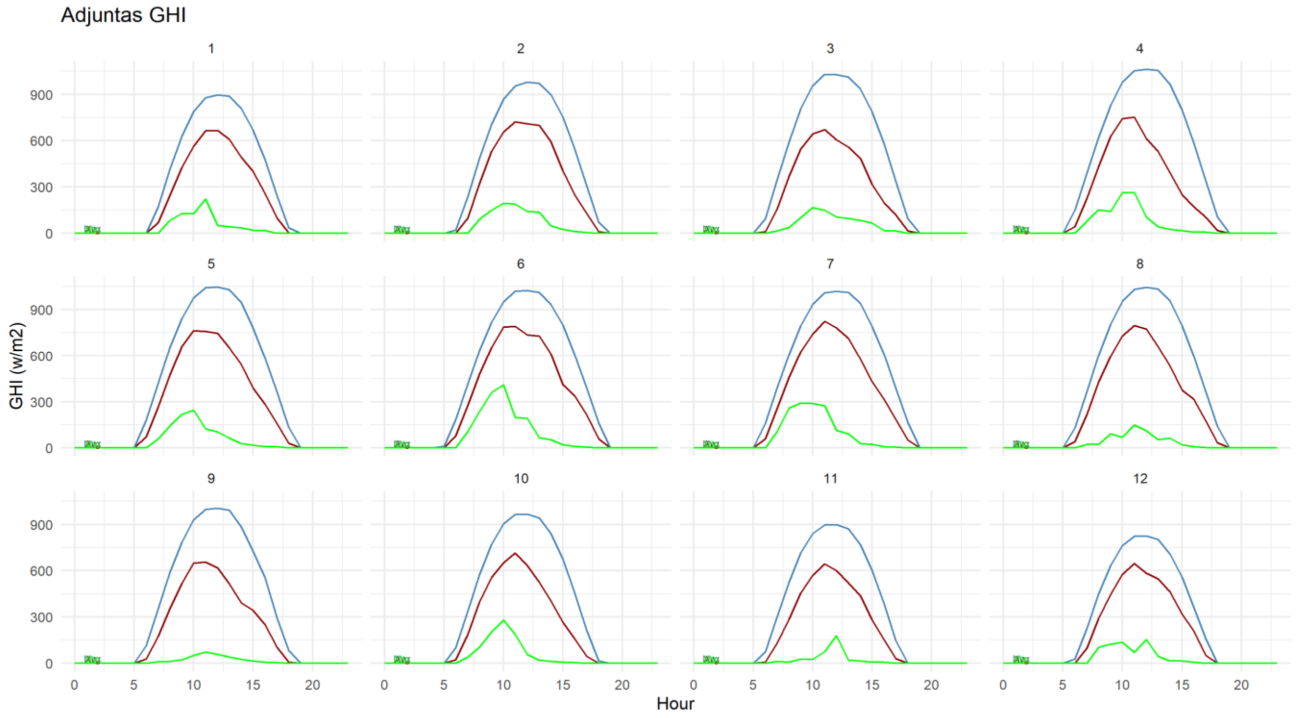

Figure III-3: Adjuntas Solar Irradiance distribution

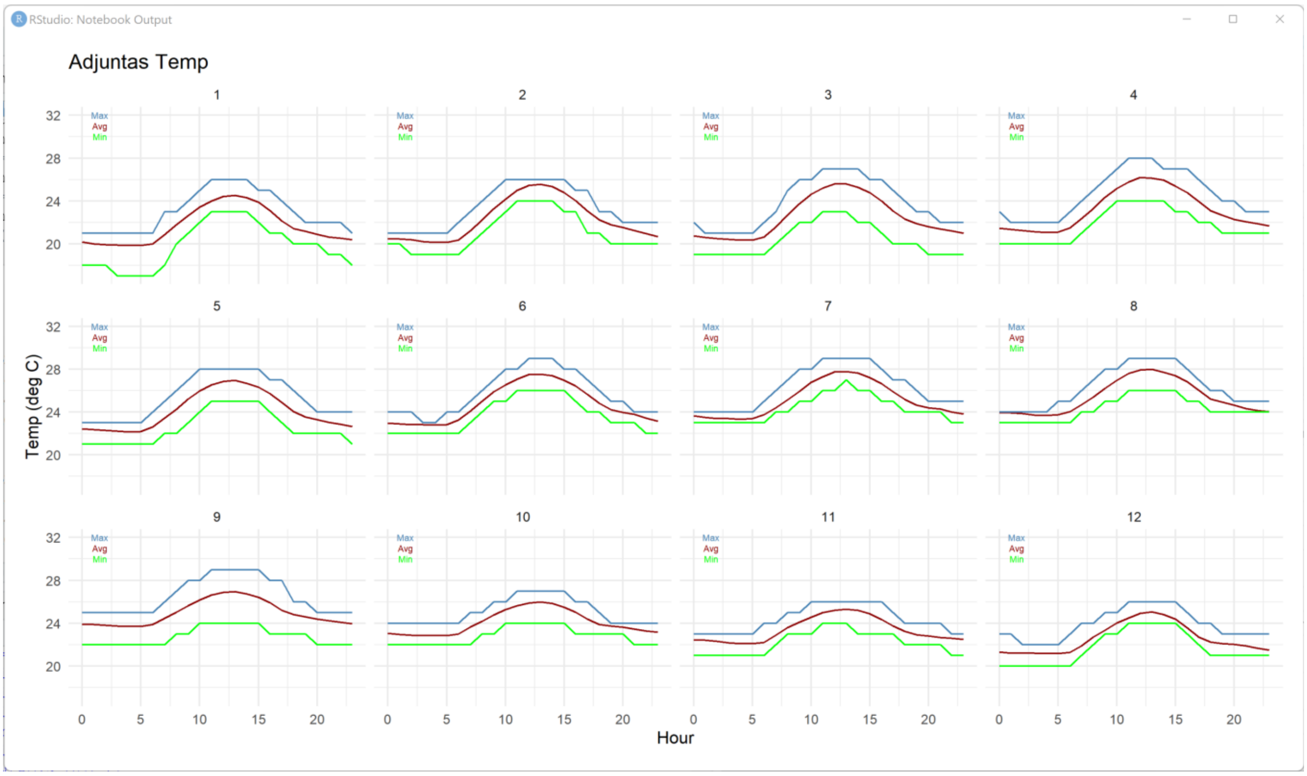

Figure III-4: Adjuntas Temperature Profile

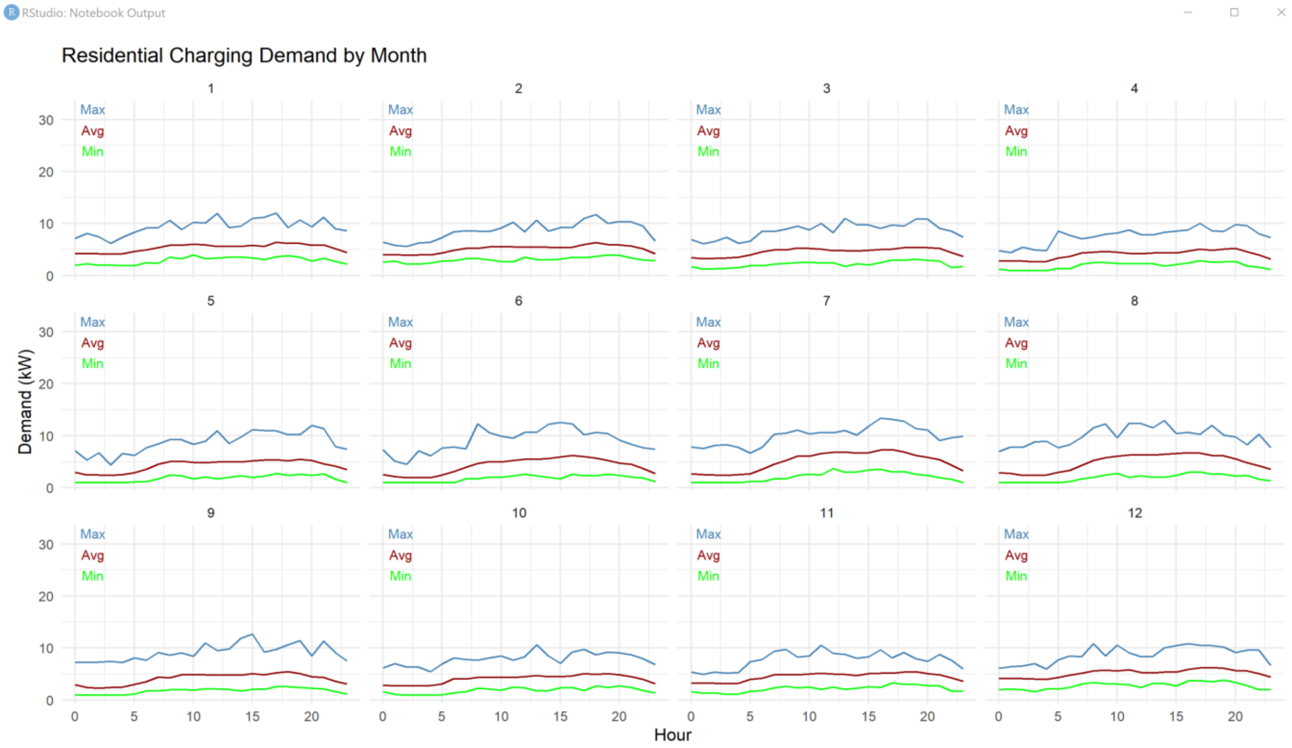

Figure III-5: Typical Residential Charging Profile

# IV. Methodology

The analytical methods used for the analysis are fairly straightforward, in that they represent incremental analyses of the same circuits, with important operating metrics extracted for each stage of the analysis. The order of the analysis is as follows:

- Examine each circuit as it is currently configured (i.e., with no improvements to accommodate future loads). The evaluation, as noted earlier, is based on the projected demand for 2035, based on the previously performed analysis. This establishes a baseline for how well the current system was able to accommodate the projected loads for 2035.
- Examine each circuit with the addition of EV charging added at random locations along the circuit, at penetration levels of 10, 20, 30 and 40%. In this context, penetration refers to the number of load locations (i.e., residences or businesses) with EV charging stations installed. This establishes the incremental impacts associated with accommodating future EV charging loads.
- Examine each circuit with 75% penetration of PV/storage (pre-EV levels) and EV charging, again at electric vehicle charging penetration levels of 10, 20, 30 and 40%.

This establishes the incremental impacts associated with accommodating future EV charging loads, coupled with the highly distributed solar / storage paradigm.

- In each case, a set of metrics are determined to assess the operational "fitness" of the system, based on established operating criteria. Along with the fitness assessment, where deficiencies are found, the approximate level of investment necessary to mitigate the deficiencies are also determined. This helps quantify the relative "cost" of each operating condition. Note that in this analysis, as opposed to the previous effort, the results of the cross-section of selected circuits were extrapolated to the entire island based on the demographics and operational characteristics of the particular circuit (i.e., urban vs rural, 4.16 kV – 13.8 kV operating voltage, total circuit length).

This process yields a total of 9 scenarios to be analyzed. These are summarized in Table IV-1 below.

**Table IV-1: Summary of Scenarios**

| Scenario | Loading | EV Penetration | PV Penetration |
|---|---|---|---|
| **Base Case** | 2035 | 0% | 0% |
| **EV10** | 2035 | 10% | 0% |
| **EV20** | 2035 | 20% | 0% |
| **EV30** | 2035 | 30% | 0% |
| **EV40** | 2035 | 40% | 0% |
| **PVEV10** | 2035 | 10% | 75% |
| **PVEV20** | 2035 | 20% | 75% |
| **PVEV30** | 2035 | 30% | 75% |
| **PVEV40** | 2035 | 40% | 75% |

The traditional metrics used to evaluate distribution system performance are the operating voltage and the thermal loading of the system. Because there are multiple operating voltages under consideration in this analysis (4.16 kV, 8.2 kV and 13.8 kV), WKE has used what is referred to as the "per-unit" representation of voltage. Per-unit is really just a way of expressing a percentage, so 1.05 per-unit or 1.05 p.u. means 105% of the normal operating voltage. So, for example, for a 4.16 kV system, the normal operating voltage is 4,160 V, so a voltage of 1.05 p.u. is the same as 1.05 * 4160 or 4,368 V. This is important because distribution equipment and most consumer products (i.e., appliances, electronics, etc.) are only designed to operate within a certain range of voltage. They may fail or have their life reduced if they operate at too low or too high a voltage. The de facto standard for the operating range of distribution systems is ANSI C84.1, which recommends that the distribution system operate in a range of 1.05 to 0.95 pu under normal operating conditions.

The other traditional metric used for distribution analysis is the ampacity or thermal rating of the physical conductors (i.e., wires and cables) that comprise the distribution system. These conductors can only carry a certain amount of current before their structural and physical integrity begins to deteriorate. Again, they may fail or have their life shortened if asked to carry to much current over an extended period of time. Short term overloads may be permissible in emergency situations, but under normal circumstances they must be limited to their capacity rating. Since all the analysis performed here are predicated on “normal” conditions, the maximum permissible load of any conductor is limited to 100% of its rating. Any situation that results in loading higher than 100% of the conductor rating is indicative of the need for mitigation.

There are additional metrics that can be used to evaluate the operational fitness of a distribution system including:

- System losses – the percentage of the power that is delivered to the circuit that is “lost” as heat radiated from the conductors;
- Violation hours per year – The number of hours per year during which there is a voltage or thermal violation in the system. Used to gauge the severity of a violation and need for mitigation.
- Violation miles per year – The number of line miles of conductor that exhibit a violation sometime during the operating year. Used to quantify the mitigation costs.
- Voltage Delta from Base – the average value of the difference between the scenario voltage profile and the base case voltage profile.

Because these concepts are not necessarily common knowledge to those outside the field of electrical distribution planning, WKE has included a series of illustrative examples to demonstrate the concepts.

## A. Voltage Violations

One of the tools used to visualize the voltage performance of a particular circuit is what is referred to as a “Voltage Profile” of the circuit. This plots each individual point along a circuit (i.e., poles, changes in wire size, loads, changes in topology, etc.), the accompanying voltage, and the distance from the source of the circuit. There is an accompanying plot, referred to as a “Circuit Plot” that shows the connectivity and physical geographic layout of each circuit. Examples of each shown in Figure IV-1 and Figure IV-2 below. For reference, a specific point has been identified on both plots. The bright blue dot in Figure IV-1 corresponds to the bright blue dots in Figure IV-2.

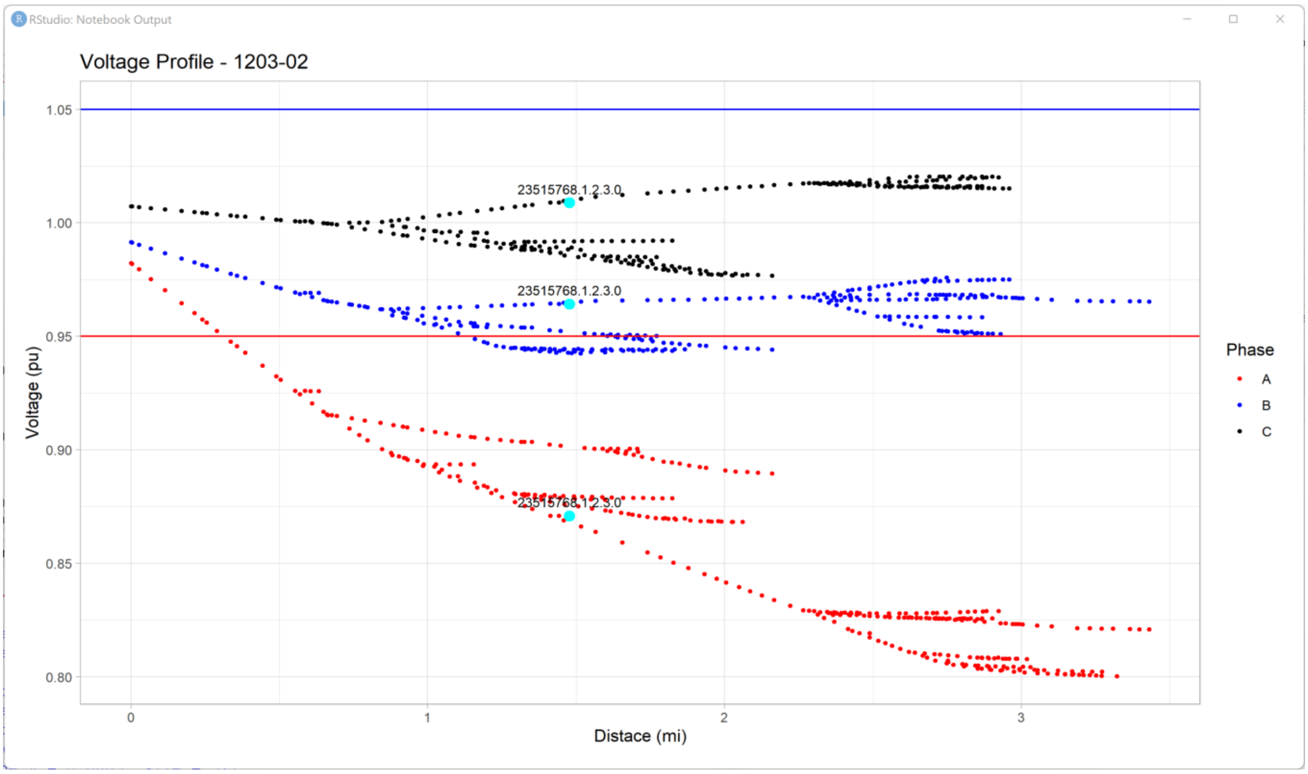

**Figure IV-1: Voltage Profile – Circuit 1203-02**

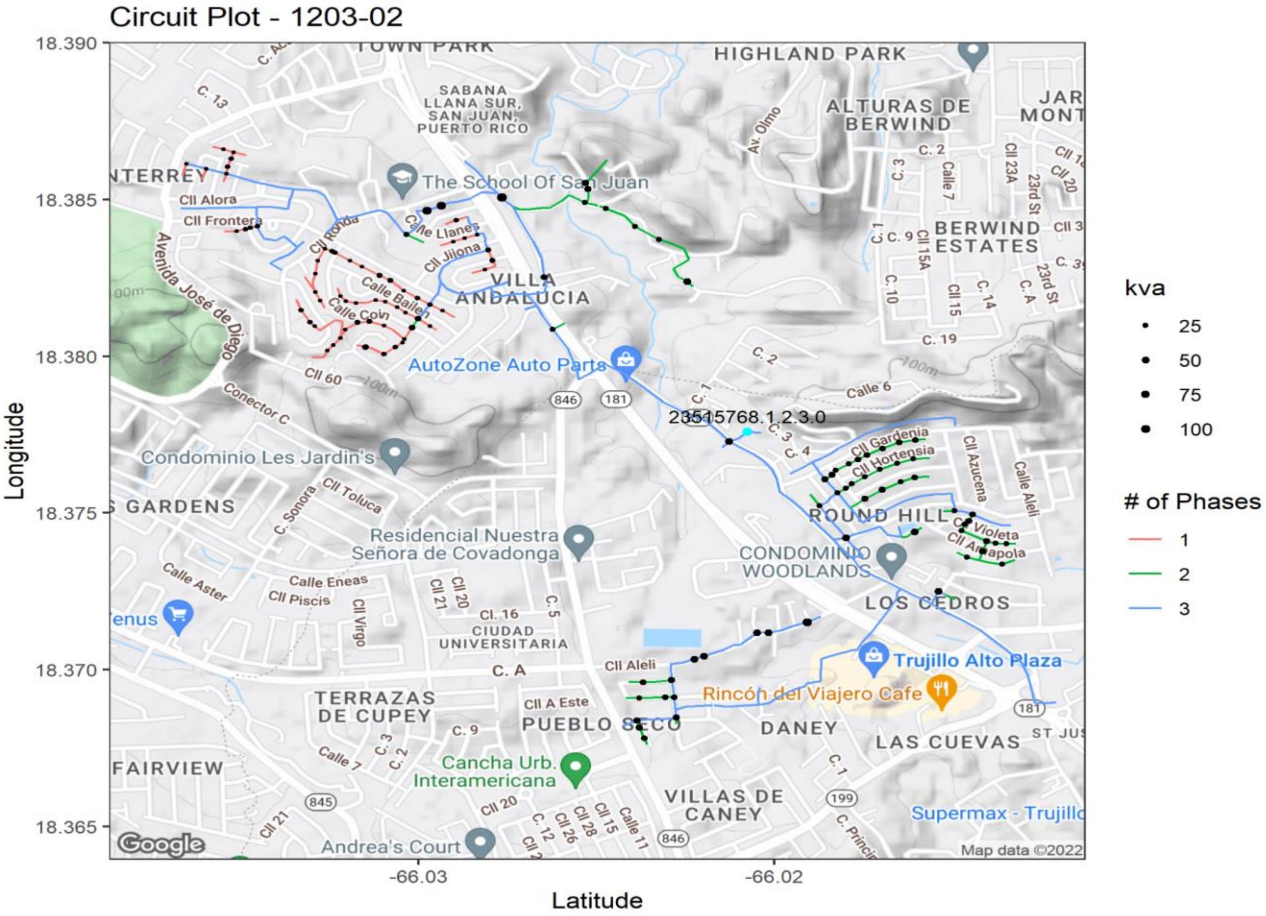

**Figure IV-2: Circuit Plot – Circuit 1203-02**

In this case, there are voltage violations, as the Phase A per unit voltage goes below 0.95 less than a mile into the circuit.

## B. Thermal Violations

Thermal violations are not related to a specific point along a circuit, but rather a line between two points (i.e., the conductor between two points). In this case, any time the conductor is loaded to greater than 100% of its rating, the conductor is flagged as a violation. This concept is illustrated in Figure IV-3 below, where the individual phase currents are above Line Rating shown in pink. Note that there is a relationship between the voltage plot and the current plot in that when currents are above their rating, the voltage drop was proportionally greater, and the resulting voltages downstream are more likely to be in violation as well.

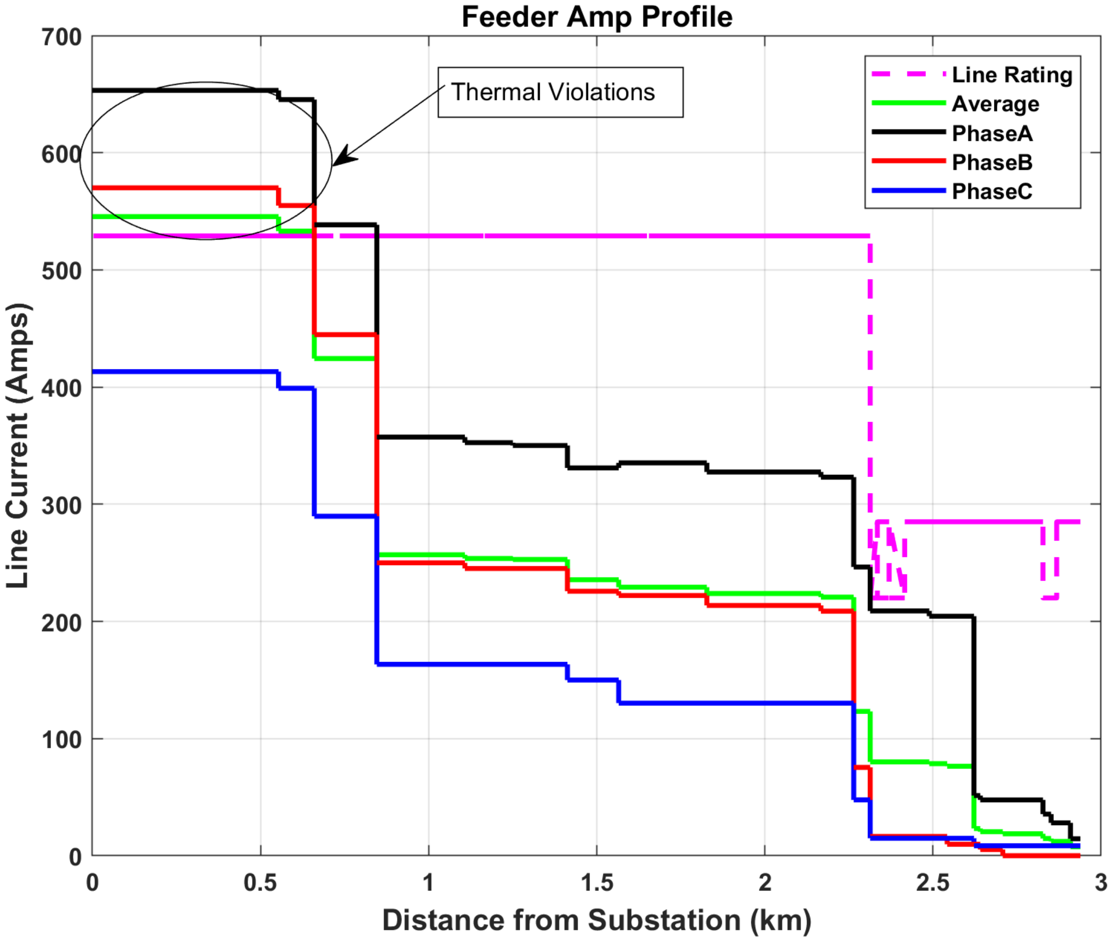

**Figure IV-3: Circuit 1203-02 Thermal Violations**

## C. Metrics

As noted above, there are additional metrics that are useful in the comparison of the impacts of the various scenarios under study. Below lists the values and units of the various metrics for the circuit illustrated above for the various scenarios.

**Table IV-2: Metrics for Feeder 1203-02**

| Metric | Base Case | EV10 | PVEV10 |
|---|---|---|---|
| Annual Losses (kWh | 996,307 | 1,040,925 | 795,330 |
| Annual Losses (%) | 4.21% | 4.29% | 3.81% |
| Voltage Violation Hours | 8760 | 8760 | 8424 |
| Thermal Violation | 0.46 | 0.46 | 0.46 |

| | | | |
|---|---|---|---|
| **Miles** | | | |
| **Voltage Delta** | 0.0 | -0.53% | 4.13% |

# V. Results – Summary by Circuit

## A. Feeder 1203-02, Saint Just Feeder 03

### 1. Circuit Summary

Feeder 1203-02 is characterized as a short, urban, commercial feeder operating at 4.16 kV. The feeder peak demand hour is August 7th, at 1:00 pm, based on the loading profile from the incumbent utility. The feeder is approximately 9.6 miles long and has 160 loads / transformers. The peak load is approximately 3.9 MVA. The performance metrics, as described above, are summarized in Table V-1 below. The feeder and load locations are illustrated in Figure V-1 below.

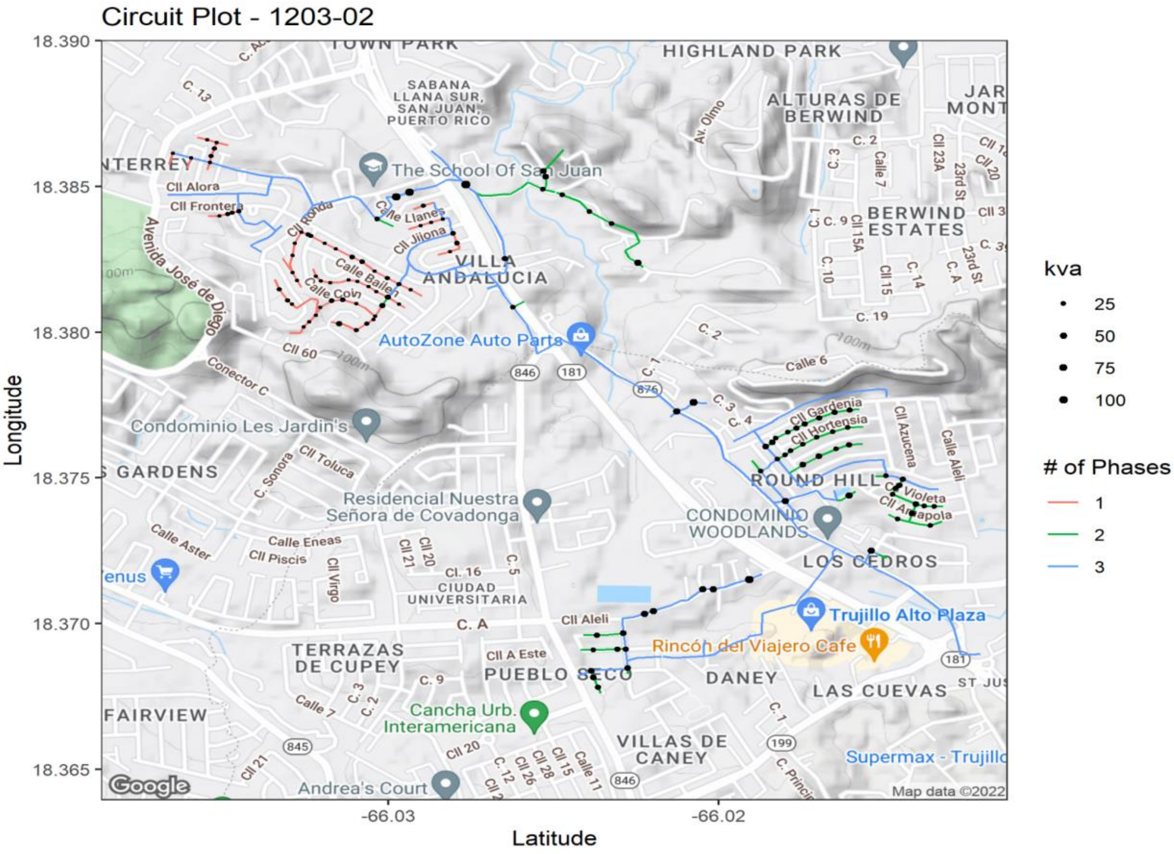

**Figure V-1: Feeder 1203-01 Feeder Summary**

**Table V-1: Metrics for Feeder 1203-02**

| Metric | Base Case | EV10 | PVEV10 | Metric | Base Case | EV20 | PVEV20 |
|---|---|---|---|---|---|---|---|
| **Annual Losses (kWh** | 996,307 | 1,040,925 | 795,330 | **Annual Losses (kWh** | 996,307 | 1,040,925 | 795,330 |
| **Annual Losses (%)** | 4.21% | 4.29% | 3.81% | **Annual Losses (%)** | 4.21% | 4.29% | 3.81% |
| **Voltage Violation Hours** | 8760 | 8760 | 8424 | **Voltage Violation Hours** | 8760 | 8760 | 8511 |
| **Thermal Violation Miles** | 0.46 | 0.46 | 0.46 | **Thermal Violation Miles** | 0.46 | 0.57 | 0.46 |
| **Voltage Delta** | 0.0 | -0.53% | 4.13% | **Voltage Delta** | 0.0 | -0.83% | 3.15% |
| **Metric** | **Base Case** | **EV30** | **PVEV30** | **Metric** | **Base Case** | **EV40** | **PVEV40** |
| **Annual Losses (kWh** | 996,307 | 1,080,021 | 828,865 | **Annual Losses (kWh** | 996,307 | 1,089,112 | 836,787 |
| **Annual Losses (%)** | 4.21% | 4.40% | 3.92% | **Annual Losses (%)** | 4.21% | 4.43% | 3.94% |
| **Voltage Violation Hours** | 8760 | 8760 | 8550 | **Voltage Violation Hours** | 8760 | 8760 | 8567 |
| **Thermal Violation Miles** | 0.46 | 0.57 | 0.46 | **Thermal Violation Miles** | 0.46 | 0.57 | 0.46 |
| **Voltage Delta** | 0.0 | -1.22% | 2.45% | **Voltage Delta** | 0.0 | -2.28% | 1.65% |

## A. Feeder 1403-01, Chardon Feeder 01

### 1. Feeder Summary

Feeder 1403-01 is characterized as a short, urban, commercial feeder operating at 4.16 kV. The feeder peak demand hour is August 7th, at 1:00 pm, based on the loading profile from the incumbent utility. The feeder is approximately 2.15 miles long and has 16 loads / transformers. The peak load is approximately 3.6 MVA. The performance metrics, as described above, are summarized in Table V-2 below. The feeder and load locations are illustrated in Figure V-2 below.

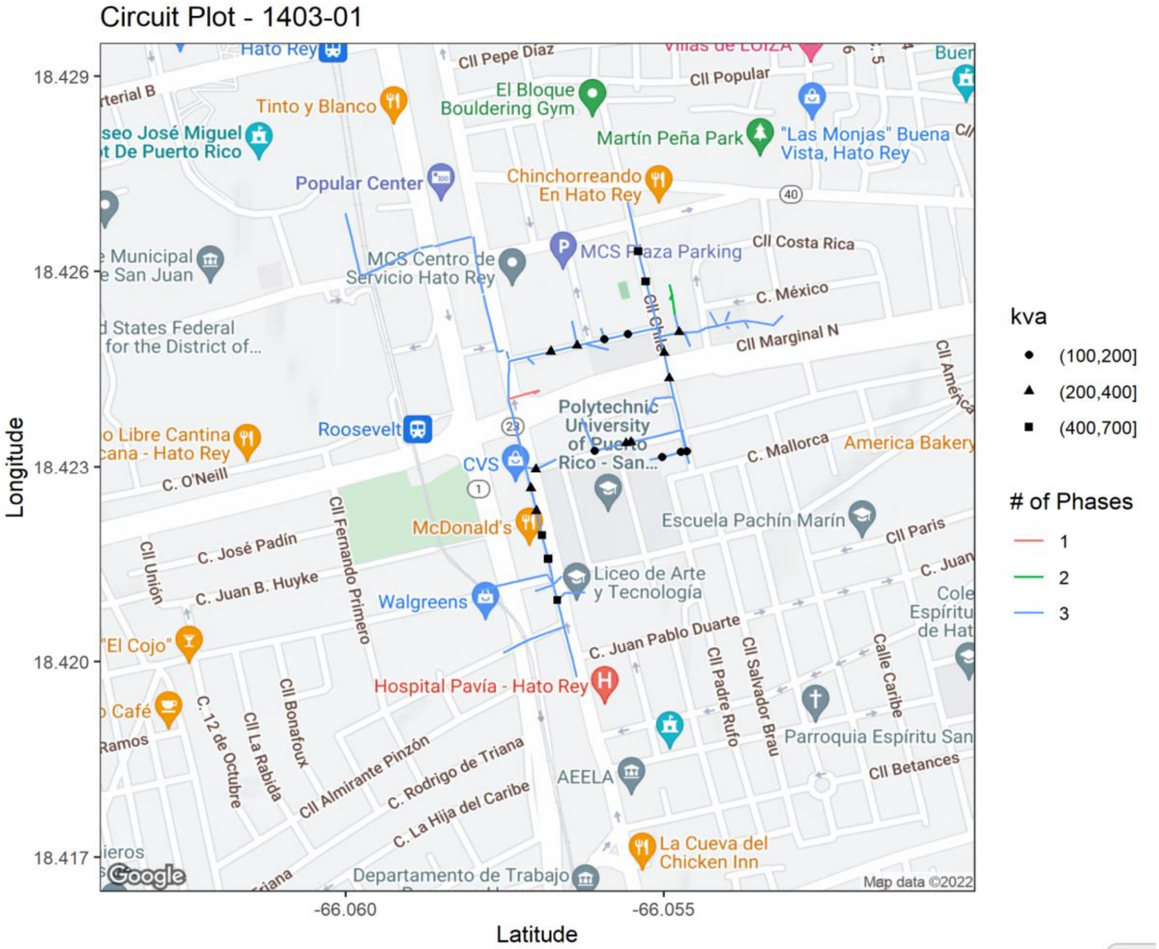

Figure V-2: Feeder 1403-01 Feeder Summary

## 2. Annual Metrics

Table V-2: Metrics for Feeder 1403-01

| Metric | Base Case | EV10 | PVEV10 | Metric | Base Case | EV20 | PVEV20 |
|---|---|---|---|---|---|---|---|
| Annual Losses (kWh) | 5,735,907 | 6,013,450 | 3,904,117 | Annual Losses (kWh) | 5,735,907 | 6,383,509 | 4,033,637 |
| Annual Losses (%) | 3.10% | 3.25% | 2.11% | Annual Losses (%) | 3.1% | 3.45% | 2.18% |
| Voltage Violation Hours | 0 | 0 | 0 | Voltage Violation Hours | 0 | 26 | 0 |
| Thermal Violation Miles | 0 | 0 | 0 | Thermal Violation Miles | 0 | 0 | 0 |
| Voltage Delta | 0.00% | -0.12% | 0.92% | Voltage Delta | 0.00% | -0.19% | 0.71% |

| Metric | Base Case | EV30 | PVEV30 | Metric | Base Case | EV40 | PVEV40 |
|---|---|---|---|---|---|---|---|
| **Annual Losses (kWh)** | 5,735,907 | 7,604,703 | 5,365,848 | **Annual Losses (kWh)** | 5,735,907 | 7,826,738 | 6,068,960 |
| **Annual Losses (%)** | 3.1% | 4.11% | 2.90% | **Annual Losses (%)** | 3.1% | 4.23% | 3.28% |
| **Voltage Violation Hours** | 0 | 88 | 0 | **Voltage Violation Hours** | 0 | 2,200 | 0 |
| **Thermal Violation Miles** | 0 | 0 | 0 | **Thermal Violation Miles** | 0 | 0 | 0 |
| **Voltage Delta** | 0.00% | -0.27% | 0.55% | **Voltage Delta** | 0.00% | -0.51% | 0.37% |

## B. Feeder 1525-01, Las Lomas Feeder 01

### 1. Feeder Summary

Feeder 1525-01 is characterized as a short, urban, residential feeder operating at 4.16 kV. The feeder peak demand hour is August 7th, at 1:00 pm, based on the loading profile from the incumbent utility. The feeder is approximately 4.32 miles long and has 93 loads / transformers. The peak load is approximately 0.5 MVA. The performance metrics, as described above, are summarized in Table V-3 below. The feeder and load locations are illustrated in Figure V-3 below.

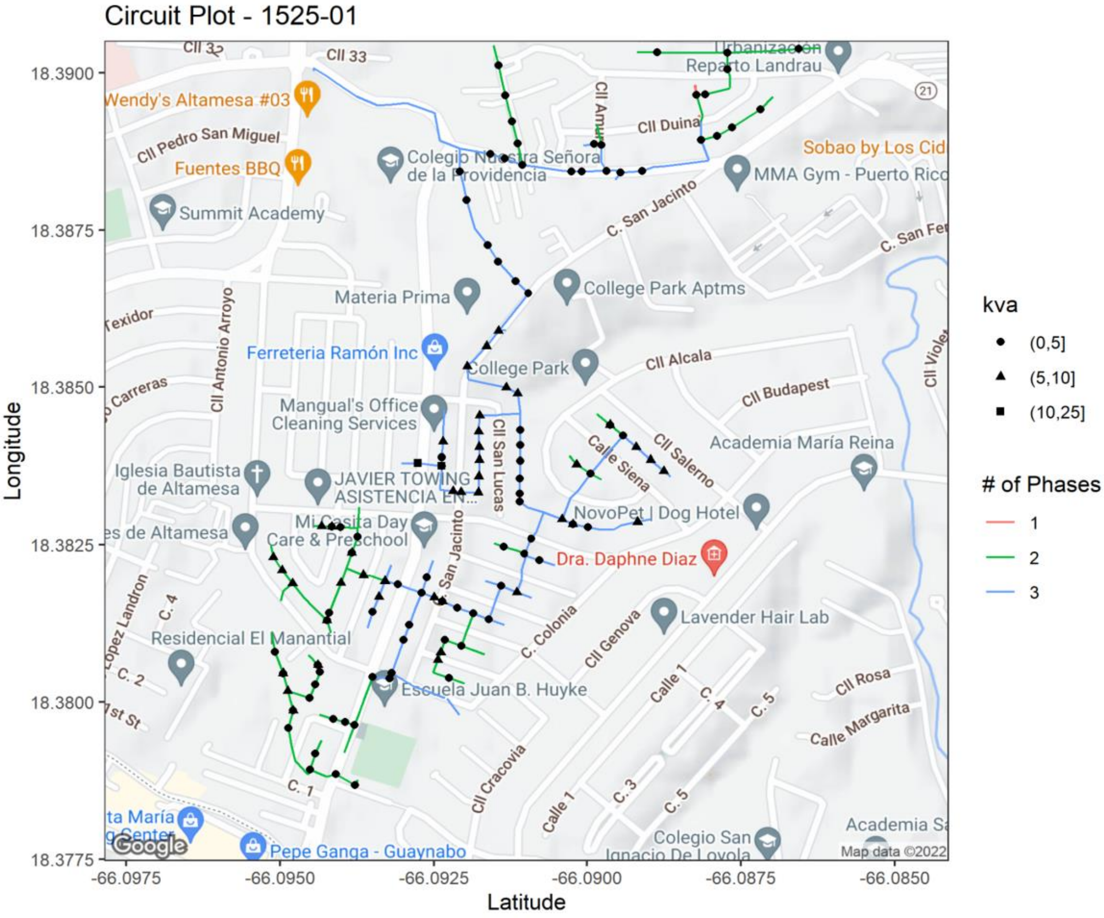

**Figure V-3: Feeder 1525-01 Feeder Summary**

## 2. Annual Metrics

**Table V-3: Metrics for Feeder 1525-01**

| Metric | Base Case | EV10 | PVEV10 | Metric | Base Case | EV20 | PVEV20 |
|---|---|---|---|---|---|---|---|
| **Annual Losses (kWh)** | 43,248 | 113,663 | 106,588 | **Annual Losses (kWh)** | 43,248 | 123,480 | 115,948 |
| **Annual Losses (%)** | 1.31% | 2.12% | 2.05% | **Annual Losses (%)** | 1.31% | 2.20% | 2.12% |
| **Voltage Violation Hours** | 0 | 0 | 0 | **Voltage Violation Hours** | 0 | 0 | 0 |
| **Thermal Violation Miles** | 0 | 0.05 | 0 | **Thermal Violation Miles** | 0 | 0.05 | 0.05 |
| **Voltage Delta** | 0.00% | -0.04% | 0.33% | **Voltage Delta** | 0.00% | -0.07% | 0.25% |

| Metric | Base Case | EV30 | PVEV30 | Metric | Base Case | EV40 | PVEV40 |
|---|---|---|---|---|---|---|---|
| **Annual Losses (kWh)** | 43,248 | 143,484 | 135,389 | **Annual Losses (kWh** | 43,248 | 154,406 | 145,840 |
| **Annual Losses (%)** | 1.31% | 2.36% | 2.28% | **Annual Losses (%)** | 1.31% | 2.45% | 2.37% |
| **Voltage Violation Hours** | 0 | 0 | 0 | **Voltage Violation Hours** | 0 | 0 | 0 |
| **Thermal Violation Miles** | 0 | 0.09 | 0.09 | **Thermal Violation Miles** | 0 | 0.17 | 0.11 |
| **Voltage Delta** | 0.00% | -0.10% | 0.20% | **Voltage Delta** | 0.00% | -0.18% | 0.13% |

## C. Feeder 1529-11, San Patricio Feeder 11

### 1. Feeder Summary

Feeder 1529-11 is characterized as a medium, urban, residential feeder operating at 13.2 kV. The feeder peak demand hour is August 7th, at 1:00 pm, based on the loading profile from the incumbent utility. The feeder is approximately 7.66 miles long and has 81 loads / transformers. The peak load is approximately 2.8 MVA. The performance metrics, as described above, are summarized in Table V-4 below. The feeder and load locations are illustrated in Figure V-4 below.

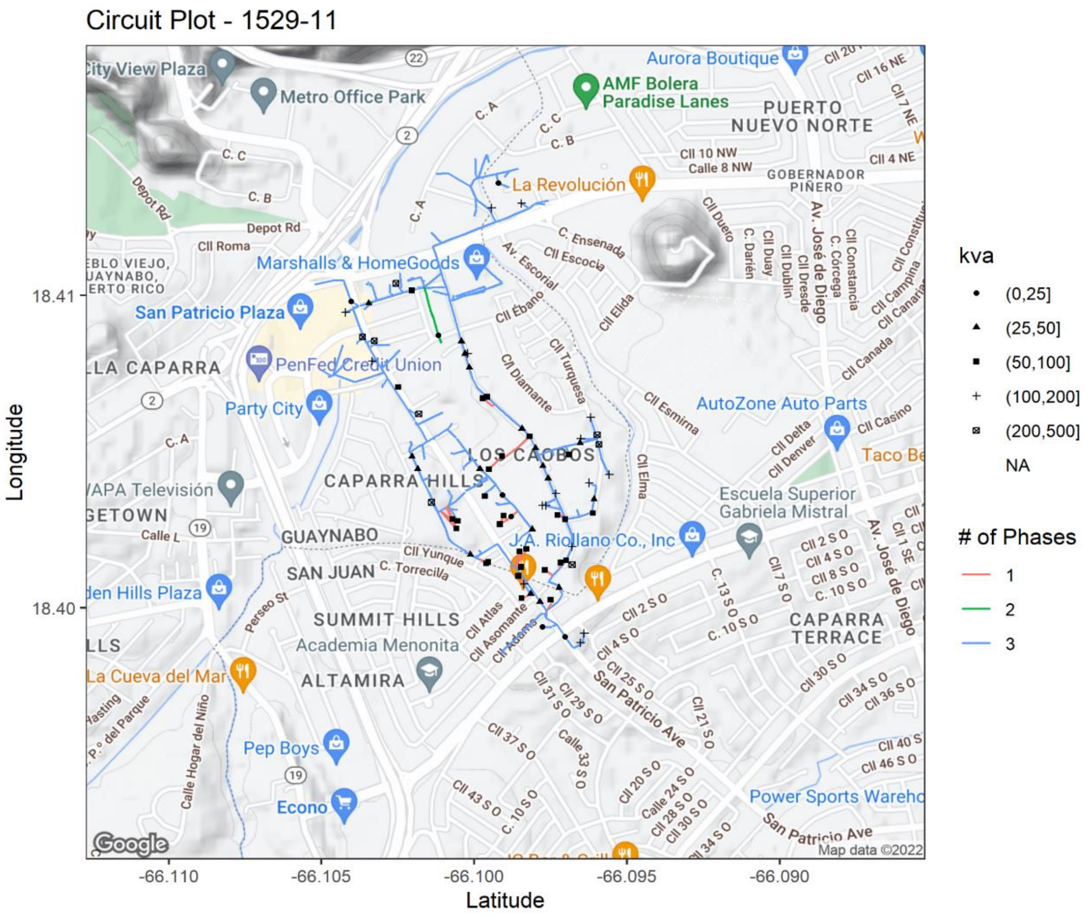

Figure V-4: Feeder 1529-11 Feeder Summary

## 2. Annual Metrics

Table V-4: Metrics for Feeder 1529-11

| Metric | Base Case | EV10 | PVEV10 | Metric | Base Case | EV20 | PVEV20 |
|---|---|---|---|---|---|---|---|
| Annual Losses (kWh) | 2,331,369 | 3,904,117 | 2,664,421 | Annual Losses (kWh) | 2,331,369 | 5,347,346 | 2,978,971 |
| Annual Losses (%) | 1.26% | 2.11% | 1.44% | Annual Losses (%) | 1.26% | 2.89% | 1.61% |
| Voltage Violation Hours | 428 | 899 | 238 | Voltage Violation Hours | 428 | 996 | 261 |
| Thermal Violation Miles | 0 | 0.22 | 0 | Thermal Violation Miles | 0 | 0.29 | 0 |
| Voltage Delta | 0.00% | -0.43% | 3.39% | Voltage Delta | 0.00% | -0.68% | 2.59% |

| Metric | Base Case | EV30 | PVEV30 | Metric | Base Case | EV40 | PVEV40 |
|---|---|---|---|---|---|---|---|
| **Annual Losses (kWh)** | 2,331,369 | 5,698,901 | 3,275,018 | **Annual Losses (kWh)** | 2,331,369 | 6,679,556 | 3,663,579 |
| **Annual Losses (%)** | 1.26% | 3.08% | 1.77% | **Annual Losses (%)** | 1.26% | 3.61% | 1.98% |
| **Voltage Violation Hours** | 428 | 1338 | 421 | **Voltage Violation Hours** | 428 | 2890 | 497 |
| **Thermal Violation Miles** | 0 | 0.42 | 0.09 | **Thermal Violation Miles** | 0 | 0.48 | 0.11 |
| **Voltage Delta** | 0.00% | -1.00% | 2.01% | **Voltage Delta** | 0.00% | -1.87% | 1.35% |

## D. Feeder 1704-01, Sierra Linda Feeder 01

### 1. Feeder Summary

Feeder 1704-01 is characterized as a medium, urban, residential feeder operating at 4.16 kV. The feeder peak demand hour is August 7th, at 1:00 pm, based on the loading profile from the incumbent utility. The feeder is approximately 8.7 miles long and has 174 loads / transformers. The peak load is approximately 4.1 MVA. The performance metrics, as described above, are summarized in Table V-5 below. The feeder and load locations are illustrated in Figure V-5 below.

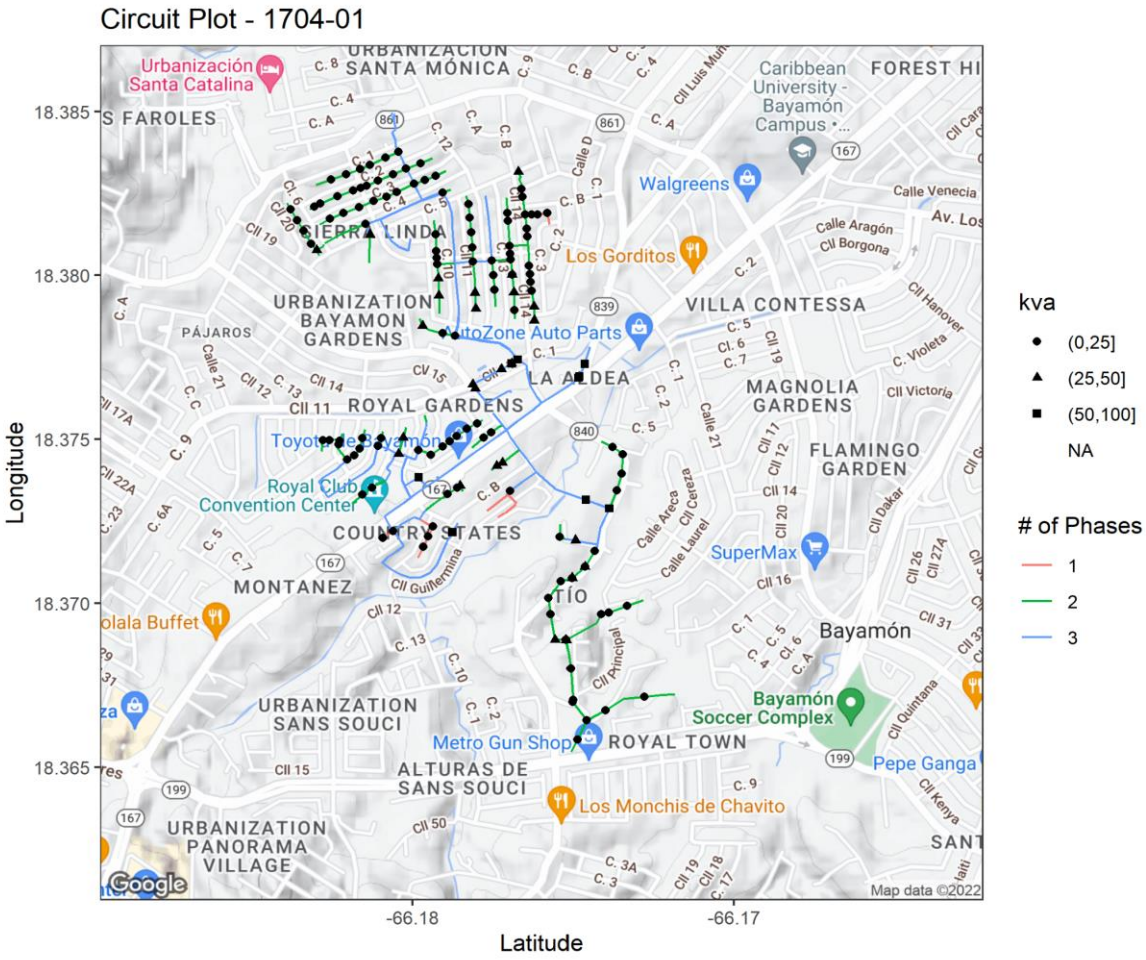

Figure V-5: Feeder 1704-01 Feeder Summary

## 2. Annual Metrics

Table V-5: Metrics for Feeder 1704-01

| Metric | Base Case | EV10 | PVEV10 | Metric | Base Case | EV20 | PVEV20 |
|---|---|---|---|---|---|---|---|
| Annual Losses (kWh) | 614,332 | 636,140 | 526,938 | Annual Losses (kWh) | 614,332 | 655,635 | 544,608 |
| Annual Losses (%) | 2.77% | 2.81% | 2.59% | Annual Losses (%) | 2.77% | 2.87% | 2.64% |
| Voltage Violation Hours | 5487 | 5634 | 4511 | Voltage Violation Hours | 5487 | 5951 | 4796 |
| Thermal Violation Miles | 0.1 | 0.21 | 0.0 | Thermal Violation Miles | 0.1 | 0.27 | 0.0 |
| Voltage Delta | 0.00% | -0.70% | 5.48% | Voltage Delta | 0.00% | -1.10% | 4.18% |

| Metric | Base Case | EV30 | PVEV30 | Metric | Base Case | EV40 | PVEV40 |
|---|---|---|---|---|---|---|---|
| **Annual Losses (kWh)** | 614,332 | 674,521 | 562,000 | **Annual Losses (kWh)** | 614,332 | 698,792 | 584,149 |
| **Annual Losses (%)** | 2.77% | 2.88% | 2.66% | **Annual Losses (%)** | 2.77% | 2.96% | 2.73% |
| **Voltage Violation Hours** | 5487 | 5954 | 4891 | **Voltage Violation Hours** | 5487 | 6474 | 5441 |
| **Thermal Violation Miles** | 0.1 | 0.39 | 0.05 | **Thermal Violation Miles** | 0.1 | 0.91 | 0.12 |
| **Voltage Delta** | 0.00% | -1.62% | 3.25% | **Voltage Delta** | 0.00% | -3.03% | 2.19% |

## E. Feeder 1806-01, Levittown Feeder 01

### 1. Feeder Summary

Feeder 1806-01 is characterized as a long, urban, residential feeder operating at 13.2 kV. The feeder peak demand hour is August 7th, at 1:00 pm, based on the loading profile from the incumbent utility. The feeder is approximately 28.7 miles long and has 306 loads / transformers. The peak load is approximately 2.8 MVA. The performance metrics, as described above, are summarized in Table V-6 below. The feeder and load locations are illustrated in Figure V-6 below.

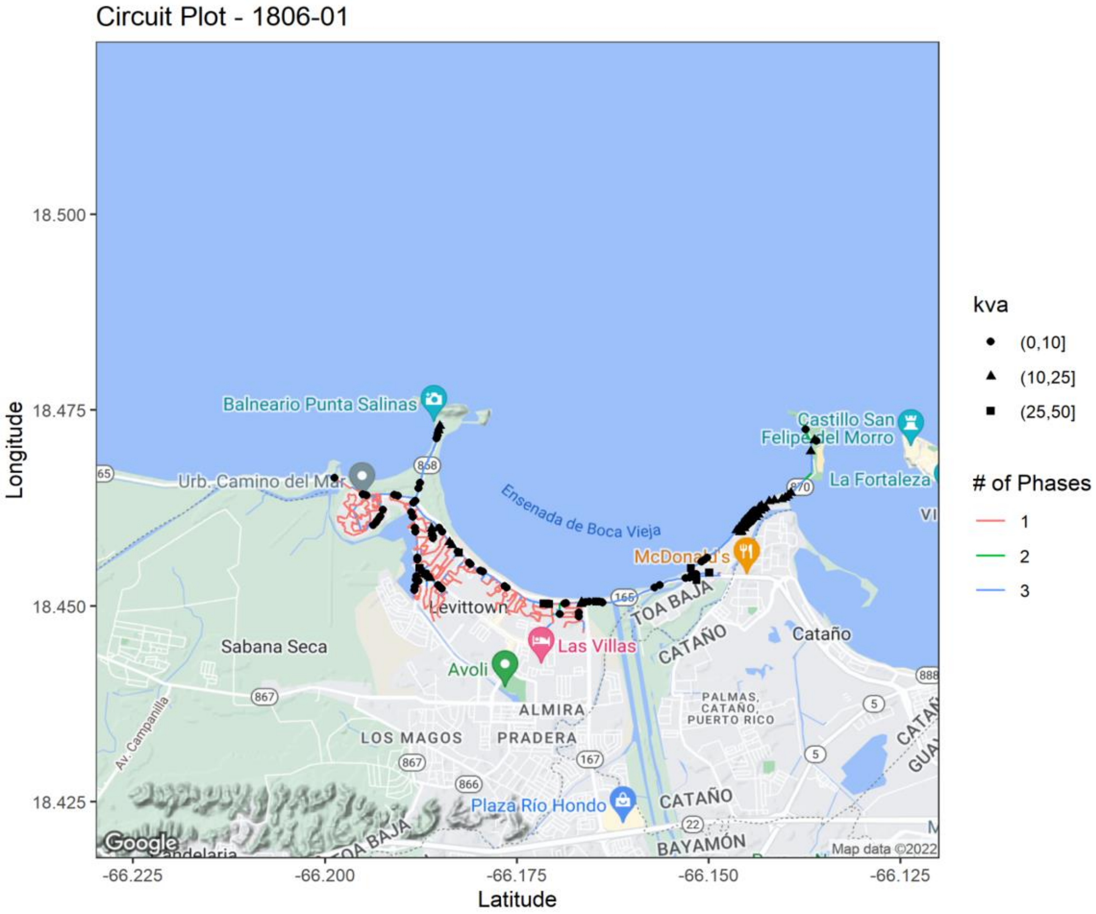

**Figure V-6: Feeder 1806-01 – Feeder Summary**

## 2. Annual Metrics

**Table V-6: Metrics for Feeder 1806-01**

| Metric | Base Case | EV10 | PVEV10 |
|---|---|---|---|
| Annual Losses (kWh) | 250,667 | 384,687 | 171,248 |
| Annual Losses (%) | 1.01% | 1.55% | 0.69% |
| Voltage Violation Hours | 0 | 0 | 0 |
| Thermal Violation Miles | 0 | 0 | 0 |
| Voltage Delta | 0.00% | -1.36% | 10.58% |

| Metric | Base Case | EV20 | PVEV20 |
|---|---|---|---|
| Annual Losses (kWh) | 250,667 | 429,360 | 243,221 |
| Annual Losses (%) | 1.01% | 1.73% | 0.98% |
| Voltage Violation Hours | 0 | 83 | 0 |
| Thermal Violation Miles | 0 | 0.11 | 0 |
| Voltage Delta | 0.00% | -2.13% | 8.07% |

| Metric | Base Case | EV30 | PVEV30 |
|---|---|---|---|
| Annual Losses (kWh) | 250,667 | 469,070 | 305,268 |
| Annual Losses (%) | 1.01% | 1.89% | 1.23% |
| Voltage Violation Hours | 0 | 277 | 2 |
| Thermal Violation Miles | 0 | 0.28 | 0.01 |
| Voltage Delta | 0.00% | -3.13% | 6.28% |

| Metric | Base Case | EV40 | PVEV40 |
|---|---|---|---|
| Annual Losses (kWh) | 250,667 | 501,334 | 362,350 |
| Annual Losses (%) | 1.01% | 2.02% | 1.46% |
| Voltage Violation Hours | 0 | 597 | 11 |
| Thermal Violation Miles | 0 | 0.87 | 0.01 |
| Voltage Delta | 0.00% | -5.84% | 4.23% |

## F. Feeder 2201-04, Luquillo Feeder 04

### 1. Feeder Summary

Feeder 2201-04 is characterized as a long, rural, residential feeder operating at 8.32 kV. The feeder peak demand hour is August 7th, at 1:00 pm, based on the loading profile from the incumbent utility. The feeder is approximately 29.4 miles long and has 255 loads / transformers. The peak load is approximately 3.1 MVA. The performance metrics, as described above, are summarized in Table V-7 below. The feeder and load locations are illustrated in Figure V-7 below.

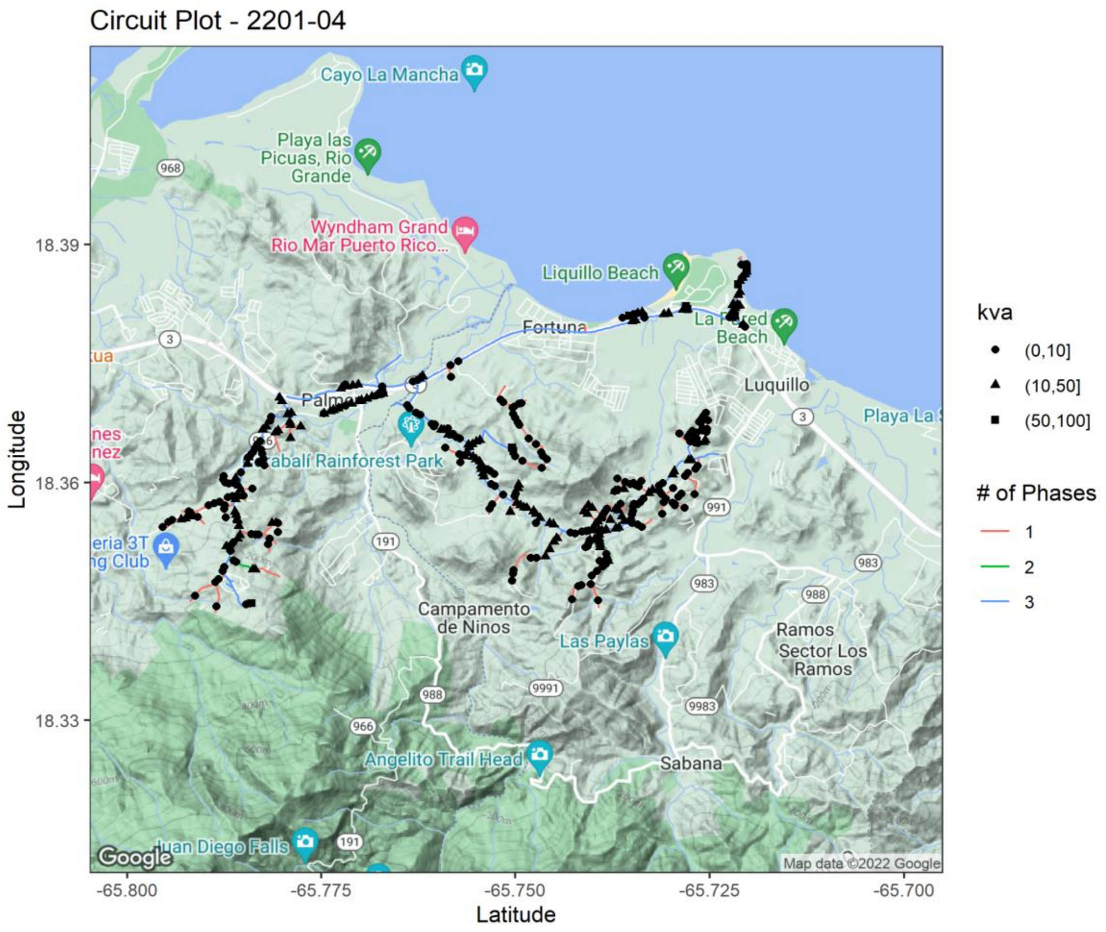

**Figure V-7: Feeder 2201-04 – Feeder Summary**

## 2. Annual Metrics

**Table V-7: Metrics for Feeder 2201-04**

| Metric | Base Case | EV10 | PVEV10 | Metric | Base Case | EV20 | PVEV20 |
|---|---|---|---|---|---|---|---|
| Annual Losses (kWh) | 1,241,292 | 1,420,145 | 811,511 | Annual Losses (kWh) | 1,241,292 | 1,671,073 | 1,073,117 |
| Annual Losses (%) | 4.65% | 5.32% | 3.04% | Annual Losses (%) | 4.65% | 6.26% | 4.02% |
| Voltage Violation Hours | 5205 | 5948 | 3938 | Voltage Violation Hours | 5205 | 7007 | 4500 |
| Thermal Violation Miles | 0 | 0 | 0 | Thermal Violation Miles | 0 | 0 | 0 |
| Voltage Delta | 0.00% | -1.80% | 14.00% | Voltage Delta | 0.00% | -2.81% | 10.68% |

| Metric | Base Case | EV30 | PVEV30 | Metric | Base Case | EV40 | PVEV40 |
|---|---|---|---|---|---|---|---|
| Annual Losses (kWh) | 1,241,292 | 1,972,720 | 1,305,359 | Annual Losses (kWh) | 1,241,292 | 2,338,434 | 1,486,881 |
| Annual Losses (%) | 4.65% | 7.39% | 4.89% | Annual Losses (%) | 4.65% | 8.76% | 5.57% |
| Voltage Violation Hours | 5205 | 8272 | 5474 | Voltage Violation Hours | 5205 | 8338 | 6235 |
| Thermal Violation Miles | 0 | 0.16 | 0 | Thermal Violation Miles | 0 | 0.22 | 0 |
| Voltage Delta | 0.00% | -4.14% | 8.31% | Voltage Delta | 0.00% | -7.73% | 5.59% |

## G. Feeder 2402-02, Loiza Valley Feeder 02

### 1. Feeder Summary

Feeder 2402-02 is characterized as a long, urban, residential feeder operating at 13.2 kV. The feeder peak demand hour is August 7th, at 1:00 pm, based on the loading profile from the incumbent utility. The feeder is approximately 46.3 miles long and has 528 loads / transformers. The peak load is approximately 6.1 MVA. The performance metrics, as described above, are summarized in Table V-8 below. The feeder and load locations are illustrated in Figure V-8 below.

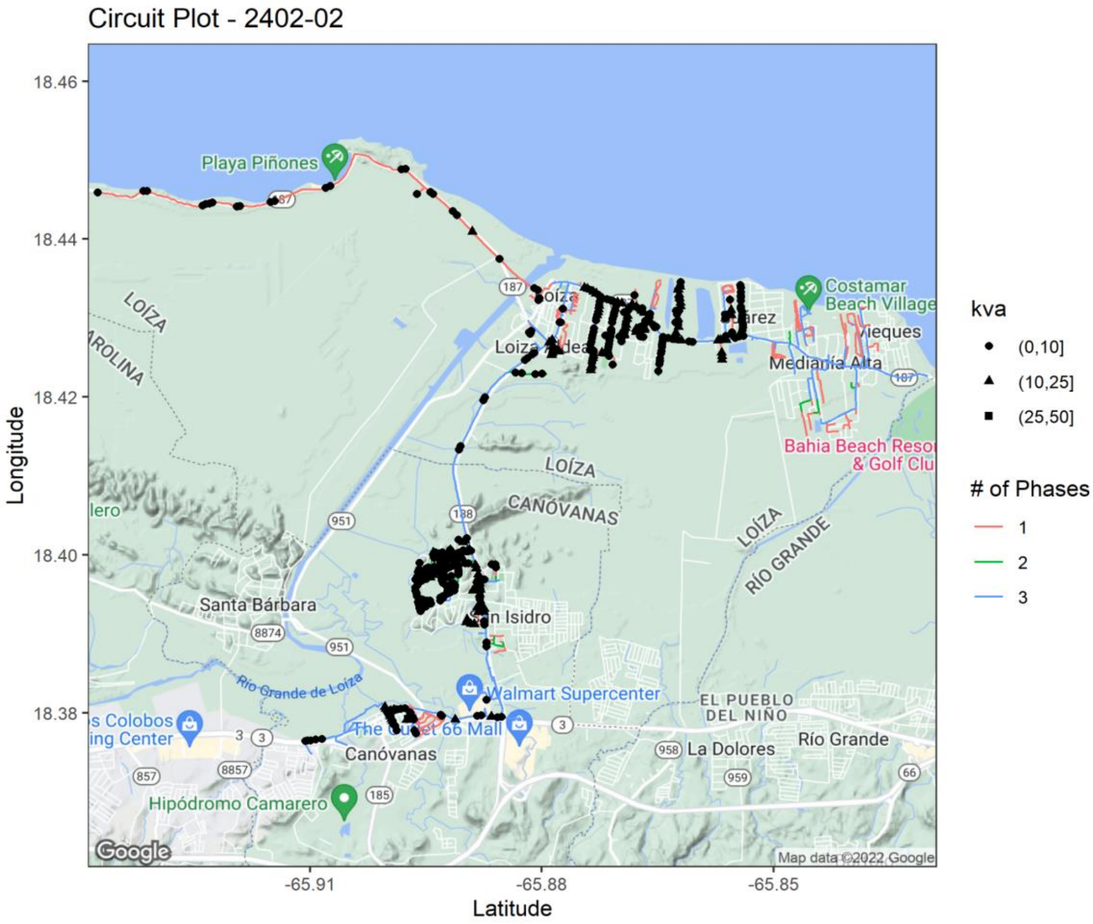

Figure V-8: Feeder 2402-02 – Feeder Summary

## 2. Annual Metrics

**Table V-8: Metrics for Feeder 2402-02**

| Metric | Base Case | EV10 | PVEV10 | Metric | Base Case | EV20 | PVEV20 |
|---|---|---|---|---|---|---|---|
| **Annual Losses (kWh)** | 350,687 | 538,183 | 239,578 | **Annual Losses (kWh)** | 350,687 | 600,682 | 340,271 |
| **Annual Losses (%)** | 1.66% | 2.54% | 1.13% | **Annual Losses (%)** | 1.66% | 2.84% | 1.61% |
| **Voltage Violation Hours** | 0 | 0 | 0 | **Voltage Violation Hours** | 0 | 3991 | 0 |
| **Thermal Violation Miles** | 0 | 0 | 0 | **Thermal Violation Miles** | 0 | 0 | 0 |
| **Voltage Delta** | 0.00% | -5.57% | 43.39% | **Voltage Delta** | 0.00% | -8.72% | 33.10% |
| **Metric** | **Base Case** | **EV30** | **PVEV30** | **Metric** | **Base Case** | **EV40** | **PVEV40** |
| **Annual Losses (kWh)** | 350,687 | 656,236 | 427,074 | **Annual Losses (kWh)** | 350,687 | 701,374 | 506,934 |
| **Annual Losses (%)** | 1.66% | 3.10% | 2.02% | **Annual Losses (%)** | 1.66% | 3.31% | 2.39% |
| **Voltage Violation Hours** | 0 | 5667 | 332 | **Voltage Violation Hours** | 0 | 8611 | 566 |
| **Thermal Violation Miles** | 0 | 0.52 | 0.01 | **Thermal Violation Miles** | 0 | 1.11 | 0.01 |
| **Voltage Delta** | 0.00% | -12.82% | 25.74% | **Voltage Delta** | 0.00% | -23.96% | 17.34% |

## A. Feeder 2501-02, Vieques Feeder 02

### 1. Feeder Summary

Feeder 2501-02 is characterized as a long, urban, residential feeder operating at 4.16 kV. The feeder peak demand hour is August 7th, at 1:00 pm, based on the loading profile from the incumbent utility. The feeder is approximately 26.9 miles long and has 221 loads / transformers. The peak load is approximately 3.4 MVA. The performance metrics, as described above, are summarized in Table V-9 below. The feeder and load locations are illustrated in Figure V-9 below.

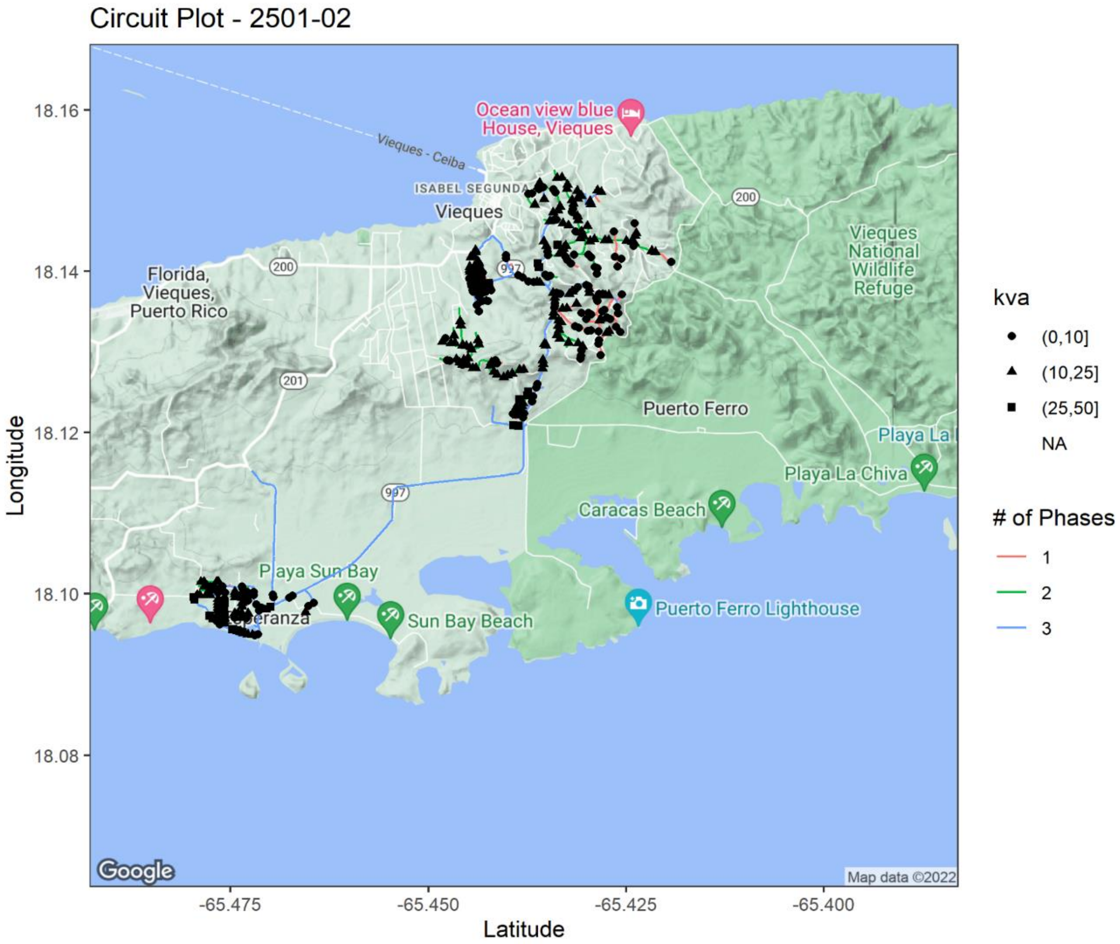

Figure V-9: Feeder 2501-02 Feeder Summary

## 2. Annual Metrics

**Table V-9: Metrics for Feeder 2501-02**

| Metric | Base Case | EV10 | PVEV10 | Metric | Base Case | EV20 | PVEV20 |
|---|---|---|---|---|---|---|---|
| Annual Losses (kWh) | 14,052,972 | 14,732,955 | 9,565,087 | Annual Losses (kWh) | 14,052,972 | 15,629,309 | 9,875,911 |
| Annual Losses (%) | 7.60% | 7.96% | 5.17% | Annual Losses (%) | 7.60% | 8.45% | 5.34% |
| Voltage Violation Hours | 422 | 879 | 383 | Voltage Violation Hours | 422 | 2709 | 399 |
| Thermal Violation Miles | 2.68 | 2.68 | 1.03 | Thermal Violation Miles | 2.68 | 2.68 | 1.03 |
| Voltage Delta | 0.00% | -1.80% | 14.05% | Voltage Delta | 0.00% | -2.82% | 10.72% |
| **Metric** | **Base Case** | **EV30** | **PVEV30** | **Metric** | **Base Case** | **EV40** | **PVEV40** |
| Annual Losses (kWh) | 14,052,972 | 20,765,115 | 14,441,278 | Annual Losses (kWh) | 14,052,972 | 25,258,368 | 15,180,908 |
| Annual Losses (%) | 7.60% | 11.23% | 7.81% | Annual Losses (%) | 7.60% | 13.66% | 8.21% |
| Voltage Violation Hours | 422 | 3760 | 455 | Voltage Violation Hours | 422 | 5201 | 530 |
| Thermal Violation Miles | 2.68 | 2.89 | 1.32 | Thermal Violation Miles | 2.68 | 3.01 | 1.55 |
| Voltage Delta | 0.00% | -4.15% | 8.34% | Voltage Delta | 0.00% | -7.76% | 5.61% |

## B. Feeder 2602-03, Humacao Feeder 03

### 1. Feeder Summary

Feeder 2602-03 is characterized as a long, rural, residential feeder operating at 8.32 kV. The feeder peak demand hour is August 7th, at 1:00 pm, based on the loading profile from the incumbent utility. The feeder is approximately 34.8 miles long and has 310 loads / transformers. The peak load is approximately 3.5 MVA. The performance metrics, as described above, are summarized in Table V-10 below. The feeder and load locations are illustrated in Figure V-10 below.

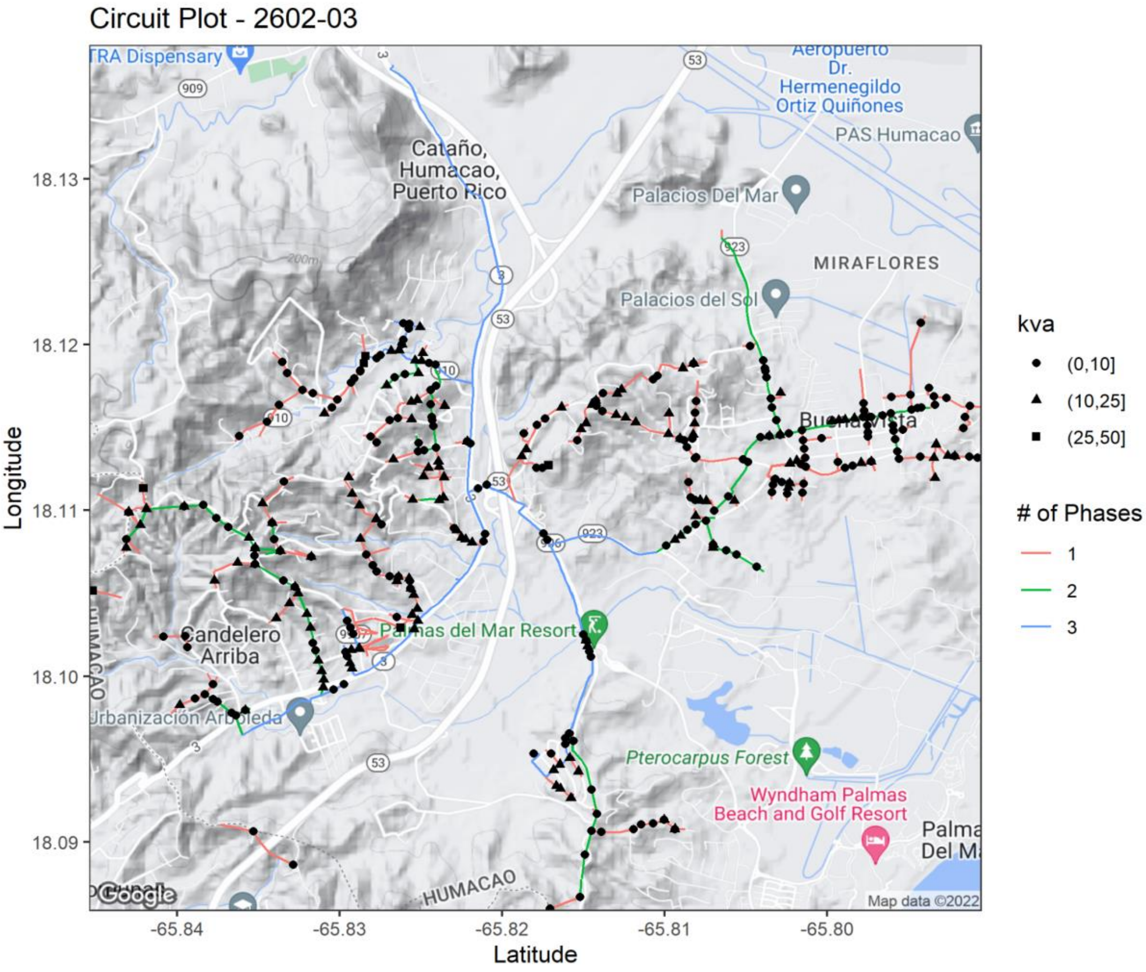

Figure V-10: Feeder 2602-03 Feeder Summary

## 2. Annual Metrics

**Table V-10: Metrics for Feeder 2602-03**

| Metric | Base Case | EV10 | PVEV10 | Metric | Base Case | EV20 | PVEV20 |
|---|---|---|---|---|---|---|---|
| Annual Losses (kWh) | 172,388 | 266,355 | 400,083 | Annual Losses (kWh) | 172,388 | 201,426 | 89,667 |
| Annual Losses (%) | 1.69% | 2.09% | 3.11% | Annual Losses (%) | 1.69% | 3.17% | 2.48% |
| Voltage Violation Hours | 0 | 9 | 0 | Voltage Violation Hours | 0 | 1159 | 430 |
| Thermal Violation Miles | 0 | 0 | 0 | Thermal Violation Miles | 0 | 0 | 0 |
| Voltage Delta | 0.00% | -2.40% | 18.71% | Voltage Delta | 0.00% | -3.76% | 14.27% |

| Metric | Base Case | EV30 | PVEV30 | Metric | Base Case | EV40 | PVEV40 |
|---|---|---|---|---|---|---|---|
| Annual Losses (kWh) | 172,388 | 536,944 | 457,856 | Annual Losses (kWh) | 172,388 | 652,817 | 508,381 |
| Annual Losses (%) | 1.69% | 2.95% | 2.51% | Annual Losses (%) | 1.69% | 3.28% | 2.55% |
| Voltage Violation Hours | 0 | 4548 | 2059 | Voltage Violation Hours | 0 | 5426 | 2686 |
| Thermal Violation Miles | 0 | 0 | 0 | Thermal Violation Miles | 0 | 0 | 0 |
| Voltage Delta | 0.00% | -5.53% | 11.10% | Voltage Delta | 0.00% | -10.33% | 7.48% |

## C. Feeder 3007-03, Gautier Benitez Feeder 03

### 1. Feeder Summary

Feeder 3007-03 is characterized as a long, rural, residential feeder operating at 8.32 kV. The feeder peak demand hour is August 7th, at 1:00 pm, based on the loading profile from the incumbent utility. The feeder is approximately 15.8 miles long and has 593 loads / transformers. The peak load is approximately 3.4 MVA. The performance metrics, as described above, are summarized in Table V-11 below. The feeder and load locations are illustrated in Figure V-10 below.

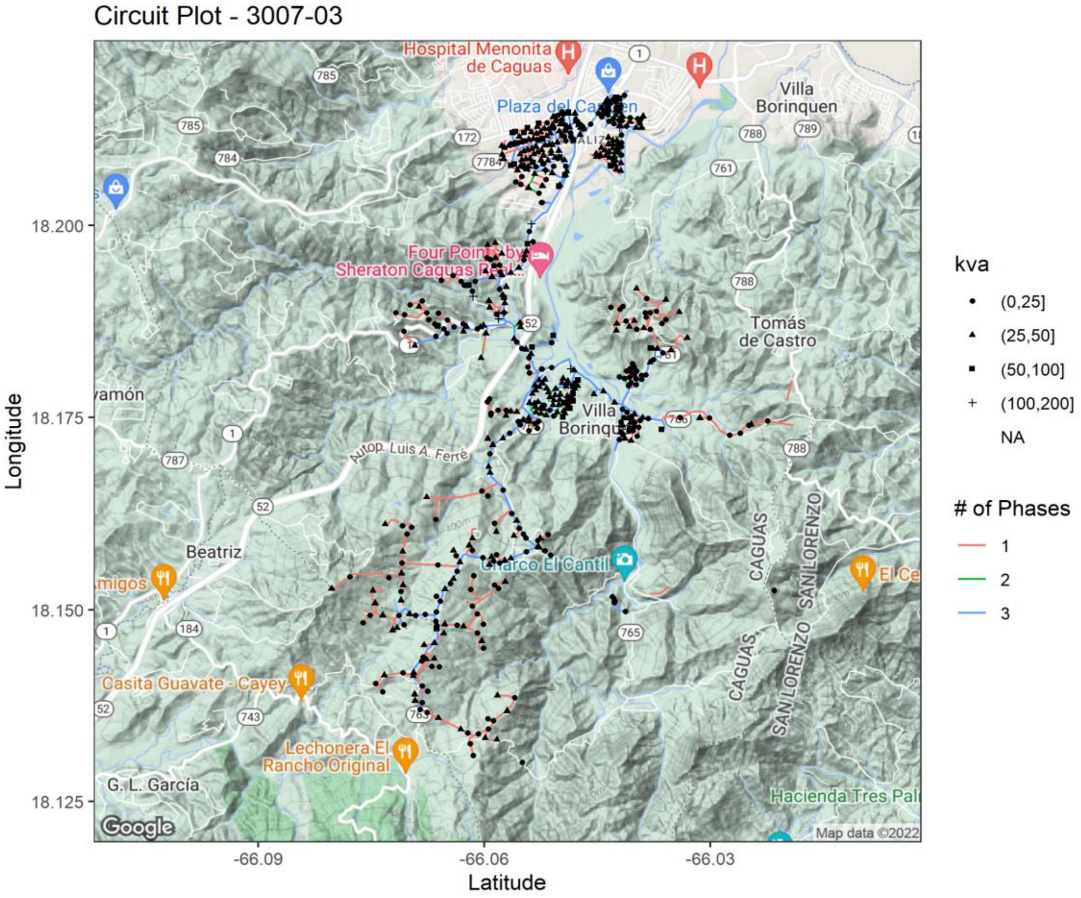

Figure V-11: Feeder 3007-03 Feeder Summary

## 2. Annual Metrics

Table V-11: Metrics for Feeder 3007-03

| Metric | Base Case | EV10 | PVEV10 | Metric | Base Case | EV20 | PVEV20 |
|---|---|---|---|---|---|---|---|
| **Annual Losses (kWh)** | 705,180 | 1,056,086 | 942,220 | **Annual Losses (kWh)** | 705,180 | 1,537,107 | 1,402,884 |
| **Annual Losses (%)** | 2.41% | 3.01% | 2.85% | **Annual Losses (%)** | 2.41% | 3.66% | 3.51% |
| **Voltage Violation Hours** | 8395 | 8395 | 8395 | **Voltage Violation Hours** | 8395 | 8405 | 8405 |
| **Thermal Violation Miles** | 0 | 0 | 0 | **Thermal Violation Miles** | 0 | 0.02 | 0 |
| **Voltage Delta** | 0.00% | -1.06% | 8.25% | **Voltage Delta** | 0.00% | -1.66% | 6.30% |

| Metric | Base Case | EV30 | PVEV30 | Metric | Base Case | EV40 | PVEV40 |
|---|---|---|---|---|---|---|---|
| **Annual Losses (kWh)** | 705,180 | 1,784,819 | 1,639,696 | **Annual Losses (kWh)** | 705,180 | 2,347,303 | 2,187,365 |
| **Annual Losses (%)** | 2.41% | 3.73% | 3.57% | **Annual Losses (%)** | 2.41% | 4.48% | 4.32% |
| **Voltage Violation Hours** | 8395 | 8433 | 8433 | **Voltage Violation Hours** | 8395 | 8574 | 8574 |
| **Thermal Violation Miles** | 0 | 0.15 | 0.02 | **Thermal Violation Miles** | 0 | 1.95 | 1.95 |
| **Voltage Delta** | 0.00% | -2.44% | 4.90% | **Voltage Delta** | 0.00% | -4.56% | 3.30% |

## D. Feeder 3201-04, Juncos Feeder 04

### 1. Feeder Summary

Feeder 3201-04 is characterized as a long, rural, residential feeder operating at 4.16 kV. The feeder peak demand hour is August 7th, at 1:00 pm, based on the loading profile from the incumbent utility. The feeder is approximately 23.8 miles long and has 265 loads / transformers. The peak load is approximately 4.4 MVA. The performance metrics, as described above, are summarized in Table V-12 below. The feeder and load locations are illustrated in Figure V-12 below.

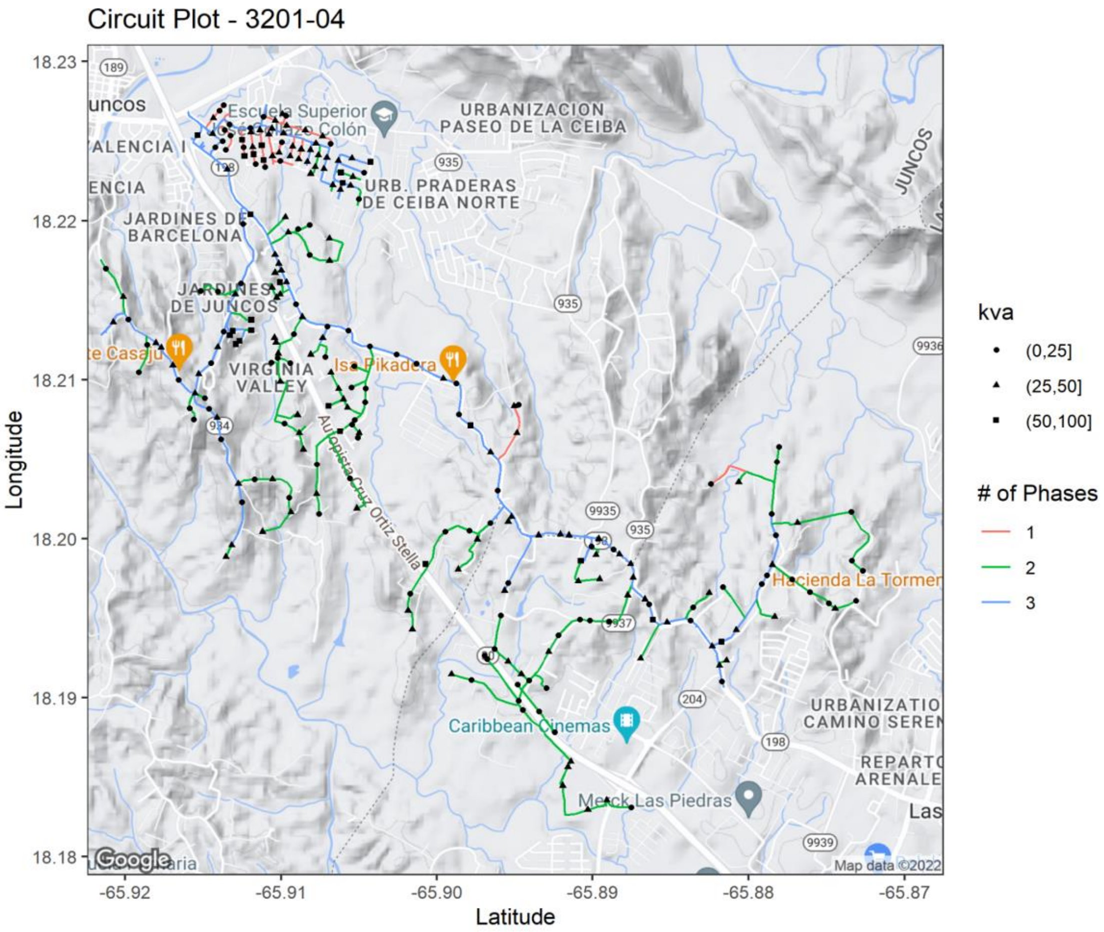

Figure V-12: Feeder 3201_04 Feeder Summary

## 2. Annual Metrics

**Table V-12: Metrics for Feeder 3201-04**

| Metric | Base Case | EV10 | PVEV10 | Metric | Base Case | EV20 | PVEV20 |
|---|---|---|---|---|---|---|---|
| **Annual Losses (kWh)** | 16,090,392 | 16,852,568 | 10,945,701 | **Annual Losses (kWh)** | 16,090,392 | 19,287,299 | 12,533,568 |
| **Annual Losses (%)** | 7.60% | 7.96% | 5.17% | **Annual Losses (%)** | 7.60% | 10.43% | 6.78% |
| **Voltage Violation Hours** | 12 | 1,006 | 13 | **Voltage Violation Hours** | 12 | 1155 | 13 |
| **Thermal Violation Miles** | 0 | 0.15 | 0 | **Thermal Violation Miles** | 0 | 0.17 | 0 |
| **Voltage Delta** | 0.00% | -2.06% | 16.09% | **Voltage Delta** | 0.00% | -3.23% | 12.27% |
| **Metric** | **Base Case** | **EV30** | **PVEV30** | **Metric** | **Base Case** | **EV40** | **PVEV40** |
| **Annual Losses (kWh)** | 16,090,392 | 27,226,637 | 18,927,382 | **Annual Losses (kWh)** | 16,090,392 | 28,920,362 | 17,381,858 |
| **Annual Losses (%)** | 7.60% | 14.72% | 9.24% | **Annual Losses (%)** | 7.60% | 15.64% | 9.40% |
| **Voltage Violation Hours** | 12 | 1891 | 26 | **Voltage Violation Hours** | 12 | 4220 | 115 |
| **Thermal Violation Miles** | 0 | 1.10 | 0.011 | **Thermal Violation Miles** | 0 | 1.22 | 0.011 |
| **Voltage Delta** | 0.00% | -4.75% | 9.54% | **Voltage Delta** | 0.00% | -8.88% | 6.43% |

## E. Feeder 3205-09, Juncos 2 Feeder 09

### 1. Feeder Summary

Feeder 3205-09 is characterized as a medium, urban, residential feeder operating at 13.2 kV. The feeder peak demand hour is August 7th, at 1:00 pm, based on the loading profile from the incumbent utility. The feeder is approximately 8.7 miles long and has 150 loads / transformers. The peak load is approximately 2.7 MVA. The performance metrics, as described above, are summarized in Table V-13 below. The feeder and load locations are illustrated in Figure V-13Figure V-10 below.

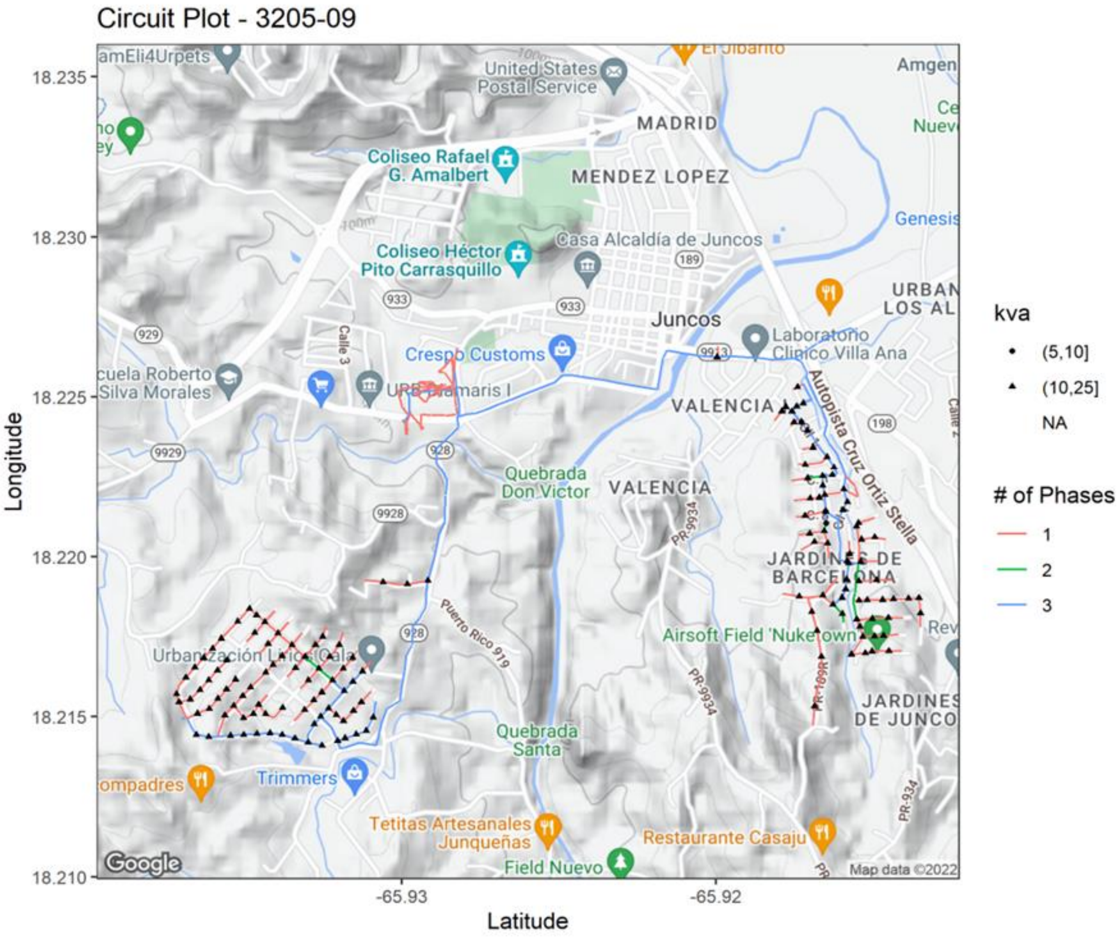

Figure V-13: Feeder 3205-09 Feeder Summary

## 2. Annual Metrics

Table V-13: Metrics for Feeder 3205-09

| Metric | Base Case | EV10 | PVEV10 | Metric | Base Case | EV20 | PVEV20 |
|---|---|---|---|---|---|---|---|
| **Annual Losses (kWh)** | 131,252 | 201,426 | 89,667 | **Annual Losses (kWh)** | 131,252 | 251,011 | 89,517 |
| **Annual Losses (%)** | 2.17% | 3.33% | 1.48% | **Annual Losses (%)** | 2.17% | 4.15% | 1.48% |
| **Voltage Violation Hours** | 0 | 0 | 0 | **Voltage Violation Hours** | 0 | 0 | 0 |
| **Thermal Violation Miles** | 0 | 0 | 0 | **Thermal Violation Miles** | 0 | 0 | 0 |
| **Voltage Delta** | 0.00% | -0.46% | 3.61% | **Voltage Delta** | 0.00% | -0.73% | 2.75% |

| Metric | Base Case | EV30 | PVEV30 | Metric | Base Case | EV40 | PVEV40 |
|---|---|---|---|---|---|---|---|
| **Annual Losses (kWh)** | 131,252 | 385,970 | 160,047 | **Annual Losses (kWh)** | 131,252 | 412,117 | 189,363 |
| **Annual Losses (%)** | 2.17% | 6.38% | 2.65% | **Annual Losses (%)** | 2.17% | 6.81% | 3.13% |
| **Voltage Violation Hours** | 0 | 331 | 0 | **Voltage Violation Hours** | 0 | 692 | 0 |
| **Thermal Violation Miles** | 0 | 0 | 0 | **Thermal Violation Miles** | 0 | 0.11 | 0 |
| **Voltage Delta** | 0.00% | -1.07% | 2.14% | **Voltage Delta** | 0.00% | -1.99% | 1.44% |

## F. Feeder 3501-03, Aibonito Feeder 03

### 1. Feeder Summary

Feeder 3501-03 is characterized as a long, rural, residential feeder operating at 8.32 kV. The feeder peak demand hour is August 7th, at 1:00 pm, based on the loading profile from the incumbent utility. The feeder is approximately 25.6 miles long and has 210 loads / transformers. The peak load is approximately 3.1 MVA. The performance metrics, as described above, are summarized in Table V-14 below. The feeder and load locations are illustrated in Figure V-14 below.

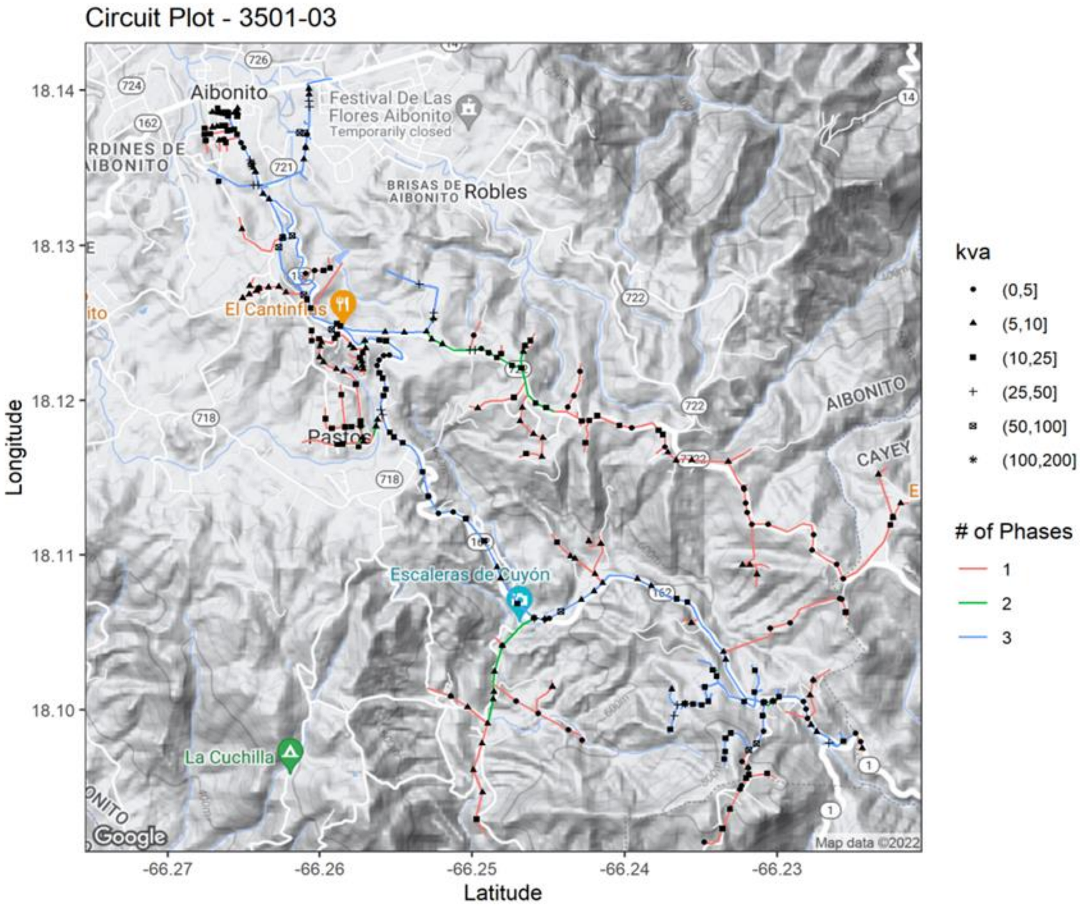

Figure V-14: Feeder 3501-03 Feeder Summary

## 2. Annual Metrics

**Table V-14: Metrics for Feeder 3501-03**

| Metric | Base Case | EV10 | PVEV10 | Metric | Base Case | EV20 | PVEV20 |
|---|---|---|---|---|---|---|---|
| **Annual Losses (kWh)** | 112,321 | 173,546 | 260,678 | **Annual Losses (kWh)** | 112,321 | 131,241 | 58,423 |
| **Annual Losses (%)** | 1.10% | 1.36% | 2.03% | **Annual Losses (%)** | 1.10% | 2.07% | 1.62% |
| **Voltage Violation Hours** | 0 | 6 | 0 | **Voltage Violation Hours** | 0 | 755 | 280 |
| **Thermal Violation Miles** | 0 | 0 | 0 | **Thermal Violation Miles** | 0 | 0 | 0 |
| **Voltage Delta** | 0.00% | -1.56% | 12.19% | **Voltage Delta** | 0.00% | -2.45% | 9.30% |

| Metric | Base Case | EV30 | PVEV30 | Metric | Base Case | EV40 | PVEV40 |
|---|---|---|---|---|---|---|---|
| **Annual Losses (kWh)** | 112,321 | 349,851 | 298,321 | **Annual Losses (kWh)** | 112,321 | 425,349 | 331,241 |
| **Annual Losses (%)** | 1.10% | 1.92% | 1.64% | **Annual Losses (%)** | 1.10% | 2.14% | 1.66% |
| **Voltage Violation Hours** | 0 | 2963 | 1342 | **Voltage Violation Hours** | 0 | 3535 | 1750 |
| **Thermal Violation Miles** | 0 | 0 | 0 | **Thermal Violation Miles** | 0 | 0 | 0 |
| **Voltage Delta** | 0.00% | -3.60% | 7.23% | **Voltage Delta** | 0.00% | -6.73% | 4.87% |

## G. Feeder 4003-03, Jobos Feeder 03

### 1. Feeder Summary

Feeder 4003-03 is characterized as a medium, urban, residential feeder operating at 13.2 kV. The feeder peak demand hour is August 7th, at 1:00 pm, based on the loading profile from the incumbent utility. The feeder is approximately 19.4 miles long and has 225 loads / transformers. The peak load is approximately 3.0 MVA. The performance metrics, as described above, are summarized in Table V-15 below. The feeder and load locations are illustrated in Figure V-15 below.

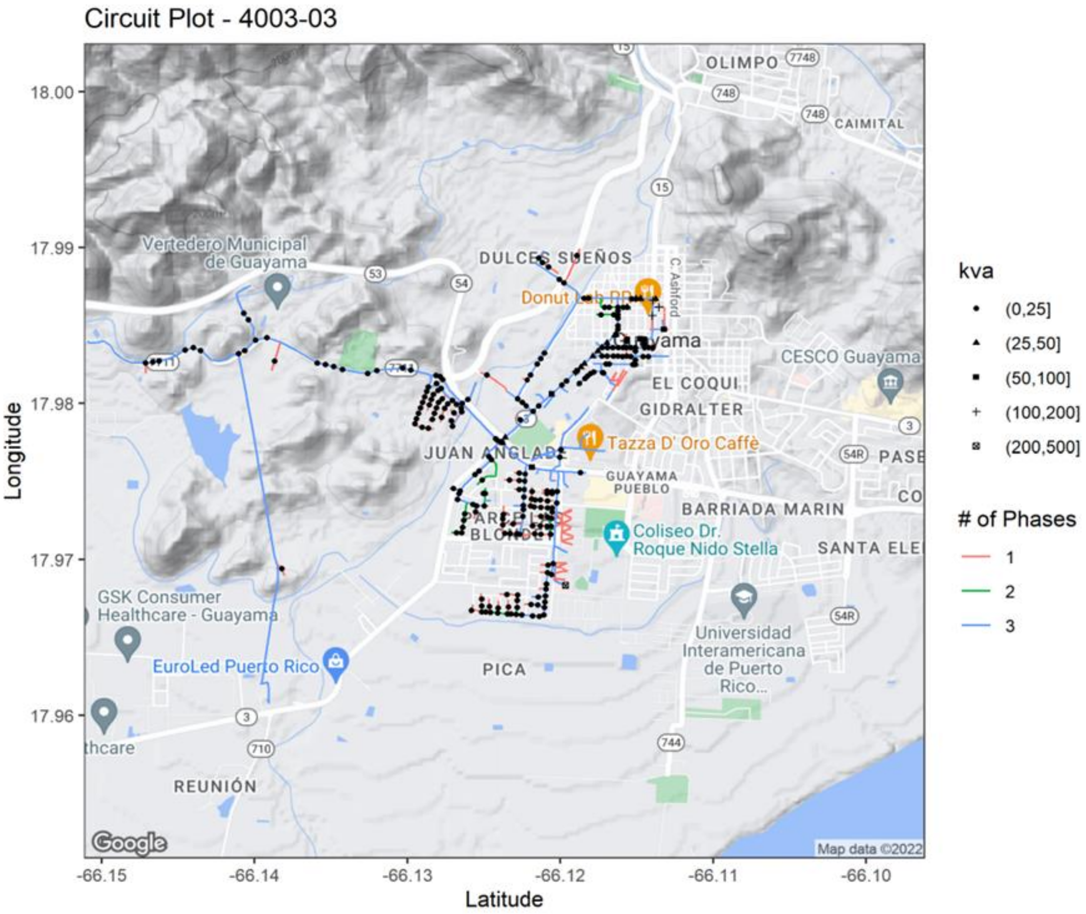

Figure V-15: Feeder 4003-03 Feeder Summary

## 2. Annual Metrics

**Table V-15: Metrics for Feeder 4003-03**

| Metric | Base Case | EV10 | PVEV10 | Metric | Base Case | EV20 | PVEV20 |
|---|---|---|---|---|---|---|---|
| **Annual Losses (kWh)** | 2,703,519 | 2,824,591 | 2,158,160 | **Annual Losses (kWh)** | 2,703,519 | 2,824,591 | 2,158,160 |
| **Annual Losses (%)** | 11.42% | 11.64% | 10.34% | **Annual Losses (%)** | 11.42% | 11.64% | 10.34% |
| **Voltage Violation Hours** | 1161 | 2439 | 646 | **Voltage Violation Hours** | 1161 | 2703 | 708 |
| **Thermal Violation Miles** | 0.00 | 0.60 | 0.00 | **Thermal Violation Miles** | 0.00 | 0.79 | 0.00 |
| **Voltage Delta** | 0.00% | -1.15% | 8.99% | **Voltage Delta** | 0.00% | -1.81% | 6.86% |

| Metric | Base Case | EV30 | PVEV30 | Metric | Base Case | EV40 | PVEV40 |
|---|---|---|---|---|---|---|---|
| **Annual Losses (kWh)** | 2,703,519 | 2,930,680 | 2,249,158 | **Annual Losses (kWh)** | 2,703,519 | 2,955,349 | 2,270,655 |
| **Annual Losses (%)** | 11.42% | 11.94% | 10.64% | **Annual Losses (%)** | 11.42% | 12.02% | 10.69% |
| **Voltage Violation Hours** | 1161 | 3631 | 1142 | **Voltage Violation Hours** | 1161 | 7842 | 1349 |
| **Thermal Violation Miles** | 0.00 | 1.14 | 0.24 | **Thermal Violation Miles** | 0.00 | 1.30 | 0.30 |
| **Voltage Delta** | 0.00% | -2.66% | 5.33% | **Voltage Delta** | 0.00% | -4.96% | 3.59% |

## H. Feeder 4301-03, Muanabo Feeder 03

### 1. Feeder Summary

Feeder 4301-03 is characterized as a long, rural, residential feeder operating at 4.16 kV. The feeder peak demand hour is August 7th, at 1:00 pm, based on the loading profile from the incumbent utility. The feeder is approximately 29.8 miles long and has 215 loads / transformers. The peak load is approximately 3.4 MVA. The performance metrics, as described above, are summarized in Table V-10 below. The feeder and load locations are illustrated in Figure V-10 below.

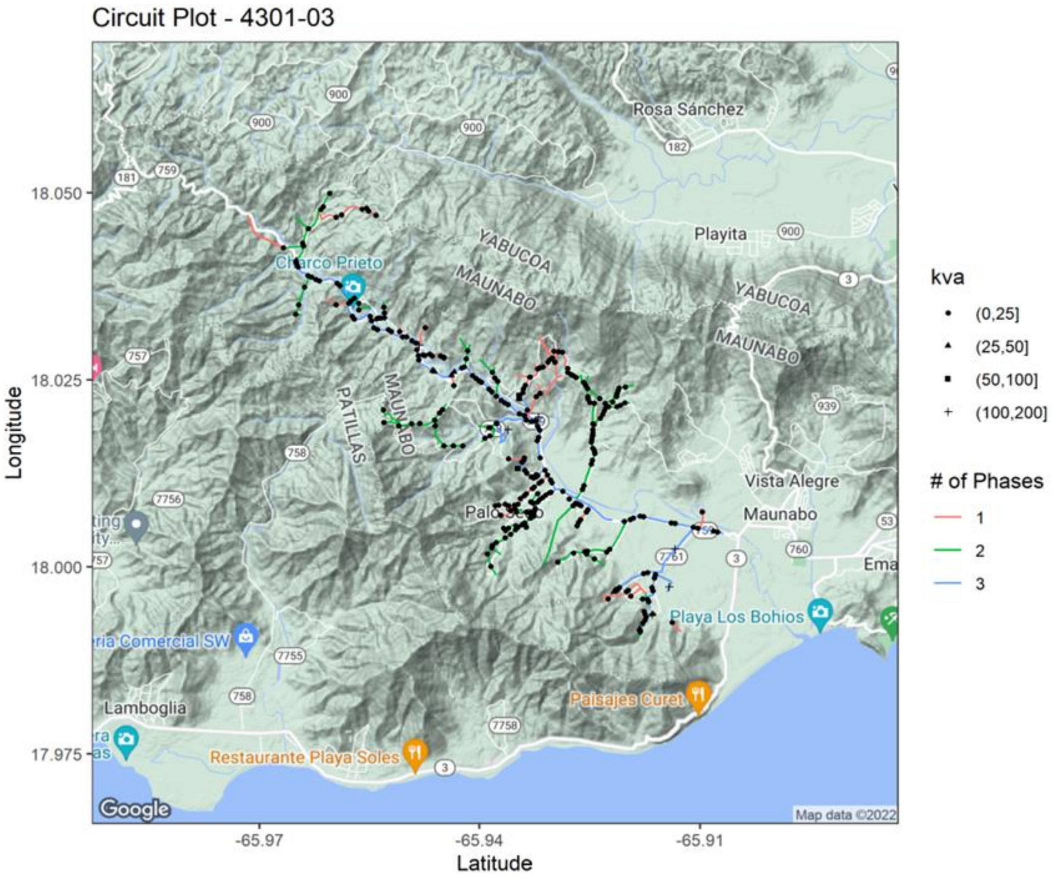

Figure V-16: Feeder 4301-03 Feeder Summary

## 2. Annual Metrics

**Table V-16: Metrics for Feeder 4301-03**

| Metric | Base Case | EV10 | PVEV10 | Metric | Base Case | EV20 | PVEV20 |
|---|---|---|---|---|---|---|---|
| Annual Losses (kWh) | 6,622,212 | 11,089,575 | 7,568,240 | Annual Losses (kWh) | 6,622,212 | 15,189,041 | 8,461,714 |
| Annual Losses (%) | 3.58% | 5.99% | 4.09% | Annual Losses (%) | 3.58% | 8.21% | 4.57% |
| Voltage Violation Hours | 1216 | 2554 | 676 | Voltage Violation Hours | 1216 | 2829 | 741 |
| Thermal Violation Miles | 0.00 | 0.62 | 0.00 | Thermal Violation Miles | 0.00 | 0.82 | 0.00 |
| Voltage Delta | 0.00% | -2.00% | 15.57% | Voltage Delta | 0.00% | -3.13% | 11.87% |

| Metric | Base Case | EV30 | PVEV30 | Metric | Base Case | EV40 | PVEV40 |
|---|---|---|---|---|---|---|---|
| Annual Losses (kWh) | 6,622,212 | 16,187,627 | 9,302,630 | Annual Losses (kWh) | 6,622,212 | 18,973,160 | 10,406,331 |
| Annual Losses (%) | 3.58% | 8.75% | 5.03% | Annual Losses (%) | 3.58% | 10.25% | 5.62% |
| Voltage Violation Hours | 1216 | 3801 | 1196 | Voltage Violation Hours | 1216 | 8209 | 1412 |
| Thermal Violation Miles | 0.00 | 1.19 | 0.26 | Thermal Violation Miles | 0.00 | 1.36 | 0.31 |
| Voltage Delta | 0.00% | -4.60% | 9.23% | Voltage Delta | 0.00% | -8.59% | 6.22% |

## I. Feeder 5005-05, Pampanos Feeder 05

### 1. Feeder Summary

Feeder 5005-05 is characterized as an urban, urban, commercial feeder operating at 4.16 kV. The feeder peak demand hour is August 7th, at 1:00 pm, based on the loading profile from the incumbent utility. The feeder is approximately 5.0 miles long and has 64 loads / transformers. The peak load is approximately 3.6 MVA. The performance metrics, as described above, are summarized in Table V-10 below. The feeder and load locations are illustrated in Figure V-10 below.

Figure V-17: Feeder 5005-05 Feeder Summary

## 2. Annual Metrics

Table V-17: Metrics for Feeder 5005-05

| Metric | Base Case | EV10 | PVEV10 | Metric | Base Case | EV20 | PVEV20 |
|---|---|---|---|---|---|---|---|
| **Annual Losses (kWh)** | 12,898,204 | 13,522,308 | 8,779,099 | **Annual Losses (kWh)** | 12,898,204 | 14,354,451 | 9,070,348 |
| **Annual Losses (%)** | 6.97% | 7.31% | 4.74% | **Annual Losses (%)** | 6.97% | 7.76% | 4.90% |
| **Voltage Violation Hours** | 0 | 0 | 0 | **Voltage Violation Hours** | 0 | 58 | 0 |
| **Thermal Violation Miles** | 0.00 | 0.00 | 0.00 | **Thermal Violation Miles** | 0.00 | 0.00 | 0.00 |
| **Voltage Delta** | 0.00% | -0.35% | 2.77% | **Voltage Delta** | 0.00% | -0.56% | 2.11% |

| Metric | Base Case | EV30 | PVEV30 | Metric | Base Case | EV40 | PVEV40 |
|---|---|---|---|---|---|---|---|
| **Annual Losses (kWh)** | 12,898,204 | 17,100,523 | 12,066,060 | **Annual Losses (kWh)** | 12,898,204 | 17,599,808 | 13,647,132 |
| **Annual Losses (%)** | 6.97% | 9.24% | 6.52% | **Annual Losses (%)** | 6.97% | 9.51% | 7.38% |
| **Voltage Violation Hours** | 0 | 198 | 0 | **Voltage Violation Hours** | 0 | 4947 | 0 |
| **Thermal Violation Miles** | 0.00 | 0.00 | 0.00 | **Thermal Violation Miles** | 0.00 | 0.00 | 0.00 |
| **Voltage Delta** | 0.00% | -0.82% | 1.64% | **Voltage Delta** | 0.00% | -1.53% | 1.10% |

## J. Feeder 5016-03, Villa Del Carmen Feeder 03

### 1. Feeder Summary

Feeder 5016-03 is characterized as a short, urban, commercial feeder operating at 13.2 kV. The feeder peak demand hour is August 7th, at 1:00 pm, based on the loading profile from the incumbent utility. The feeder is approximately 8.8 miles long and has 107 loads / transformers. The peak load is approximately 2.7 MVA. The performance metrics, as described above, are summarized in Table V-10 below. The feeder and load locations are illustrated in Figure V-10 below.

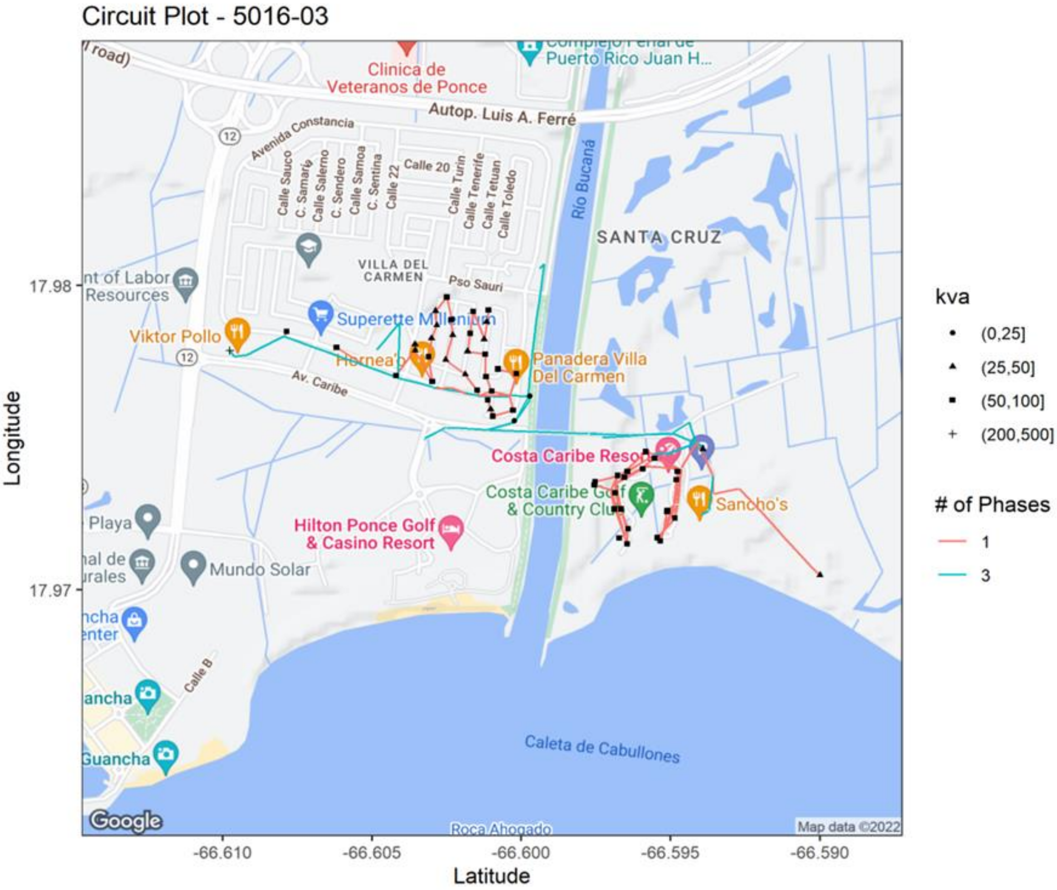

**Figure V-18: Feeder 5016-03 Feeder Summary**

## 2. Annual Metrics

**Table V-18: Metrics for Feeder 5016-03**

| Metric | Base Case | EV10 | PVEV10 | Metric | Base Case | EV20 | PVEV20 |
|---|---|---|---|---|---|---|---|
| Annual Losses (kWh) | 2,569,264 | 4,302,496 | 2,936,301 | Annual Losses (kWh) | 2,569,264 | 5,892,994 | 3,282,948 |
| Annual Losses (%) | 1.39% | 2.33% | 1.59% | Annual Losses (%) | 1.39% | 3.18% | 1.77% |
| Voltage Violation Hours | 123 | 991 | 262 | Voltage Violation Hours | 123 | 1098 | 288 |
| Thermal Violation Miles | 0.00 | 0.24 | 0.00 | Thermal Violation Miles | 0.00 | 0.32 | 0.00 |
| Voltage Delta | 0.00% | -0.47% | 3.65% | Voltage Delta | 0.00% | -0.73% | 2.78% |

| Metric | Base Case | EV30 | PVEV30 | Metric | Base Case | EV40 | PVEV40 |
|---|---|---|---|---|---|---|---|
| **Annual Losses (kWh)** | 2,569,264 | 6,280,422 | 3,609,204 | **Annual Losses (kWh)** | 2,569,264 | 7,361,143 | 4,037,414 |
| **Annual Losses (%)** | 1.39% | 3.39% | 1.95% | **Annual Losses (%)** | 1.39% | 3.98% | 2.18% |
| **Voltage Violation Hours** | 123 | 1475 | 464 | **Voltage Violation Hours** | 123 | 3185 | 548 |
| **Thermal Violation Miles** | 0.00 | 0.46 | 0.10 | **Thermal Violation Miles** | 0.00 | 0.53 | 0.12 |
| **Voltage Delta** | 0.00% | -1.08% | 2.17% | **Voltage Delta** | 0.00% | -2.02% | 1.46% |

## K. Feeder 6002-04, McKinley Feeder 04

### 1. Feeder Summary

Feeder 6002-04 is characterized as a short, urban, commercial feeder operating at 4.16 kV. The feeder peak demand hour is August 7th, at 1:00 pm, based on the loading profile from the incumbent utility. The feeder is approximately 1.6 miles long and has 26 loads / transformers. The peak load is approximately 3.4 MVA. The performance metrics, as described above, are summarized in Table V-10 below. The feeder and load locations are illustrated in Figure V-10 below.

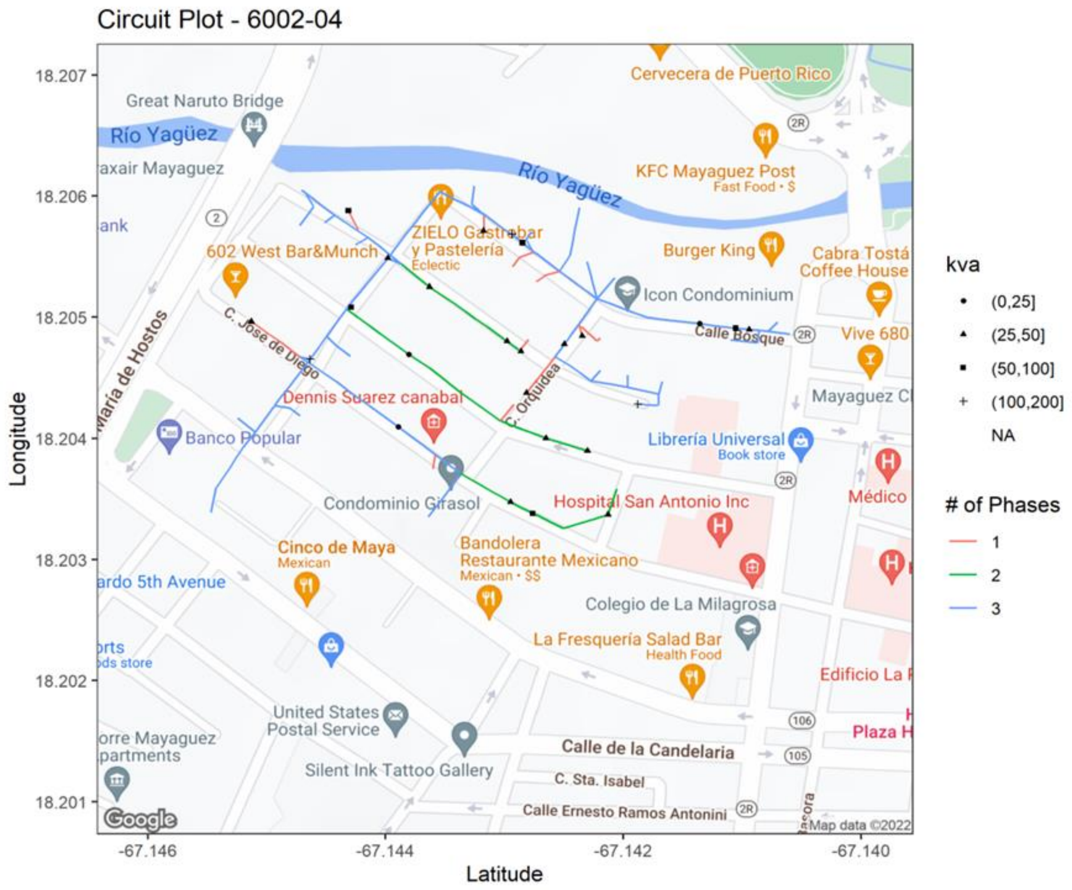

Figure V-19: Feeder 6002-04 Feeder Summary

## 2. Annual Metrics

Table V-19: Metrics for Feeder 6002-04

| Metric | Base Case | EV10 | PVEV10 | Metric | Base Case | EV20 | PVEV20 |
|---|---|---|---|---|---|---|---|
| Annual Losses (kWh) | 93,691 | 97,017 | 80,363 | Annual Losses (kWh) | 93,691 | 99,990 | 83,058 |
| Annual Losses (%) | 0.42% | 0.43% | 0.39% | Annual Losses (%) | 0.42% | 0.44% | 0.40% |
| Voltage Violation Hours | 227 | 859 | 78 | Voltage Violation Hours | 227 | 908 | 121 |
| Thermal Violation Miles | 0.02 | 0.03 | 0.00 | Thermal Violation Miles | 0.02 | 0.04 | 0.00 |
| Voltage Delta | 0.00% | -0.11% | 0.84% | Voltage Delta | 0.00% | -0.17% | 0.64% |

| Metric | Base Case | EV30 | PVEV30 | Metric | Base Case | EV40 | PVEV40 |
|---|---|---|---|---|---|---|---|
| **Annual Losses (kWh)** | 93,691 | 102,871 | 85,710 | **Annual Losses (kWh)** | 93,691 | 106,572 | 89,088 |
| **Annual Losses (%)** | 0.42% | 0.44% | 0.41% | **Annual Losses (%)** | 0.42% | 0.45% | 0.42% |
| **Voltage Violation Hours** | 227 | 908 | 123 | **Voltage Violation Hours** | 227 | 987 | 144 |
| **Thermal Violation Miles** | 0.02 | 0.06 | 0.01 | **Thermal Violation Miles** | 0.02 | 0.14 | 0.02 |
| **Voltage Delta** | 0.00% | -0.25% | 0.50% | **Voltage Delta** | 0.00% | -0.46% | 0.33% |

## L. Feeder 6702-04, Boqueron Feeder 04

### 1. Feeder Summary

Feeder 6702-04 is characterized as a long, rural, residential feeder operating at 7.2 kV. The feeder peak demand hour is August 7th, at 1:00 pm, based on the loading profile from the incumbent utility. The feeder is approximately 21.5 miles long and has 233 loads / transformers. The peak load is approximately 3.1 MVA. The performance metrics, as described above, are summarized in Table V-10 below. The feeder and load locations are illustrated in Figure V-10 below.

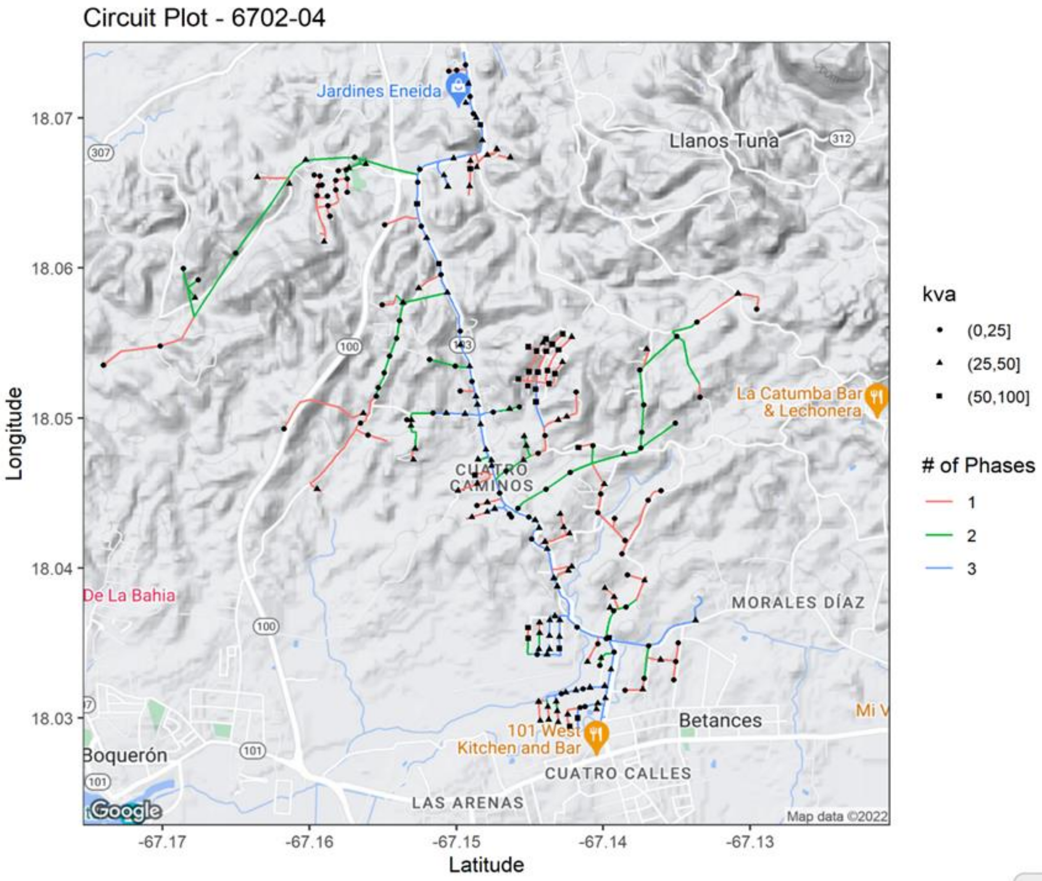

**Figure V-20: Feeder 6702-04 Feeder Summary**

## 2. Annual Metrics

**Table V-20: Metrics for Feeder 6702-04**

| Metric | Base Case | EV10 | PVEV10 | Metric | Base Case | EV20 | PVEV20 |
|---|---|---|---|---|---|---|---|
| Annual Losses (kWh) | 94,332 | 145,752 | 218,929 | Annual Losses (kWh) | 94,332 | 110,222 | 49,066 |
| Annual Losses (%) | 0.92% | 1.14% | 1.70% | Annual Losses (%) | 0.92% | 1.74% | 1.36% |
| Voltage Violation Hours | 0 | 5 | 0 | Voltage Violation Hours | 0 | 634 | 9 |
| Thermal Violation Miles | 0.00 | 0.00 | 0.00 | Thermal Violation Miles | 0.00 | 0.00 | 0.00 |
| Voltage Delta | 0.00% | -1.48% | 11.56% | Voltage Delta | 0.00% | -2.32% | 8.82% |

| Metric | Base Case | EV30 | PVEV30 | Metric | Base Case | EV40 | PVEV40 |
|---|---|---|---|---|---|---|---|
| **Annual Losses (kWh)** | 94,332 | 293,820 | 250,543 | **Annual Losses (kWh)** | 94,332 | 357,227 | 278,191 |
| **Annual Losses (%)** | 0.92% | 1.61% | 1.38% | **Annual Losses (%)** | 0.92% | 1.80% | 1.39% |
| **Voltage Violation Hours** | 0 | 2488 | 297 | **Voltage Violation Hours** | 0 | 2969 | 462 |
| **Thermal Violation Miles** | 0.00 | 0.00 | 0.00 | **Thermal Violation Miles** | 0.00 | 0.00 | 0.00 |
| **Voltage Delta** | 0.00% | -3.42% | 6.86% | **Voltage Delta** | 0.00% | -6.38% | 4.62% |

## M. Feeder 7011-02, T Bone Feeder 02

### 1. Feeder Summary

Feeder 7011-02 is characterized as a medium, urban, commercial feeder operating at 13.2 kV. The feeder peak demand hour is August 7th, at 1:00 pm, based on the loading profile from the incumbent utility. The feeder is approximately 12.7 miles long and has 79 loads / transformers. The peak load is approximately 2.9 MVA. The performance metrics, as described above, are summarized in Table V-10 below. The feeder and load locations are illustrated in Figure V-10 below.

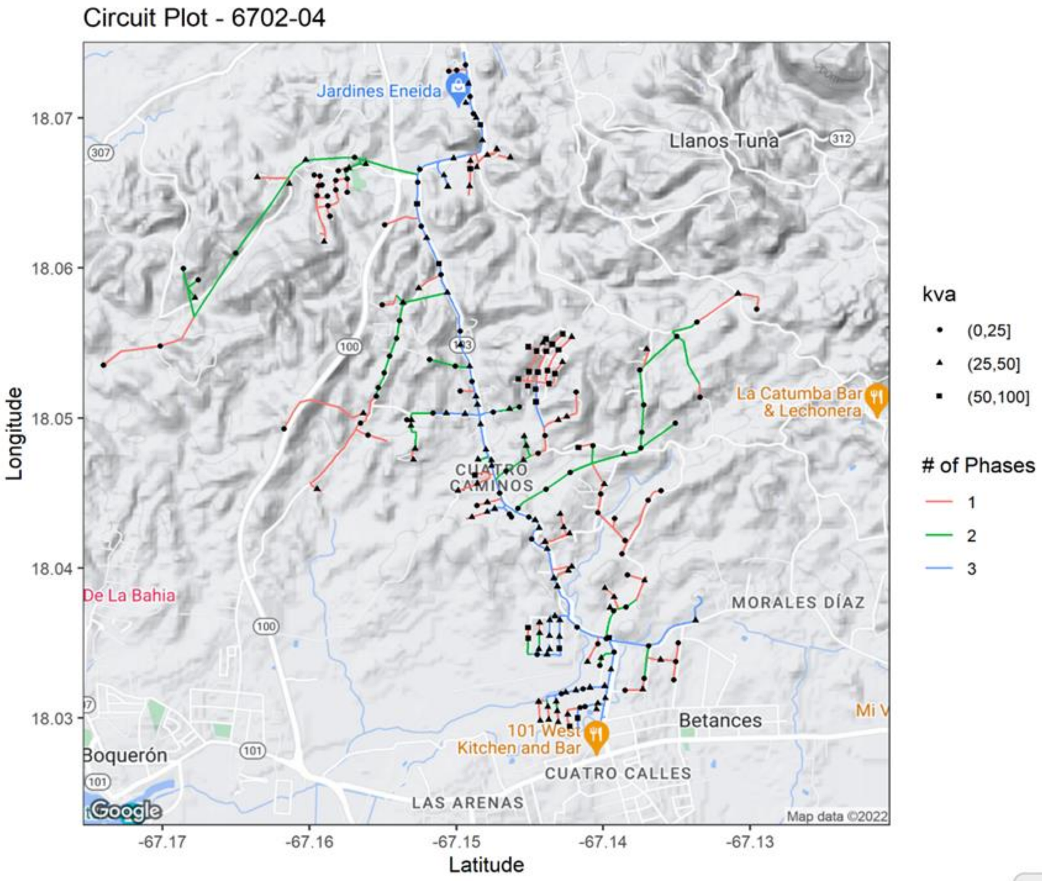

**Figure V-21: Feeder 6011-02 Feeder Summary**

## 2. Annual Metrics

**Table V-21: Metrics for Feeder 7011-02**

| Metric | Base Case | EV10 | PVEV10 | Metric | Base Case | EV20 | PVEV20 |
|---|---|---|---|---|---|---|---|
| Annual Losses (kWh) | 377,324 | 579,062 | 257,776 | Annual Losses (kWh) | 377,324 | 646,308 | 366,117 |
| Annual Losses (%) | 1.79% | 2.73% | 1.22% | Annual Losses (%) | 1.79% | 3.06% | 1.73% |
| Voltage Violation Hours | 0 | 0 | 0 | Voltage Violation Hours | 0 | 4294 | 0 |
| Thermal Violation Miles | 0.00 | 0.00 | 0.00 | Thermal Violation Miles | 0.00 | 0.00 | 0.00 |
| Voltage Delta | 0.00% | -0.73% | 5.66% | Voltage Delta | 0.00% | -1.14% | 4.32% |

| Metric | Base Case | EV30 | PVEV30 | Metric | Base Case | EV40 | PVEV40 |
|---|---|---|---|---|---|---|---|
| **Annual Losses (kWh)** | 377,324 | 706,082 | 459,513 | **Annual Losses (kWh)** | 377,324 | 754,648 | 545,439 |
| **Annual Losses (%)** | 1.79% | 3.34% | 2.17% | **Annual Losses (%)** | 1.79% | 3.56% | 2.57% |
| **Voltage Violation Hours** | 0 | 6097 | 357 | **Voltage Violation Hours** | 0 | 8189 | 609 |
| **Thermal Violation Miles** | 0.00 | 0.56 | 0.01 | **Thermal Violation Miles** | 0.00 | 1.19 | 0.01 |
| **Voltage Delta** | 0.00% | -1.67% | 3.36% | **Voltage Delta** | 0.00% | -3.12% | 2.26% |

## N. Feeder 7701-01, Hatillo Feeder 01

### 1. Feeder Summary

Feeder 7701-01 is characterized as a medium, rural, residential feeder operating at 4.16 kV. The feeder peak demand hour is August 7th, at 1:00 pm, based on the loading profile from the incumbent utility. The feeder is approximately 16.3 miles long and has 190 loads / transformers. The peak load is approximately 4.0 MVA. The performance metrics, as described above, are summarized in Table V-10 below. The feeder and load locations are illustrated in Figure V-10 below.

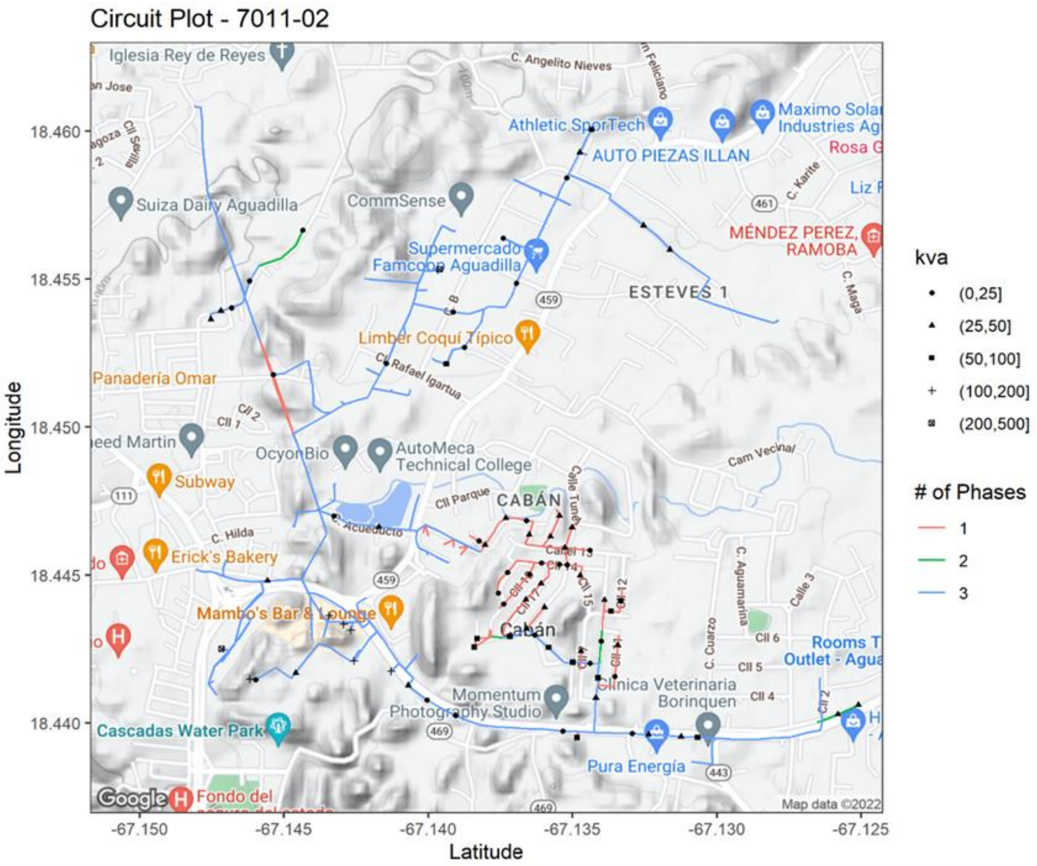

Figure V-22: Feeder 7701-01 Feeder Summary

## 2. Annual Metrics

Table V-22: Metrics for Feeder 7701-01

| Metric | Base Case | EV10 | PVEV10 | Metric | Base Case | EV20 | PVEV20 |
|---|---|---|---|---|---|---|---|
| Annual Losses (kWh) | 2,112,618 | 2,160,209 | 1,840,871 | Annual Losses (kWh) | 2,112,618 | 2,197,382 | 1,876,023 |
| Annual Losses (%) | 9.62% | 9.72% | 9.06% | Annual Losses (%) | 9.62% | 9.70% | 9.05% |
| Voltage Violation Hours | 8395 | 8395 | 8395 | Voltage Violation Hours | 8395 | 8395 | 8395 |
| Thermal Violation Miles | 1.18 | 1.18 | 1.18 | Thermal Violation Miles | 1.18 | 1.18 | 1.18 |
| Voltage Delta | 0.00% | -1.29% | 10.02% | Voltage Delta | 0.00% | -2.01% | 7.64% |

| Metric | Base Case | EV30 | PVEV30 | Metric | Base Case | EV40 | PVEV40 |
|---|---|---|---|---|---|---|---|
| **Annual Losses (kWh)** | 2,112,618 | 2,275,292 | 1,950,138 | **Annual Losses (kWh)** | 2,112,618 | 2,327,747 | 1,999,402 |
| **Annual Losses (%)** | 9.62% | 9.92% | 9.27% | **Annual Losses (%)** | 9.62% | 10.03% | 9.37% |
| **Voltage Violation Hours** | 8395 | 8395 | 8395 | **Voltage Violation Hours** | 8395 | 8395 | 8395 |
| **Thermal Violation Miles** | 1.18 | 1.18 | 1.18 | **Thermal Violation Miles** | 1.18 | 1.18 | 1.18 |
| **Voltage Delta** | 0.00% | -2.96% | 5.94% | **Voltage Delta** | 0.00% | -5.53% | 4.00% |

## T. Feeder 8202-03, Adjuntas Feeder 03

### 1. Feeder Summary

Feeder 8202-03 is characterized as a medium, rural, residential feeder operating at 4.16 kV. The feeder peak demand hour is August 7th, at 1:00 pm, based on the loading profile from the incumbent utility. The feeder is approximately 18.5 miles long and has 108 loads / transformers. The peak load is approximately 3.4 MVA. The performance metrics, as described above, are summarized in Table V-10 below. The feeder and load locations are illustrated in Figure V-10 below.

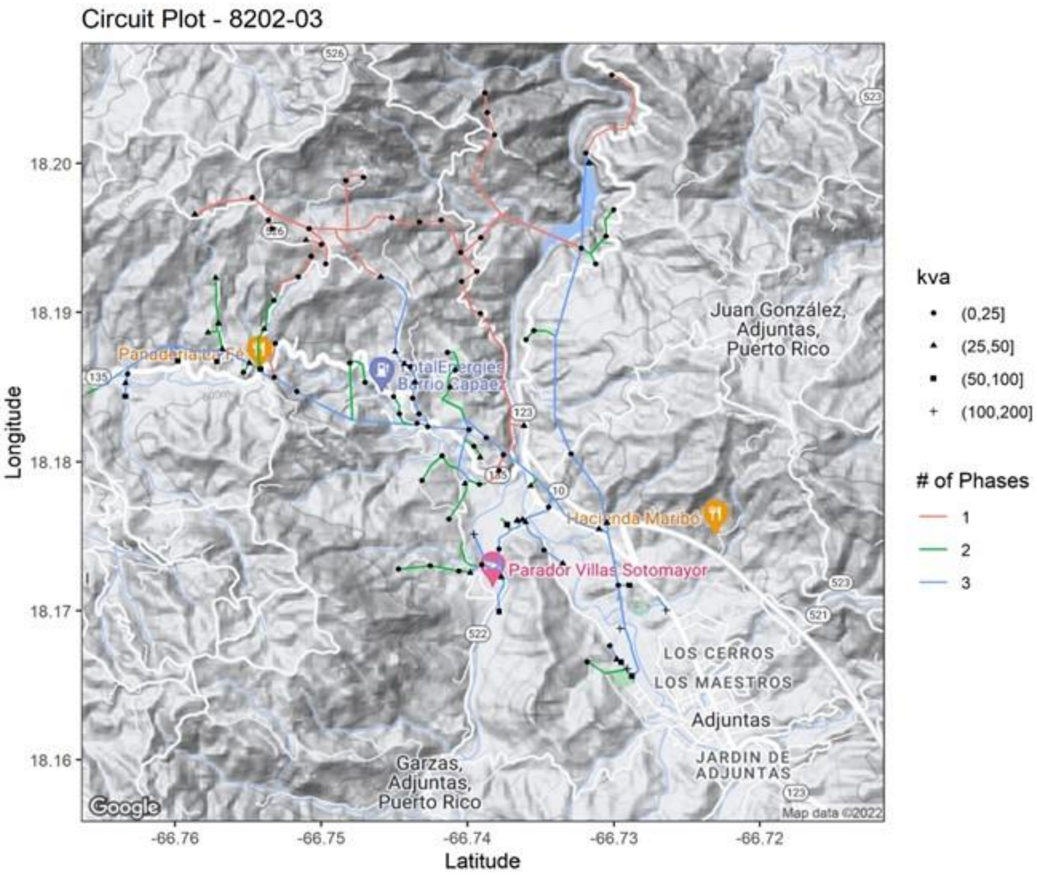

Figure V-23: Feeder 8203-03 Feeder Summary

## 2. Annual Metrics

Table V-23: Metrics for Feeder 8203-03

| Metric | Base Case | EV10 | PVEV10 | Metric | Base Case | EV20 | PVEV20 |
|---|---|---|---|---|---|---|---|
| Annual Losses (kWh) | 4,111,105 | 6,884,468 | 4,698,404 | Annual Losses (kWh) | 4,111,105 | 9,429,438 | 5,253,077 |
| Annual Losses (%) | 2.22% | 3.72% | 2.54% | Annual Losses (%) | 2.22% | 5.10% | 2.84% |
| Voltage Violation Hours | 755 | 1586 | 420 | Voltage Violation Hours | 755 | 1756 | 460 |
| Thermal Violation Miles | 0.00 | 0.38 | 0.00 | Thermal Violation Miles | 0.00 | 0.51 | 0.00 |
| Voltage Delta | 0.00% | -1.24% | 9.66% | Voltage Delta | 0.00% | -1.94% | 7.37% |

| Metric | Base Case | EV30 | PVEV30 | Metric | Base Case | EV40 | PVEV40 |
|---|---|---|---|---|---|---|---|
| **Annual Losses (kWh)** | 4,111,105 | 10,049,366 | 5,775,123 | **Annual Losses (kWh)** | 4,111,105 | 11,778,640 | 6,460,306 |
| **Annual Losses (%)** | 2.22% | 5.43% | 3.12% | **Annual Losses (%)** | 2.22% | 6.36% | 3.49% |
| **Voltage Violation Hours** | 755 | 2360 | 742 | **Voltage Violation Hours** | 755 | 5096 | 877 |
| **Thermal Violation Miles** | 0.00 | 0.74 | 0.16 | **Thermal Violation Miles** | 0.00 | 0.84 | 0.19 |
| **Voltage Delta** | 0.00% | -2.85% | 5.73% | **Voltage Delta** | 0.00% | -5.34% | 3.86% |

## U. Feeder 8405-02, Manati Urbano Feeder 02

### 1. Feeder Summary

Feeder 8405-02 is characterized as a medium, urban, residential feeder operating at 13.2 kV. The feeder peak demand hour is August 7th, at 1:00 pm, based on the loading profile from the incumbent utility. The feeder is approximately 9.8 miles long and has 46 loads / transformers. The peak load is approximately 2.8 MVA. The performance metrics, as described above, are summarized in Table V-10 below. The feeder and load locations are illustrated in Figure V-10 below.

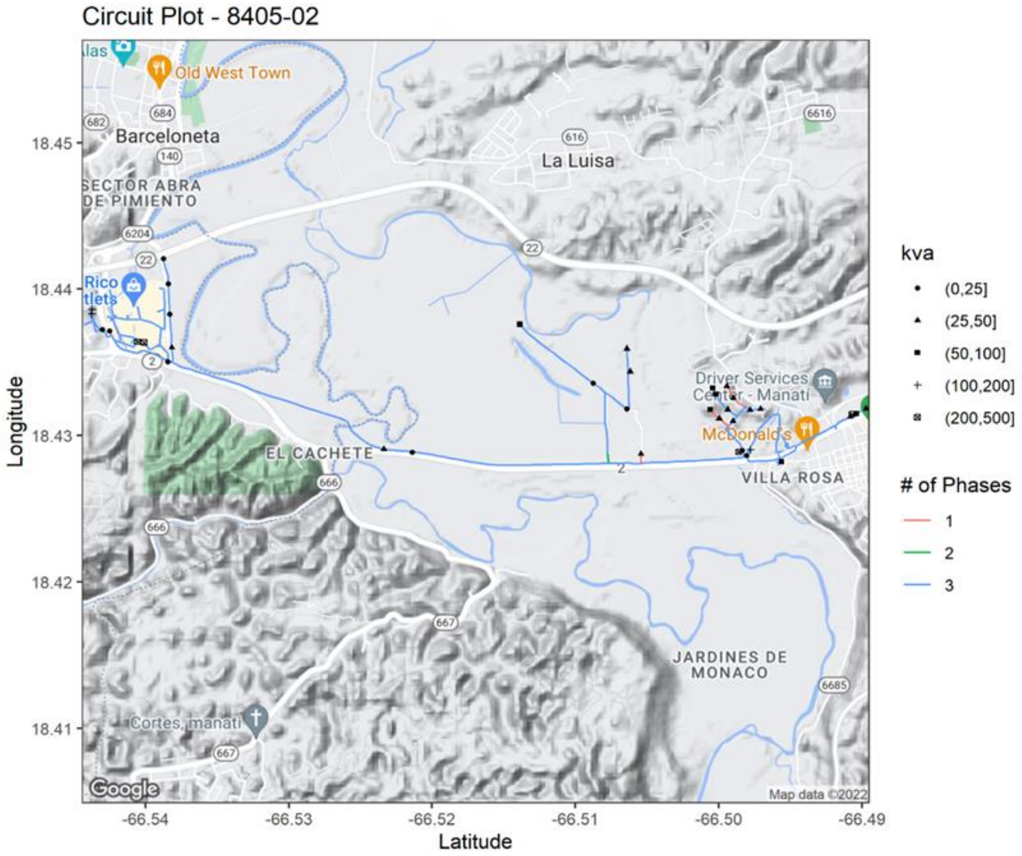

Figure V-24: Feeder 8405-02 Feeder Summary

## 2. Annual Metrics

Table V-24: Metrics for Feeder 8405-02

| Metric | Base Case | EV10 | PVEV10 | Metric | Base Case | EV20 | PVEV20 |
|---|---|---|---|---|---|---|---|
| Annual Losses (kWh) | 3,067,911 | 5,137,533 | 3,506,183 | Annual Losses (kWh) | 3,067,911 | 7,036,716 | 3,920,108 |
| Annual Losses (%) | 1.66% | 2.78% | 1.89% | Annual Losses (%) | 1.66% | 3.80% | 2.12% |
| Voltage Violation Hours | 261 | 1183 | 313 | Voltage Violation Hours | 261 | 1311 | 343 |
| Thermal Violation Miles | 0.00 | 0.29 | 0.00 | Thermal Violation Miles | 0.00 | 0.38 | 0.00 |
| Voltage Delta | 0.00% | -0.54% | 4.22% | Voltage Delta | 0.00% | -0.85% | 3.22% |

| Metric | Base Case | EV30 | PVEV30 | Metric | Base Case | EV40 | PVEV40 |
|---|---|---|---|---|---|---|---|
| **Annual Losses (kWh)** | 3,067,911 | 7,499,337 | 4,309,684 | **Annual Losses (kWh)** | 3,067,911 | 8,789,807 | 4,821,002 |
| **Annual Losses (%)** | 1.66% | 4.05% | 2.33% | **Annual Losses (%)** | 1.66% | 4.75% | 2.61% |
| **Voltage Violation Hours** | 261 | 1761 | 554 | **Voltage Violation Hours** | 261 | 3803 | 654 |
| **Thermal Violation Miles** | 0.00 | 0.55 | 0.12 | **Thermal Violation Miles** | 0.00 | 0.63 | 0.14 |
| **Voltage Delta** | 0.00% | -1.25% | 2.50% | **Voltage Delta** | 0.00% | -2.33% | 1.68% |

## V. Feeder 9203-04, Santa Ana Feeder 04

### 1. Feeder Summary

Feeder 9203-04 is characterized as a medium, rural, residential feeder operating at 8.32 kV. The feeder peak demand hour is August 7th, at 1:00 pm, based on the loading profile from the incumbent utility. The feeder is approximately 17.7 miles long and has 192 loads / transformers. The peak load is approximately 2.8 MVA. The performance metrics, as described above, are summarized in Table V-10 below. The feeder and load locations are illustrated in Figure V-10 below.

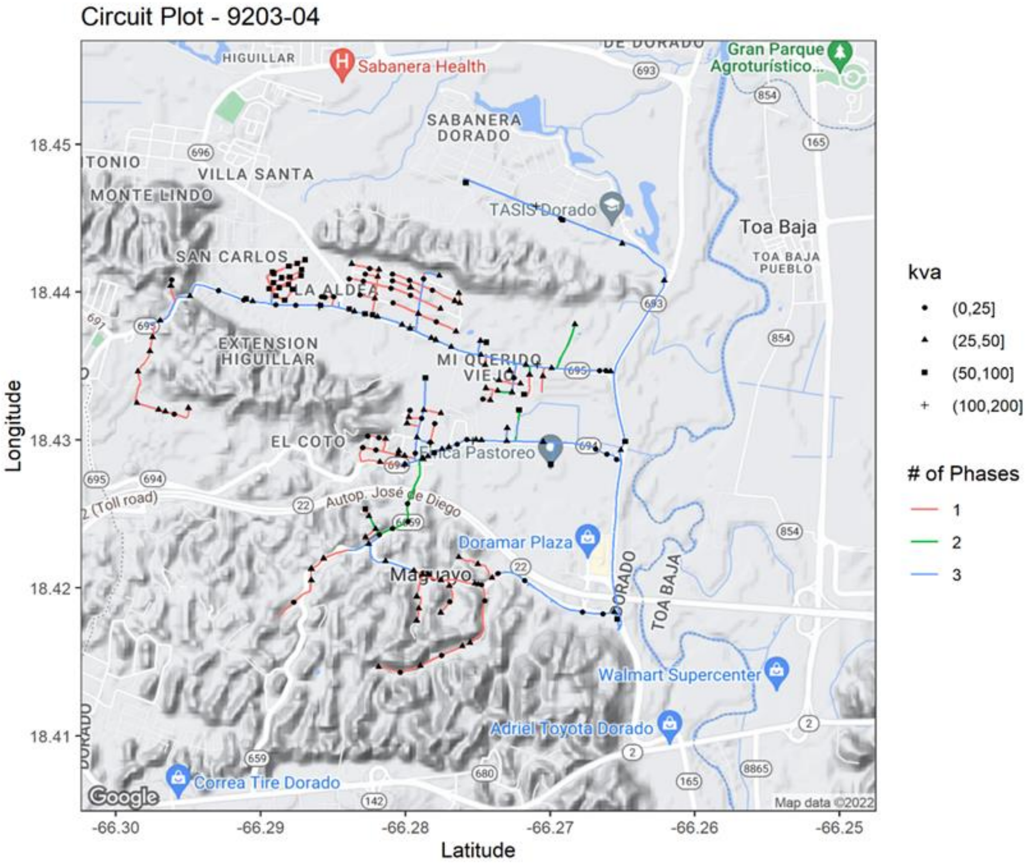

**Figure V-25: Feeder 9203-04 Feeder Summary**

## 2. Annual Metrics

**Table V-25: Metrics for Feeder 9203-04**

| Metric | Base Case | EV10 | PVEV10 | Metric | Base Case | EV20 | PVEV20 |
|---|---|---|---|---|---|---|---|
| **Annual Losses (kWh)** | 765,535 | 875,839 | 500,479 | **Annual Losses (kWh)** | 765,535 | 1,030,592 | 661,818 |
| **Annual Losses (%)** | 2.87% | 3.28% | 1.87% | **Annual Losses (%)** | 2.87% | 3.86% | 2.48% |
| **Voltage Violation Hours** | 3210 | 3668 | 2429 | **Voltage Violation Hours** | 3210 | 4321 | 2775 |
| **Thermal Violation Miles** | 0.00 | 0.00 | 0.00 | **Thermal Violation Miles** | 0.00 | 0.00 | 0.00 |
| **Voltage Delta** | 0.00% | -0.98% | 7.61% | **Voltage Delta** | 0.00% | -1.53% | 5.81% |

| Metric | Base Case | EV30 | PVEV30 | Metric | Base Case | EV40 | PVEV40 |
|---|---|---|---|---|---|---|---|
| **Annual Losses (kWh)** | 765,535 | 1,216,625 | 805,047 | **Annual Losses (kWh)** | 765,535 | 1,442,170 | 916,996 |
| **Annual Losses (%)** | 2.87% | 4.56% | 3.02% | **Annual Losses (%)** | 2.87% | 5.40% | 3.44% |
| **Voltage Violation Hours** | 3210 | 5102 | 3376 | **Voltage Violation Hours** | 3210 | 5142 | 3845 |
| **Thermal Violation Miles** | 0.00 | 0.10 | 0.00 | **Thermal Violation Miles** | 0.00 | 0.14 | 0.00 |
| **Voltage Delta** | 0.00% | -2.25% | 4.52% | **Voltage Delta** | 0.00% | -4.20% | 3.04% |

# VI. Interpretation

## A. Impact Analysis – Summary

The impact of the penetration of electric vehicles into the distribution system is widely variant, based on the sample circuits reviewed. However, the impacts can be generally characterized by several parameters, including:

- Change in losses
- Change in voltage profile / violations
- Change in current profile / violations

The primary variables that were analyzed were the:

- Operating Voltage
- Circuit length
- Total demand

The impacts are summarized in Table VI-5 below. It is clear from the summary that the introduction of EV charging, whether commercial or residential:

- Increases system losses
- Increases voltage violation hours
- May increase thermal violations

The tables below summarize the changes from the Base Case and the relevant change cases based on operating voltage, circuit length and demand range. The listed ranges are defined as:

Voltage: 4.16 kV, 7.2 / 8.32 kV and 13.2 kV

Length: < 5 miles, > 5 miles and < 20 miles and > 20 miles

Demand: < 3 MW, >= 3 MW and < 4 MW and > = 4 MW

**Table VI-1: Summary of Raw Results**

| | Base | EV10 | EV20 | EV30 | EV40 |
|---|---|---|---|---|---|
| **Losses** | 3.50% | 4.11% | 4.78% | 5.44% | 5.98% |
| **Voltage Violations** | 1,835.71 | 2,217.33 | 2,887.67 | 3,687.42 | 5,178.42 |
| **Thermal Violations** | 0.19 | 0.29 | 0.34 | 0.52 | 0.74 |
| | **Base** | **PVEV10** | **PVEV20** | **PVEV30** | **PVEV40** |
| **Losses** | 3.50% | 3.09% | 3.32% | 3.86% | 4.16% |
| **Voltage Violations** | 1,835.71 | 1,630.04 | 1,726.46 | 2,026.29 | 2,219.46 |
| **Thermal Violations** | 0.19 | 0.11 | 0.11 | 0.17 | 0.27 |

**Table VI-2: Summary of Loss Impacts by Voltage**

| | EV10 | EV20 | EV30 | EV40 |
|---|---|---|---|---|
| **4.16** | 0.56% | 1.23% | 2.19% | 2.78% |
| **7.2 / 8.32** | 0.43% | 1.19% | 1.42% | 2.04% |
| **13.2** | 0.83% | 1.37% | 1.85% | 2.14% |
| | **PVEV10** | **PVEV20** | **PVEV30** | **PVEV40** |
| **4.16** | -0.70% | -0.43% | 0.43% | 0.62% |
| **7.2 / 8.32** | 0.16% | 0.31% | 0.56% | 0.88% |
| **13.2** | -0.32% | -0.09% | 0.30% | 0.58% |

**Table VI-3: Summary of Loss Impacts by Length**

| | EV10 | EV20 | EV30 | EV40 |
|---|---|---|---|---|
| **Short** | 0.33% | 0.51% | 1.09% | 1.21% |
| **Medium** | 0.66% | 1.20% | 1.61% | 2.00% |
| **Long** | 0.68% | 1.68% | 2.64% | 3.45% |
| | **PVEV10** | **PVEV20** | **PVEV30** | **PVEV40** |
| **Short** | -0.63% | -0.55% | 0.08% | 0.41% |
| **Medium** | -0.26% | -0.03% | 0.27% | 0.56% |
| **Long** | -0.41% | -0.12% | 0.77% | 0.94% |

### Table VI-4: Summary of Loss Impacts by Demand

| | EV10 | EV20 | EV30 | EV40 |
|---|---|---|---|---|
| **Light** | 0.85% | 1.43% | 1.95% | 2.39% |
| **Medium** | 0.56% | 1.23% | 1.76% | 2.34% |
| **Heavy** | 0.29% | 0.85% | 1.83% | 2.10% |
| | **PVEV10** | **PVEV20** | **PVEV30** | **PVEV40** |
| **Light** | -0.15% | 0.10% | 0.49% | 0.79% |
| **Medium** | -0.34% | -0.22% | 0.31% | 0.63% |
| **Heavy** | -0.82% | -0.39% | 0.45% | 0.39% |

### Table VI-5: Summary of Voltage Impacts by Voltage

| Voltage | Annual Hours of Voltage Violations | | | |
|---|---|---|---|---|
| | **EV10** | **EV20** | **EV30** | **EV40** |
| **4.16** | 400 | 661 | 986 | 2656 |
| **7.2 / 8.32** | 204 | 912 | 2499 | 2862 |
| **13.2** | 442 | 1563 | 2326 | 3394 |
| | **PVEV10** | **PVEV20** | **PVEV30** | **PVEV40** |
| **4.16** | -616 | -567 | -481 | -381 |
| **7.2 / 8.32** | -545 | -272 | 492 | 920 |
| **13.2** | -507 | -489 | -280 | -160 |

### Table VI-6: Summary of Voltage Impacts by Length

| Length | Annual Hours of Voltage Violations | | | |
|---|---|---|---|---|
| | **EV10** | **EV20** | **EV30** | **EV40** |
| **Short** | 158 | 191 | 242 | 1977 |
| **Medium** | 415 | 918 | 1389 | 2116 |
| **Long** | 395 | 1496 | 2979 | 4472 |
| | **PVEV10** | **PVEV20** | **PVEV30** | **PVEV40** |
| **Short** | -195 | -185 | -184 | -179 |
| **Medium** | -660 | -584 | -385 | -216 |
| **Long** | -600 | -448 | 86 | 373 |

### Table VI-7: Summary of Voltage Impacts by Demand

| | **Annual Hours of Voltage Violations** | | | |
|---|---|---|---|---|
| **Demand** | **EV10** | **EV20** | **EV30** | **EV40** |
| **Light** | 340 | 1010 | 1545 | 2560 |
| **Medium** | 408 | 890 | 1851 | 3020 |
| **Heavy** | 285 | 1400 | 2003 | 3452 |
| | **PVEV10** | **PVEV20** | **PVEV30** | **PVEV40** |
| **Light** | -437 | -384 | -196 | -72 |
| **Medium** | -652 | -529 | -125 | 88 |
| **Heavy** | -529 | -458 | -348 | -130 |

### Table VI-8: Summary of Thermal Impacts by Voltage

| | **Line Miles of Thermal Violations** | | | |
|---|---|---|---|---|
| **Voltage** | **EV10** | **EV20** | **EV30** | **EV40** |
| **4.16** | 0.12 | 0.17 | 0.34 | 0.45 |
| **7.2 / 8.32** | 0.08 | 0.10 | 0.25 | 0.47 |
| **13.2** | 0.17 | 0.24 | 0.49 | 0.62 |
| | **PVEV10** | **PVEV20** | **PVEV30** | **PVEV40** |
| **4.16** | -0.30 | -0.32 | -0.24 | -0.21 |
| **7.2 / 8.32** | -0.09 | -0.09 | -0.06 | 0.10 |
| **13.2** | -0.17 | -0.17 | -0.10 | -0.08 |

### Table VI-9: Summary of Thermal Impacts by Length

| | **Line Miles of Thermal Violations** | | | |
|---|---|---|---|---|
| **Length** | **EV10** | **EV20** | **EV30** | **EV40** |
| **Short** | 0.02 | 0.02 | 0.03 | 0.07 |
| **Medium** | 0.15 | 0.22 | 0.38 | 0.57 |
| **Long** | 0.09 | 0.12 | 0.38 | 0.57 |
| | **PVEV10** | **PVEV20** | **PVEV30** | **PVEV40** |
| **Short** | -0.02 | -0.01 | 0.01 | 0.01 |
| **Medium** | -0.20 | -0.20 | -0.13 | 0.05 |
| **Long** | -0.27 | -0.27 | -0.20 | -0.17 |

### Table VI-10: Summary of Thermal Impacts by Demand

| | **Line Miles of Thermal Violations** | | | |
|---|---|---|---|---|
| **Demand** | **EV10** | **EV20** | **EV30** | **EV40** |

| | | | | |
|---|---|---|---|---|
| **Light** | 0.10 | 0.14 | 0.31 | 0.52 |
| **Medium** | 0.12 | 0.17 | 0.29 | 0.38 |
| **Heavy** | 0.06 | 0.09 | 0.48 | 0.79 |
| | **PVEV10** | **PVEV20** | **PVEV30** | **PVEV40** |
| **Light** | -0.10 | -0.09 | -0.05 | -0.04 |
| **Medium** | -0.28 | -0.29 | -0.21 | -0.03 |
| **Heavy** | -0.09 | -0.09 | -0.07 | -0.05 |

Examination of the preceding tables indicates that:

- The total system losses increase by an average of 2.32% for the worst case (EV40) level of penetration versus the base case. By comparison, again under the worst case penetration coupled with PV & storage (PVEV40), the system losses increase by 0.64% compared to the base case. This represents an annual difference of approximately 5.3 GWh in production and production costs. Given the volatile and increasing costs of fuel this difference is significant, representing as much as $1M USD in annual operating costs just to cover the loss differential.

- The voltage violation hours (the annual hours during which the voltage is outside of acceptable operating range), increases by an average of 5178 hours across all stratifications (voltage, length and demand) for the worst case penetration versus the base case. They increase by only 2219 hours across all stratifications versus the base case when PV and storage is included, better than a two-fold improvement. While there is no direct operating cost associated with this improvement, as may be seen in the subsequent section, it does represent a significant improvement in mitigation costs.

- The thermal violation miles (the number of miles of conductor overloaded annually), increased by an average of 0.55 miles across all stratifications (voltage, length and demand) for the worst case penetration versus the base case. They increase by only 0.08 miles across all stratifications versus the base case when PV and storage is included, a nearly seven fold improvement. While there is no direct operating cost associated with this improvement, as may be seen in the subsequent section, it does represent a significant improvement in mitigation costs.

While there is considerable variability in individual feeders, the preceding values are quite consistent across the summary variables. There was degradation, and potentially significant degradation in system performance as the EV penetration is increased. Offsetting the EV demand with solar and storage, even at a modest level not only mitigates the performance degradation associated with EV penetration, but it also improves base case performance. The potential cost implications are discussed in Section B below.

## B. Impact Analysis – Extrapolation

The impacts discussed above are based on the selected feeders only. Extrapolating these values to the general system requires that the feeder characteristics be broadly summarized based on characterization variables of operating voltage, length and demand. The categories to be used for each are as follows:

| | |
|---|---|
| Voltage: | 4.16 kV, 7.2 / 8.32 kV and 13.2 kV |
| Length: | < 5 miles, > 5 miles and < 20 miles and > 20 miles |
| Demand: | < 3 MW, >= 3 MW and < 4 MW and > = 4 MW |

Based on the available information, assuming 1130 feeders, the breakdown in each category is as follows:

**Table VI-11: Stratification of System by Category**

| | Low | Medium | High |
|---|---|---|---|
| **Voltage** | 60% | 17% | 23% |
| **Length** | 36% | 35% | 29% |
| **Demand** | 11% | 63% | 26% |

The investment differential associated with deployment scenarios (i.e., EV alone or EV with PV) is predicated on both the thermal overload miles identified directly and a graduated percentage of the total circuit miles based on the total voltage violation hours. That is, when a feeder exhibits both thermal and voltage violations, the total miles of thermal violations are added to a percentage of the total line length based on the number of voltage violations hours. The greater the number of voltage violation hours, the larger the percentage of the feeder that is assumed to be impacted. The graduation levels are:

Violation hours < 1000 - 5% of line miles

Violation hours > 1000 & < 2500 - 10% of line miles

Violations hours >2500 & < 5000 – 15% of line miles

Violation hours > 5000 - 20% of line miles

Upgrade costs are estimated to be $175,000 USD per mile. Upgrades are based on rebuilding / replacing lines that exhibit thermal violations and / or voltage violations. This estimate is based on both recent experience with line upgrades in the Caribbean, as well as typical numbers from the rural electric cooperative market in the US. Note that only the "violating" sections are assumed to be replaced.

**Table VI-12: Summary of Cost Impacts by Voltage**

| | **EV10** | **EV20** | **EV30** | **EV40** |
|---|---|---|---|---|
| **4.16** | $75M | $150M | $150M | $225M |
| **7.2 / 8.32** | $41M | $41M | $82M | $123M |
| **13.2** | $30M | $60M | $60M | $90M |
| **Total** | $146M | $251M | $292M | $438M |

**Table VI-13: Summary of Cost Impacts by Voltage**

| | **PVEV10** | **PVEV20** | **PVEV30** | **PVEV40** |
|---|---|---|---|---|
| **4.16** | $0M | $0M | $0M | $0M |
| **7.2 / 8.32** | $0M | $0M | $41M | $41M |
| **13.2** | $0M | $0M | $0M | $0M |
| **Total** | $0M | $0M | $41M | $41M |

**Table VI-14: Summary of Cost Impacts by Length**

| | **EV10** | **EV20** | **EV30** | **EV40** |
|---|---|---|---|---|
| **Short** | $53M | $53M | $53M | $106M |
| **Medium** | $52M | $72M | $104M | $144M |
| **Long** | $41M | $126M | $135M | $188M |
| **Total** | $146M | $251M | $292M | $438M |

**Table VI-15: Summary of Cost Impacts by Length**

| | **PVEV10** | **PVEV20** | **PVEV30** | **PVEV40** |
|---|---|---|---|---|
| **Short** | $0M | $0M | $0M | $0M |
| **Medium** | $0M | $0M | $0M | $0M |
| **Long** | $0M | $0M | $41M | $41M |

| | | | | |
|---|---|---|---|---|
| **Total** | $0M | $0M | $41M | $41M |

**Table VI-16: Summary of Cost Impacts by Demand**

| | **EV10** | **EV20** | **EV30** | **EV40** |
|---|---|---|---|---|
| **Low** | $16M | $27M | $29M | $70M |
| **Medium** | $92M | $128M | $154M | $196M |
| **High** | $38M | $96M | $109M | $172M |
| **Total** | $146M | $251M | $292M | $438M |

**Table VI-17: Summary of Cost Impacts by Demand**

| | **PVEV10** | **PVEV20** | **PVEV30** | **PVEV40** |
|---|---|---|---|---|
| **Low** | $0M | $0M | $0M | $0M |
| **Medium** | $0M | $0M | $0M | $0M |
| **High** | $0M | $0M | $41M | $41M |
| **Total** | $0M | $0M | $41M | $41M |

# VII. Conclusions

The analysis reveals that the existing distribution infrastructure can sustain a modest amount of EV penetration (10 – 20%) without exorbitant investment. Beyond approximately 20% the investment and performance degradation become problematic. This is especially true for lower voltage (4.16 kV) systems and longer rural feeders. Because the variability in individual feeder characteristics, it is quite possible that the investment costs could be as much as 30% higher that those presented in the preceding tables.

The inclusion of PV and storage in the analysis reduces the required infrastructure investment substantially across all EV scenarios. It also dramatically improves system performance as demonstrated by losses, voltage and thermal violation values. Note that there is obviously the need for the initial PV and storage investment to realize the savings associated with this scenario. However, there are standalone benefits derived from the investment in PV and storage that may independently justify their deployment. These have been presented in a separate report.