Title:	***Final Report for EV Integration Analysis***
Synopsis:	*Final Report on results of the subject analysis.*
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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.

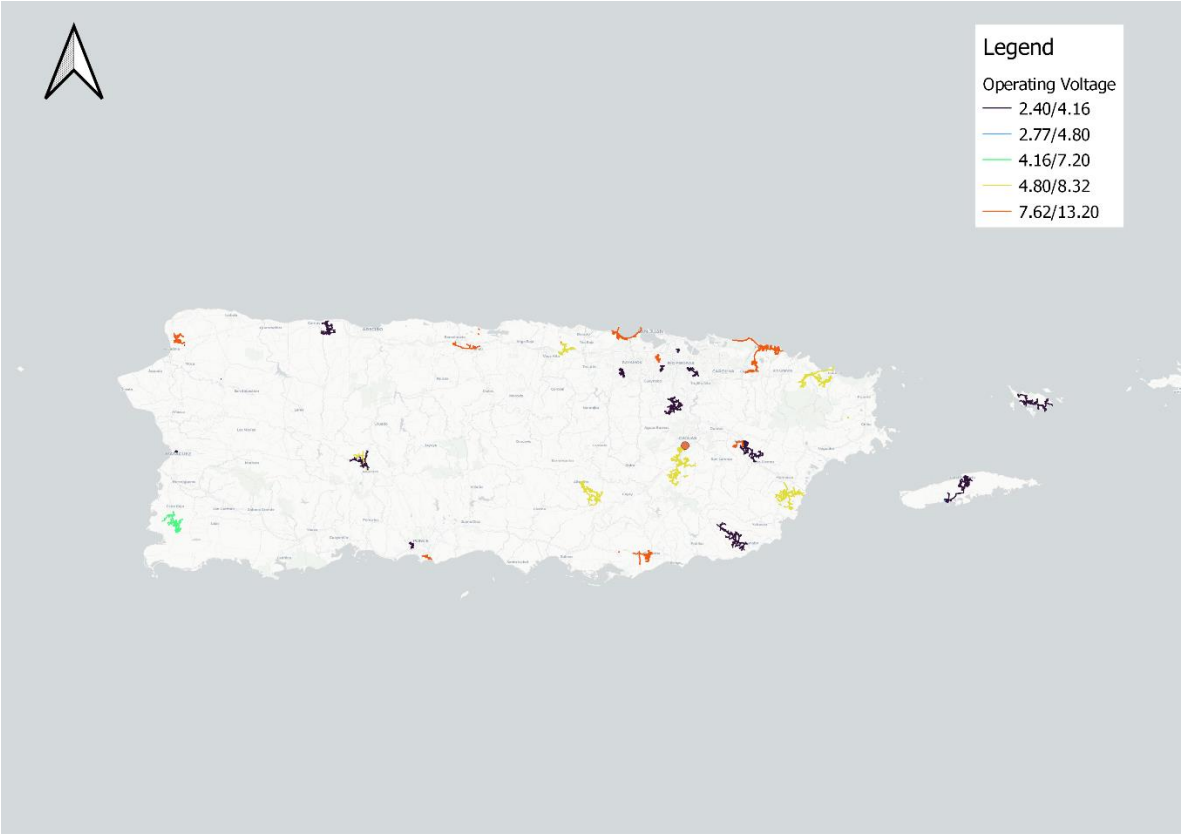

Figure III-1: Analyzed Circuits

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.

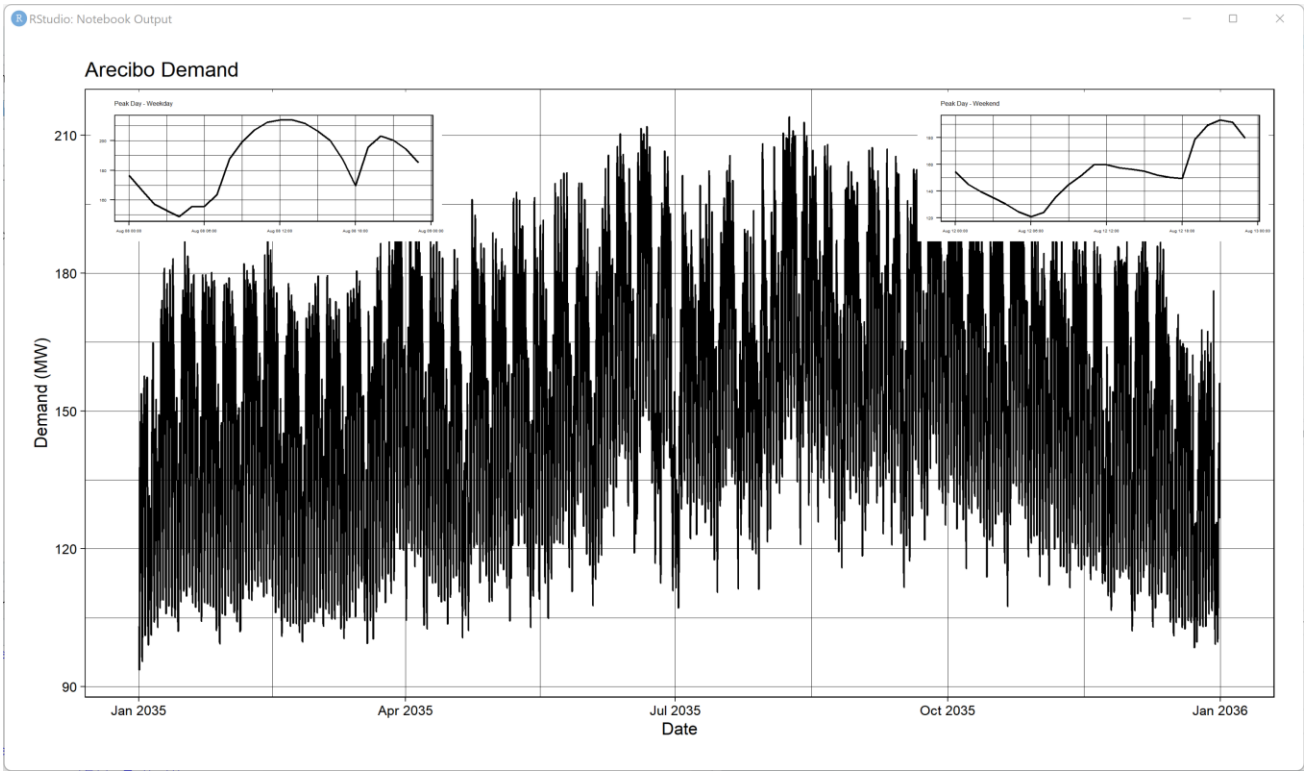

Figure III-2: Arecibo Region Demand Profile

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.

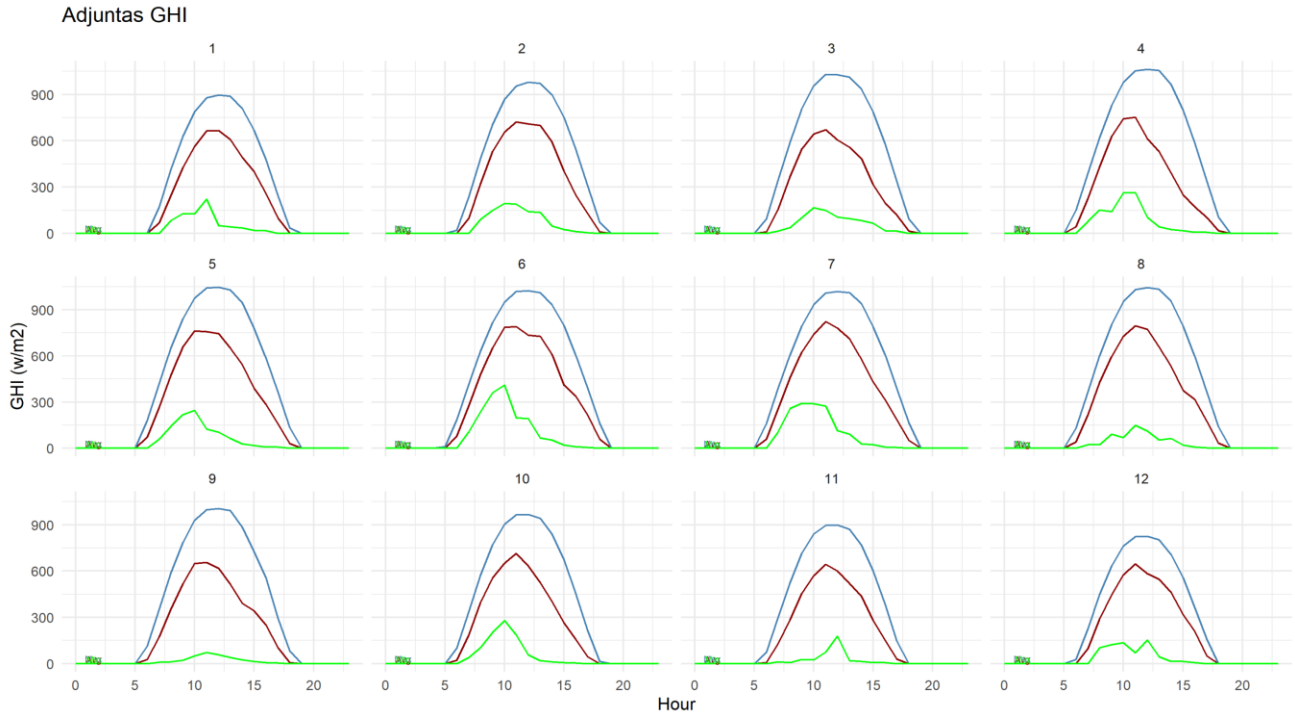

Figure III-3: Adjuntas Solar Irradiance distribution

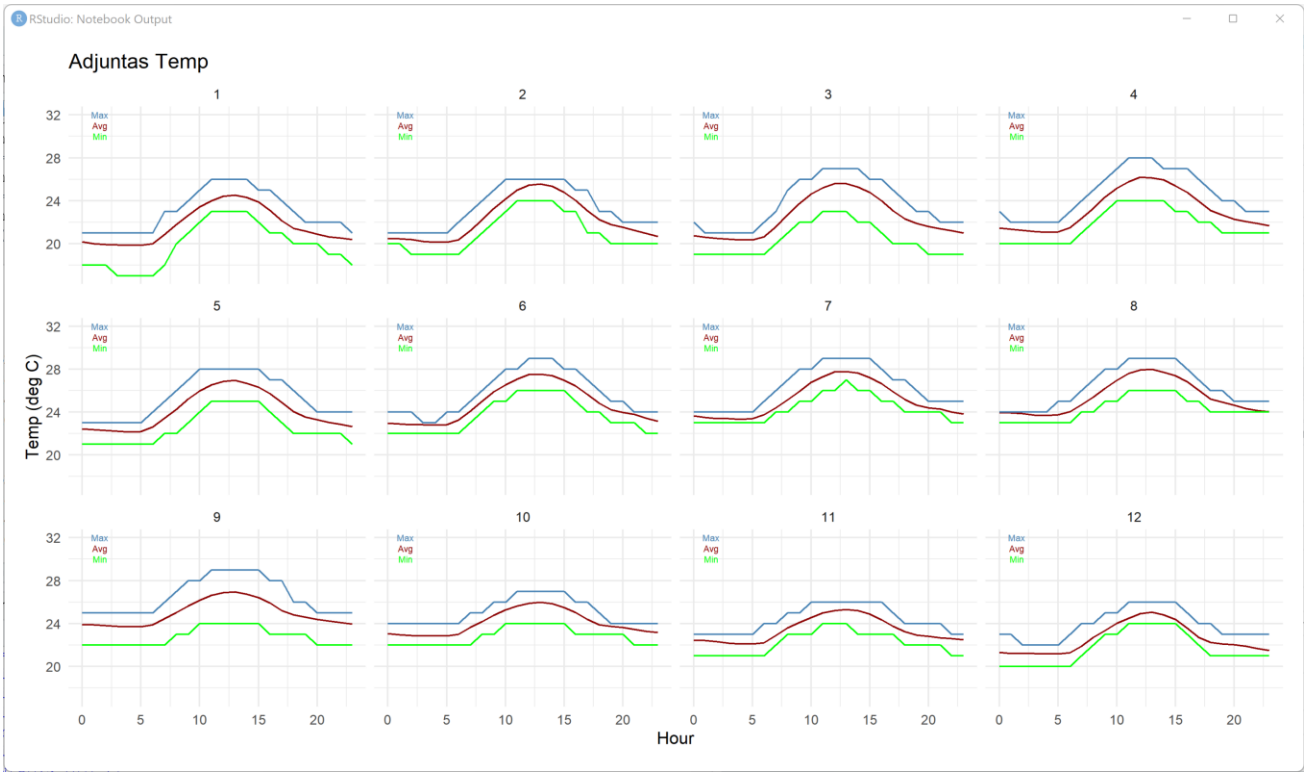

Figure III-4: Adjuntas Temperature Profile

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.

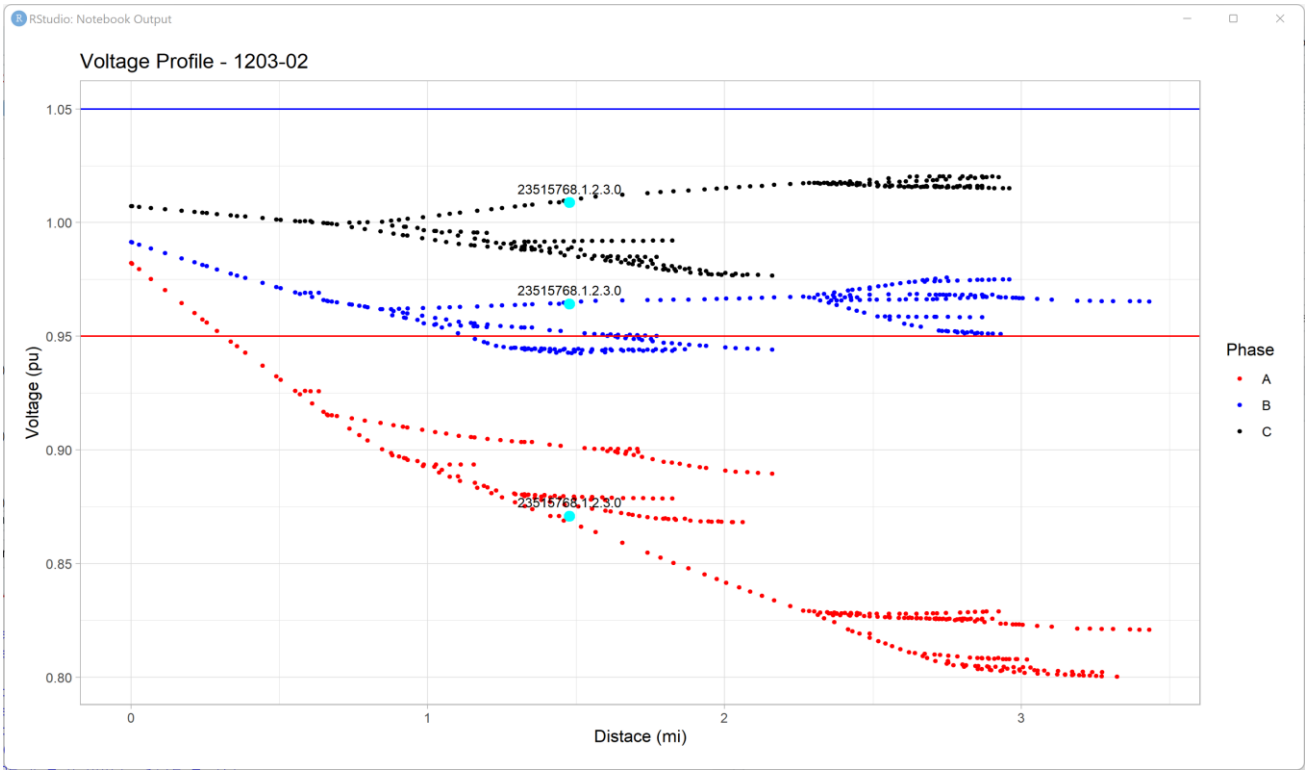

Figure IV-1: Voltage Profile – Circuit 1203-02

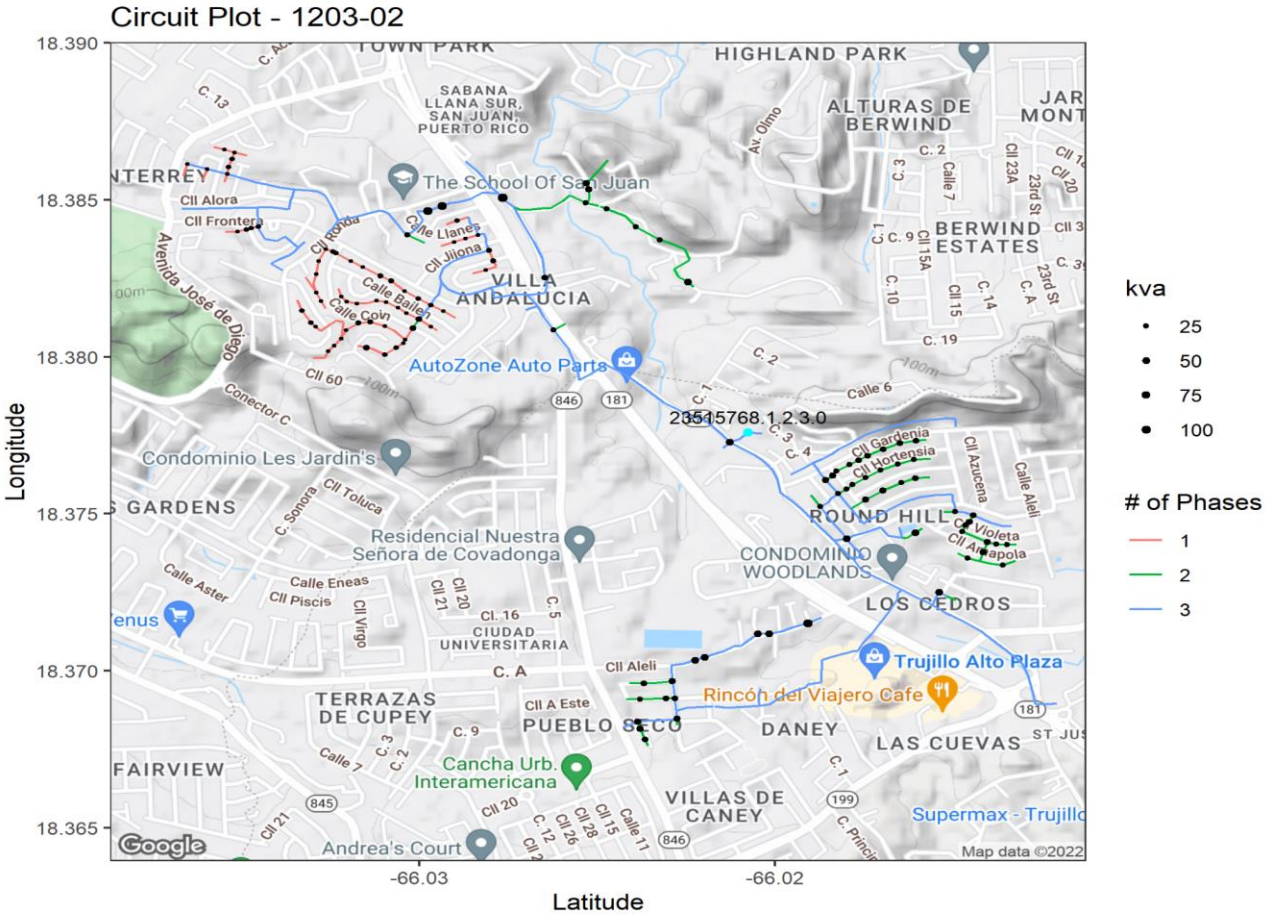

Figure IV-2: Circuit Plot – Circuit 1203-02

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.

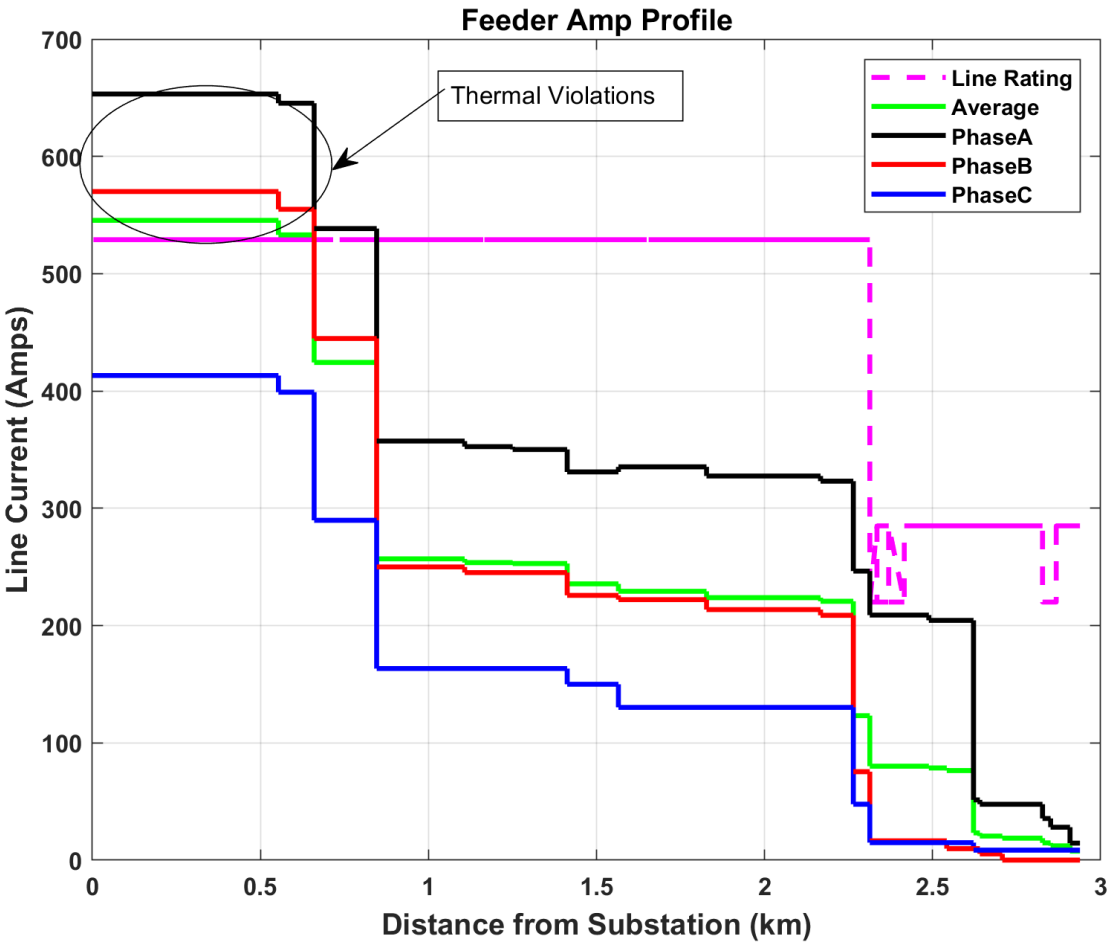

Figure IV-3: Circuit 1203-02 Thermal Violations

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.

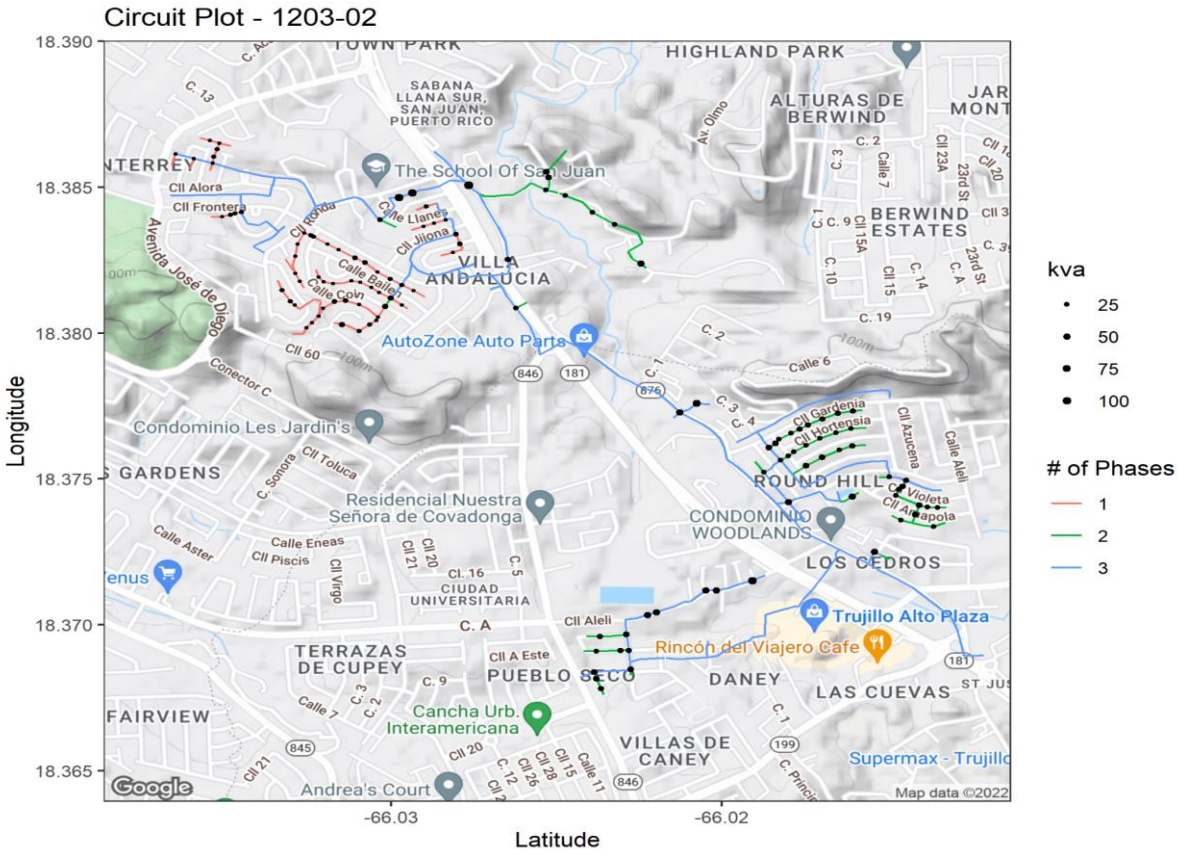

Figure V-1: Feeder 1203-01 Feeder Summary

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.

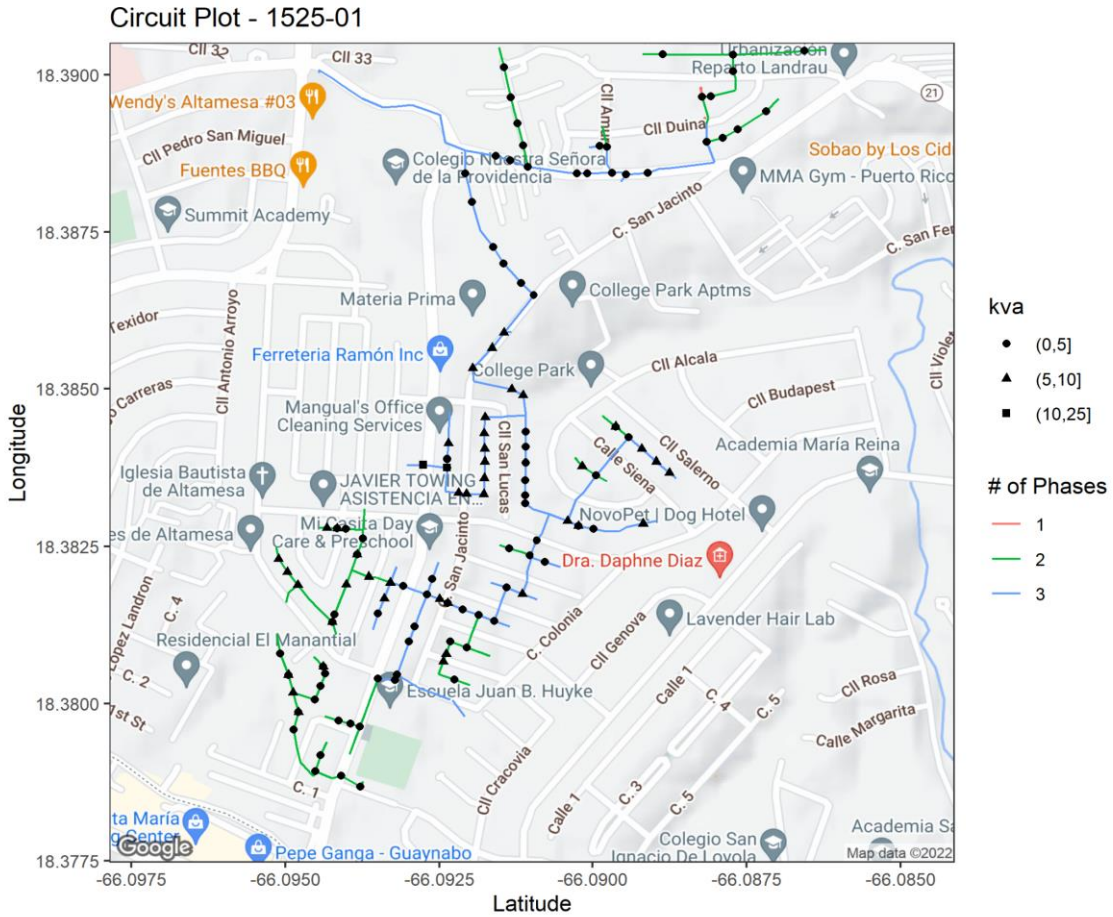

Figure V-3: Feeder 1525-01 Feeder Summary

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.

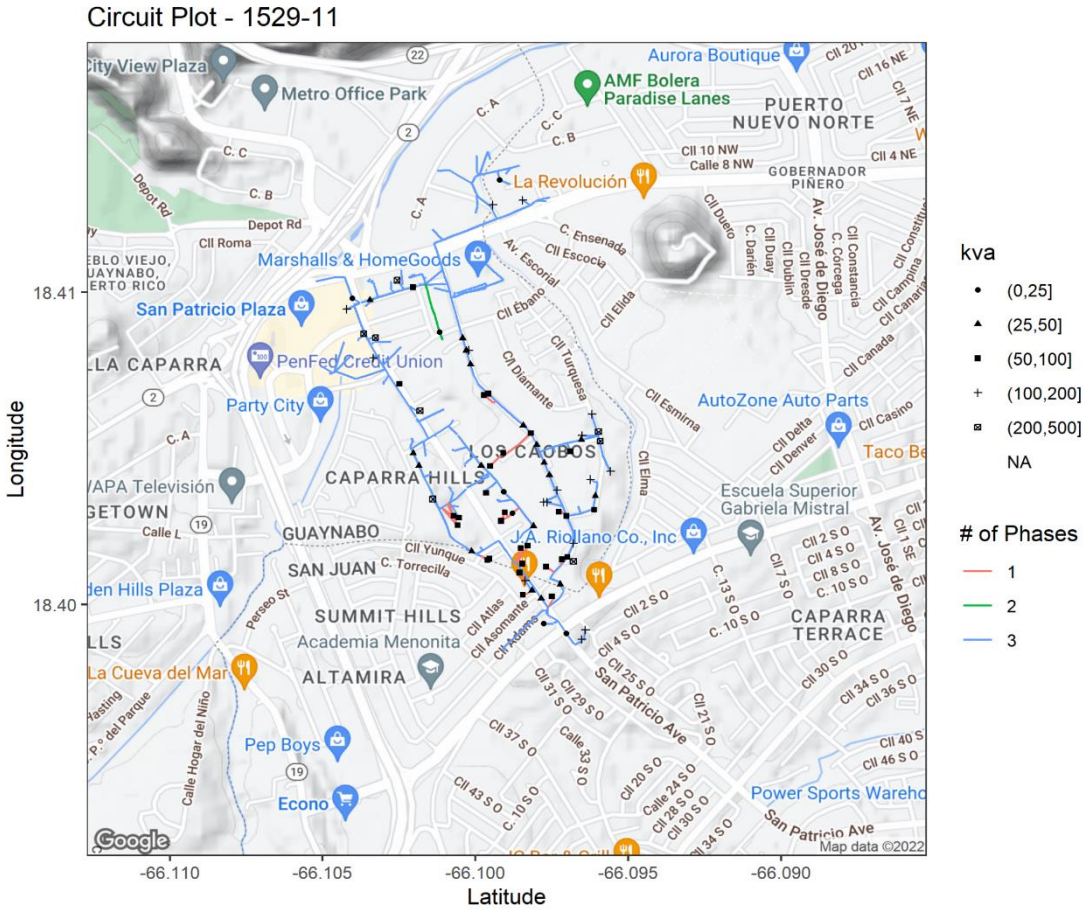

Figure V-4: Feeder 1529-11 Feeder Summary

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.

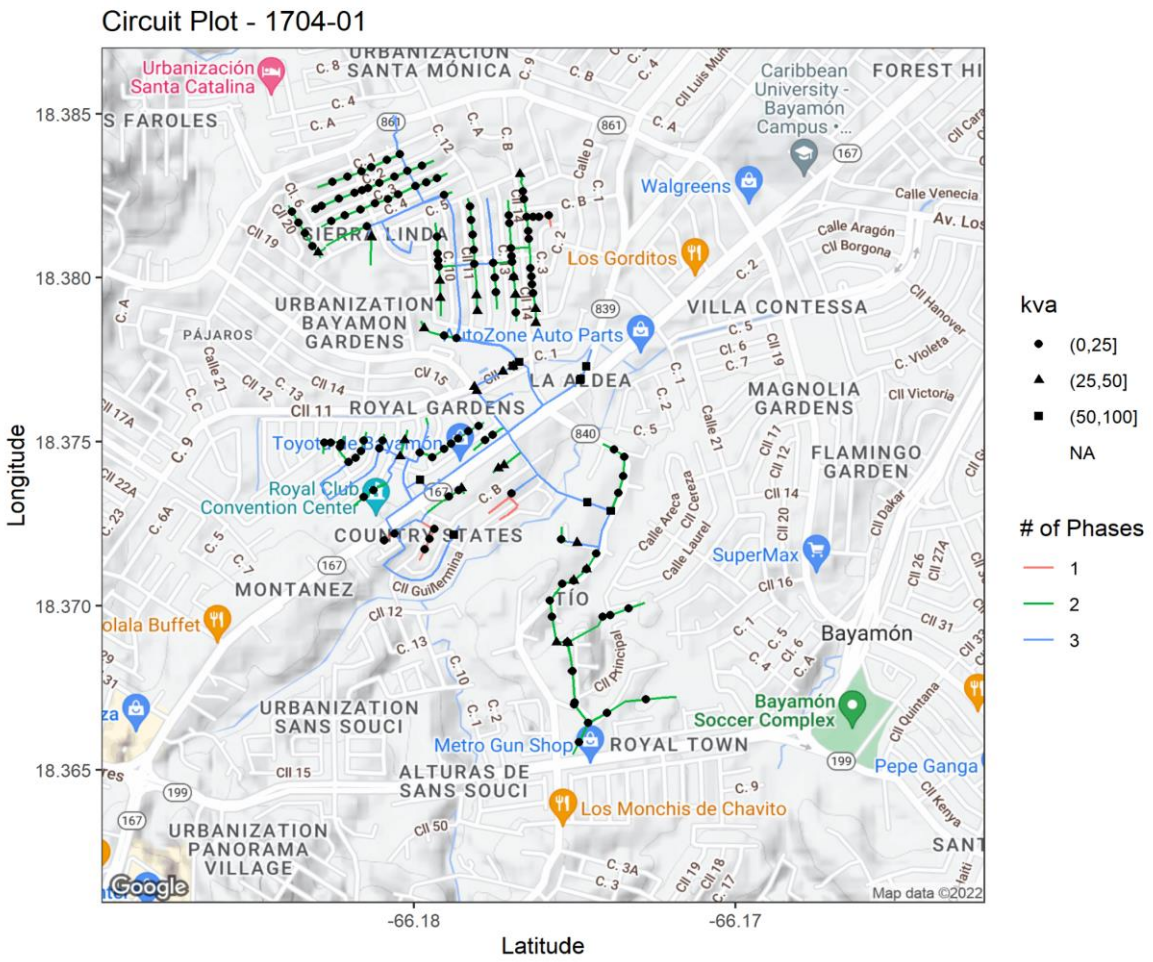

Figure V-5: Feeder 1704-01 Feeder Summary

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.

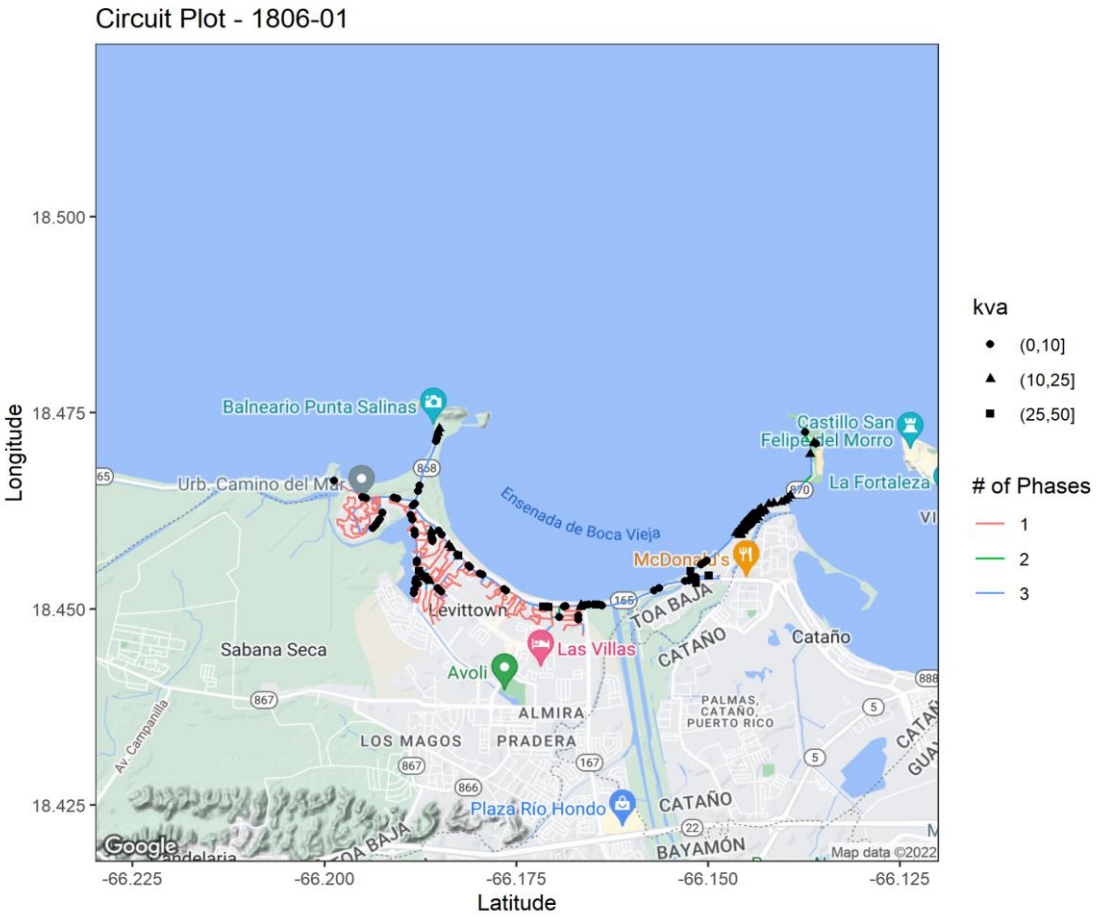

Figure V-6: Feeder 1806-01 – Feeder Summary

2. Annual Metrics

Table V-6: Metrics for Feeder 1806-01

Metric	Base Case	EV10	PVEV10	Metric	Base Case	EV20	PVEV20
Annual Losses (kWh)	250,667	384,687	171,248	Annual Losses (kWh)	250,667	429,360	243,221
Annual Losses (%)	1.01%	1.55%	0.69%	Annual Losses (%)	1.01%	1.73%	0.98%
Voltage Violation Hours	0	0	0	Voltage Violation Hours	0	83	0
Thermal Violation Miles	0	0	0	Thermal Violation Miles	0	0.11	0
Voltage Delta	0.00%	-1.36%	10.58%	Voltage Delta	0.00%	-2.13%	8.07%
Metric	**Base Case**	**EV30**	**PVEV30**	**Metric**	**Base Case**	**EV40**	**PVEV40**
Annual Losses (kWh)	250,667	469,070	305,268	Annual Losses (kWh)	250,667	501,334	362,350
Annual Losses (%)	1.01%	1.89%	1.23%	Annual Losses (%)	1.01%	2.02%	1.46%
Voltage Violation Hours	0	277	2	Voltage Violation Hours	0	597	11
Thermal Violation Miles	0	0.28	0.01	Thermal Violation Miles	0	0.87	0.01
Voltage Delta	0.00%	-3.13%	6.28%	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.

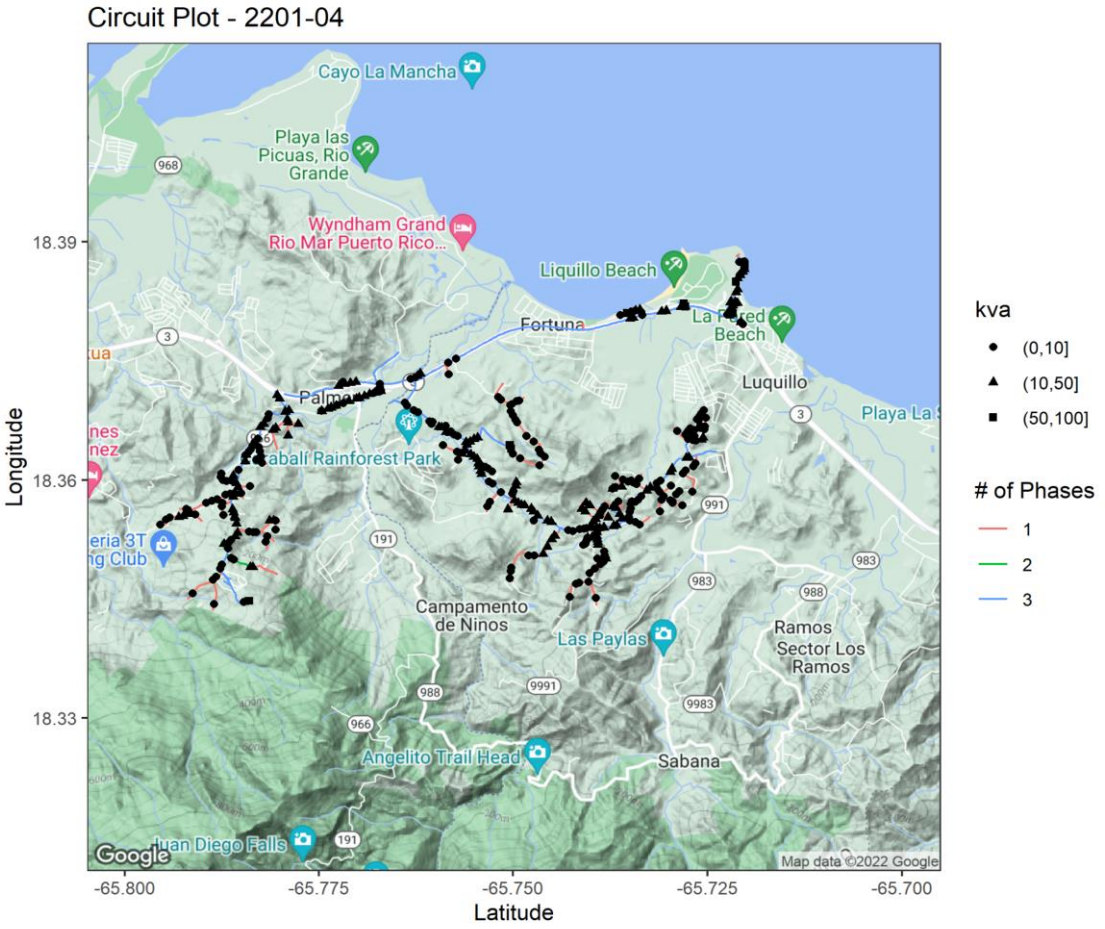

Figure V-7: Feeder 2201-04 – Feeder Summary

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.

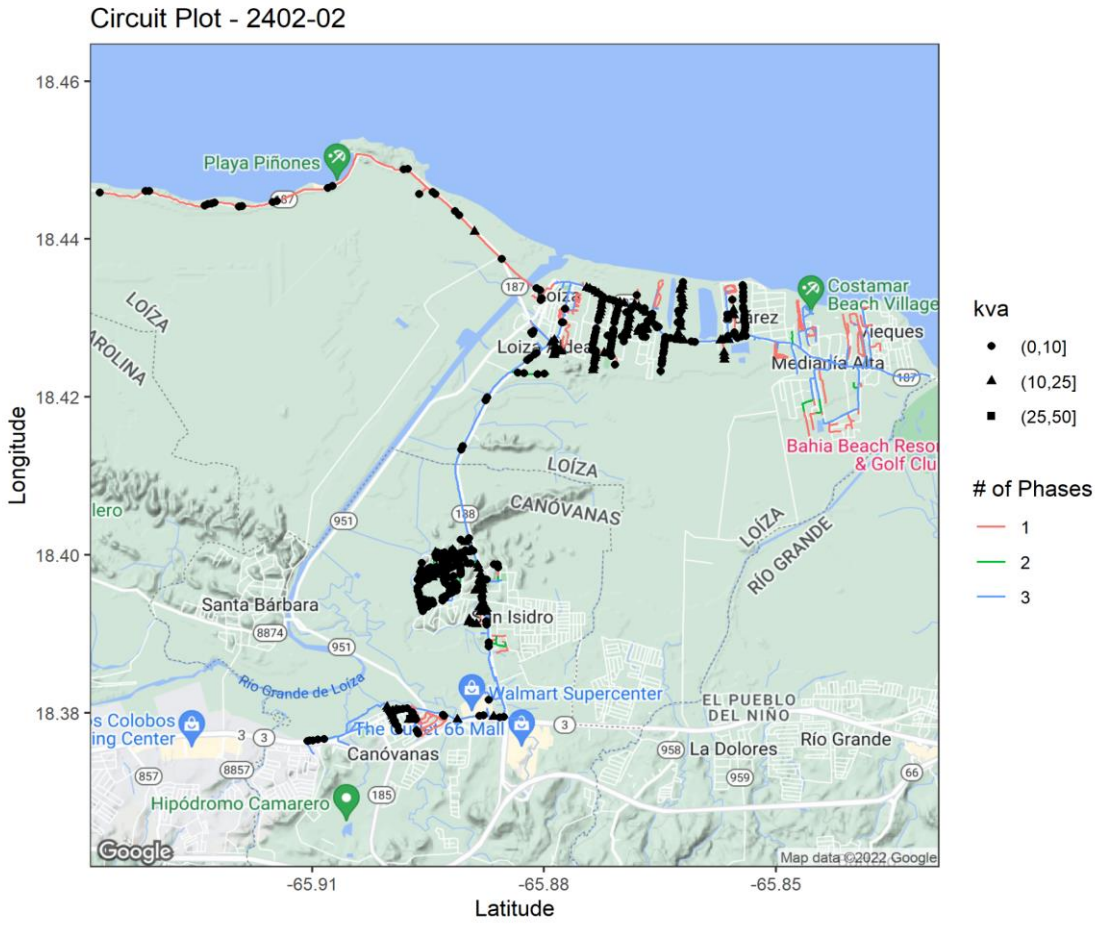

Figure V-8: Feeder 2402-02 – Feeder Summary

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.

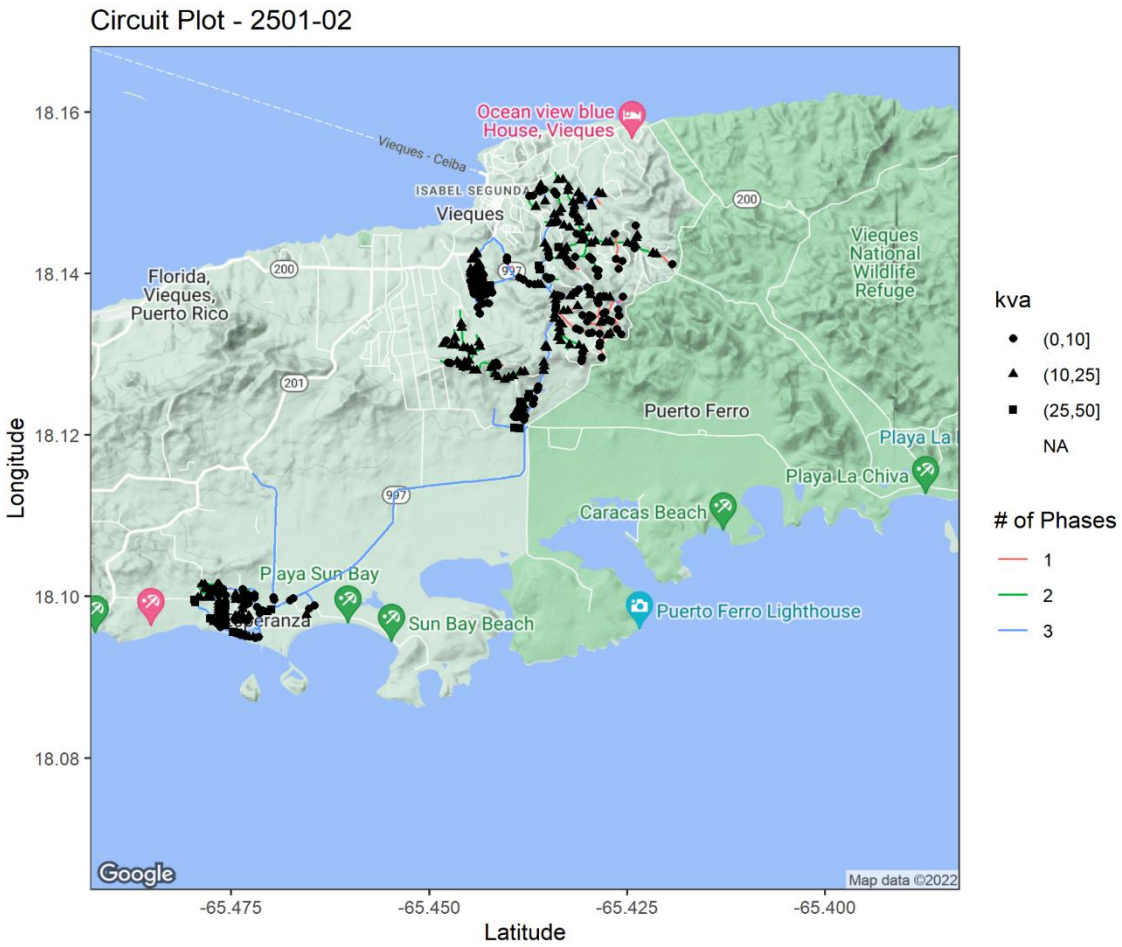

Figure V-9: Feeder 2501-02 Feeder Summary

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.

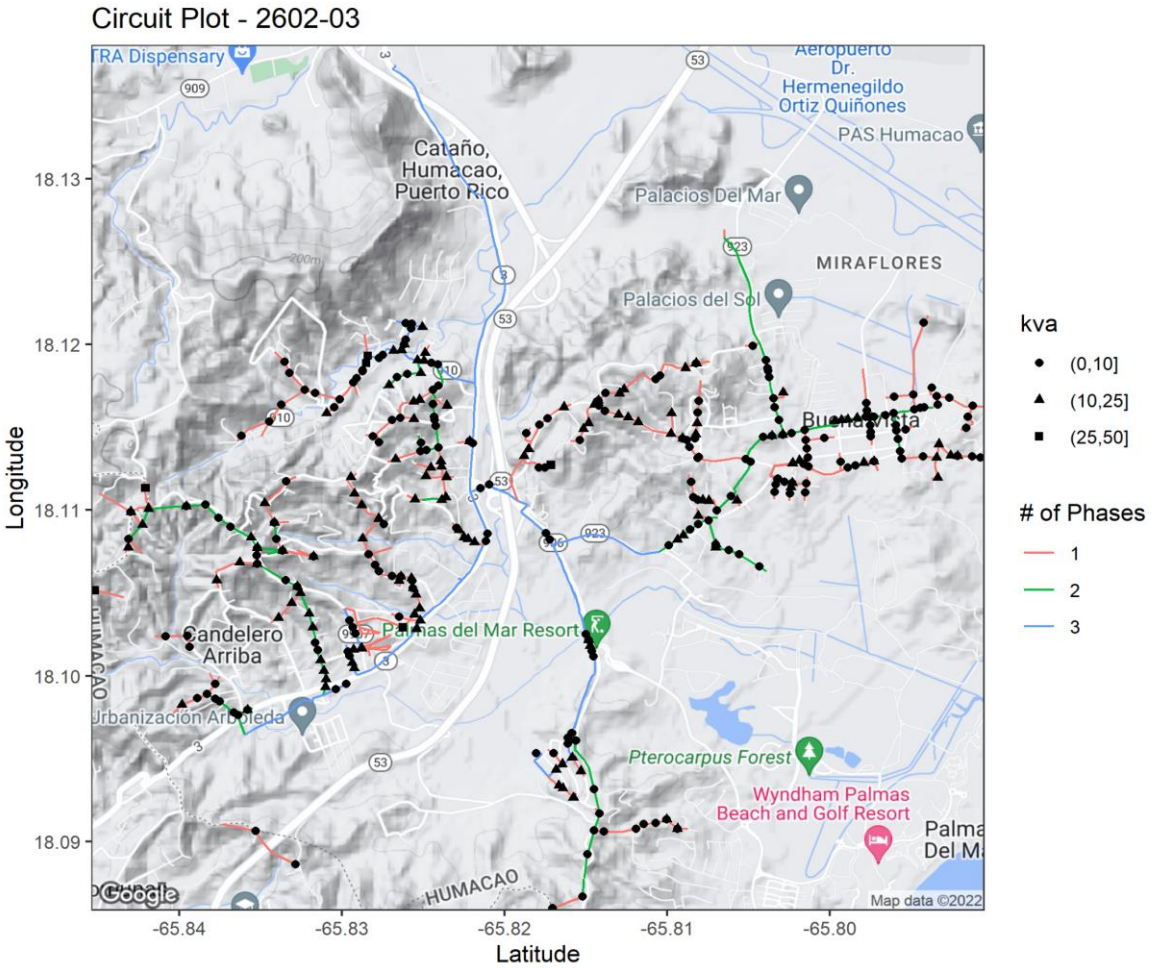

Figure V-10: Feeder 2602-03 Feeder Summary

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.

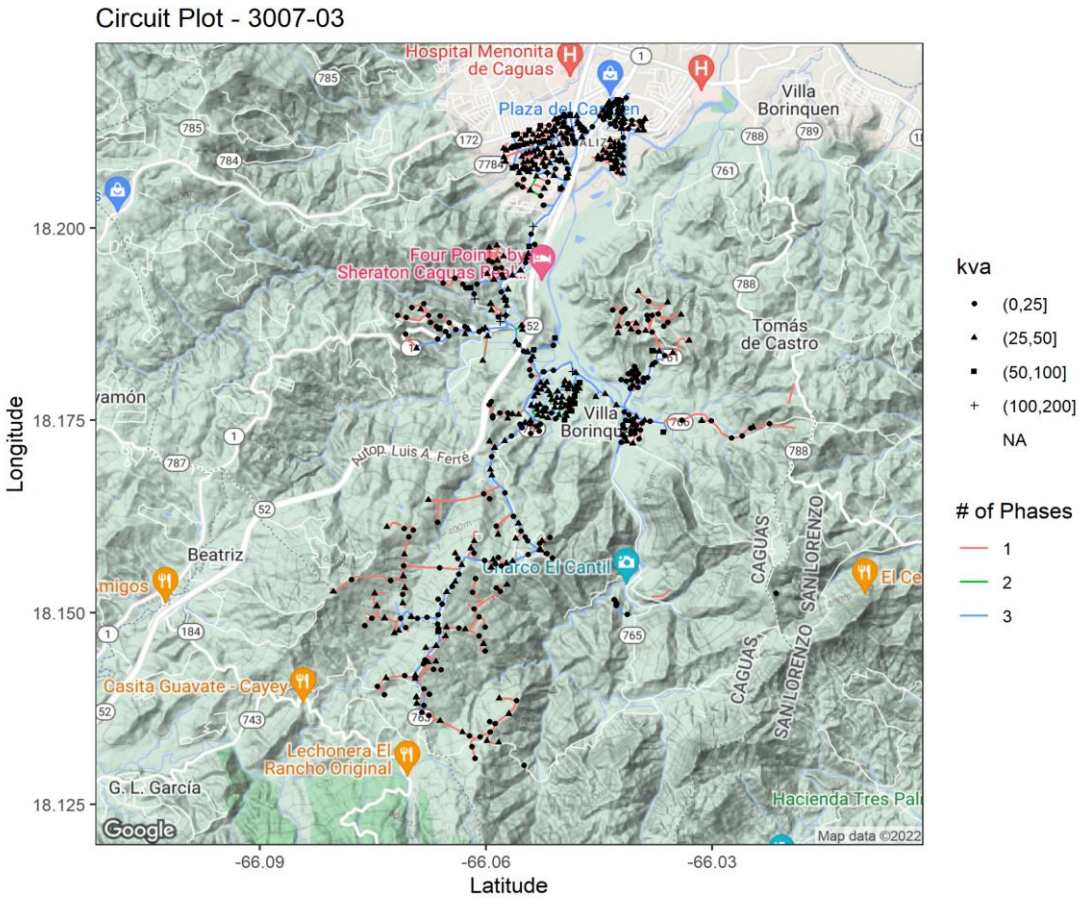

Figure V-11: Feeder 3007-03 Feeder Summary

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.

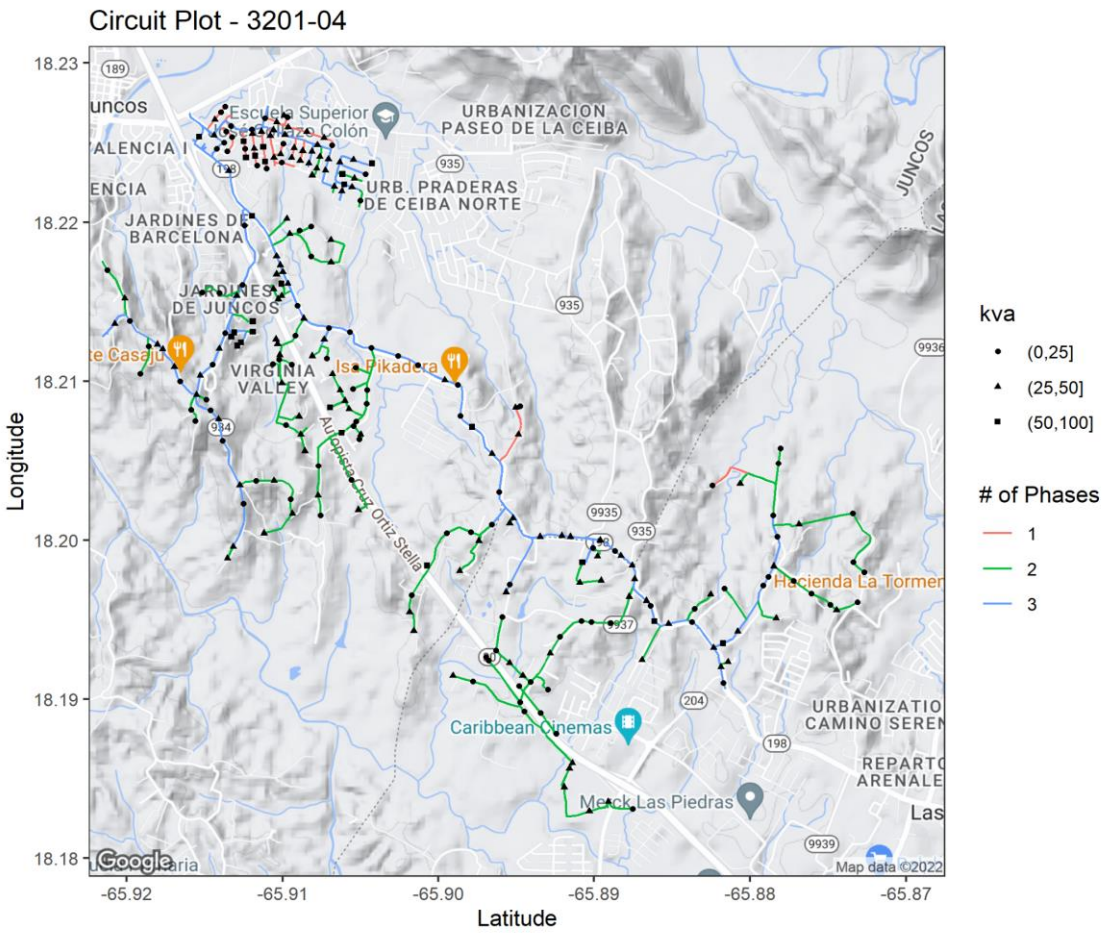

Figure V-12: Feeder 3201_04 Feeder Summary

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.

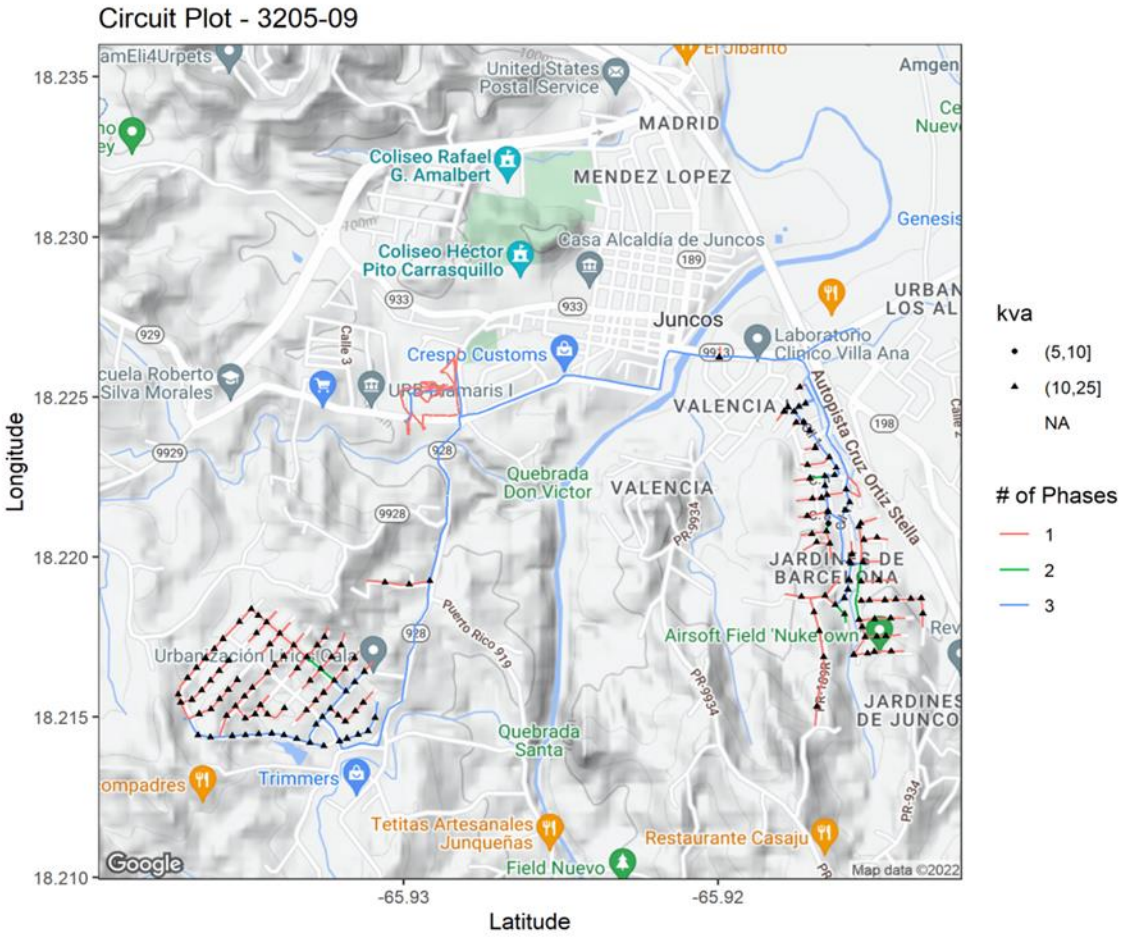

Figure V-13: Feeder 3205-09 Feeder Summary

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.

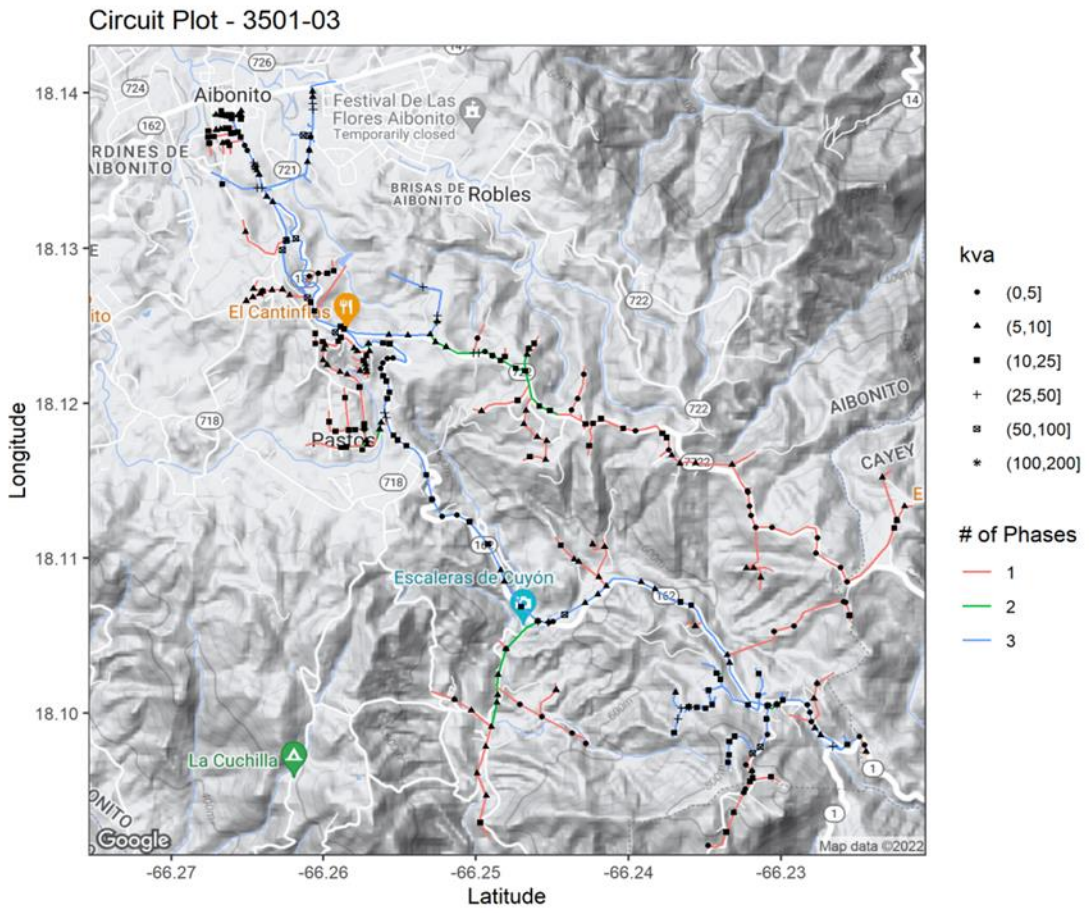

Figure V-14: Feeder 3501-03 Feeder Summary

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.

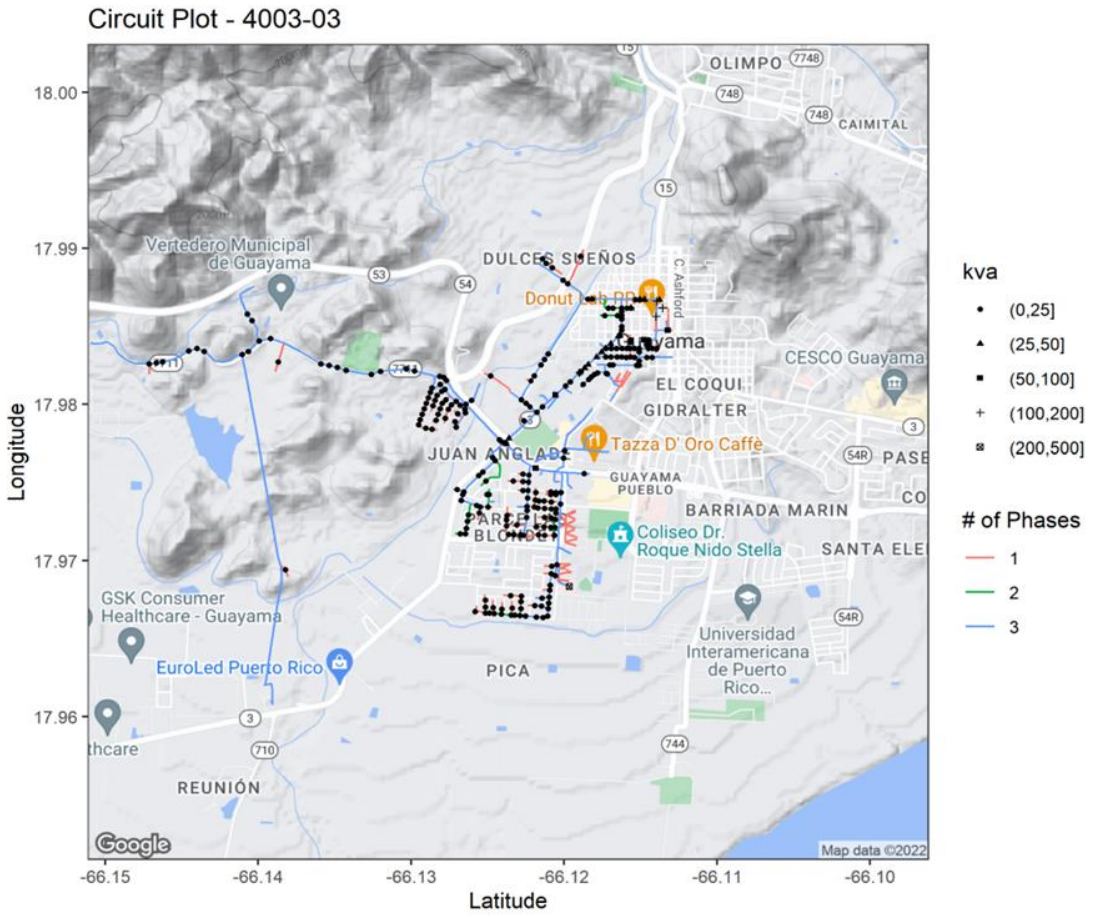

Figure V-15: Feeder 4003-03 Feeder Summary

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.

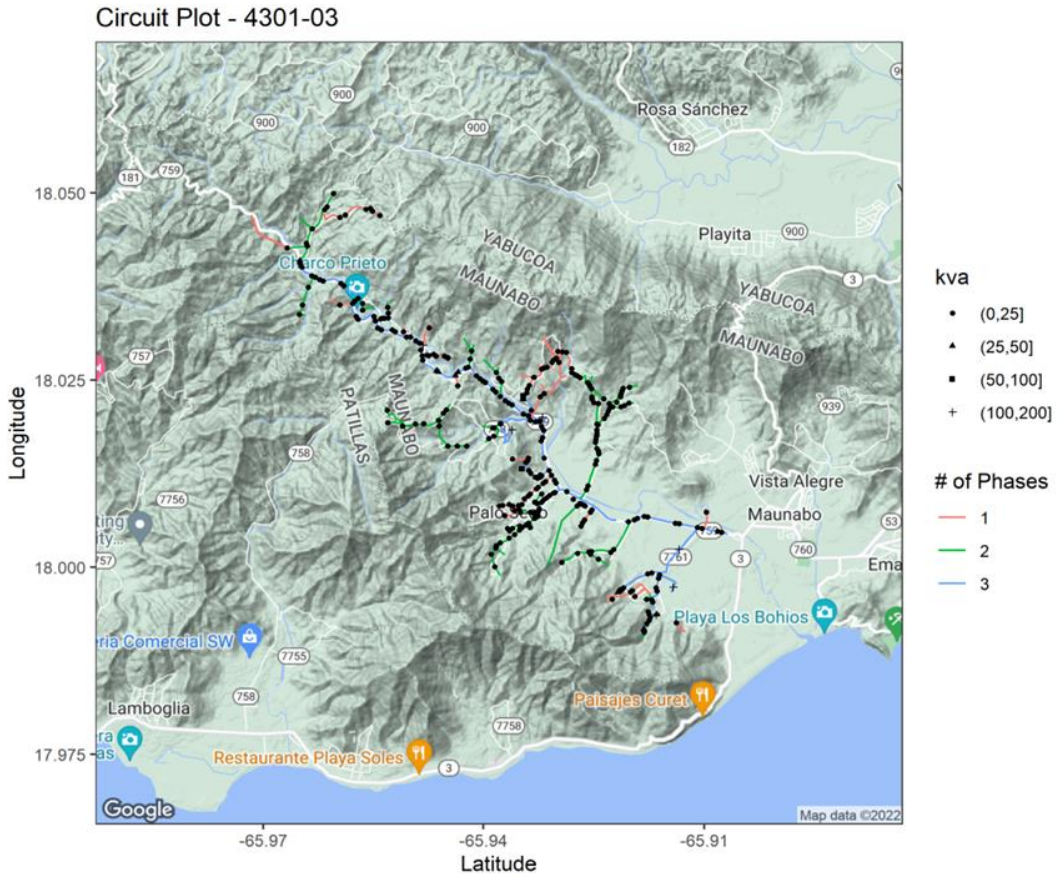

Figure V-16: Feeder 4301-03 Feeder Summary

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.

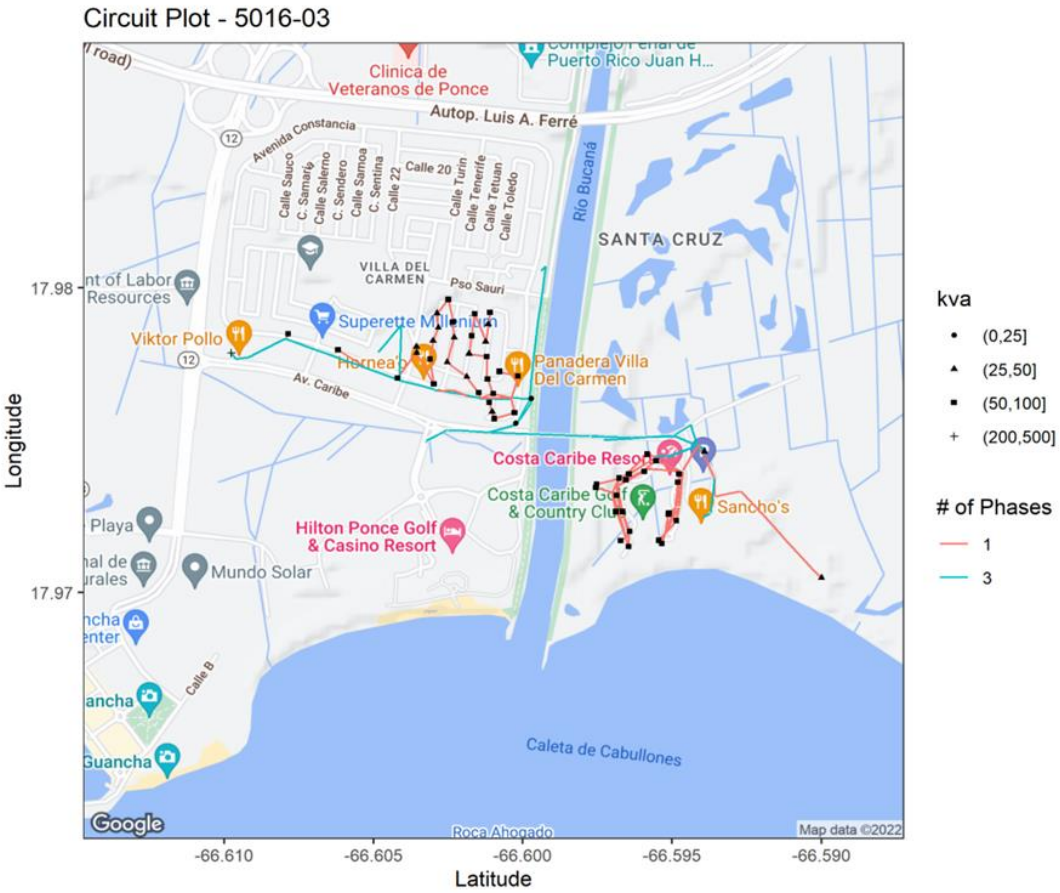

Figure V-18: Feeder 5016-03 Feeder Summary

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.

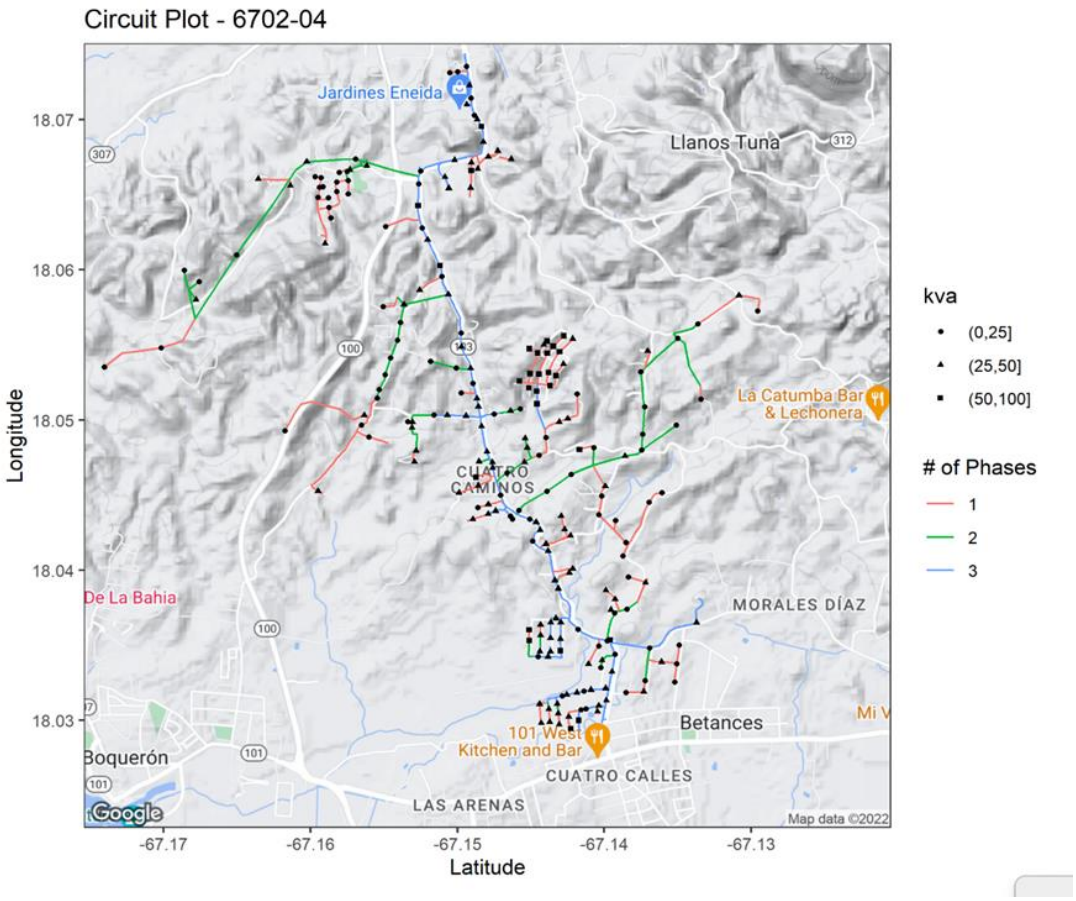

Figure V-20: Feeder 6702-04 Feeder Summary

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.

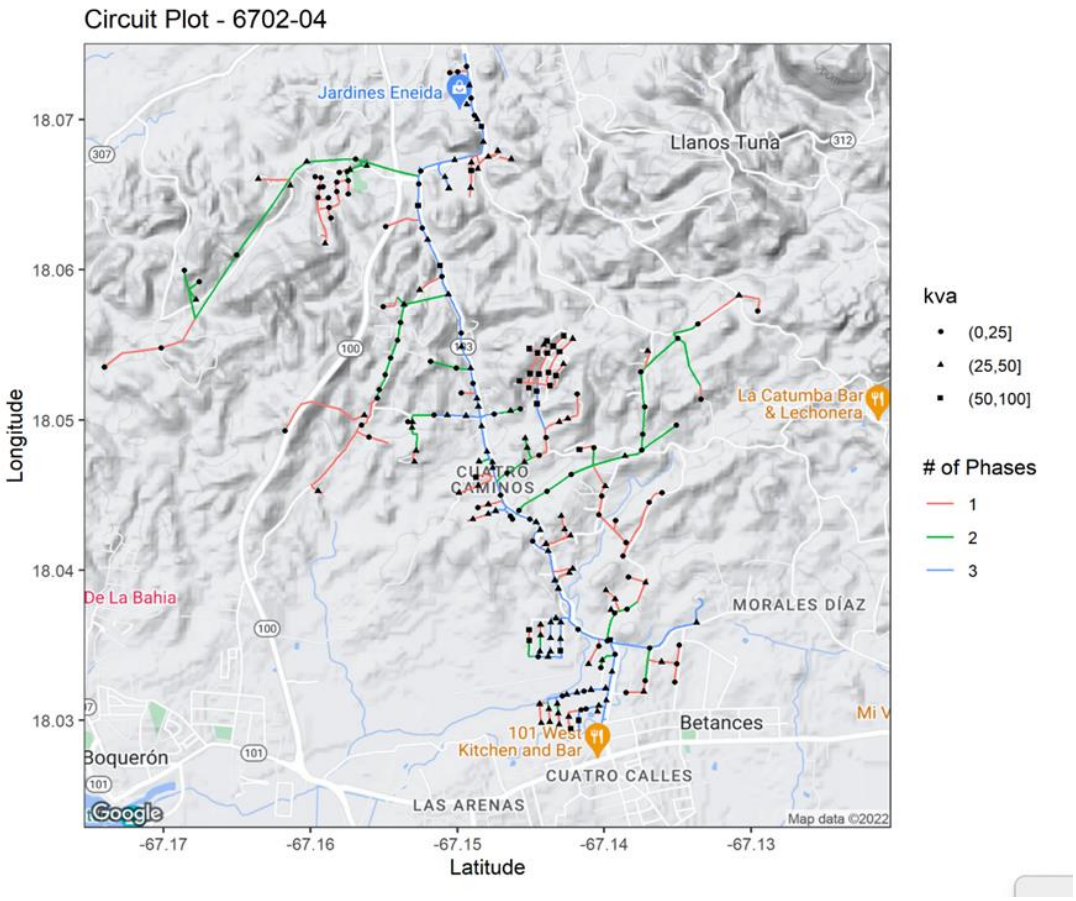

Figure V-21: Feeder 6011-02 Feeder Summary

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.

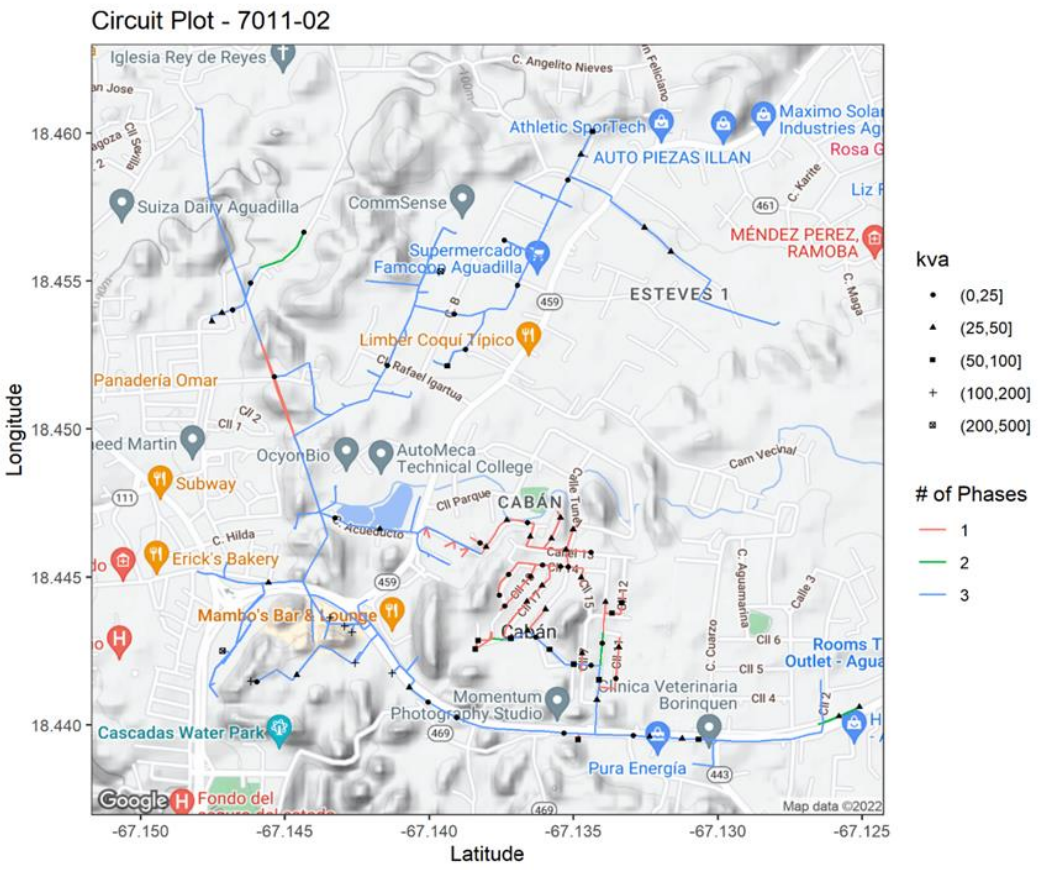

Figure V-22: Feeder 7701-01 Feeder Summary

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.

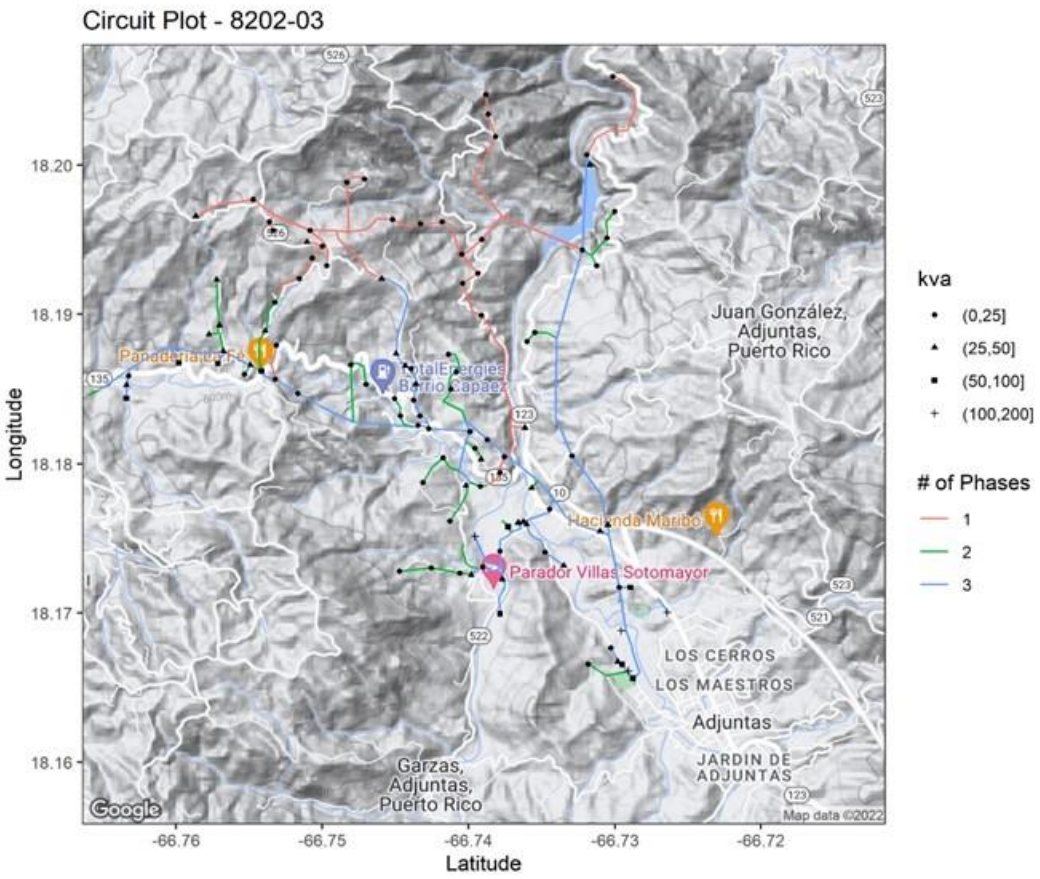

Figure V-23: Feeder 8203-03 Feeder Summary

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.

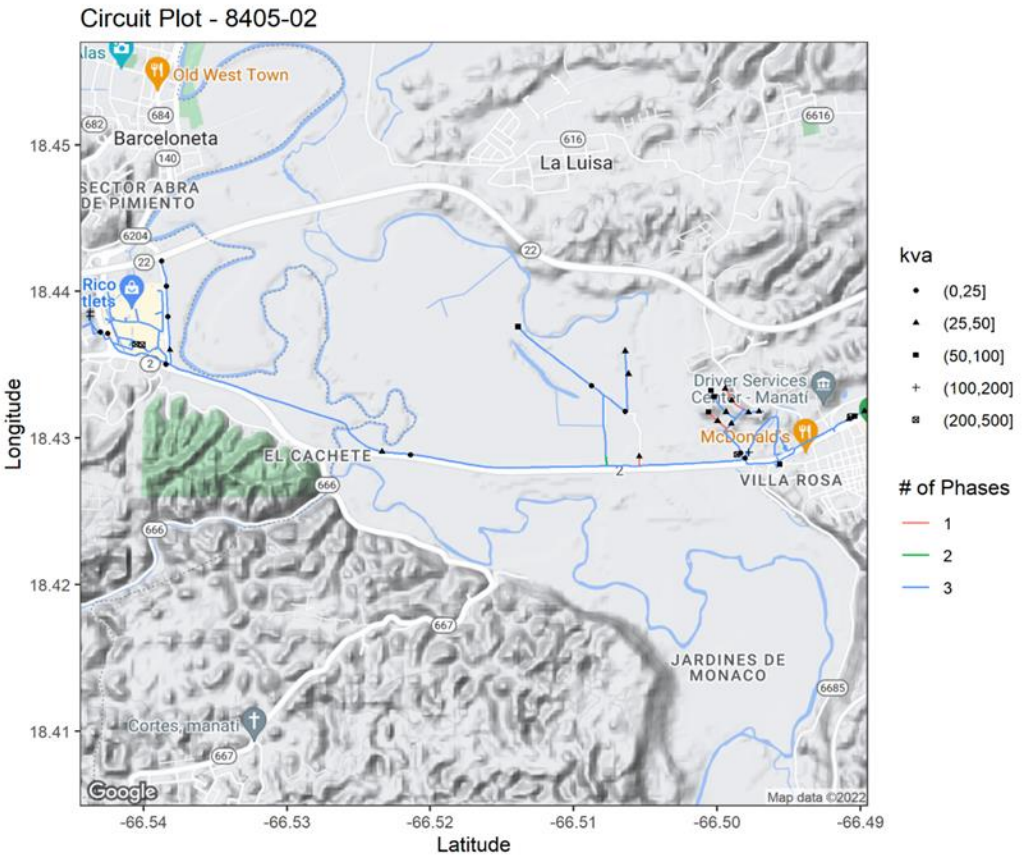

Figure V-24: Feeder 8405-02 Feeder Summary

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.

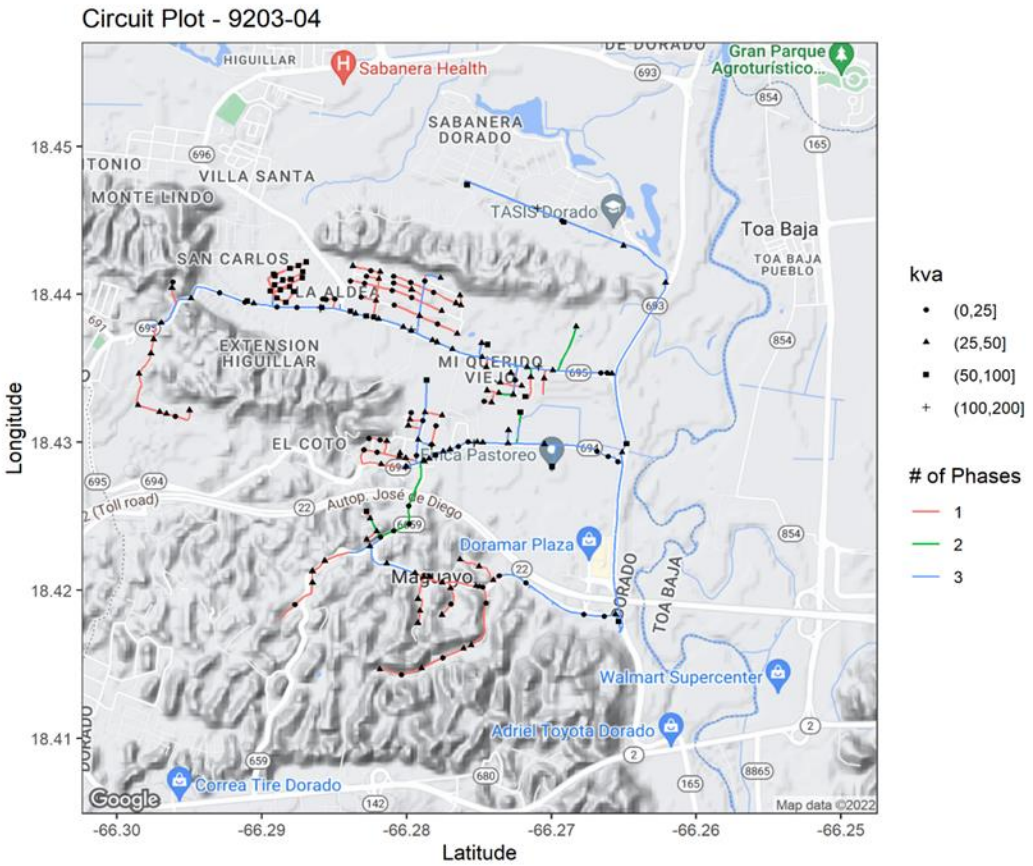

Figure V-25: Feeder 9203-04 Feeder Summary

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

Demand	Annual Hours of Voltage Violations			
	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

Voltage	Line Miles of Thermal Violations			
	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

Length	Line Miles of Thermal Violations			
	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

Demand	Line Miles of Thermal Violations			
	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.