# KCP&L Green Circuits Analysis

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# 1
# INTRODUCTION AND LOSS STUDY SUMMARY

This report summarizes the modeling and simulation results for the 9111, 3111, 5051, and 7812 circuits as part of the EPRI Green Circuits collaborative project. The Green Circuits project is aimed at evaluating the effectiveness of various distribution system efficiency initiatives on specific feeders through detailed modeling and simulation. Section 2 of this report provides results from the model-based efficiency evaluations for the four circuits. Section 3 compares the results of Section 2 to other circuits that have been modeled in the Green Circuits project.

## Summary of Loss Study

As stated, Section 2 of this document presents the model results of 9111, 3111, 5051, and 7812 circuits that were presented in the October 2009 and February 2010 Green Circuits briefings. The feeder models were used to evaluate various loss reduction options such as phase balancing, capacitor controls, re-conductoring, and/or voltage optimization. The 5051 circuit also included a look at possible savings when a 4.16kV section was converted to 12.47kV.

A summary of the base case model (base case – model as is with no loss reduction techniques included) losses are shown in Figure 1-1 through Figure 1-4 for each circuit studied. Overall, voltage optimization resulted in a reduction in losses for all circuits studied. Table 1-1 and Table 1-2 provides a summary of the voltage optimization annual and peak simulation results, respectively. Circuit #5051 had the smallest improvement of savings from voltage optimization due to the fact that additional var support had to be included on the 4.16kV section for voltage regulation purposes. Circuit #9111 had the second smallest improvement because its losses were dominated by line losses as seen in Figure 1-1. Because the other circuits were dominated by no-load transformer losses they had significant improvement in their losses when voltage optimization was implemented.

Each circuit had loss reductions when an ideal var case was simulated. This would be the case if capacitors could be 'perfectly' controlled from a var perspective at the customer location. Because of the difficulty in achieving this, a realistic var control case was modeled where capacitor control was included on existing capacitors and in some cases capacitors were added or reduced in order to improve var flow. Circuit #9111 resulted in the greatest improvement when the capacitor control was altered. If the capacitor var control was permitted to control the capacitors during the non-summer months opposed to switching to temperature control, it would result in an annual loss reduction of 10.2MWh.

Circuit #5051 benefited when the 4.16kV section was upgraded to 12.47kV. This upgrade resulted in an annual loss reduction of 22.1MWh. This loss reduction was primarily due to the elimination of the 12.47/4.16 transformer and reduced line losses.

All circuits benefited from an increased conductor size on its primary backbone; however, the loss savings obtained from re-conductoring would not justify the costs associated with re-conductoring.

**Table 1-1**
**Voltage Optimization Annual Summary**

| Circuit | Average % Voltage Decrease | Annual Loss Reduction (MWh) | Annual Consumption Reduction (MWh) | Annual Consumption Reduction (%) | Annual Loss Reduction (%) | Transformer Loss Reduction (Load and No-Load Loss) | Line Loss Reduction (Primary and Secondary Line Losses) | Effective CVR factor |
|---|---|---|---|---|---|---|---|---|
| 9111 | 2.01% | 7.08 | 348.90 | 1.72% | 1.27% | 3.41% | -0.12% | 0.85 |
| 3111 | 3.33% | 12.49 | 408.64 | 2.72% | 4.25% | 5.70% | 1.26% | 0.83 |
| 7812 | 3.57% | 20.49 | 699.90 | 3.15% | 3.83% | 6.23% | 1.13% | 0.89 |
| 5051* | 3.33% | 5.88 | 484.79 | 3.21% | 1.54% | 2.89% | -0.01% | N/A* |

* Circuit 5051 had to include additional capacitance for voltage regulation purposes during the CVR case; therefore, the CVR factor would include savings/losses from the additional capacitance in addition to any CVR savings.

**Table 1-2**
**Voltage Optimization Peak Summary**

| Circuit | % Voltage Decrease at Peak | Peak Loss Reduction (kW) | Peak Consumption Reduction (kW) | Peak Consumption Reduction (%) | Peak Loss Reduction (%) | Transformer Loss Reduction (Load and No-Load Loss) | Line Loss Reduction (Primary and Secondary Line Losses) | Effective CVR Factor |
|---|---|---|---|---|---|---|---|---|
| 9111 | 1.97% | 1.47 | 83.66 | 1.94% | 0.90% | 2.71% | 0.40% | 0.96* |
| 3111 | 3.14% | 2.36 | 119.16 | 2.80% | 2.32% | 3.85% | 1.43% | 0.89 |
| 7812 | 1.89% | 2.00 | 94.00 | 1.66% | 1.16% | 2.00% | 0.00% | 0.87 |
| 5051** | 0.00% | 3.00 | 192.00 | 3.78% | 1.48% | 5.45% | -0.68% | N/A** |

* Circuit 9111 had significant power factor improvement at CVR peak which will skew the effective CVR factor favorably.

** Circuit 5051 had to include additional capacitance for voltage regulation purposes during the CVR case; therefore, the CVR factor would include savings/losses from the additional capacitance in addition to any CVR savings.

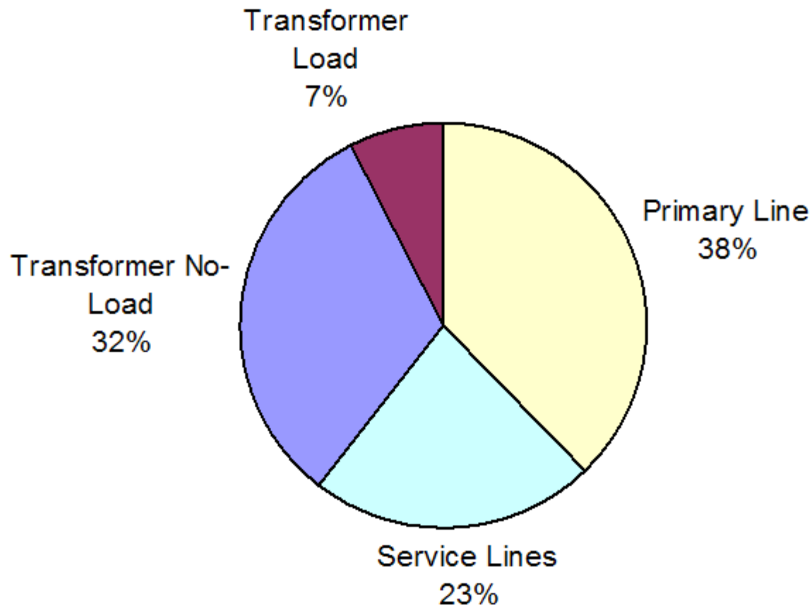


**Figure 1-1:**
**Circuit 9111 Base Case Loss Break-Down**

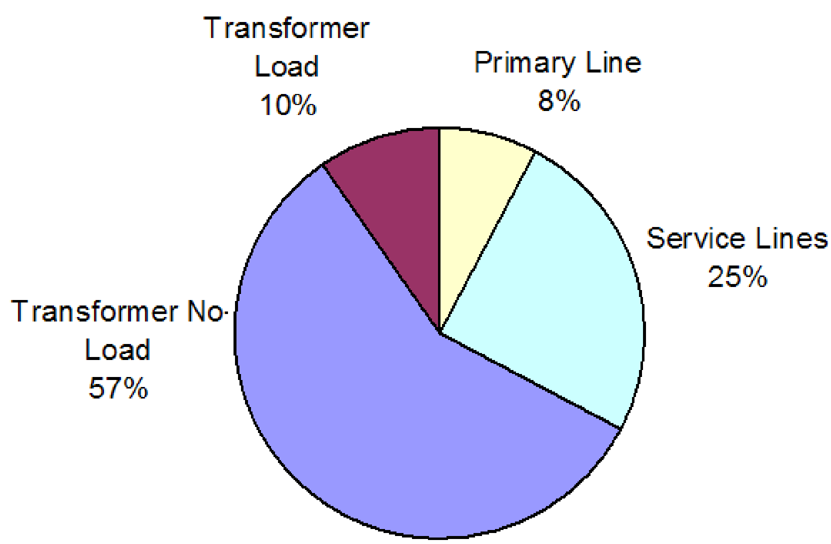


**Figure 1-2:**
**Circuit 3111 Base Case Loss Break-Down**

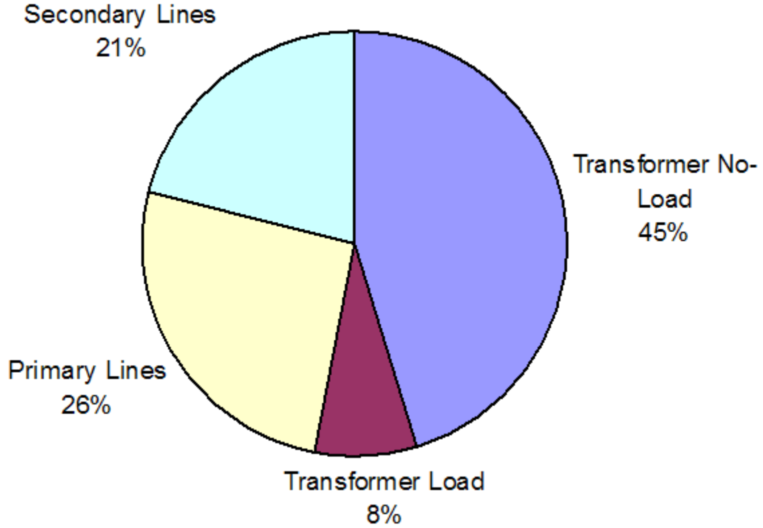


**Figure 1-3:**
**Circuit 7812 Base Case Loss Break-Down**

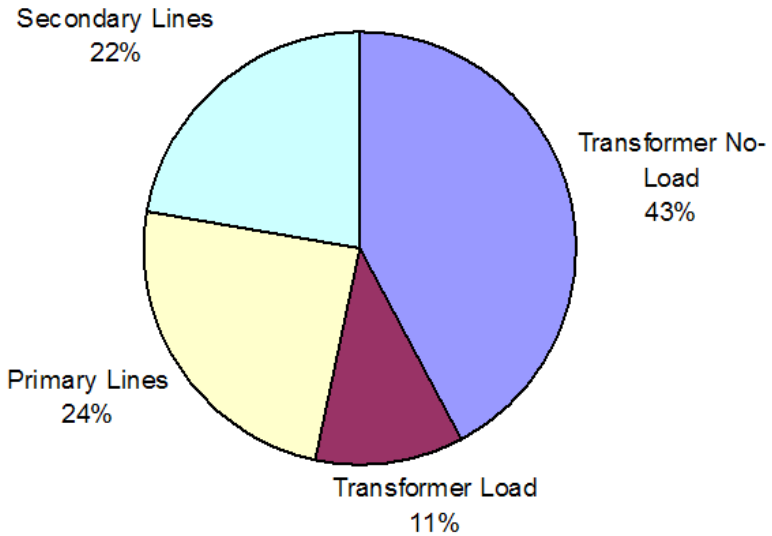


**Figure 1-4:**
**Circuit 5051 Base Case Loss Break-Down**

# 2
# MODELING DETAILS AND ORIGINAL ANALYSIS

This section covers some of the background and modeling used in evaluating the four circuits from the October 2009 and February 2010 Green Circuits briefing.

## Green Circuit Project Background

The Green Circuit project is a field demonstration of circuits with a goal of improving distribution efficiency. Loss-reduction approaches could include optimal var reduction using switched capacitors, voltage control, and targeted design changes (re-conductoring or reconfiguring).

Member utilities have wide latitude in circuit selections, and utilities are ultimately responsible for their selection. The selection depends on several factors, including the overall goals of the utility and the type of circuit that they are most interested in. The three main criteria considered when selecting the Green Circuits are:

- Diversity – Do the circuits represent a good cross section of circuits and customer load types?
- Metering – Do the circuits have AMI or other advanced metering? Are there voltage and current measurements available at the substation on all three phases?
- Modeling – Are circuits modeled in CYMDIST, SYNERGEE, WindMil, or other circuit modeling program with accurate phasing and customer data?

Other considerations include ability to control voltage and that the circuits were readily accessible to local personnel.

## Modeling Approach

The main steps in the modeling approach for KCP&L are:

- Convert SYNERGEE data to OpenDSS
- Scale loads based on measurement data
- Evaluate base-case losses
- Evaluate loss reduction options

The Distribution System Simulator (DSS) is a comprehensive electrical system simulation tool for electric utility distribution systems. The OpenDSS is being provided as an open source program to the electric power system analysis community at large by EPRI under a BSD license. The OpenDSS is available at http://electricdss.wiki.sourceforge.net/. The main advantages of OpenDSS for modeling distribution efficiency include:

- *Yearly simulations* – The OpenDSS can run yearly simulations where the load, regulators, and switched capacitor banks are adjusted on an hour-by-hour basis, allowing accurate estimates of energy losses.
- *Custom load model* – A voltage-sensitive load model with user-configurable parameters is available to help predict changes in load based on voltage.
- *Custom control modes* – Custom controllers for switched capacitor banks and for voltage regulators can be readily implemented.

To determine the best load model, we need to know the impacts of voltage on loads. Even if a circuit is not amenable to voltage optimization for either demand reduction or for energy reduction, a voltage-sensitive load model will best reflect how loads change for other circuit improvement options such as changes in var management. The impact of voltage on loads is often quantified as a CVR factor (conservation-voltage reduction factor), the percent change in load for a 1% change in voltage. Kirshner and Giorsetto[1] analyzed trials of voltage reduction at several utilities. While results varied significantly, most test circuits had energy savings of between 0.5 and 1% for each 1% voltage reduction. Their regression analysis of the feeders found that residential energy savings were 0.76% for each 1% reduction in voltage, while commercial and industrial loads had reductions of 0.99% and 0.41% (but, the correlations between load class and energy reduction were fairly small).

More recently, the Northwest Energy Efficiency Alliance (NEEA) and their contractor RW Beck and several utilities evaluated voltage reduction in the US pacific northwest.[2] They evaluated changes at the circuit level and also changes directly to residential customers. In their evaluation of voltage changes at the circuit level, using temperature adjusted regressions, they found an average CVR factor of 0.69 based on a voltage change of 2.5%. In their evaluation of 395 residential customer evaluations, they estimated a CVR factor of 0.57 based on a voltage change of 4.3%.

The NEEA study found seasonal differences. In the customer evaluation, they found a CVR factor in the winter of 0.5 compared to a summer CVR factor of 0.78.

The NEEA study found even more dramatic changes with reactive power. In their feeder monitoring study, they found that $CVR_{var}$ factors between 3.0 and 3.5 (vars drop by 3% for every 1% drop in voltage). That indicates that a large component of the change is due to the reduction in magnetizing current in motors and transformers as this exciting current is highly nonlinear. The change in vars was not particularly sensitive to season.

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1 Kirshner, D. and Giorsetto, P., "Statistical Tests of Energy Savings Due to Voltage Reduction," *IEEE Transactions on Power Apparatus and Systems*, vol. PAS-103, no. 6, pp. 1205-10, June 1984.
2 NEEA 1207, Distribution Efficiency Initiative, Northwest Energy Efficiency Alliance, 2007. Available at http://rwbeck.com/neea/.

A voltage-sensitive load model was used for all modeling in OpenDSS, where the watts and vars both vary with voltage based on a linear relationship. For these simulations, a CVR factor of 0.9 (provided by KCP&L) was used for watts and a CVR factor of 3.0 was used for vars. As the study progresses, we will fine-tune these models based on the feeder and measurements for any circuit for which voltage reduction is implemented in the field. In the modeling, the CVR factor does not vary by customer type or by season; hopefully, we will learn more about both of these during the Green Circuits studies.

The distribution transformers were modeled based on information obtained from KCP&L 2007 transformer specifications. The services were modeled with 100 ft of overhead and underground services based on kVA size of transformer.

## KCP&L Circuits

The following table summarizes some of the characteristics of the KCP&L circuits selected for the Green Circuits study.

**Table 2-1**
**KCP&L Green Circuits Summary**

| **Base characteristics** | **9111** | **3111** | **5051** | **7812** |
|---|---|---|---|---|
| System voltage (kV) | 12.47 kV | 13.2 kV | 12.47 / 4.16 kV | 12.47 kV |
| Residential | 74% | 88.4% | 92% | 64% |
| 3-phase primary circuit miles total | 8.0 | 2.8 | 5.4 | 6.9 |
| Non 3-phase primary circuit miles total | 1.5 | 2.3 | 5.5 | 5.6 |
| 2008 Load Factor | 54% | 40% | 36% | 44% |
| Substation Control | LTC | LTC | LTC | LTC |

### *Circuit #9111*

Circuit #9111 is primarily an urban residential circuit. It has a primary voltage of 12.47 kV. Figure 2-1 shows the layout of the circuit.

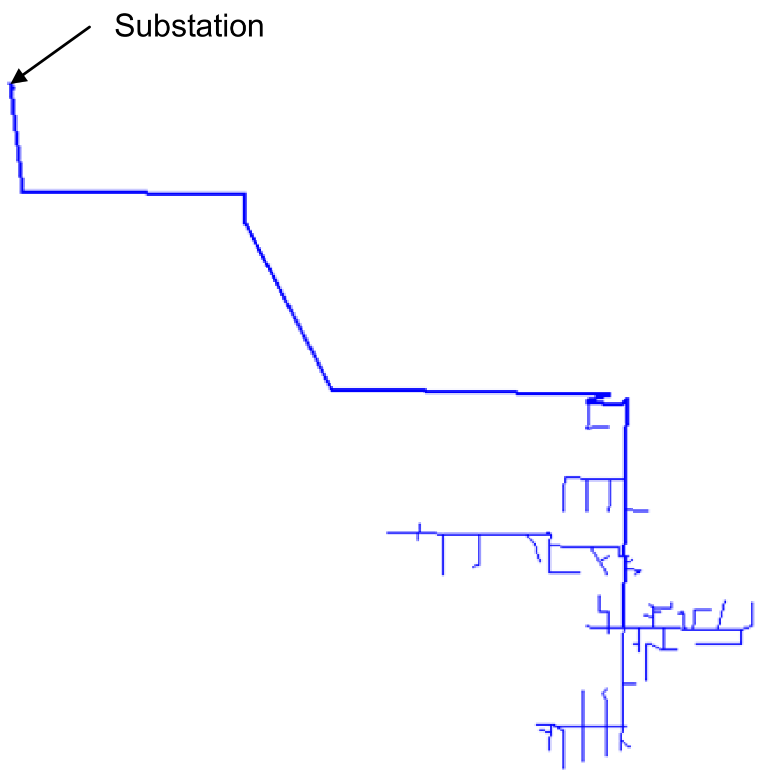


**Figure 2-1:**
**Circuit 9111**

## Base Case

Using a peak-load case provided by KCP&L in the 2008 loadshape, the real power load is scaled on each phase to match the measurements. The capacitor controls were implemented in the model to match the operation of the line capacitors. The implemented capacitor controls are as follows:

- JO-4284 (600kvar)
  - Voltage Override
    - Low Voltage Override Setpoint – 119.0 V
    - High Voltage Override Setpoint – 127.5 V
  - Summer Season Operation – Temperature Control
    - High Temperature at Which Bank Switches In – 85°F
    - High Temperature at Which Bank Switches Out – 70°F
  - Non Summer Season Operation – Var Control
    - Var Control Which Bank Switches In – 400 kvar
    - Var Control Which Bank Switches Out – -400 kvar
- JO-87031 (600kvar)
  - Voltage Override
    - Low Voltage Override Setpoint – 119.0 V
    - High Voltage Override Setpoint – 127.5 V

- o Summer Season Operation – Temperature Control
    - ▪ High Temperature at Which Bank Switches In – 85°F
    - ▪ High Temperature at Which Bank Switches Out – 70°F
- o Non Summer Season Operation – Var Control
    - ▪ Var Control Which Bank Switches In – 300 var
    - ▪ Var Control Which Bank Switches Out – -500 var
- JO-2285 (900kvar)
    - o Fixed

Because JO-4284 and JO87031 capacitors include temperature control in the summer season the temperature fluctuations were included in the model. Figure 2-2 illustrates the capacitor switching operation in the during the summer season (May 15 to September 15). The capacitor switches OFF at 70F and switches ON above 85F.

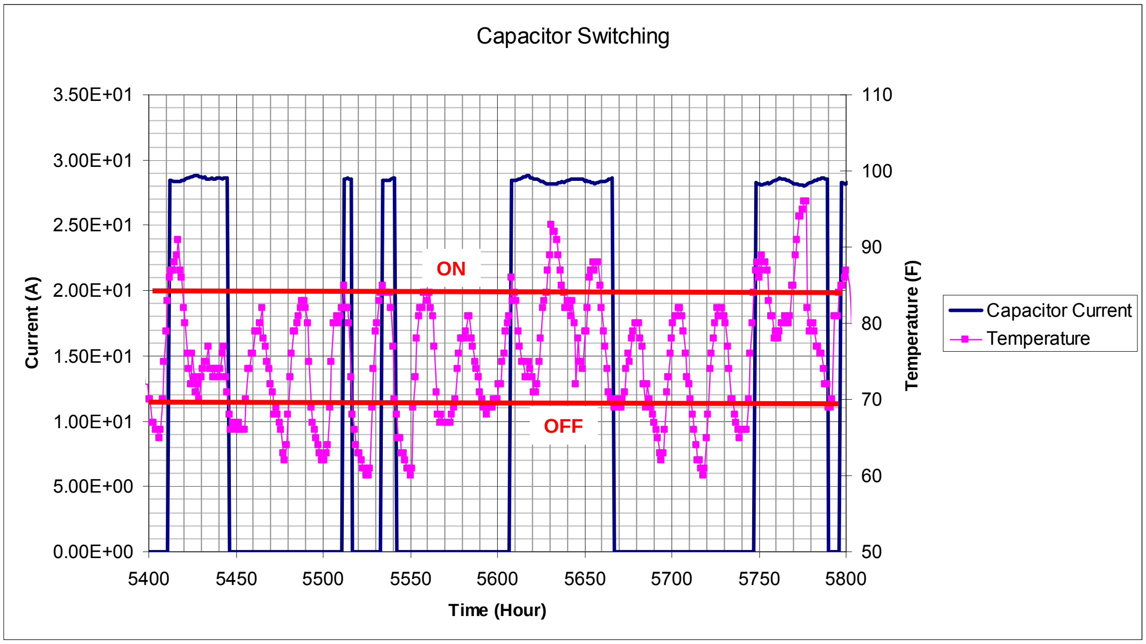


**Figure 2-2**
**Summer Capacitor Switching**

The implementation of the capacitor's summer temperature control and non-summer var control along with the load allocations, allowed for the base model current to match the measured current provide from the substation metering. Figure 2-3 shows the comparison between the measured feeder current and the simulated feeder current. The load factor of this loadshape (2008) was 54% and the average power factor was 0.965.

The annual losses were calculated to be 2.75% with the primary and service lines dominating the majority of losses (61%).

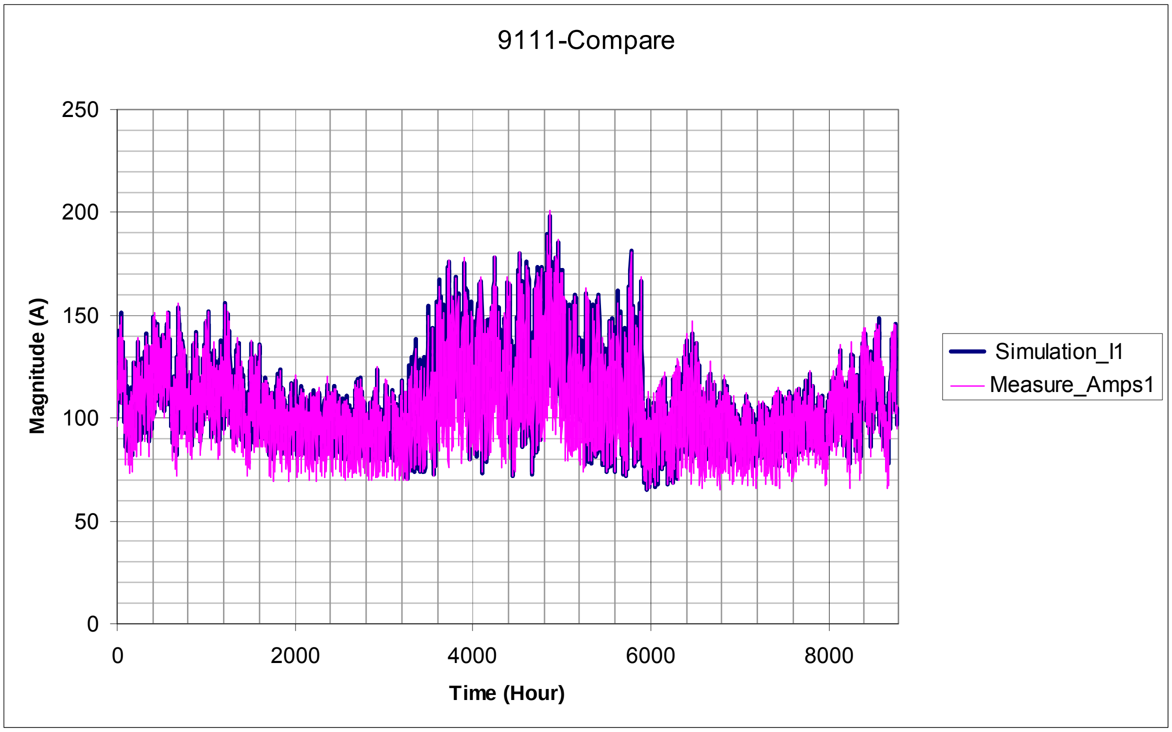


**Figure 2-3**
**9111 Current Simulated vs. Measured**

Figure 2-4 summarizes the results of the yearly and peak-day losses for the 9111 circuit.

| | Peak Demand | | Annual Energy | |
|---|---|---|---|---|
| | kW | % Peak | kWh | % Consumpt. |
| Consumption/Demand | **4315** | | **20321760** | |
| Total Losses | 163 | 3.77% | 559103 | 2.75% |
| Line Losses | 127 | 2.94% | 339313 | 1.67% |
| Xfmr Losses | 36 | 0.83% | 219790 | 1.08% |
| Load Losses | 143 | 3.32% | 380592 | 1.87% |
| No-Load Losses | 20 | 0.45% | 178511 | 0.88% |
| Primary Losses | 113 | 2.61% | 431413 | 2.12% |
| Secondary Losses | 50 | 1.16% | 127691 | 0.63% |

**Figure 2-4:**
**9111 modeled losses at the peak-hour and annual energy losses**

## Phase Balancing

The phase currents were balanced at the peak hour for the circuits which had some unbalance. The average unbalance in the base case was 9.9% and this was improved to 0.4% in the Phase Balancing Case. The unbalanced calculation is based on the ANSI/NEMA Standard MG1-1993 definition. Figure 2-5 shows the results of the phase balancing simulation. Generally, the loss reductions were very low.

| | Peak Demand kW | % Peak | Annual Energy kWh | % Consumpt. |
|---|---|---|---|---|
| Consumption/Demand | **4332** | | **20385722** | |
| Total Losses | 164 | 3.78% | 558977 | 2.74% |
| Line Losses | 128 | 2.95% | 338873 | 1.66% |
| Xfmr Losses | 36 | 0.83% | 220104 | 1.08% |
| Load Losses | 144 | 3.33% | 380469 | 1.87% |
| No-Load Losses | 20 | 0.45% | 178508 | 0.88% |
| Primary Losses | 113 | 2.61% | 429971 | 2.11% |
| Secondary Losses | 51 | 1.17% | 129006 | 0.63% |

**Figure 2-5:**
**9111 phase balance modeled losses at the peak-hour and annual energy losses**

## Voltage Optimization

To model voltage optimization the LTC base was reduced to 120V from 122.5V. This reduction maintained a minimum voltage above 0.949 pu at the customer service. Before the voltage reduction the minimum voltage on the feeder was maintained at 0.967 pu. See Figure 2-6.

Figure 2-7 shows the results of the voltage optimization simulation. For the annual simulation the consumption was reduced by 348.9 MWh and the loss was reduced by 7.1 MWh. At peak, the consumption was reduced by 83 kW and the losses reduce by 2 kW.

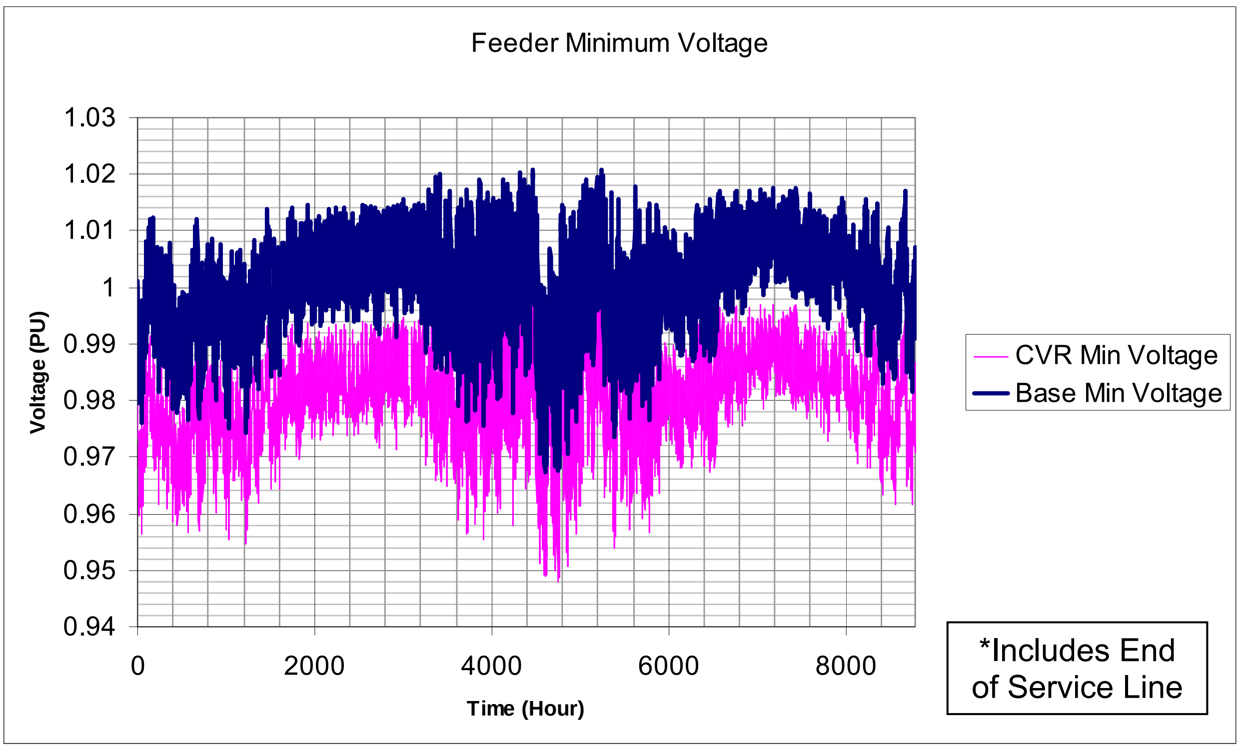


**Figure 2-6:**
**9111 minimum voltage across entire feeder during yearly loadflow**

| | Peak Demand | | Annual Energy | |
|---|---|---|---|---|
| | kW | % Peak | kWh | % Consumpt. |
| Consumption/Demand | **4232** | | **19972858** | |
| Total Losses | 161 | 3.81% | 552025 | 2.76% |
| Line Losses | 127 | 2.99% | 339727 | 1.70% |
| Xfmr Losses | 35 | 0.82% | 212298 | 1.06% |
| Load Losses | 142 | 3.37% | 380621 | 1.91% |
| No-Load Losses | 19 | 0.45% | 171404 | 0.86% |
| Primary Losses | 112 | 2.64% | 425504 | 2.13% |
| Secondary Losses | 49 | 1.17% | 126521 | 0.63% |

**Figure 2-7:**
**9111 voltage optimization modeled losses at the peak-hour and annual energy losses**

## Re-conductoring

A loss reduction approach could be to re-conductor the circuit. The conductor simulation replaced the all AAC 477 with AAC 795 on the overhead three phase mains. The annual energy savings reduced to 2.66% from 2.75%. Figure 2-8 shows the results of the re-conductor simulation.

| | Peak Demand | | Annual Energy | |
|---|---|---|---|---|
| | kW | % Peak | kWh | % Consumpt. |
| Consumption/Demand | **4321** | | **20332799** | |
| Total Losses | 156 | 3.61% | 540814 | 2.66% |
| Line Losses | 120 | 2.79% | 320788 | 1.58% |
| Xfmr Losses | 36 | 0.83% | 220026 | 1.08% |
| Load Losses | 137 | 3.16% | 362079 | 1.78% |
| No-Load Losses | 20 | 0.46% | 178735 | 0.88% |
| Primary Losses | 106 | 2.46% | 413089 | 2.03% |
| Secondary Losses | 50 | 1.16% | 127725 | 0.63% |

**Figure 2-8:**
**9111 re-conductor model losses at the peak-hour and annual energy losses**

## Ideal var Optimization

A somewhat theoretical case is the ideal var optimization case. The ideal var optimization case attempts to answer what the maximum achievable losses would be if all capacitors were removed from the circuit and the loads power factors were set to 1.0 across the circuit. This would be the case if the capacitors could be ‘perfectly’ controlled from a var perspective. The annual energy losses were improved to 2.51% from 2.75%. The average power factor was improved to 0.9998 from 0.965.

Figure 2-9 shows the results of the ideal var simulation.

| | Peak Demand | | Annual Energy | |
|---|---|---|---|---|
| | kW | % Peak | kWh | % Consumpt. |
| Consumption/Demand | **4337** | | **20316692** | |
| Total Losses | 149 | 3.43% | 509363 | 2.51% |
| Line Losses | 115 | 2.66% | 294185 | 1.45% |
| Xfmr Losses | 33 | 0.77% | 215177 | 1.06% |
| Load Losses | 129 | 2.96% | 327436 | 1.61% |
| No-Load Losses | 20 | 0.47% | 181927 | 0.90% |
| Primary Losses | 108 | 2.49% | 406809 | 2.00% |
| Secondary Losses | 41 | 0.94% | 102554 | 0.50% |

**Figure 2-9:**
**9111 ideal var model losses at the peak-hour and annual energy losses**

## Capacitor Control

Added capacitor control was studied for 9111 as another approach to reduce losses. For the capacitor control case the existing var control was continued throughout the year (opposed to switching to temperature control during the summer season) and the JO-2285 capacitor was disabled. This change in capacitor control improves the average power factor from 0.965 to 0.992. The annual energy savings reduced to 2.70% from 2.75%.

Figure 2-10 shows the results of the capacitor control simulation.

| | Peak Demand | | Annual Energy | |
|---|---|---|---|---|
| | kW | % Peak | kWh | % Consumpt. |
| Consumption/Demand | **4301** | | **20358181** | |
| Total Losses | 165 | 3.83% | 548890 | 2.70% |
| Line Losses | 129 | 3.00% | 328172 | 1.61% |
| Xfmr Losses | 36 | 0.83% | 220718 | 1.08% |
| Load Losses | 145 | 3.38% | 369482 | 1.81% |
| No-Load Losses | 19 | 0.45% | 179408 | 0.88% |
| Primary Losses | 115 | 2.67% | 421105 | 2.07% |
| Secondary Losses | 50 | 1.16% | 127785 | 0.63% |

**Figure 2-10:**
**9111 capacitor control model losses at the peak-hour and annual energy losses**

## Summary

Figure 2-11 and Figure 2-12 below compares the results to the base case. As can be seen the var control results in the biggest savings followed by the re-conductoring case. However, the voltage optimization (referred to as CVR, Conservation -Voltage Reduction) may be the most cost effective approach to reduce losses.

| | Base | Ideal var | Balance | CVR 0.9 | Capacitor Control | Reconductor |
|---|---|---|---|---|---|---|
| GWh Consumption | 20.32 | 20.32 | 20.39 | 19.97 | 20.36 | 20.33 |
| GWh Losses | 0.5591 | 0.5094 | 0.5590 | 0.5520 | 0.5489 | 0.5408 |
| Delta Loss (MWh) | | **49.7** | **0.1** | **7.1** | **10.2** | **18.3** |
| Delta Consumption (MWh) | | 5.1 | -64.0 | 348.9 | -36.4 | -11.0 |
| % Loss (Base) | 2.75% | 2.51% | 2.75% | 2.72% | 2.70% | 2.66% |
| % Consumption (Base) | | 100.0% | 100.3% | 98.3% | 100.2% | 100.1% |
| % Base | | 8.90% | 0.02% | 1.27% | 1.83% | 3.27% |

**Figure 2-11:**
**9111 efficiency analysis comparison summary**

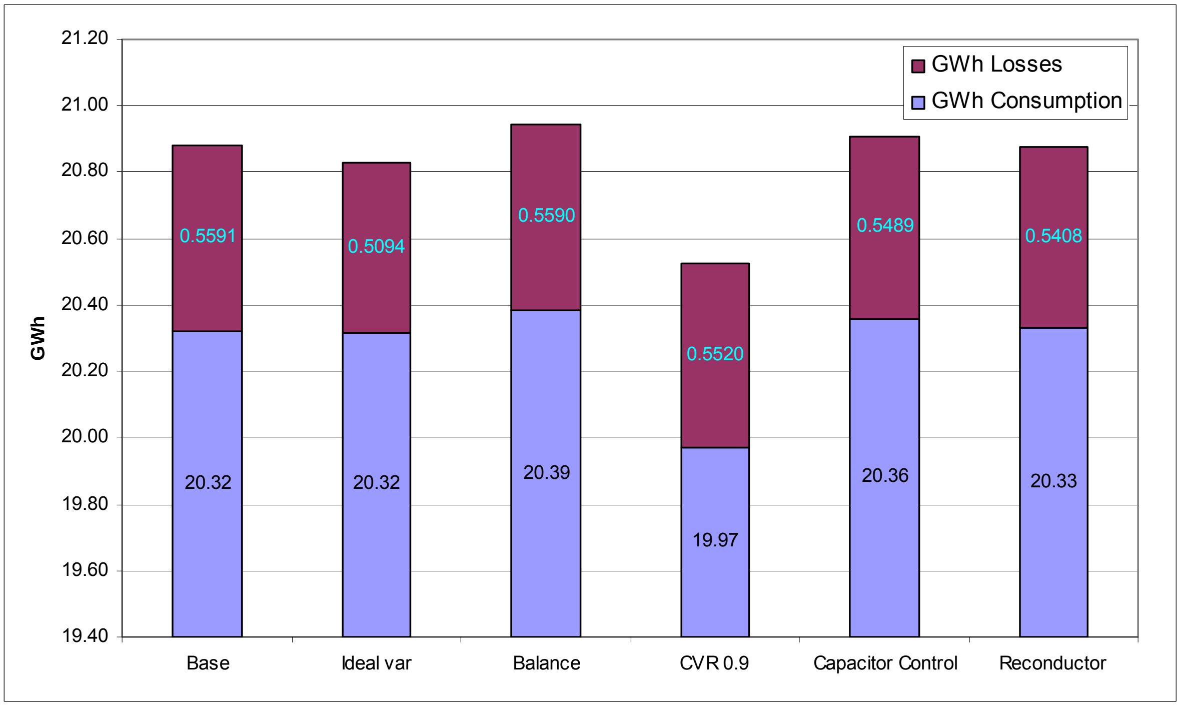


**Figure 2-12:**
**9111 efficiency comparison summary graph**

## *Circuit #3111*

Circuit #3111 is primarily an urban residential circuit. It has a primary voltage of 13.2 kV. Figure 2-13 shows the layout of the circuit.


**Figure 2-13:**
**Circuit 3111**

## Base Case

Using a peak-load case provided by KCP&L in the 2008 loadshape, the real power load is scaled on each phase to match the measurements. The capacitor controls provided by KCP&L were implemented in the model. The provided capacitor controls are as follows:

- JA-85076 (1200kvar), JA-86271 (1200kvar)
  - Temperature with Voltage Override
    - Voltage Override
      - Low Voltage Override Setpoint – 119.9 V
      - High Voltage Override Setpoint – 126.1 V
  - Summer Season Operation
    - High Temperature at Which Bank Switches In – 85°F
    - High Temperature at Which Bank Switches Out – 70°F
  - Non Summer Season Operation
    - Low Temperature at Which Bank Switches Out – 40°F
    - Low Temperature at Which Bank Switches In – 30°F
- JA-90031 (600kvar)
  - Fixed

Because JA-85076 and JA-86271 capacitors include temperature control in the summer and non-summer season the temperature fluctuations were included in the model. Figure 2-14 illustrates the capacitor switching operation in the during the summer season (May 15 to September 15). Figure 2-15 illustrates the capacitor switching operation in the during the non-summer season

(September 15 to May 15). In the summer the capacitor switches OFF at 70F and switches ON above 85F. During the non-summer season the capacitor switches OFF at 40F and switches ON below 30F.

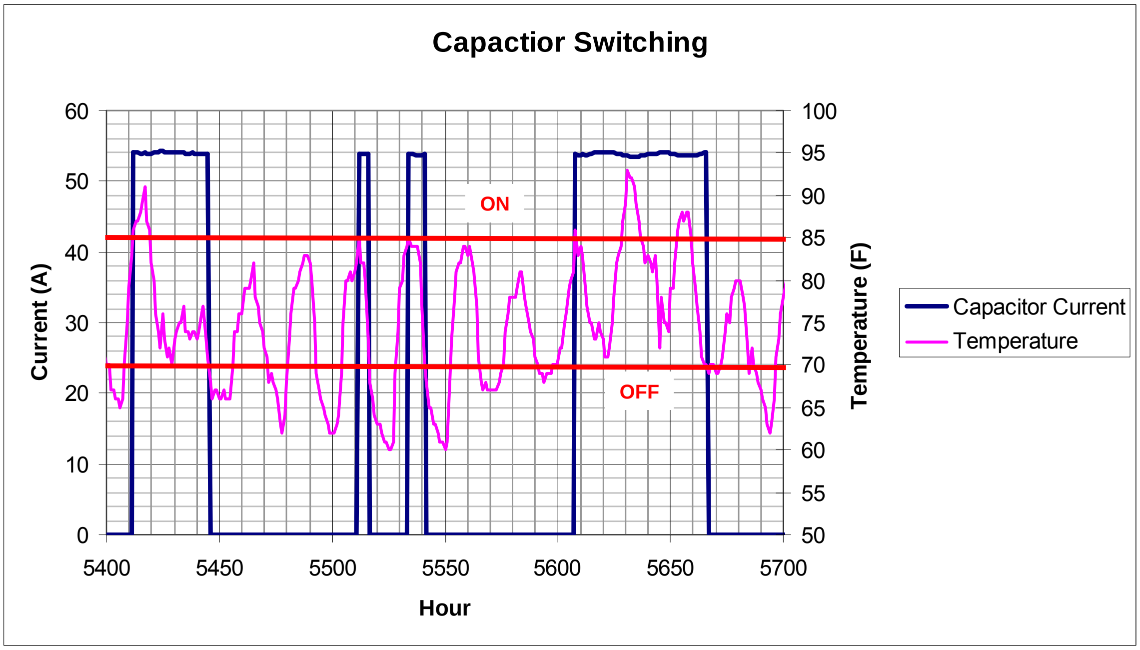


**Figure 2-14**
**Summer Capacitor Switching**

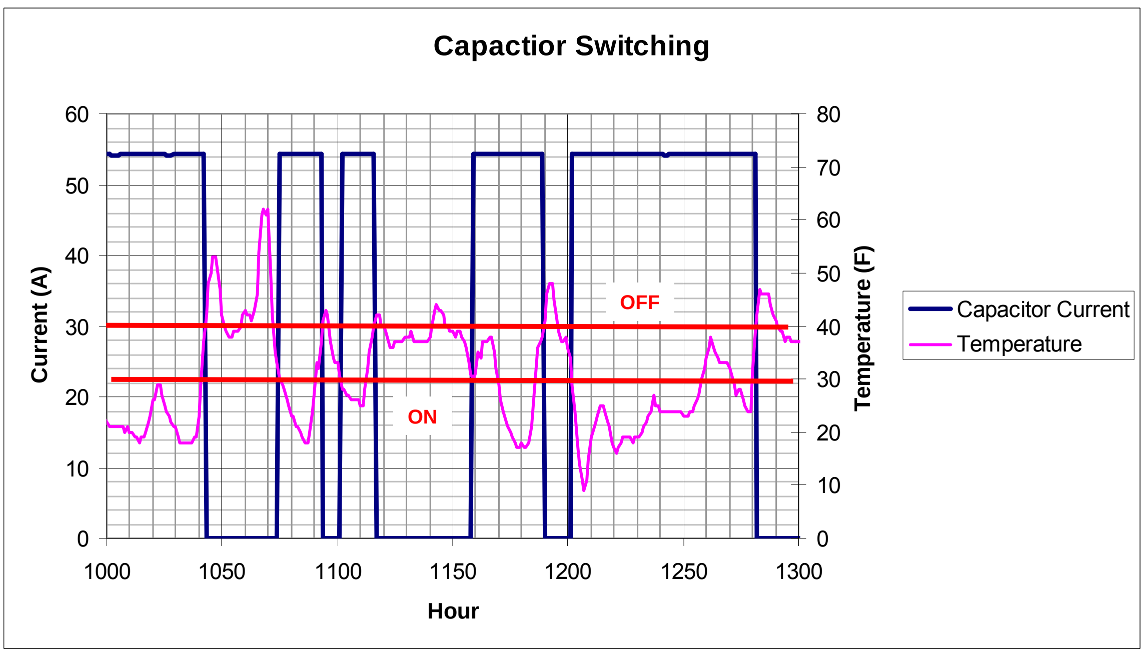


**Figure 2-15**
**Non-Summer Capacitor Switching**

The implementation of the capacitor's summer and non-summer temperature control along with the load allocations, did not result in a match between the base model current and the measured current provide from the substation metering. Figure 2-16 shows the comparison between the measured feeder current and the simulated feeder current with the summer and non-summer controls included. This simulated results indicated an excess of vars in the circuit. A second base case was developed with JA-86271, JA-85076 disabled, and JA-90031 enabled. As can be seen in Figure 2-17 this new case resulted in a closer match between the simulated and measured current values; therefore, this was the base case used for the 3111 analysis. The load factor of this loadshape (2008) was 40% and the average power factor was 0.992.

The annual losses were calculated to be 1.96% with the transformer no-load losses dominating (57%).

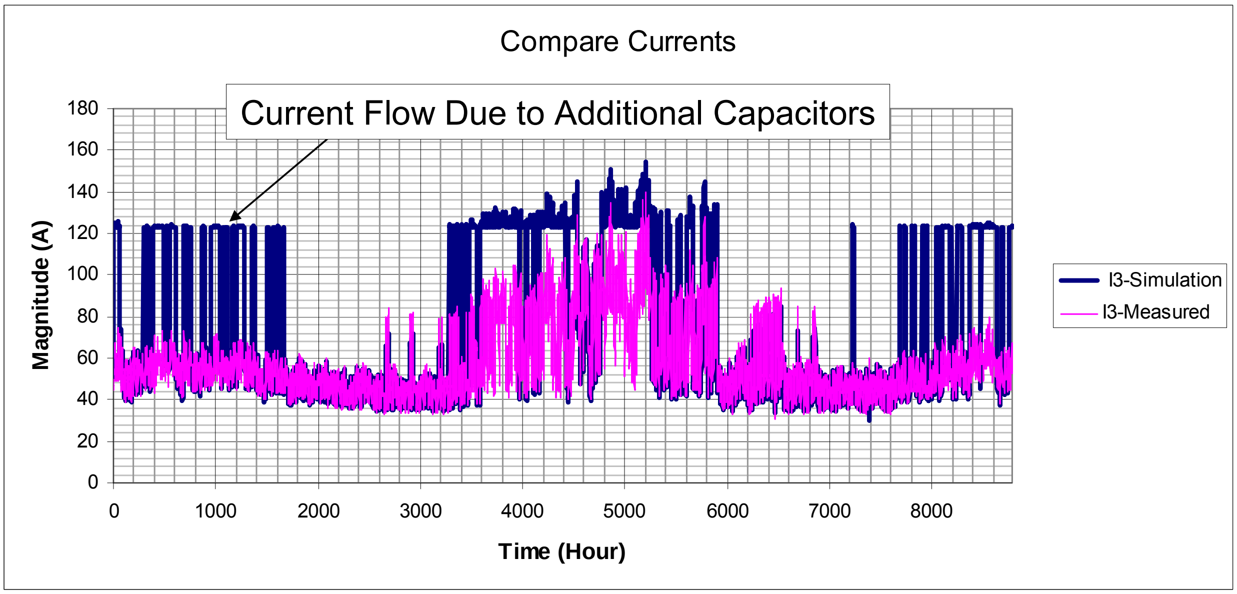


**Figure 2-16**
**3111 Current Simulated vs. Measured (With Capacitor Controls)**

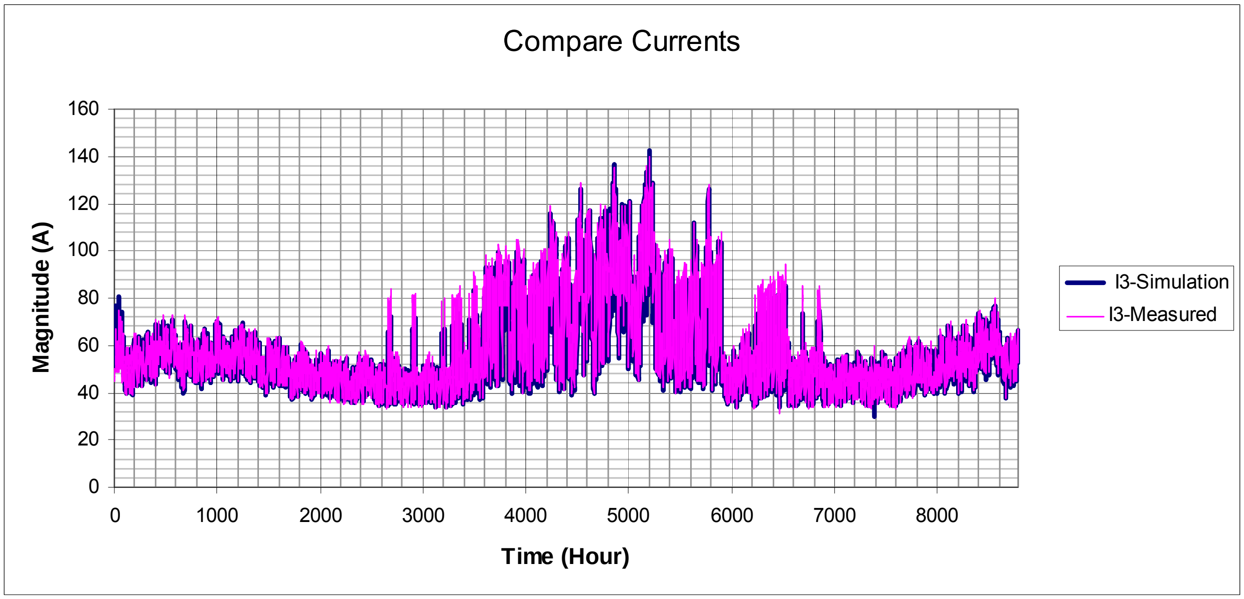


**Figure 2-17**
**3111 Current Simulated vs. Measured (Without Capacitor Controls)**

Figure 2-18 summarizes the results of the yearly and peak-day losses for the 3111 circuit.

| | Peak Demand | | Annual Energy | |
|---|---|---|---|---|
| | kW | % Peak | kWh | % Consumpt. |
| Consumption/Demand | **4261** | | **15004676** | |
| Total Losses | 102 | 2.38% | 294191 | 1.96% |
| Line Losses | 64 | 1.50% | 96238 | 0.64% |
| Xfmr Losses | 37 | 0.88% | 197953 | 1.32% |
| Load Losses | 83 | 1.94% | 124523 | 0.83% |
| No-Load Losses | 19 | 0.44% | 169668 | 1.13% |
| Primary Losses | 53 | 1.24% | 220822 | 1.47% |
| Secondary Losses | 49 | 1.14% | 73369 | 0.49% |

**Figure 2-18:**
**3111 modeled losses at the peak-hour and annual energy losses**

## Phase Balancing

The phase currents were balanced at the peak hour for the circuits which had some unbalance. The average unbalance in the base case was 11% and this was improved to 0.4% at the substation. The unbalanced calculation is based on the ANSI/NEMA Standard MG1-1993 definition. Figure 2-19 shows the results of the phase balancing simulation. Generally, there was a slight increase in the overall losses. This had to do with the fact that balancing the current at the head of the feeder resulted in more unbalance downstream of the feeder, see Figure 2-20. This indicates that the phase balancing has been reasonably optimized already.

| | Peak Demand | | Annual Energy | |
|---|---|---|---|---|
| | kW | % Peak | kWh | % Consumpt. |
| Consumption/Demand | **4247** | | **14998264** | |
| Total Losses | 102 | 2.40% | 295626 | 1.97% |
| Line Losses | 64 | 1.50% | 96342 | 0.64% |
| Xfmr Losses | 38 | 0.90% | 199284 | 1.33% |
| Load Losses | 83 | 1.95% | 125879 | 0.84% |
| No-Load Losses | 19 | 0.45% | 169747 | 1.13% |
| Primary Losses | 52 | 1.21% | 219280 | 1.46% |
| Secondary Losses | 50 | 1.18% | 76346 | 0.51% |

**Figure 2-19:**
**3111 phase balance modeled losses at the peak-hour and annual energy losses**

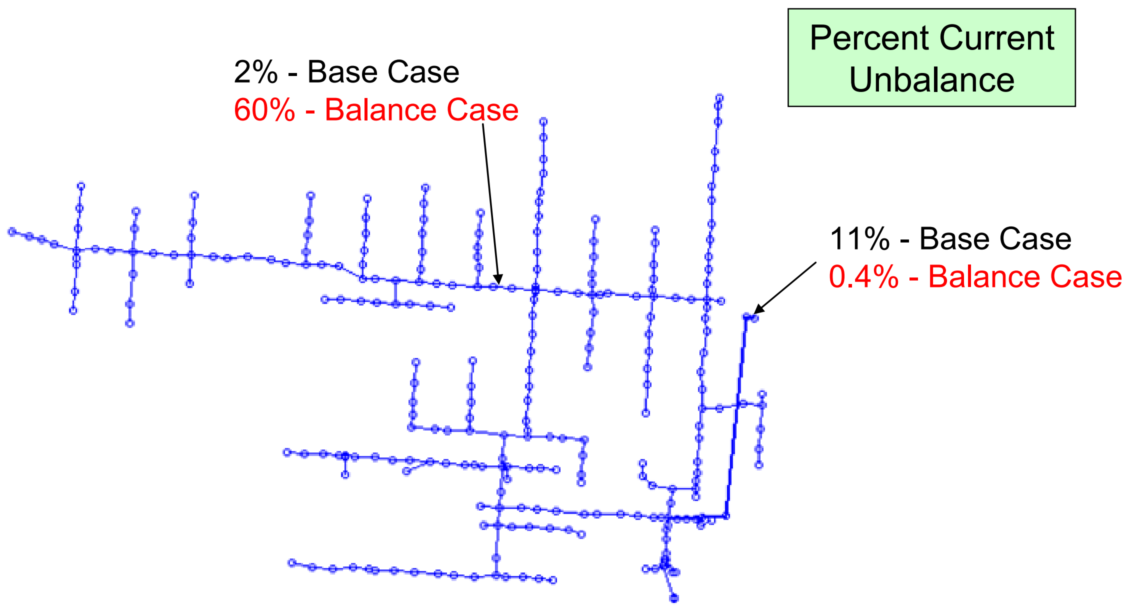


**Figure 2-20:**
**3111 phase balance model percent unbalances in the circuit**

## Voltage Optimization

To model voltage optimization the LTC base was reduced to 118V from 122.5V. This reduction maintained a minimum voltage above 0.965 pu at the customer service. Before the voltage reduction the minimum voltage on the feeder was maintained at 0.99 pu. See Figure 2-21.

Figure 2-22 shows the results of the voltage optimization simulation. For the annual simulation the consumption was reduced by 408.6 MWh and the loss was reduced by 12.5 MWh. At peak, the consumption was reduced by 119 kW and the losses reduce by 3 kW.

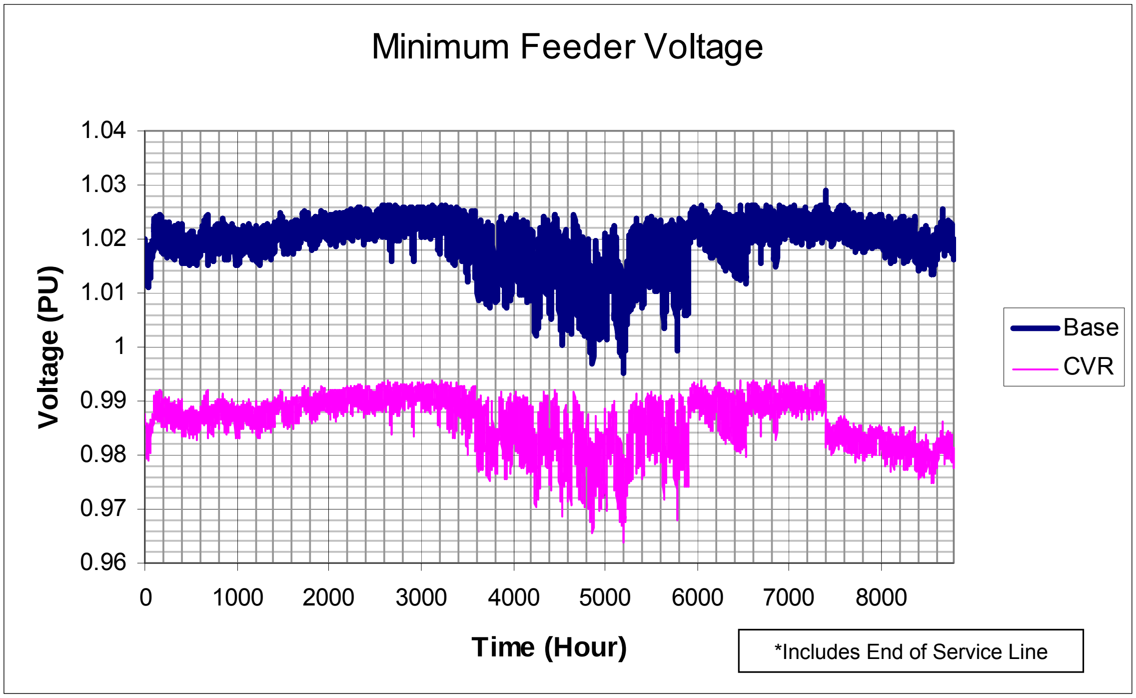


**Figure 2-21:**
**3111 minimum voltage across entire feeder during yearly loadflow**

| | Peak Demand | | Annual Energy | |
|---|---|---|---|---|
| | kW | % Peak | kWh | % Consumpt. |
| Consumption/Demand | **4142** | | **14596031** | |
| Total Losses | 99 | 2.40% | 281700 | 1.93% |
| Line Losses | 63 | 1.53% | 95027 | 0.65% |
| Xfmr Losses | 36 | 0.87% | 186673 | 1.28% |
| Load Losses | 81 | 1.97% | 122901 | 0.84% |
| No-Load Losses | 18 | 0.43% | 158799 | 1.09% |
| Primary Losses | 51 | 1.24% | 209369 | 1.43% |
| Secondary Losses | 48 | 1.16% | 72331 | 0.50% |

**Figure 2-22:**
**3111 voltage optimization modeled losses at the peak-hour and annual energy losses**

## Re-conductoring

A loss reduction approach could be to re-conductor the circuit. The conductor simulation replaced the all 477 AAC with 795 AAC on the overhead three phase mains. The annual energy savings reduced to 1.95% from 1.96%. Figure 2-23 shows the results of the re-conductor simulation.

| | **Peak Demand** | | **Annual Energy** | |
|---|---|---|---|---|
| | kW | % Peak | kWh | % Consumpt. |
| Consumption/Demand | **4262** | | **15005802** | |
| Total Losses | 101 | 2.36% | 292984 | 1.95% |
| Line Losses | 63 | 1.48% | 94999 | 0.63% |
| Xfmr Losses | 38 | 0.88% | 197986 | 1.32% |
| Load Losses | 82 | 1.92% | 123285 | 0.82% |
| No-Load Losses | 19 | 0.44% | 169699 | 1.13% |
| Primary Losses | 52 | 1.22% | 219612 | 1.46% |
| Secondary Losses | 49 | 1.14% | 73372 | 0.49% |

**Figure 2-23:**
**3111 re-conductor model losses at the peak-hour and annual energy losses**

## Ideal var Optimization

A somewhat theoretical case is the ideal var optimization case. The ideal var optimization case attempts to answer what the maximum achievable losses would be if all capacitors were removed from the circuit and the loads power factors were set to 1.0 across the circuit. This would be the case if the capacitors could be 'perfectly' controlled from a var perspective. The annual energy losses were improved to 1.81% from 1.96%. The average power factor was improved to 0.999 from 0.992.

Figure 2-24 shows the results of the ideal var simulation.

| | **Peak Demand** | | **Annual Energy** | |
|---|---|---|---|---|
| | kW | % Peak | kWh | % Consumpt. |
| Consumption/Demand | **4286** | | **15005208** | |
| Total Losses | 87 | 2.03% | 271920 | 1.81% |
| Line Losses | 53 | 1.23% | 78627 | 0.52% |
| Xfmr Losses | 34 | 0.80% | 193293 | 1.29% |
| Load Losses | 68 | 1.58% | 101471 | 0.68% |
| No-Load Losses | 19 | 0.45% | 170449 | 1.14% |
| Primary Losses | 47 | 1.10% | 212669 | 1.42% |
| Secondary Losses | 40 | 0.92% | 59251 | 0.39% |

**Figure 2-24:**
**3111 ideal var model losses at the peak-hour and annual energy losses**

## Capacitor Control

Added capacitor control was studied for 3111 as another approach to reduce losses. For the capacitor control case, var control was added to the two temperature controlled capacitors and all capacitors were reduced to 300kvar each. This change in capacitor control improves the average power factor from 0.992 to 0.995. The annual energy savings reduced to 1.95% from 1.96%.

Figure 2-25 shows the results of the capacitor control simulation.

| | Peak Demand | | Annual Energy | |
|---|---|---|---|---|
| | kW | % Peak | kWh | % Consumpt. |
| Consumption/Demand | **4264** | | **15004908** | |
| Total Losses | 101 | 2.36% | 292777 | 1.95% |
| Line Losses | 63 | 1.48% | 94717 | 0.63% |
| Xfmr Losses | 38 | 0.88% | 198060 | 1.32% |
| Load Losses | 82 | 1.92% | 122990 | 0.82% |
| No-Load Losses | 19 | 0.44% | 169787 | 1.13% |
| Primary Losses | 52 | 1.22% | 219440 | 1.46% |
| Secondary Losses | 49 | 1.14% | 73337 | 0.49% |

**Figure 2-25:**
**3111 capacitor control model losses at the peak-hour and annual energy losses**

## Summary

Figure 2-26 and Figure 2-27 below compares the results to the base case. As can be seen the ideal var control results but this may not be practical in achieving. The voltage optimization (referred to as CVR, Conservation -Voltage Reduction) may be the most cost effective approach to reduce losses.

| | Base | Ideal var | Balance | CVR 0.9 | Capacitor Control | Reconductor |
|---|---|---|---|---|---|---|
| GWh Consumption | 15.0 | 15.0 | 15.0 | 14.6 | 15.0 | 15.0 |
| GWh Losses | 0.2942 | 0.2719 | 0.2956 | 0.2817 | 0.2928 | 0.2930 |
| Delta Loss (MWh) | | **22.3** | **-1.4** | **12.5** | **1.4** | **1.2** |
| Delta Consumption (MWh) | | -0.5 | 6.4 | 408.6 | -0.2 | -1.1 |
| % Loss (Base) | 1.96% | 1.81% | 1.97% | 1.88% | 1.95% | 1.95% |
| % Consumption (Base) | | 100.0% | 100.0% | 97.3% | 100.0% | 100.0% |
| % Base | | 7.57% | -0.49% | 4.25% | 0.48% | 0.41% |

**Figure 2-26:**
**3111 efficiency analysis comparison summary**

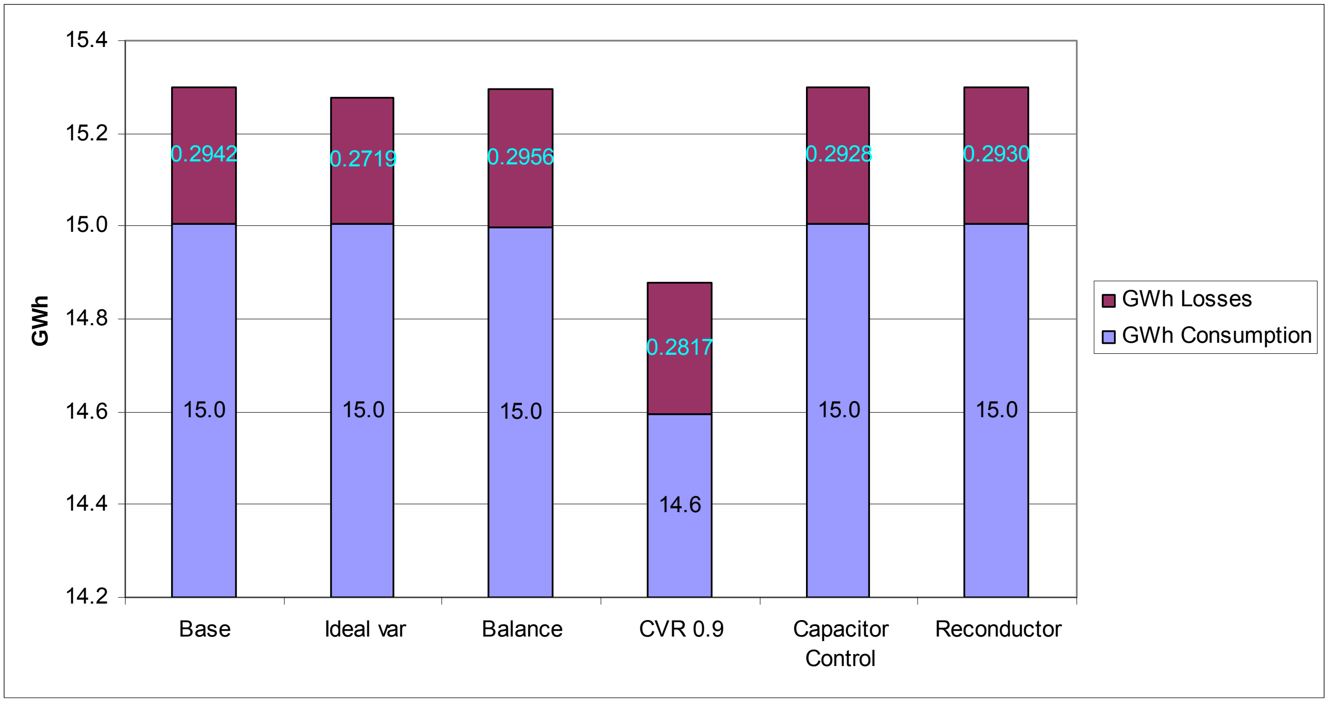


**Figure 2-27:**
**3111 efficiency comparison summary graph**

### *Circuit #7812*

Circuit #7812 is primarily an urban residential circuit. It has a primary voltage of 12.47 kV. Figure 2-28 shows the layout of the circuit.

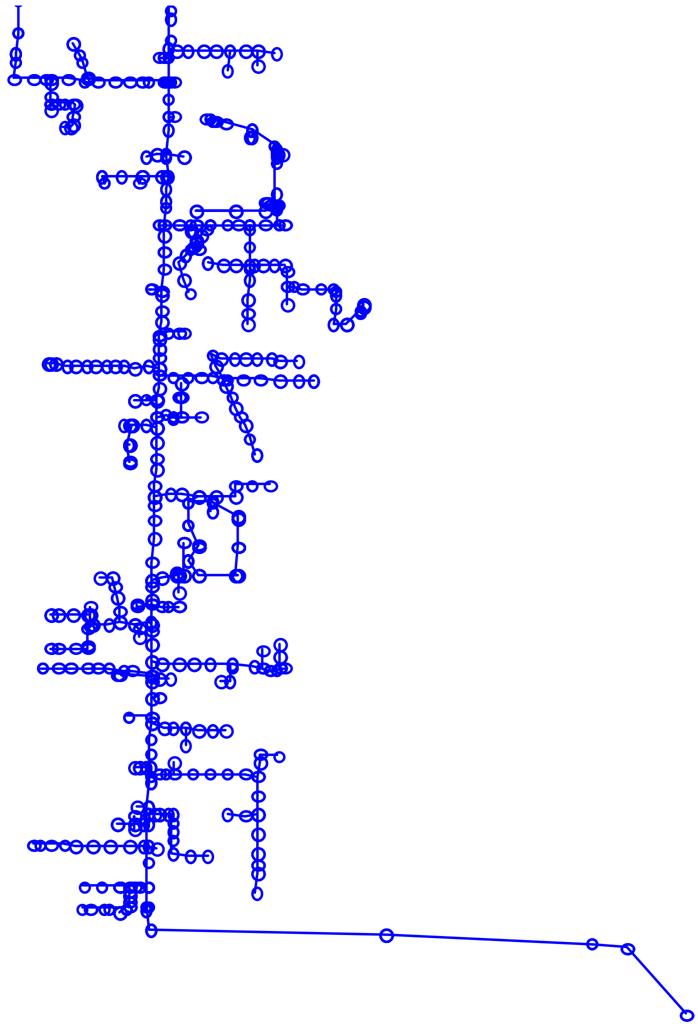

**Figure 2-28:**
**Circuit 7812**

## Base Case

Using a peak-load case provided by KCP&L in the 2008 loadshape, the real power load is scaled on each phase to match the measurements. The capacitor controls were implemented in the model to match the operation of the line capacitors. The implemented capacitor controls are as follows:

- CL-1484 (900kvar)
  - Voltage Override
    - Low Voltage Override Setpoint – 119.9 V
    - High Voltage Override Setpoint – 126.1 V
  - Summer Season Operation – Temperature Control
    - High Temperature at Which Bank Switches In – 85°F
    - High Temperature at Which Bank Switches Out – 70°F
  - Non Summer Season Operation – Temperature Control

        - Low Temperature at Which Bank Switches Out – 40°F
        - Low Temperature at Which Bank Switches In – 30°F
- CL-85094 (1200kvar)
    - Voltage Override
        - Low Voltage Override Setpoint – 119.9 V
        - High Voltage Override Setpoint – 126.1 V
    - Summer Season Operation
        - High Temperature at Which Bank Switches In – 85°F
        - High Temperature at Which Bank Switches Out – 70°F
        - Var Control Which Bank Switches In – 600 kvar
        - Var Control Which Bank Switches Out – -1000 kvar
    - Non Summer Season Operation – Var Control
        - Low Temperature at Which Bank Switches Out – 40°F
        - Low Temperature at Which Bank Switches In – 30°F

Because CL-1484 and CL-85094 capacitors include temperature control in the summer season the temperature (provided by KCP&L) the temperature fluctuations were included in the model.

The implementation of the capacitor's summer control and non-summer control along with the load allocations, allowed for the base model current to match the measured current provide from the substation metering. Figure 2-29 shows the comparison between the measured feeder current and the simulated feeder current. The load factor of this loadshape (2008) was 44% and the average power factor was 0.9.

The annual losses were calculated to be 2.4% with the transformer no-load loss dominating (45%).

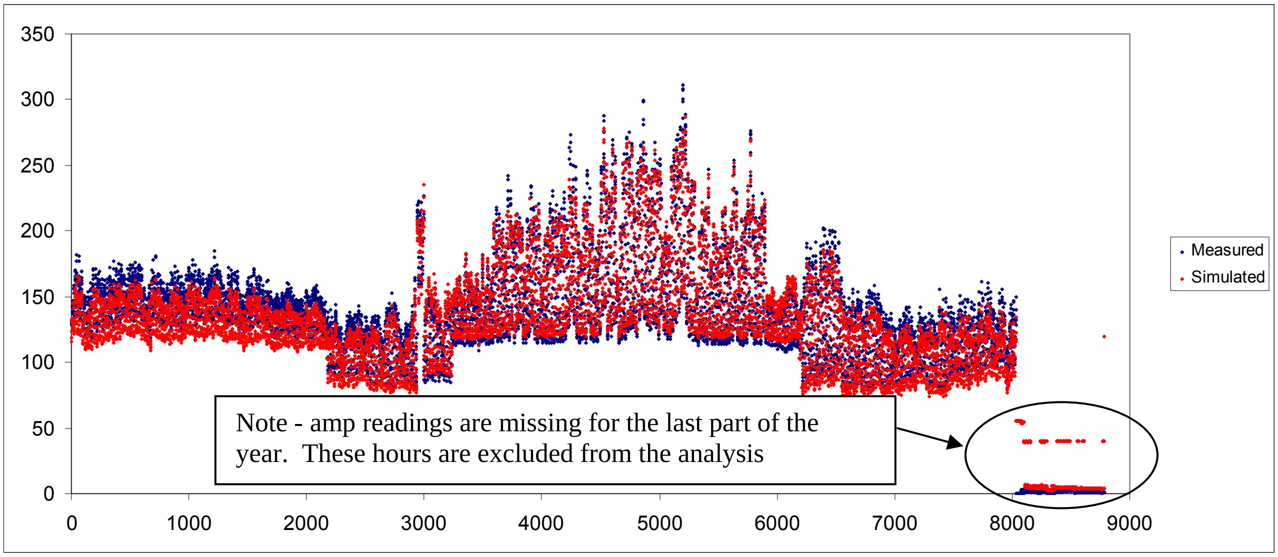


**Figure 2-29**
**7812 Current Simulated vs. Measured**

Figure 2-30 summarizes the results of the yearly and peak-day losses for the 7812 circuit.

| | At Peak Hour | | Annual Energy | |
|---|---|---|---|---|
| Demand values for the peak hour of (load + loss) | Total kW | % of Consump | Total kWh | % of Consumpt |
| Consumption/Demand | **5665** | | **22222498** | |
| Total Loss | 173 | 3.06% | 534293 | 2.40% |
| Line Loss (Wires) | 123 | 2.18% | 250568 | 1.13% |
| Transformer Loss (load plus no-load) | 50 | 0.88% | 283726 | 1.28% |
| Load Loss (Wires and transformers) | 144 | 2.54% | 291879 | 1.31% |
| No-Load Loss (Transformer magnetizing) | 29 | 0.52% | 242414 | 1.09% |
| Primary Loss (Includes transformers) | 116 | 2.05% | 421316 | 1.90% |
| Secondary Loss (No transformers) | 57 | 1.01% | 112978 | 0.51% |
| Primary Lines (Wires) | 66 | 1.17% | 137590 | 0.62% |
| Secondary Lines (Wires) | 57 | 1.01% | 112978 | 0.51% |
| No-Load Loss (Transformer magnetizing) | 29 | 0.52% | 242414 | 1.09% |
| Transformer Load Loss | 21 | 0.36% | 41312 | 0.19% |

**Figure 2-30:**
**7812 modeled losses at the peak-hour and annual energy losses**

## Phase Balancing

The phase currents were balanced at the peak hour for the circuits which had some unbalance. The average unbalance in the base case was 9.1% and this was improved to 1.0% in the Phase Balancing Case. The unbalanced calculation is based on the ANSI/NEMA Standard MG1-1993 definition. Figure 2-5 shows the results of the phase balancing simulation. Generally, the loss reductions were very low.

| | At Peak Hour | | Annual Energy | |
|---|---|---|---|---|
| | Total kW | % of Consump | Total kWh | % of Consumpt |
| Consumption/Demand | **5662** | | **22243050** | |
| Total Loss | 172 | 3.04% | 533611 | 2.40% |
| Line Loss (Wires) | 122 | 2.16% | 249736 | 1.12% |
| Transformer Loss (load plus no-load) | 50 | 0.88% | 283876 | 1.28% |
| Load Loss (Wires and transformers) | 143 | 2.52% | 291232 | 1.31% |
| No-Load Loss (Transformer magnetizing) | 29 | 0.52% | 242379 | 1.09% |
| Primary Loss (Includes transformers) | 115 | 2.03% | 420155 | 1.89% |
| Secondary Loss (No transformers) | 57 | 1.01% | 113457 | 0.51% |

**Figure 2-31:**
**7812 phase balance modeled losses at the peak-hour and annual energy losses**

## Voltage Optimization

To model voltage optimization the LTC base was reduced from 122.5V to 117.5V with line compensation implemented (monitoring end of feeder). This reduction maintained a minimum voltage above 0.95 pu at the customer service. Before the voltage reduction the minimum voltage on the feeder was maintained at 0.97 pu. See Figure 2-32.

Figure 2-33 shows the results of the voltage optimization simulation. For the annual simulation the consumption was reduced by 700 MWh and the loss was reduced by 20.5 MWh.

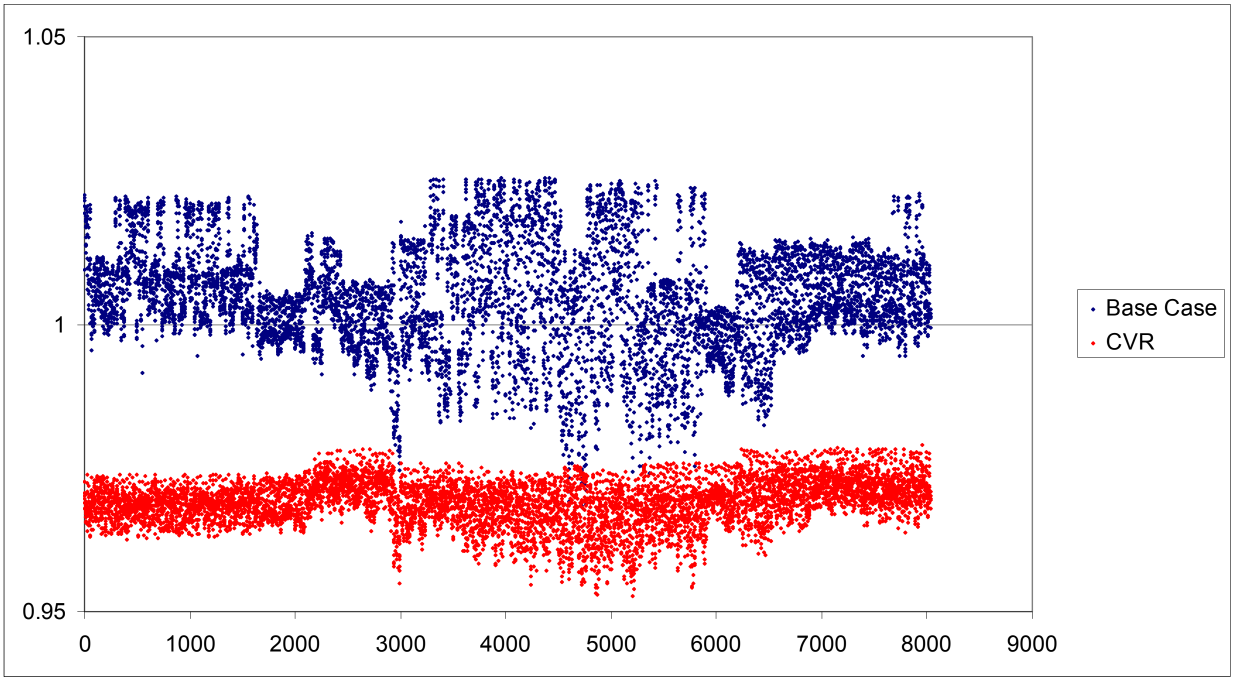


**Figure 2-32:**
**7812 minimum voltage across entire feeder during yearly loadflow**

| | At Peak Hour | | Annual Energy | |
|---|---|---|---|---|
| | Total kW | % of Consump | Total kWh | % of Consumpt |
| Consumption/Demand | **5571** | | **21522594** | |
| Total Loss | 171 | 3.08% | 513803 | 2.39% |
| Line Loss (Wires) | 123 | 2.20% | 247748 | 1.15% |
| Transformer Loss (load plus no-load) | 49 | 0.87% | 266055 | 1.24% |
| Load Loss (Wires and transformers) | 143 | 2.57% | 288143 | 1.34% |
| No-Load Loss (Transformer magnetizing) | 28 | 0.51% | 225660 | 1.05% |
| Primary Loss (Includes transformers) | 115 | 2.06% | 403117 | 1.87% |
| Secondary Loss (No transformers) | 57 | 1.02% | 110685 | 0.51% |

**Figure 2-33:**
**7812 voltage optimization modeled losses at the peak-hour and annual energy losses**

## Re-conductoring

A loss reduction approach could be to re-conductor the circuit. The conductor simulation replaced:

1.3 miles of U_2_AL upgraded with U_1/0_AL,
0.7 miles of U_600_CU upgraded with U_750_CU,
2.2 miles of O_477_AL upgraded with O_750_AL,
1.0 mile of O_2_Al upgraded with O_3/0_AL

The annual energy savings reduced to 2.33% from 2.40%. Figure 2-34 shows the results of the re-conductor simulation.

| | **At Peak Hour** | | **Annual Energy** | |
|---|---|---|---|---|
| | Total kW | % of Consump | Total kWh | % of Consumpt |
| Consumption/Demand | **5672** | | **22235364** | |
| Total Loss | 166 | 2.93% | 518749 | 2.33% |
| Line Loss (Wires) | 116 | 2.05% | 234715 | 1.06% |
| Transformer Loss (load plus no-load) | 50 | 0.88% | 284034 | 1.28% |
| Load Loss (Wires and transformers) | 137 | 2.41% | 276045 | 1.24% |
| No-Load Loss (Transformer magnetizing) | 29 | 0.52% | 242704 | 1.09% |
| Primary Loss (Includes transformers) | 109 | 1.92% | 405724 | 1.82% |
| Secondary Loss (No transformers) | 57 | 1.01% | 113026 | 0.51% |

**Figure 2-34:**
**7812 re-conductor model losses at the peak-hour and annual energy losses**

## Ideal var Optimization

A somewhat theoretical case is the ideal var optimization case. The ideal var optimization case attempts to answer what the maximum achievable losses would be if all capacitors were removed from the circuit and the loads power factors were set to 1.0 across the circuit. This would be the case if the capacitors could be ‘perfectly’ controlled from a var perspective. The annual energy losses were improved by 43.6MWh. The average power factor was improved to 0.99 from 0.9.

Figure 2-35 shows the results of the ideal var simulation.

| | At Peak Hour | | Annual Energy | |
|---|---|---|---|---|
| | Total kW | % of Consump | Total kWh | % of Consumpt |
| Consumption/Demand | **5725** | | **22286731** | |
| Total Loss | 156 | 2.73% | 490687 | 2.20% |
| Line Loss (Wires) | 110 | 1.91% | 214009 | 0.96% |
| Transformer Loss (load plus no-load) | 46 | 0.81% | 276678 | 1.24% |
| Load Loss (Wires and transformers) | 126 | 2.20% | 246451 | 1.11% |
| No-Load Loss (Transformer magnetizing) | 30 | 0.52% | 244236 | 1.10% |
| Primary Loss (Includes transformers) | 110 | 1.92% | 400515 | 1.80% |
| Secondary Loss (No transformers) | 46 | 0.81% | 90172 | 0.40% |

**Figure 2-35:**
**7812 ideal var model losses at the peak-hour and annual energy losses**

## Capacitor Control

Added capacitor control was studied for 7812 as another approach to reduce losses. This is a more realistic approach to var control opposed to the ideal var case. For the capacitor control the summer temperature settings were reduced to increase kvar hours produced by existing capacitors. This had minimal impact on losses.

Figure 2-36 shows the results of the capacitor control simulation.

| | At Peak Hour | | Annual Energy | |
|---|---|---|---|---|
| | Total kW | % of Consump | Total kWh | % of Consumpt |
| Consumption/Demand | **5665** | | **22236894** | |
| Total Loss | 173 | 3.06% | 533109 | 2.40% |
| Line Loss (Wires) | 123 | 2.18% | 249034 | 1.12% |
| Transformer Loss (load plus no-load) | 50 | 0.88% | 284075 | 1.28% |
| Load Loss (Wires and transformers) | 144 | 2.54% | 290366 | 1.31% |
| No-Load Loss (Transformer magnetizing) | 29 | 0.52% | 242742 | 1.09% |
| Primary Loss (Includes transformers) | 116 | 2.05% | 420078 | 1.89% |
| Secondary Loss (No transformers) | 57 | 1.01% | 113030 | 0.51% |

**Figure 2-36:**
**7812 capacitor control model losses at the peak-hour and annual energy losses**

## Summary

Figure 2-37 and Figure 2-38 below compares the results to the base case. As can be seen the ideal var control results in the biggest savings in loss reduction followed by the voltage optimization case (referred to as CVR, Conservation -Voltage Reduction) case. However, the voltage optimization may be the most cost effective approach to reduce losses.

| | Base | Ideal var | Balance | CVR 0.9 | Capacitor Control | Reconductor |
|---|---|---|---|---|---|---|
| GWh Consumption | 22.2 | 22.3 | 22.2 | 21.5 | 22.2 | 22.2 |
| GWh Losses | 0.53 | 0.49 | 0.53 | 0.51 | 0.53 | 0.52 |
| Delta Loss (MWh) | | **43.6** | **0.7** | **20.5** | **1.2** | **15.5** |
| Delta Consumption (MWh) | | -64.2 | -20.6 | 699.9 | -14.4 | -12.9 |
| % Loss (Base) | 2.40% | 2.21% | 2.40% | 2.31% | 2.40% | 2.33% |
| % Consumption (Base) | | 100.3% | 100.1% | 96.9% | 100.1% | 100.1% |
| % Base | | 8.16% | 0.13% | 3.83% | 0.22% | 2.91% |

**Figure 2-37:**
**7812 efficiency analysis comparison summary**

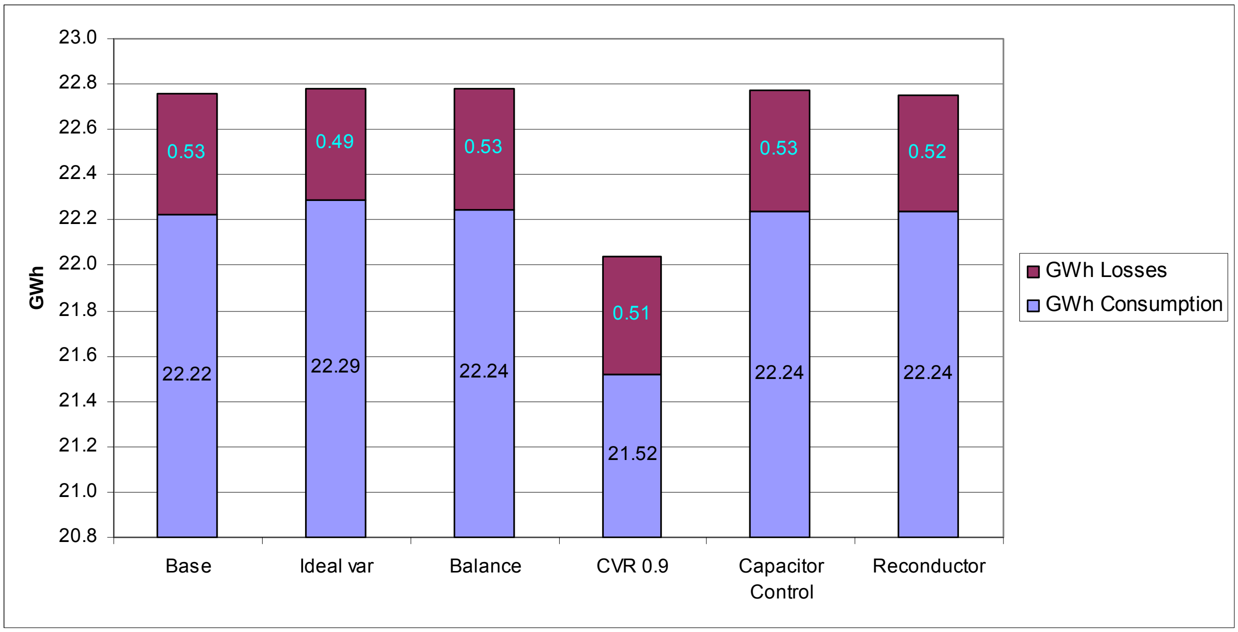


**Figure 2-38:**
**7812 efficiency comparison summary graph**

### *Circuit #5051*

Circuit #5051 is primarily an urban residential circuit. It has a primary voltage of 12.47 kV with a portion 4.16kV. Figure 2-28 shows the layout of the circuit.

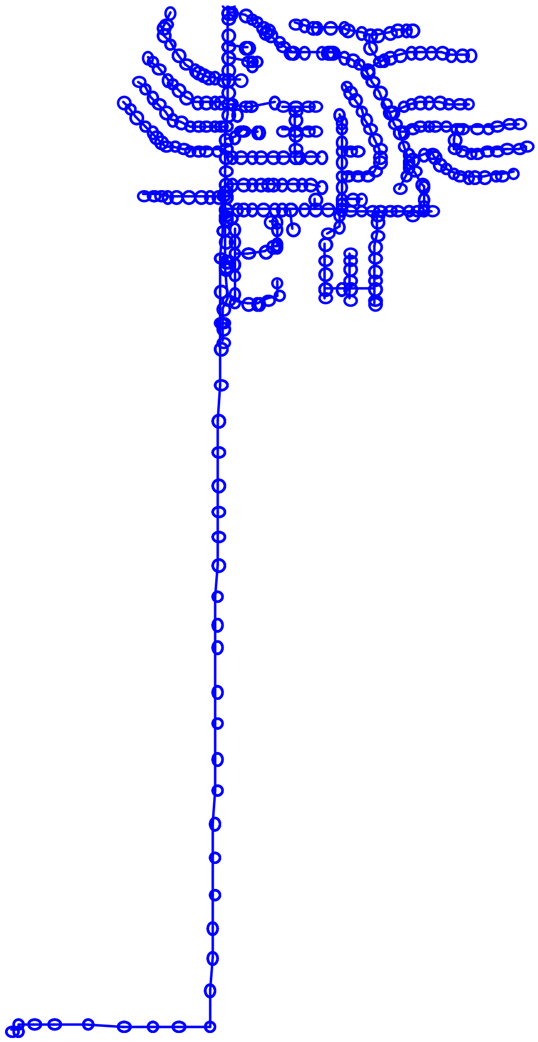

**Figure 2-39:**
**Circuit 5051**

## Base Case

Using a peak-load case provided by KCP&L in the 2008 loadshape, the real power load is scaled on each phase to match the measurements. The capacitor controls were implemented in the model to match the operation of the line capacitors. The implemented capacitor controls are as follows:

- JO-86186 (1200kvar)
  - Voltage Override
    - Low Voltage Override Setpoint – 119.9 V
    - High Voltage Override Setpoint – 126.1 V
  - Summer Season Operation – Temperature Control
    - High Temperature at Which Bank Switches In – 85°F
    - High Temperature at Which Bank Switches Out – 70°F
  - Non Summer Season Operation – Temperature Control

        - High Temperature at Which Bank Switches Out – 40°F
        - Low Temperature at Which Bank Switches In – 30°F
- JO-2384 (600 kVAr), JO-86307 (1200 kVAr)
        - Low Voltage Override Setpoint – 119.9 V
        - High Voltage Override Setpoint – 126.1 V
    - Summer Season Operation
        - High Temperature at Which Bank Switches In – 85°F
        - High Temperature at Which Bank Switches Out – 70°F
        - Var Control Which Bank Switches In – 600 kvar
        - Var Control Which Bank Switches Out – -1000 kvar
    - Non Summer Season Operation – Var Control
        - High Temperature at Which Bank Switches Out – 40°F
        - Low Temperature at Which Bank Switches In – 30°F
- JO-86190 (600kVAr)
    - Fixed

Because the JO-86186, JO-2384, and JO-86307 capacitors include temperature control in the temperature fluctuations were included in the model.

The simulated models are developed to replicate the actual feeder; therefore, it is imperative to validate simulations with substation measurements. In this case, when the provided temperature control settings were used on 5051, too many capacitors were switching on in the summer season. To match the measured values, especially during the shoulder regions, the summer temperature settings had to be raised to 95F/85F, to compensate for any temperature difference at 5051. This may be in part due to C5051 being cooler than the temperature monitoring point, and also in part that C5051 is almost entirely residential load.

The implementation of the modified capacitor's summer control and non-summer control along with the load allocations, the base model current matched the measured current provide from the substation metering. Figure 2-40 shows the comparison between the measured feeder current and the simulated feeder current. The load factor of this loadshape (2008) was 36% and the average power factor was 0.9.

The annual losses were calculated to be 2.53% with the transformer no-load loss dominating (43%).

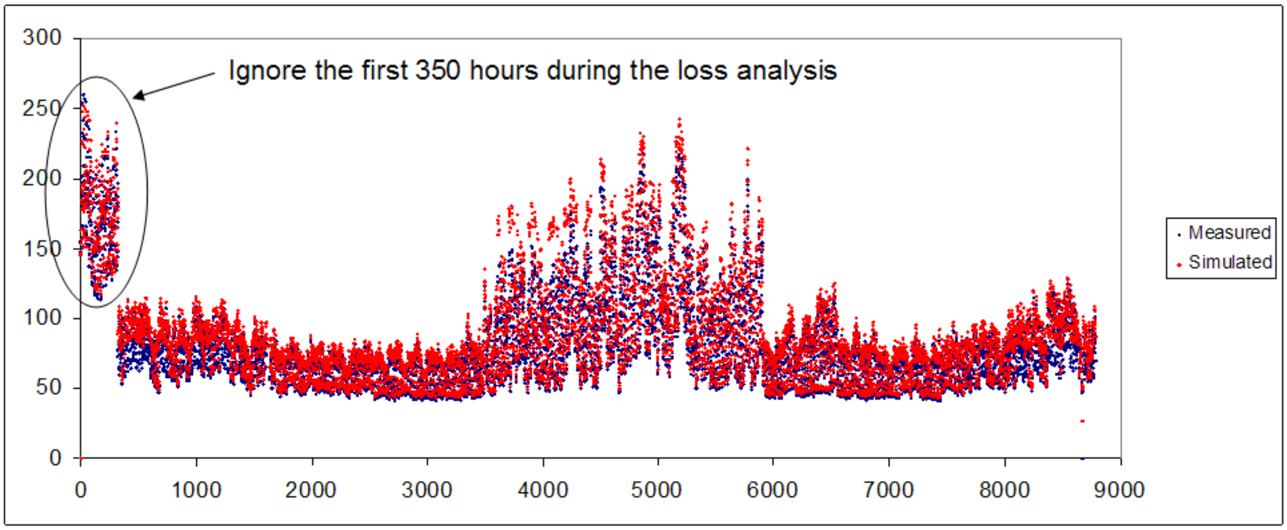


**Figure 2-40**
**5051 Current Simulated vs. Measured**

Figure 2-41 summarizes the results of the yearly and peak-day losses for the 9111 circuit.

| | At Peak Hour | | Annual Energy | |
|---|---|---|---|---|
| | Total kW | % of Consump | Total kWh | % of Consumpt |
| Consumption/Demand | **5079** | | **15121877** | |
| Total Loss | 203 | 3.99% | 382523 | 2.53% |
| Line Loss (Wires) | 147 | 2.90% | 178201 | 1.18% |
| Transformer Loss (load plus no-load) | 55 | 1.08% | 204322 | 1.35% |
| Load Loss (Wires and transformers) | 184 | 3.62% | 221432 | 1.46% |
| No-Load Loss (Transformer magnetizing) | 19 | 0.37% | 161092 | 1.07% |
| Primary Loss (Includes transformers) | 129 | 2.55% | 297824 | 1.97% |
| Secondary Loss (No transformers) | 73 | 1.44% | 84700 | 0.56% |

**Figure 2-41:**
**5051 modeled losses at the peak-hour and annual energy losses**

## Phase Balancing

The phase currents were balanced at the peak hour for the circuits which had some unbalance. The average unbalance in the base case was 11.2% and this was improved to 1.0% in the Phase Balancing Case. The unbalanced calculation is based on the ANSI/NEMA Standard MG1-1993 definition. Figure 2-42 shows the results of the phase balancing simulation. The loss reductions were very low and with a slight increase in some areas.

| | At Peak Hour | | Annual Energy | |
|---|---|---|---|---|
| | Total kW | % of Consump | Total kWh | % of Consumpt |
| Consumption/Demand | **5097** | | **15158859** | |
| Total Loss | 205 | 4.03% | 383787 | 2.53% |
| Line Loss (Wires) | 149 | 2.93% | 178640 | 1.18% |
| Transformer Loss (load plus no-load) | 56 | 1.10% | 205146 | 1.35% |
| Load Loss (Wires and transformers) | 187 | 3.66% | 222749 | 1.47% |
| No-Load Loss (Transformer magnetizing) | 19 | 0.37% | 161038 | 1.06% |
| Primary Loss (Includes transformers) | 131 | 2.58% | 298432 | 1.97% |
| Secondary Loss (No transformers) | 74 | 1.45% | 85355 | 0.56% |

**Figure 2-42:**
**5051 phase balance modeled losses at the peak-hour and annual energy losses**

## Voltage Optimization

To model voltage optimization the LTC base was reduced from 122.5V to 118.5V with line compensation implemented (monitoring end of 12.47kV feeder). This reduction maintained a minimum voltage equivalent to the minimum voltage from the base case. See Figure 2-43. **Note: It was necessary to add a 450kvar capacitor at the 4.16kV bus of the 12.47/4.16 transformer to keep voltage in the 4.16kV section from dropping lower than the base case.**

Figure 2-44 shows the results of the voltage optimization simulation. For the annual simulation the consumption was reduced by 484.79 MWh and the loss was reduced by 5.88 MWh.

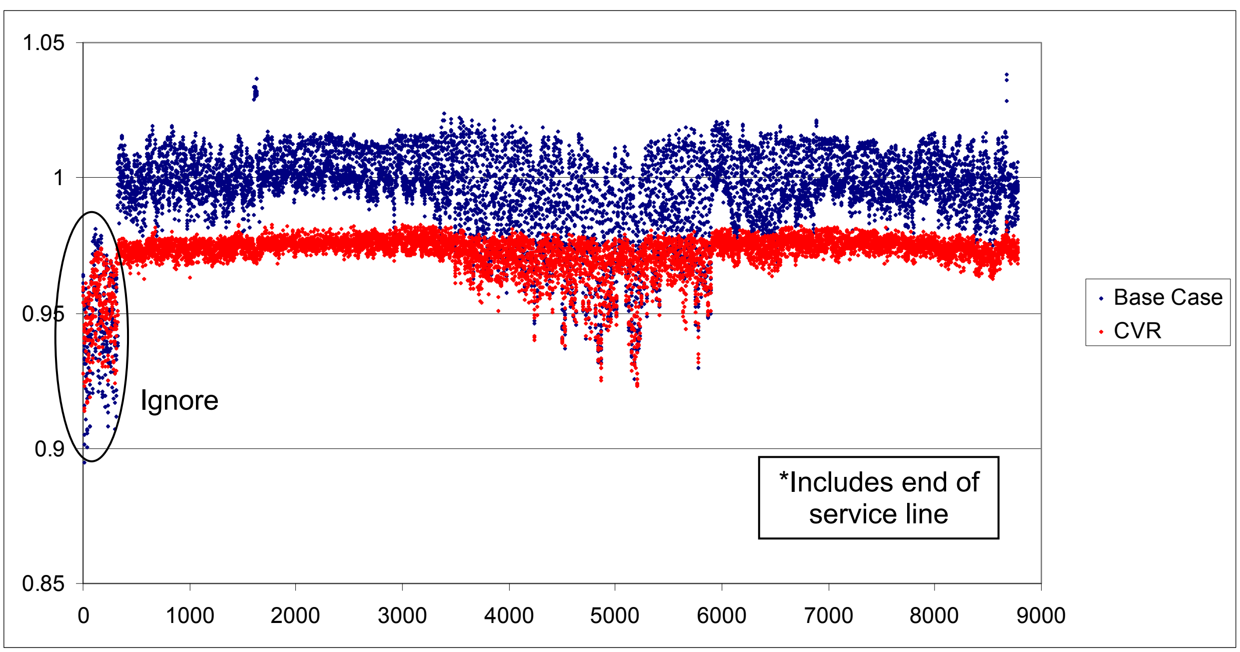


**Figure 2-43:**
**5051 minimum voltage across entire feeder during yearly loadflow**

| | At Peak Hour | | Annual Energy | |
|---|---|---|---|---|
| | Total kW | % of Consump | Total kWh | % of Consumpt |
| Consumption/Demand | **4887** | | **14637088** | |
| Total Loss | 200 | 4.08% | 376648 | 2.57% |
| Line Loss (Wires) | 148 | 3.03% | 178224 | 1.22% |
| Transformer Loss (load plus no-load) | 52 | 1.05% | 198424 | 1.36% |
| Load Loss (Wires and transformers) | 182 | 3.73% | 226721 | 1.55% |
| No-Load Loss (Transformer magnetizing) | 17 | 0.35% | 149927 | 1.02% |
| Primary Loss (Includes transformers) | 128 | 2.62% | 293722 | 2.01% |
| Secondary Loss (No transformers) | 71 | 1.46% | 82926 | 0.57% |

**Figure 2-44:**
**5051 voltage optimization modeled losses at the peak-hour and annual energy losses**

## Re-conductoring

A loss reduction approach could be to re-conductor the circuit. The conductor simulation replaced:

1 2 miles of U_600_CU with U_750_CU;
1 mile of O_477_AL with O_750_AL;

The annual energy savings reduced by 11.46MWh. Figure 2-45 shows the results of the re-conductor simulation.

| | At Peak Hour | | Annual Energy | |
|---|---|---|---|---|
| | Total kW | % of Consump | Total kWh | % of Consumpt |
| Consumption/Demand | **5086** | | **15131157** | |
| Total Loss | 193 | 3.80% | 371062 | 2.45% |
| Line Loss (Wires) | 138 | 2.71% | 166523 | 1.10% |
| Transformer Loss (load plus no-load) | 55 | 1.09% | 204539 | 1.35% |
| Load Loss (Wires and transformers) | 174 | 3.43% | 209774 | 1.39% |
| No-Load Loss (Transformer magnetizing) | 19 | 0.37% | 161287 | 1.07% |
| Primary Loss (Includes transformers) | 120 | 2.36% | 286321 | 1.89% |
| Secondary Loss (No transformers) | 73 | 1.44% | 84740 | 0.56% |

**Figure 2-45:**
**5051 re-conductor model losses at the peak-hour and annual energy losses**

## Ideal var Optimization

A somewhat theoretical case is the ideal var optimization case. The ideal var optimization case attempts to answer what the maximum achievable losses would be if all capacitors were removed from the circuit and the loads power factors were set to 1.0 across the circuit. This would be the case if the capacitors could be ‘perfectly’ controlled from a var perspective. The annual energy losses were improved by 38Mhr. The average power factor was improved to 0.99 from 0.9.

Figure 2-46 shows the results of the ideal var simulation.

| | At Peak Hour | | Annual Energy | |
|---|---|---|---|---|
| | Total kW | % of Consump | Total kWh | % of Consumpt |
| Consumption/Demand | **5102** | | **15236063** | |
| Total Loss | 176 | 3.45% | 344540 | 2.26% |
| Line Loss (Wires) | 127 | 2.50% | 147368 | 0.97% |
| Transformer Loss (load plus no-load) | 48 | 0.95% | 197172 | 1.29% |
| Load Loss (Wires and transformers) | 157 | 3.08% | 181616 | 1.19% |
| No-Load Loss (Transformer magnetizing) | 19 | 0.37% | 162924 | 1.07% |
| Primary Loss (Includes transformers) | 116 | 2.28% | 276606 | 1.82% |
| Secondary Loss (No transformers) | 59 | 1.16% | 67935 | 0.45% |

**Figure 2-46:**
**5051 ideal var model losses at the peak-hour and annual energy losses**

## Capacitor Control

Added capacitor control was studied for 5051 as another approach to reduce losses. This is a more realistic approach to var control opposed to the ideal var case. For better var control, a 300kvar capacitor was added to the 4.16kV section. This had minimal impact on losses.

Figure 2-47 shows the results of the capacitor control simulation.

| | At Peak Hour | | Annual Energy | |
|---|---|---|---|---|
| | Total kW | % of Consump | Total kWh | % of Consumpt |
| Consumption/Demand | **5055** | | **15193953** | |
| Total Loss | 199 | 3.93% | 384578 | 2.53% |
| Line Loss (Wires) | 145 | 2.88% | 178146 | 1.17% |
| Transformer Loss (load plus no-load) | 53 | 1.06% | 206432 | 1.36% |
| Load Loss (Wires and transformers) | 180 | 3.57% | 221620 | 1.46% |
| No-Load Loss (Transformer magnetizing) | 19 | 0.37% | 162958 | 1.07% |
| Primary Loss (Includes transformers) | 126 | 2.49% | 299622 | 1.97% |
| Secondary Loss (No transformers) | 73 | 1.44% | 84956 | 0.56% |

**Figure 2-47:**
**5051 capacitor control model losses at the peak-hour and annual energy losses**

## Upgrade 4.16kV Section with 12.47kV

Upgrading the 4.16kV section to 12.47kV was studied for 5051 as another approach to reduce losses. This upgrade resulted in removing the 12.47/4.16kV step-down transformer. This resulted in an annual 22.08Mhr reduction in losses. Figure 2-48 shows the results of the 4.16kV upgrade simulation. **Note: No change to service transformer impedances or line impedances of the 4.16kV section when upgraded to 12.47kV.**

| | At Peak Hour | | Annual Energy | |
|---|---|---|---|---|
| | Total kW | % of Consump | Total kWh | % of Consumpt |
| Consumption/Demand | **5123** | | **15173630** | |
| Total Loss | 184 | 3.59% | 360441 | 2.38% |
| Line Loss (Wires) | 138 | 2.69% | 166376 | 1.10% |
| Transformer Loss (load plus no-load) | 46 | 0.90% | 194065 | 1.28% |
| Load Loss (Wires and transformers) | 165 | 3.22% | 198174 | 1.31% |
| No-Load Loss (Transformer magnetizing) | 19 | 0.37% | 162266 | 1.07% |
| Primary Loss (Includes transformers) | 111 | 2.16% | 275529 | 1.82% |
| Secondary Loss (No transformers) | 73 | 1.43% | 84912 | 0.56% |

**Figure 2-48:**
**5051 4.16kV upgrade model losses at the peak-hour and annual energy losses**

## Summary

Figure 2-49 and Figure 2-50 below compares the results to the base case. As can be seen the ideal var results in the biggest savings followed by the upgrade to 4.16kV upgrade. The voltage optimization case (referred to as CVR, Conservation Voltage Reduction) resulted in an annual savings of 5.9MWh.

| | **Base** | **Ideal var** | **Balance** | **CVR 0.9** | **Capacitor Control** | **Reconductor** | **Upgrade 4.16kV** |
|---|---|---|---|---|---|---|---|
| GWh Consumption | 15.1 | 15.2 | 15.2 | 14.6 | 15.2 | 15.1 | 15.2 |
| GWh Losses | 0.38 | 0.34 | 0.38 | 0.38 | 0.38 | 0.37 | 0.36 |
| Delta Loss (MWh) | | **38.0** | **-1.3** | **5.9** | **-2.1** | **11.5** | **22.1** |
| Delta Consumption (MWh) | | -114.2 | -37.0 | 484.8 | -72.1 | -9.3 | -51.8 |
| % Loss (Base) | 2.53% | 2.28% | 2.54% | 2.49% | 2.54% | 2.45% | 2.38% |
| % Consumption (Base) | | 100.8% | 100.2% | 96.8% | 100.5% | 100.1% | 100.3% |
| % Base | | 9.93% | -0.33% | 1.54% | -0.54% | 3.00% | 5.77% |

**Figure 2-49:**
**5051 efficiency analysis comparison summary**

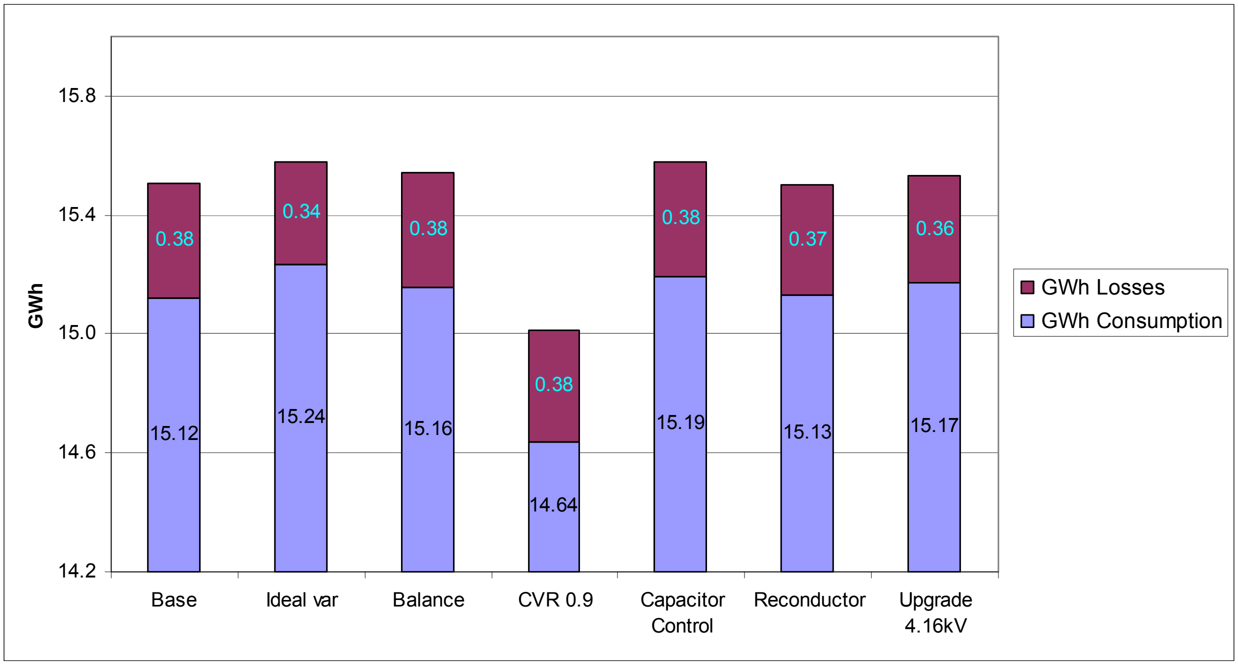


**Figure 2-50:**
**5051 efficiency comparison summary graph**

# 3
# MODELING RESULTS

## General Characteristics

The following series of graphs shows how the KCP&L circuits compare with general characteristics of the other circuits that have been modeled in the Green Circuits project.

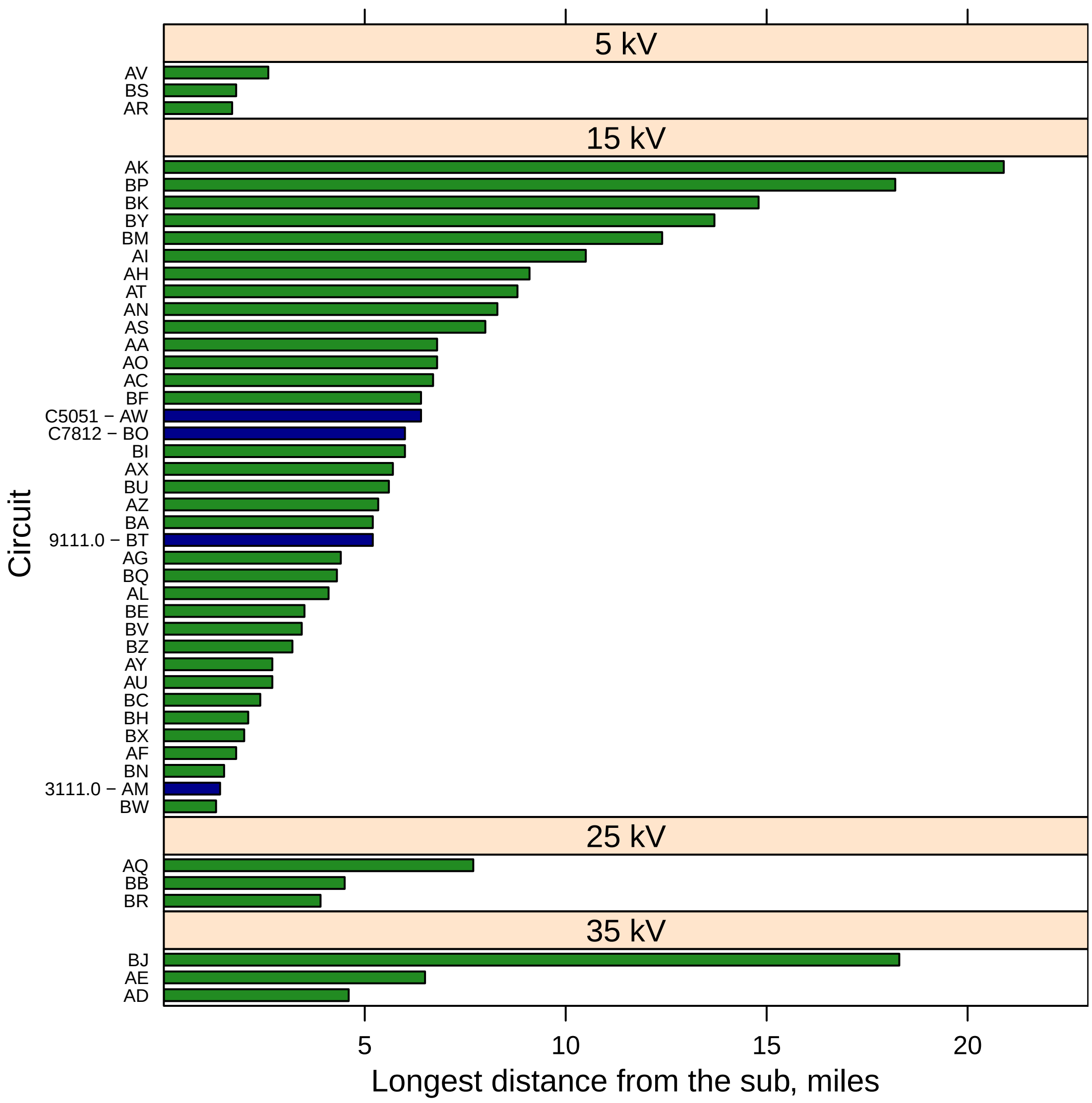


**Figure 3-1**
**Circuits by Voltage and Distance from the Substation**

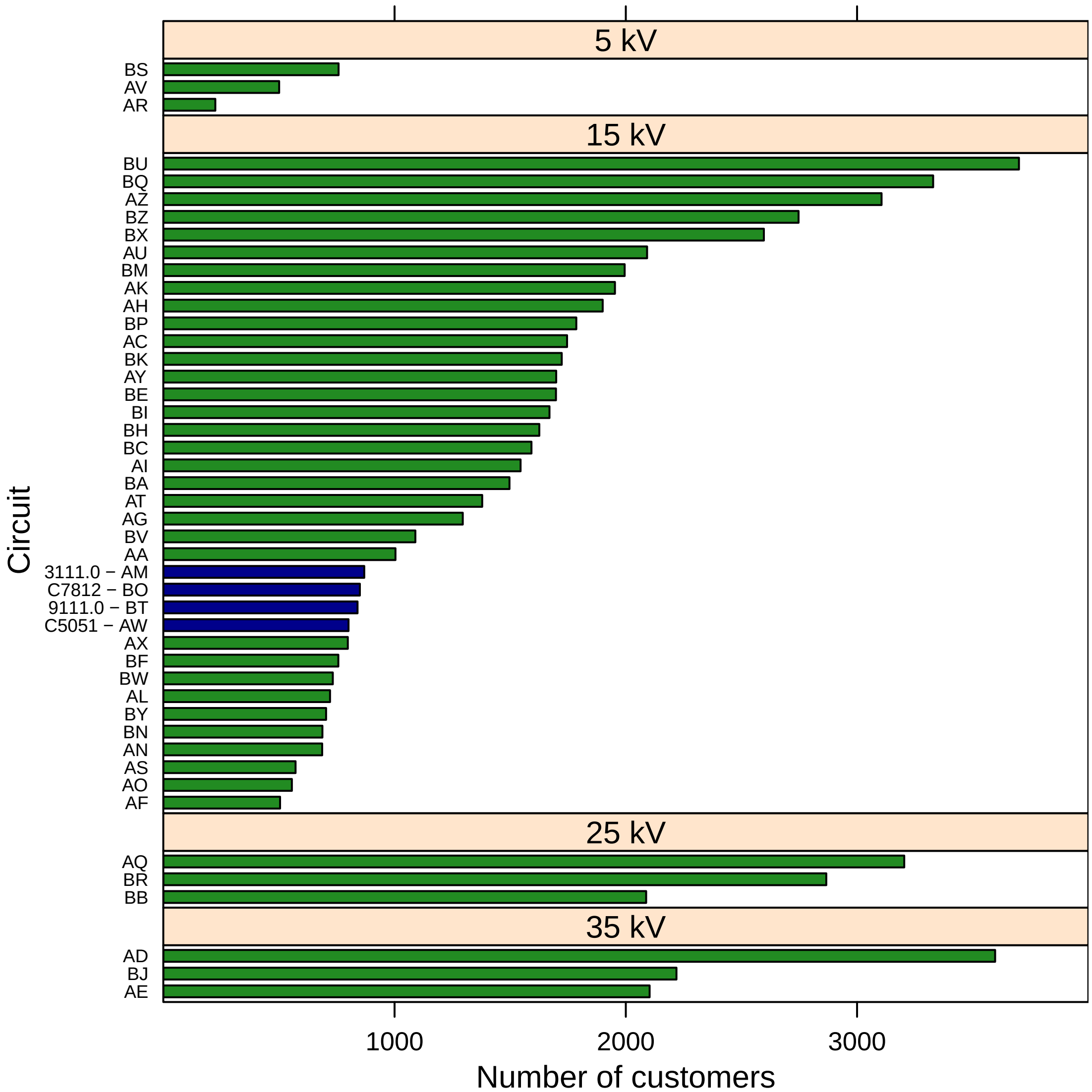


**Figure 3-2**
**Number of Customers per Circuit**

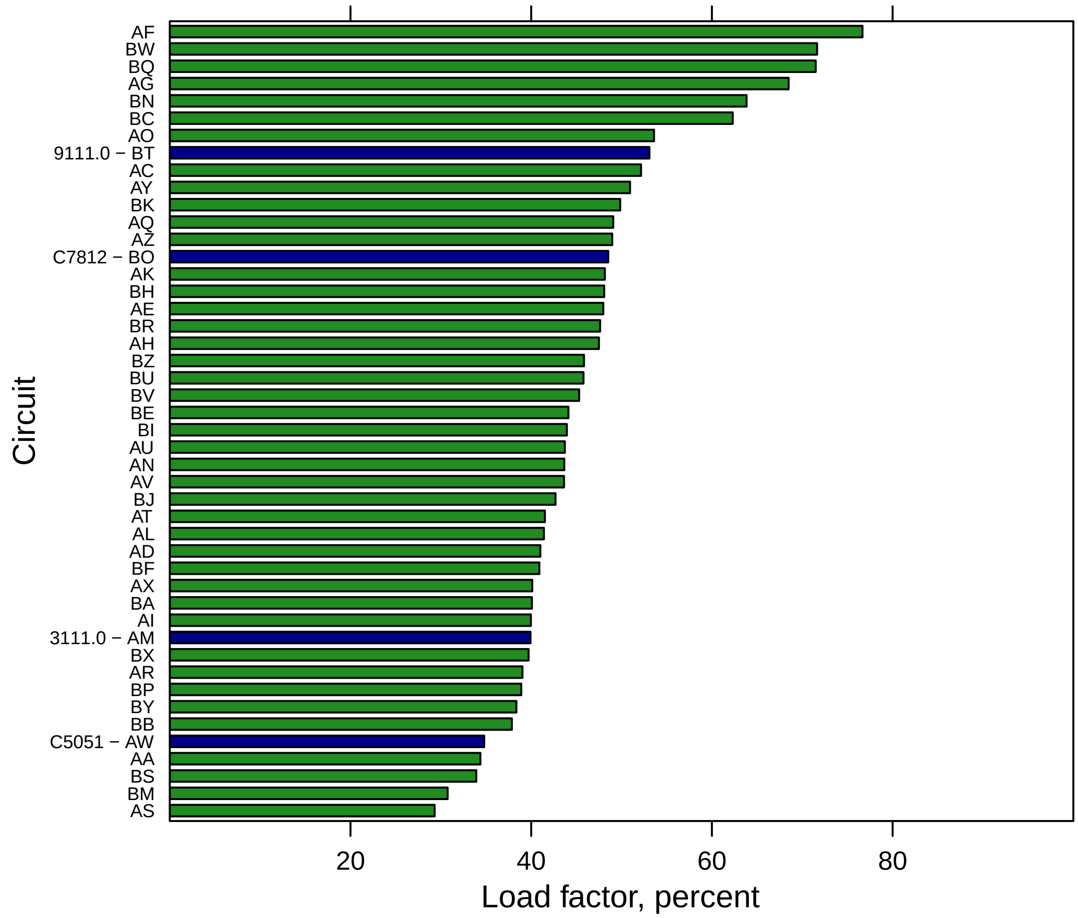


**Figure 3-3**
**Circuit Load Factors**

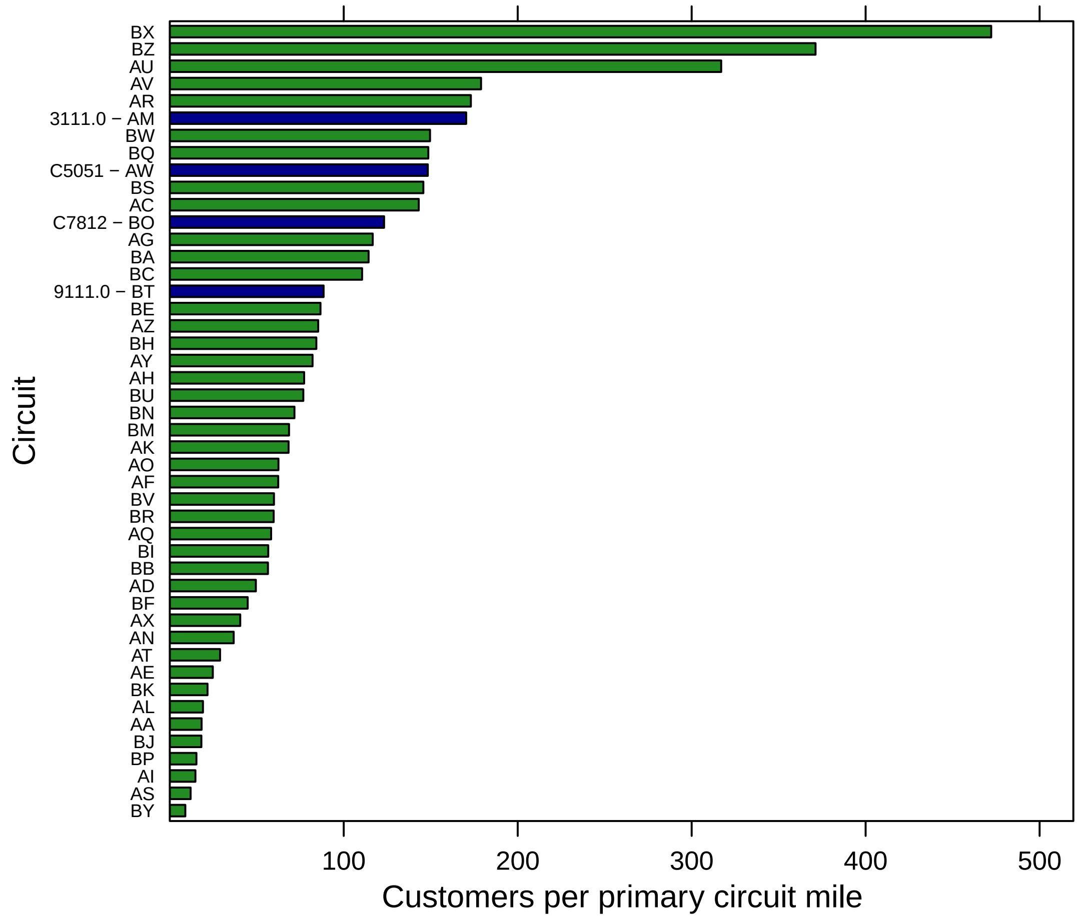


**Figure 3-4**
**Load Densities**

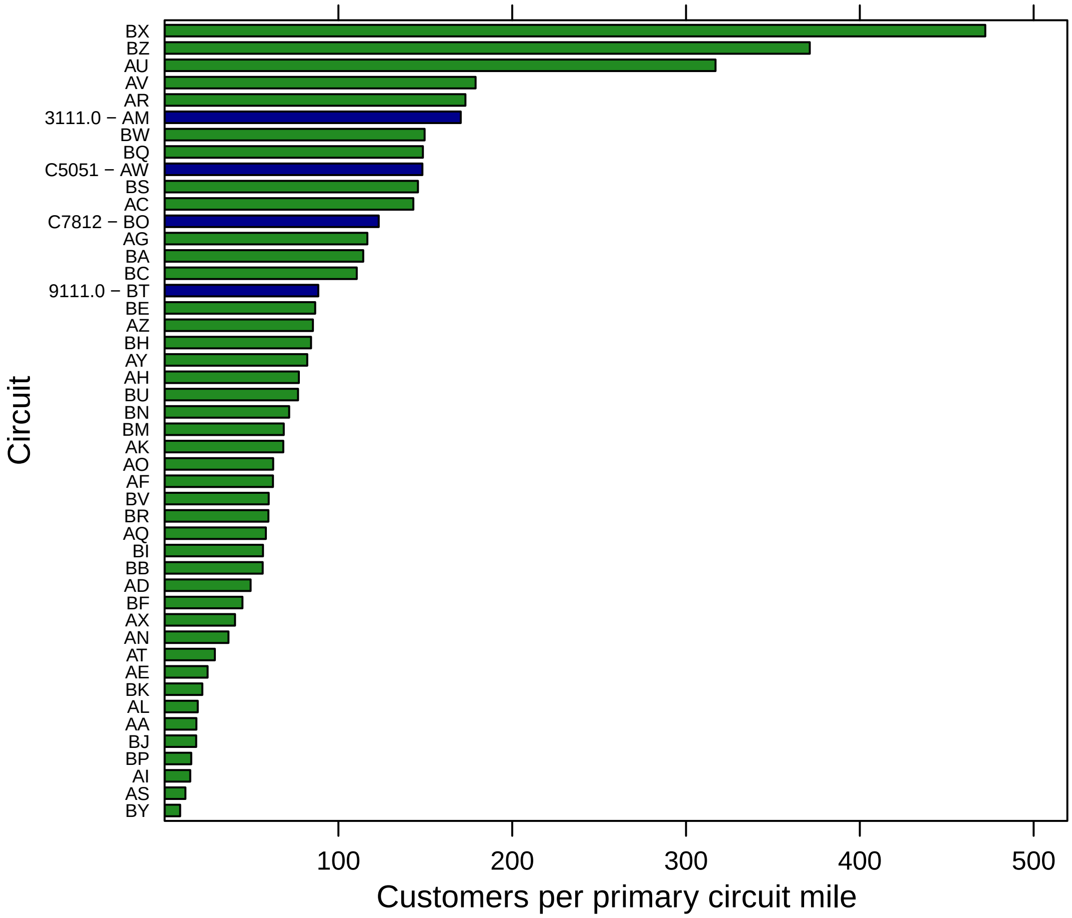


**Figure 3-5**
**Load Densities**

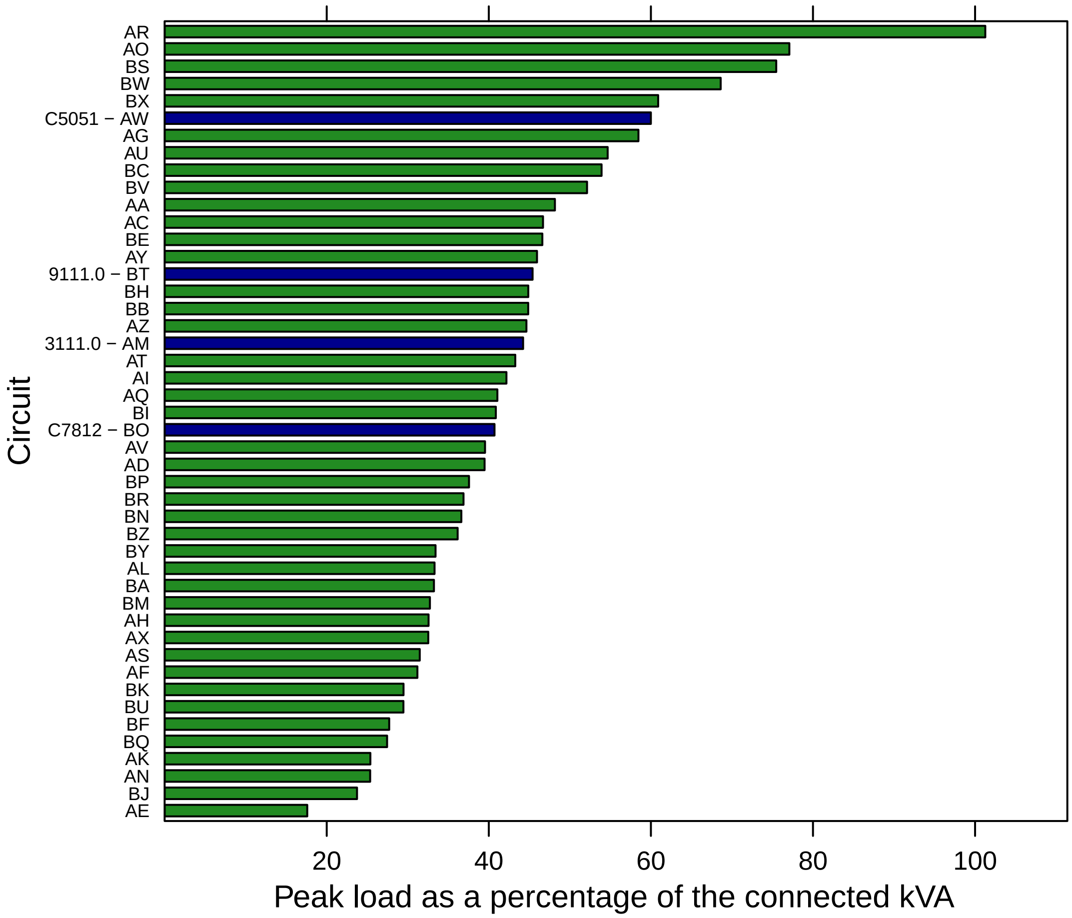


**Figure 3-6**
**Load versus Connected kVA**

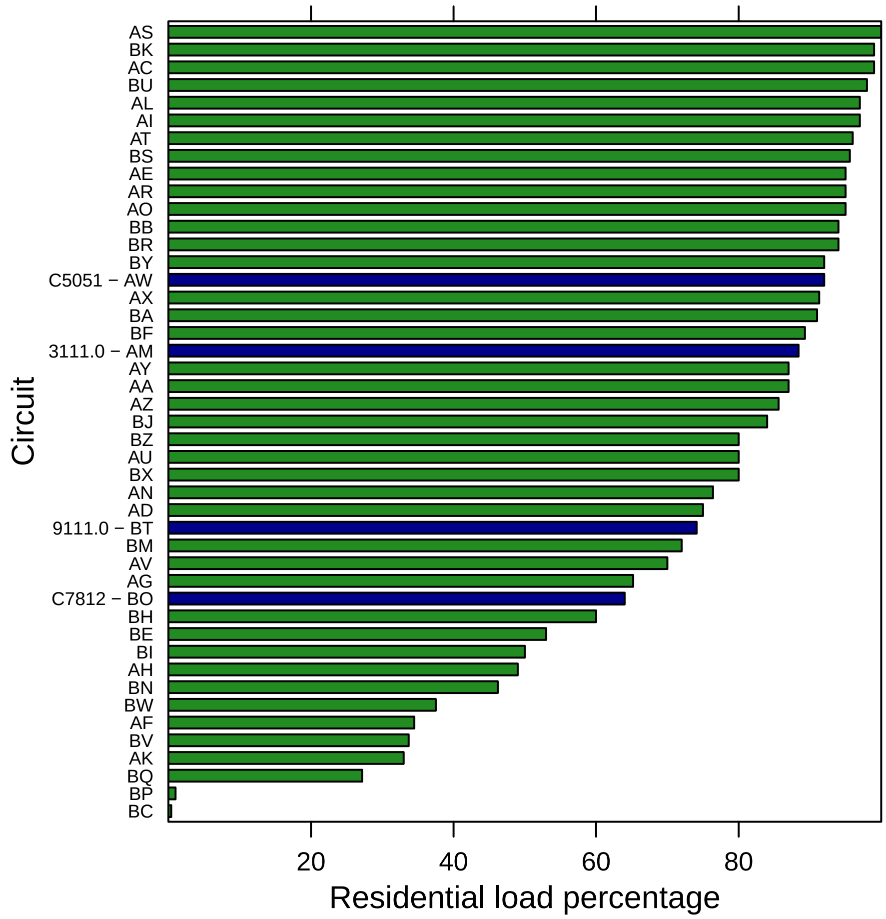


**Figure 3-7**
**Residential Load as a Percentage of Connected kVA**

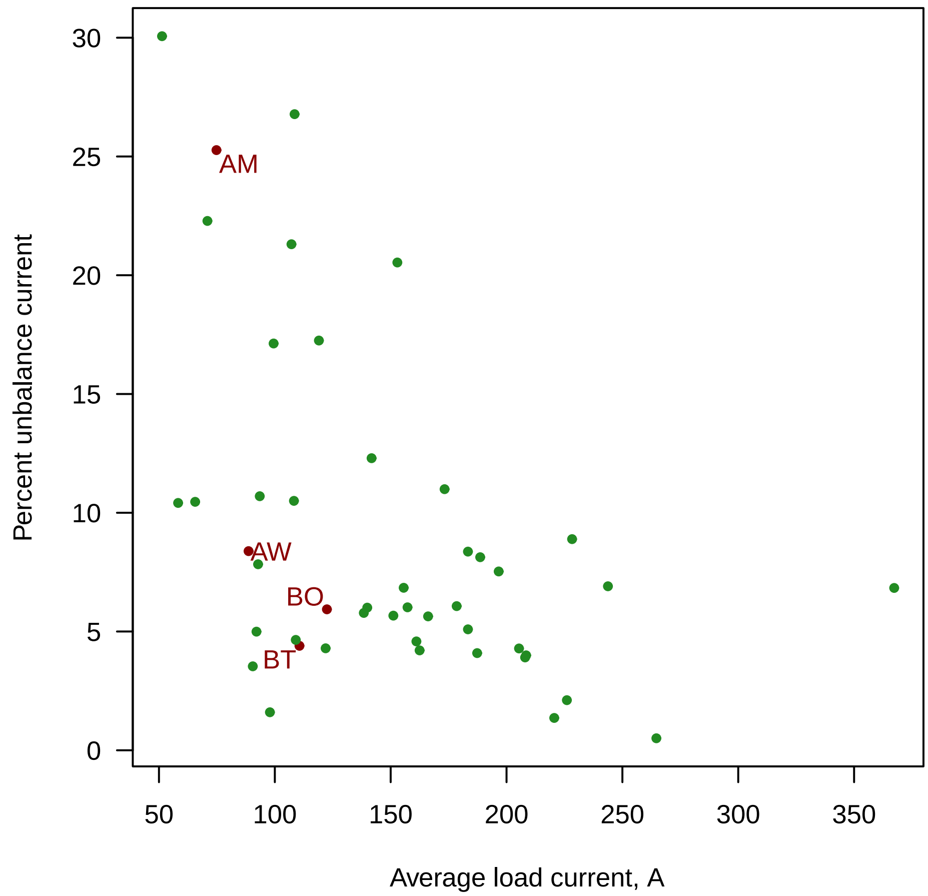


**Figure 3-8**
**Unbalance versus Load Current**

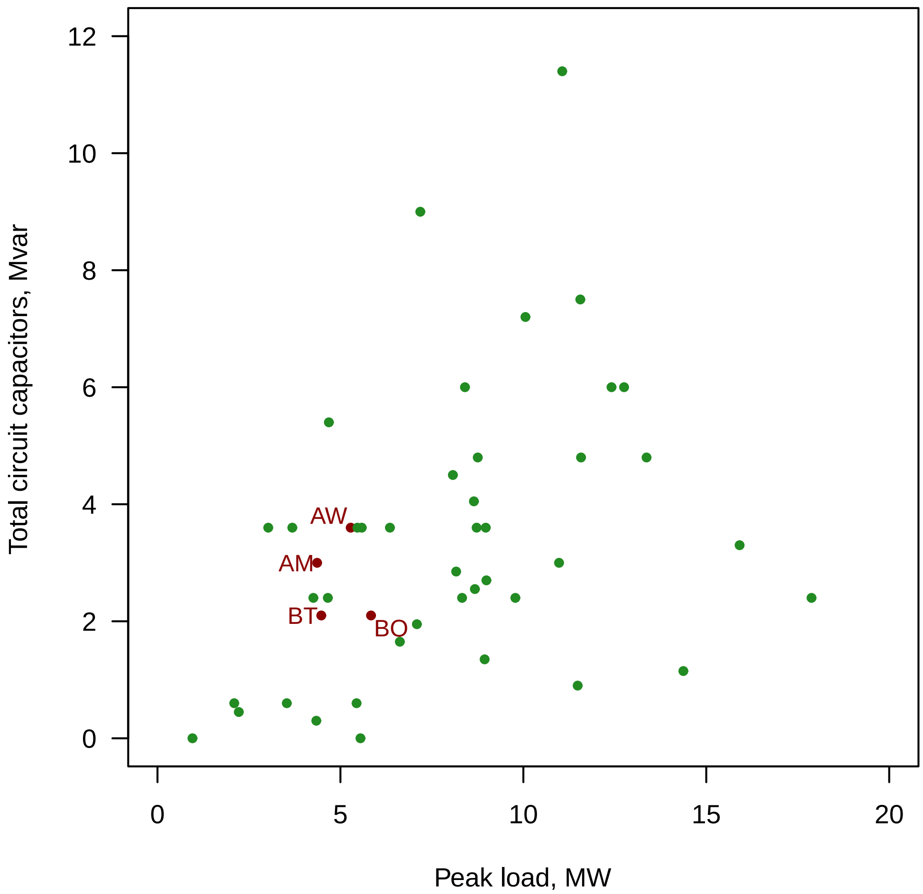


**Figure 3-9**
**Peak Load and Total Connected Capacitance**

## Loss Characteristics

The following series of graphs shows how the losses on the KCPL circuits compare with those on other circuits that have been modeled in the Green Circuits project.

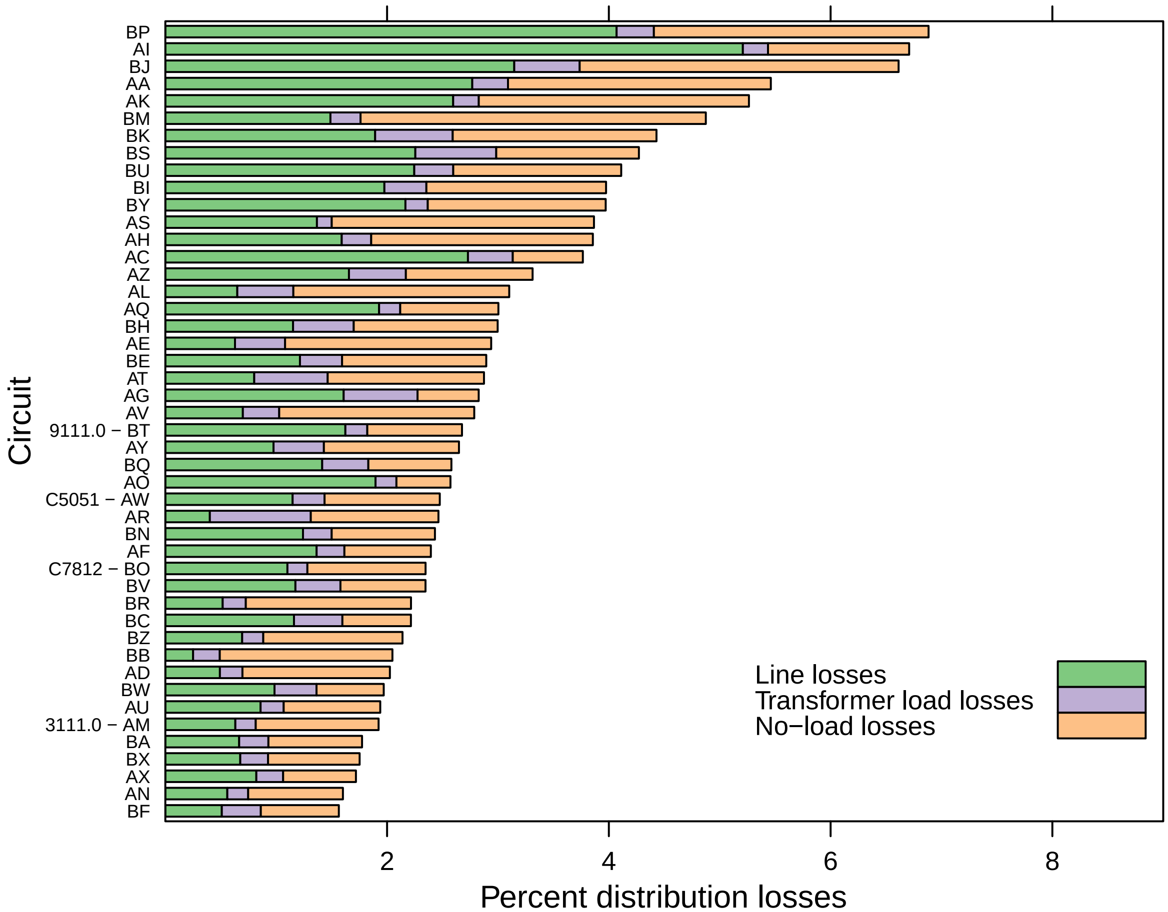


**Figure 3-10**
**Circuit Loss Breakdowns**

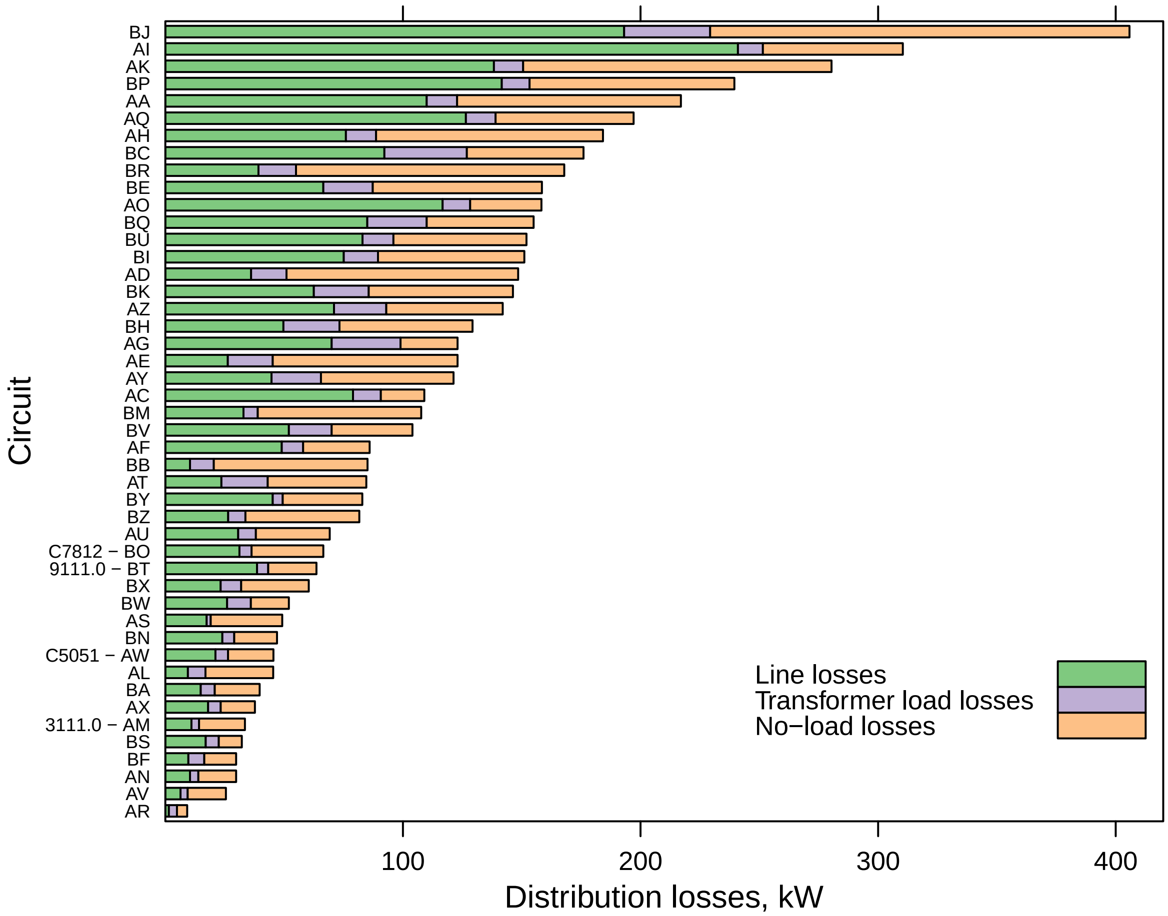


**Figure 3-11**
**Circuit Loss Breakdowns in Average kW**

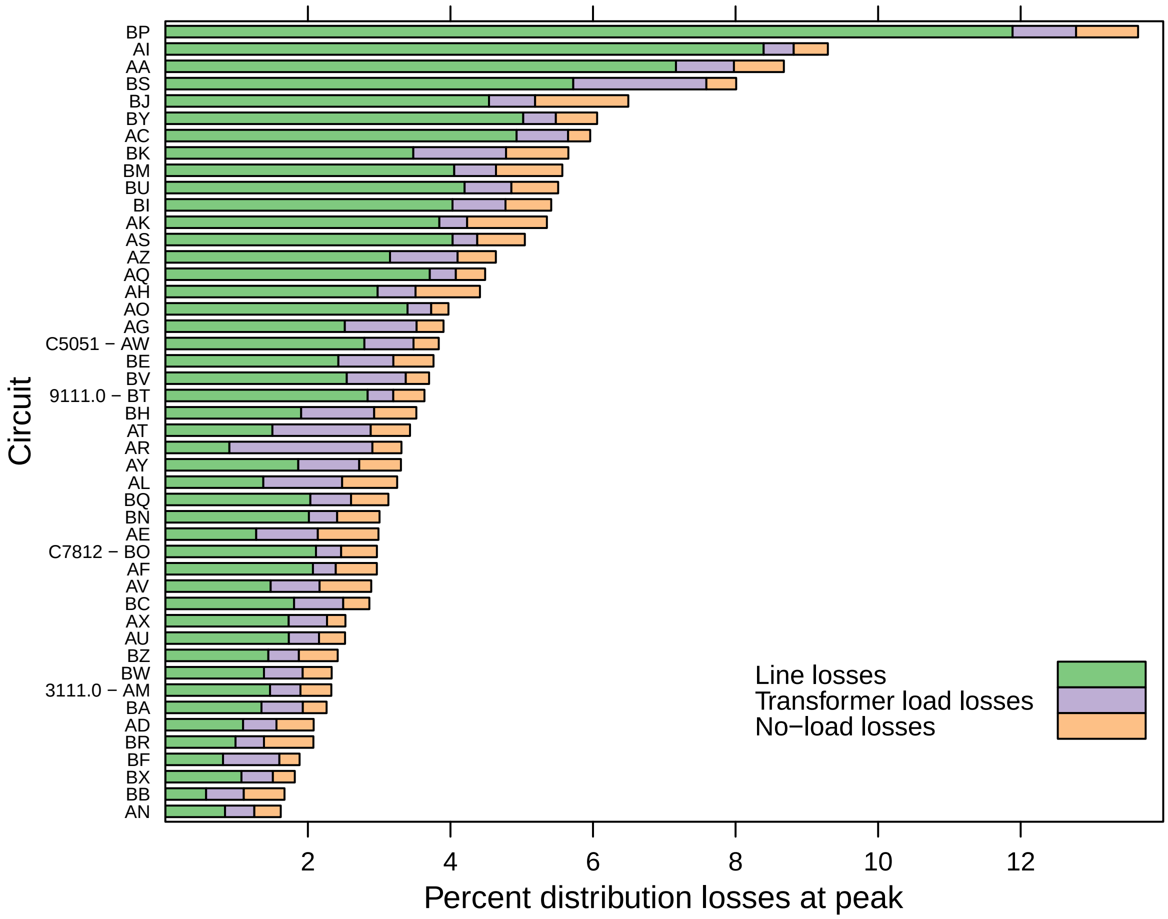


**Figure 3-12**
**Circuit Losses at Peak Load**

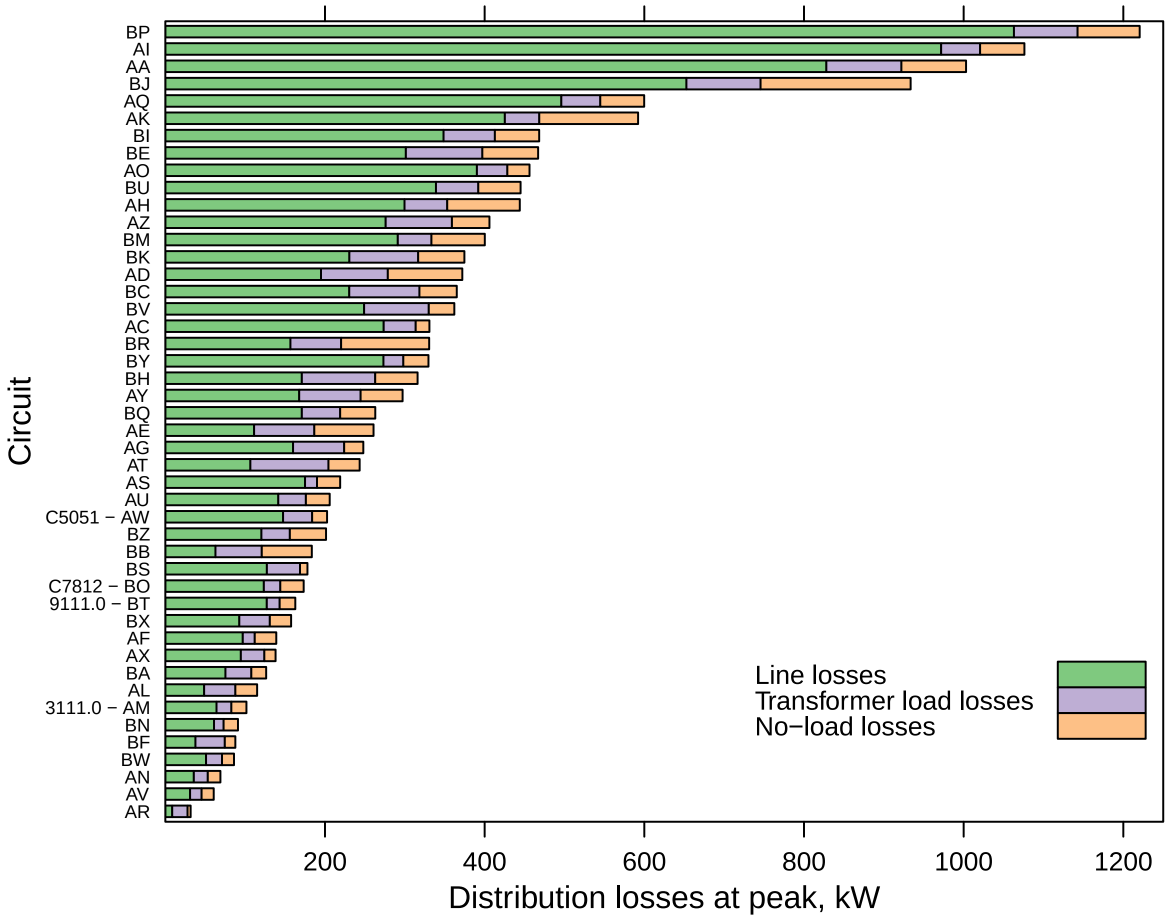


**Figure 3-13**
**Circuit Losses at Peak Load in kW**

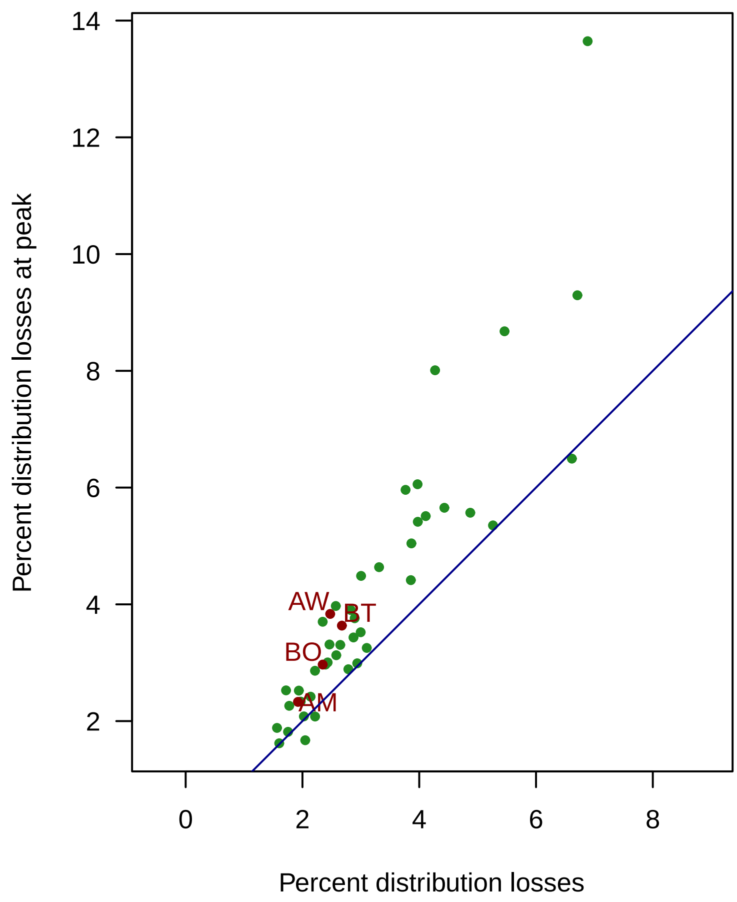


**Figure 3-14**
**Peak versus Average Losses**

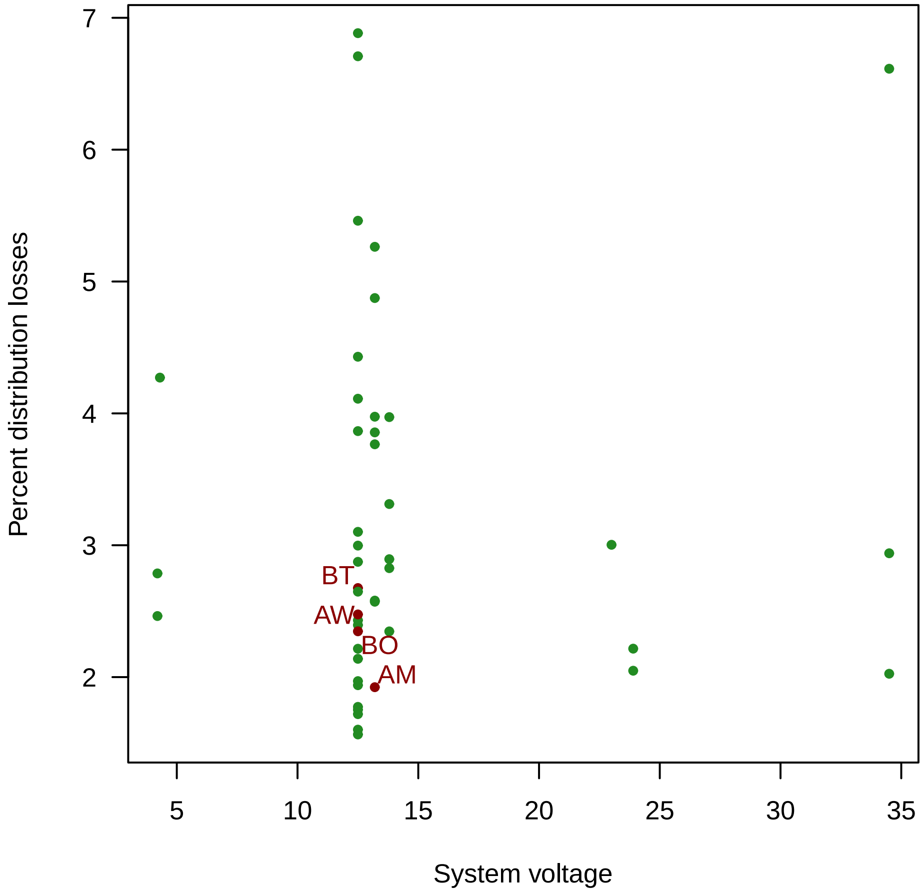


**Figure 3-15**
**Losses by System Voltage**

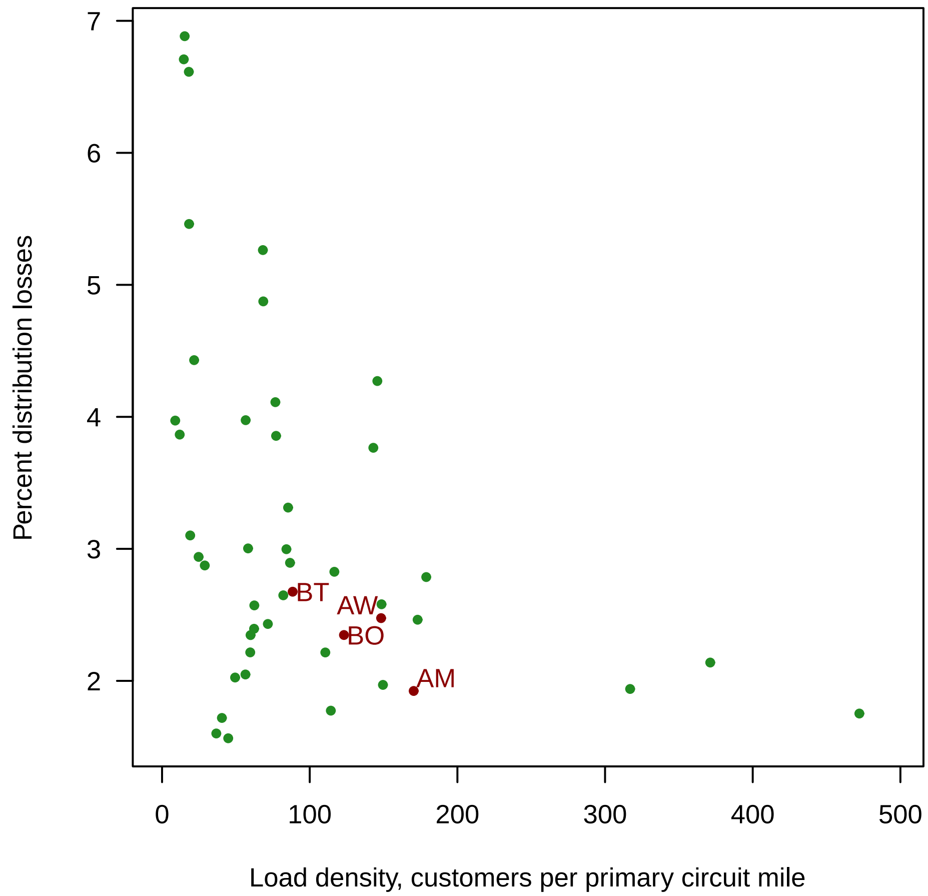


**Figure 3-16**
**Losses by Load Density**

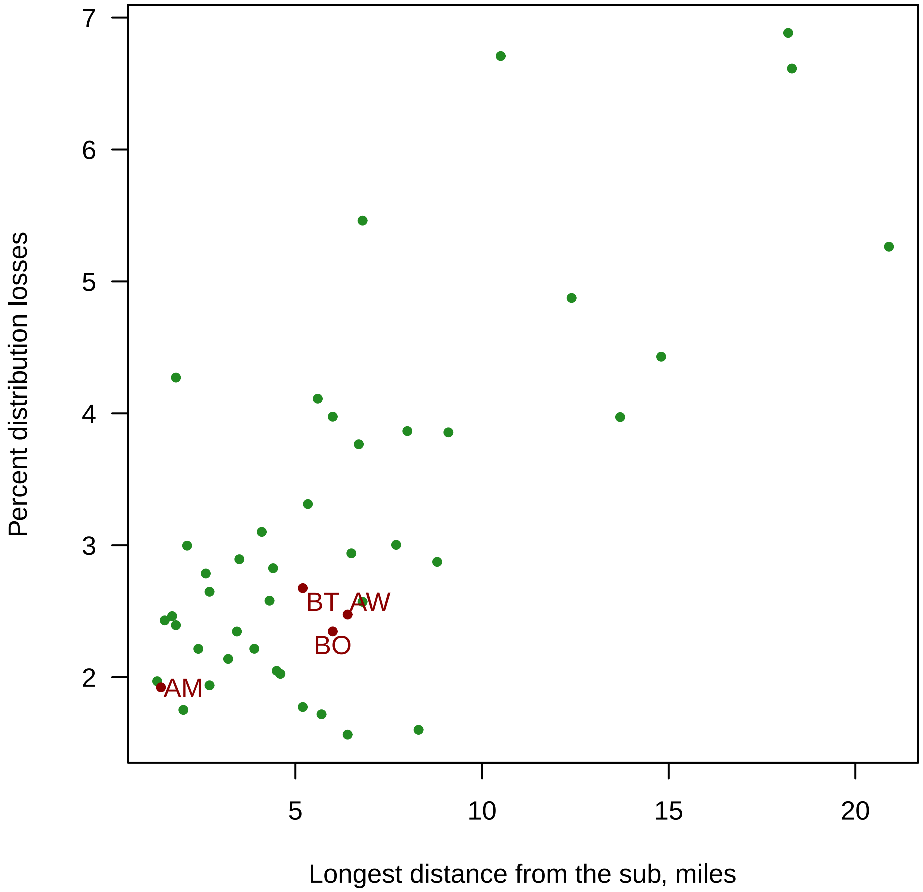


**Figure 3-17**
**Losses by Circuit Length**

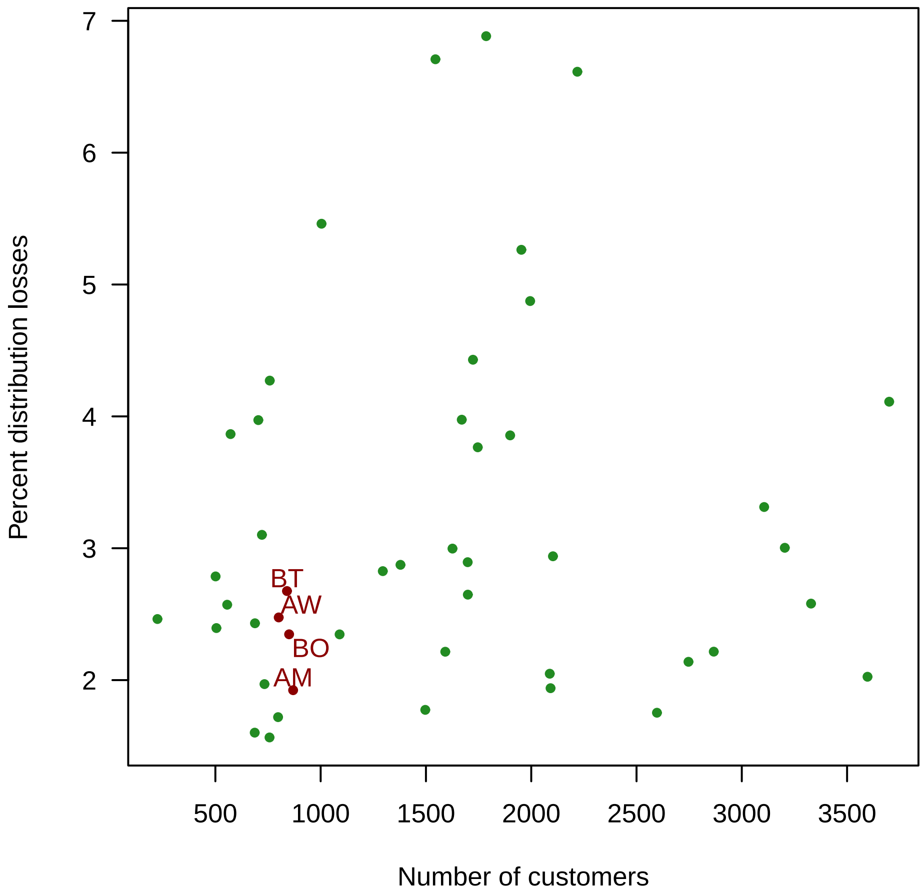


**Figure 3-18**
**Losses by Number of Customers**

## Improvement Options

The following series of graphs shows how several generic efficiency improvements on the KCPL circuits compare with those of other circuits.

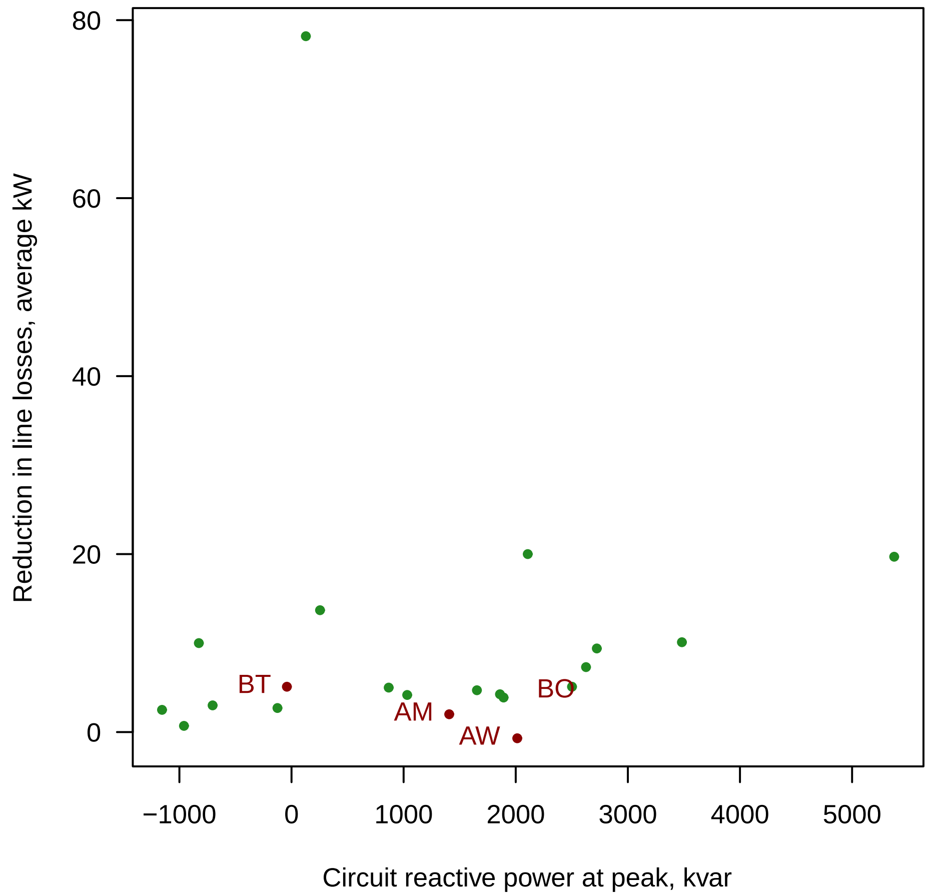


**Figure 3-19**
**Reduction in Line Losses with Ideal VAR Improvement**

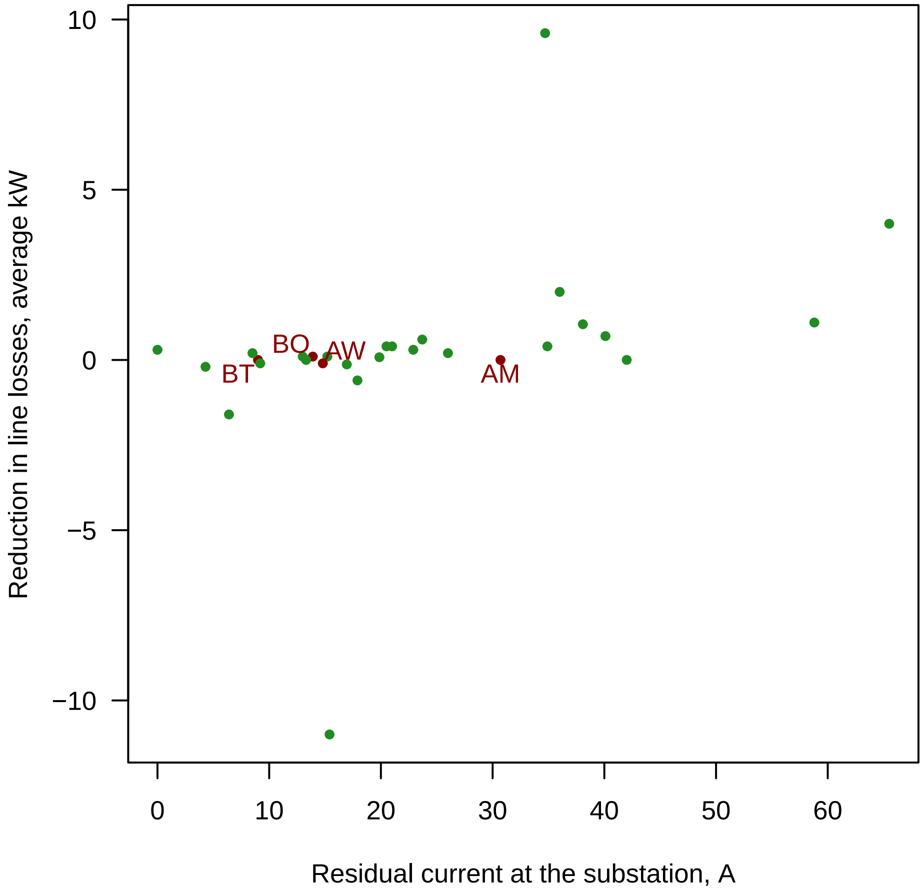


**Figure 3-20**
**Reduction in Line Losses with Ideal Load Balancing**

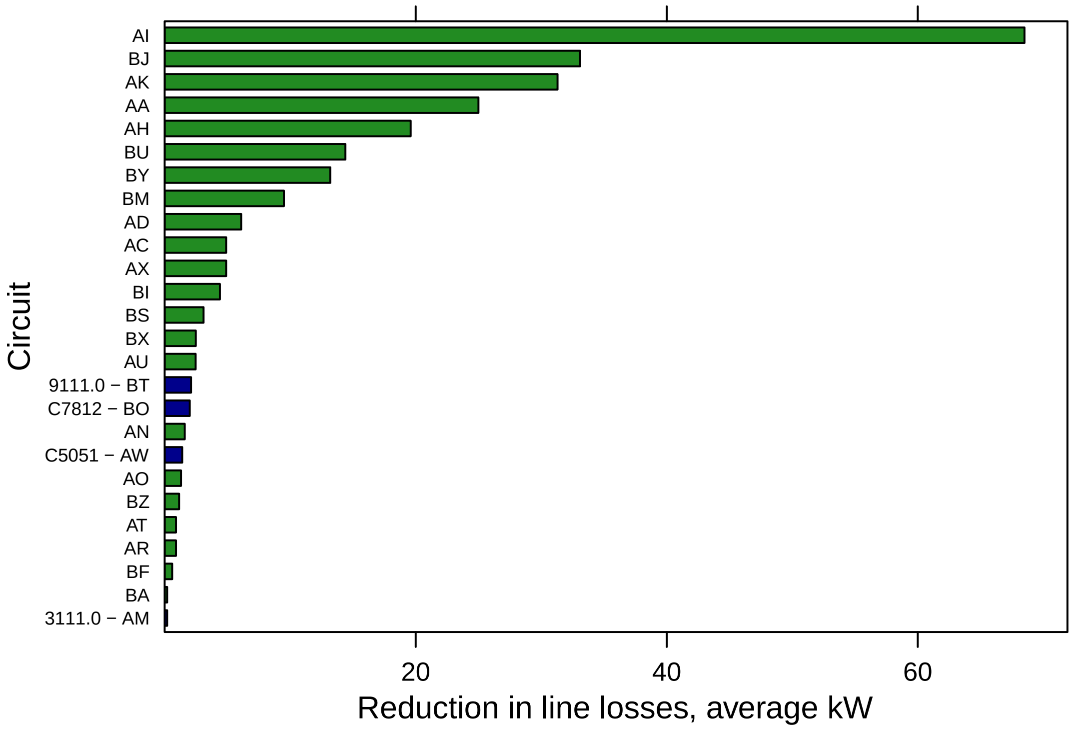


**Figure 3-21**
**Reconductoring Impact on Line Losses**

Figure 3-22 shows the reduction in load when voltage optimization is used. Figure 3-23 shows the same information on a kilowatt basis. Figure 3-24 shows similar results but for peak losses.

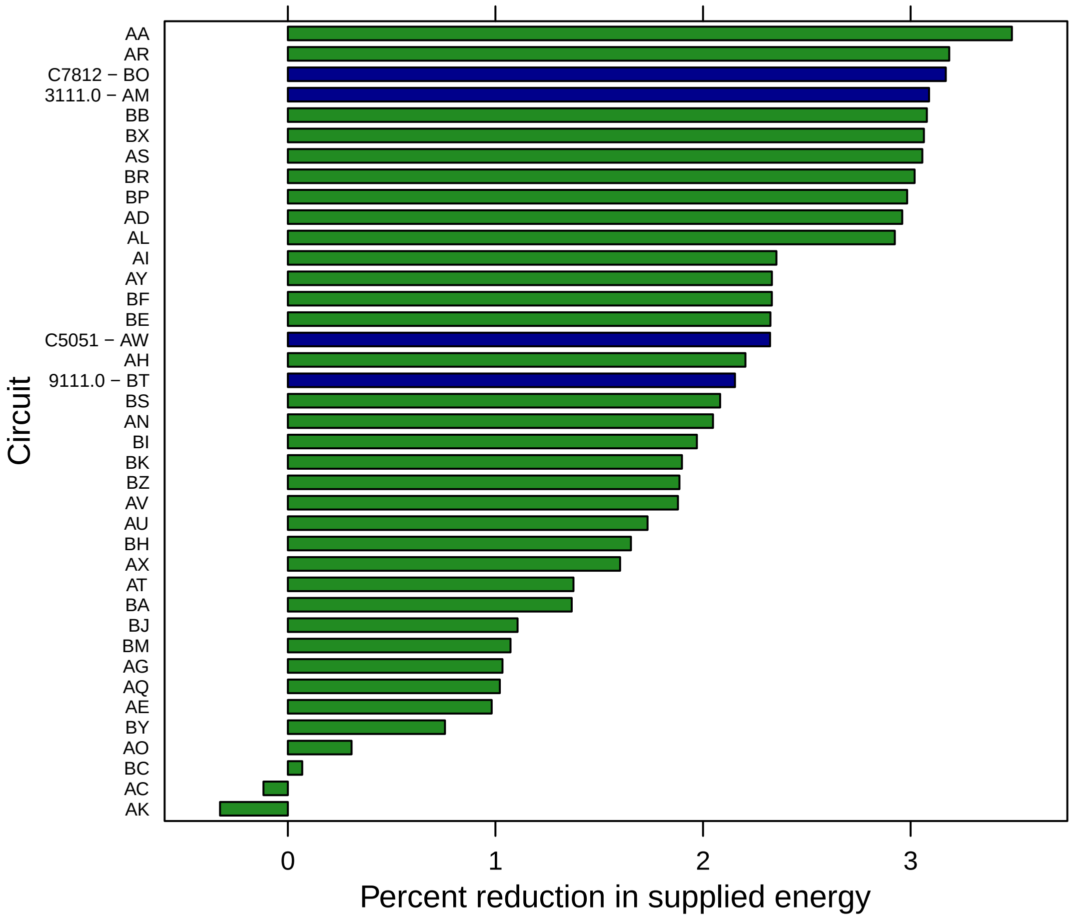


**Figure 3-22**
**Reduction in Energy Supplied with Voltage Optimization**

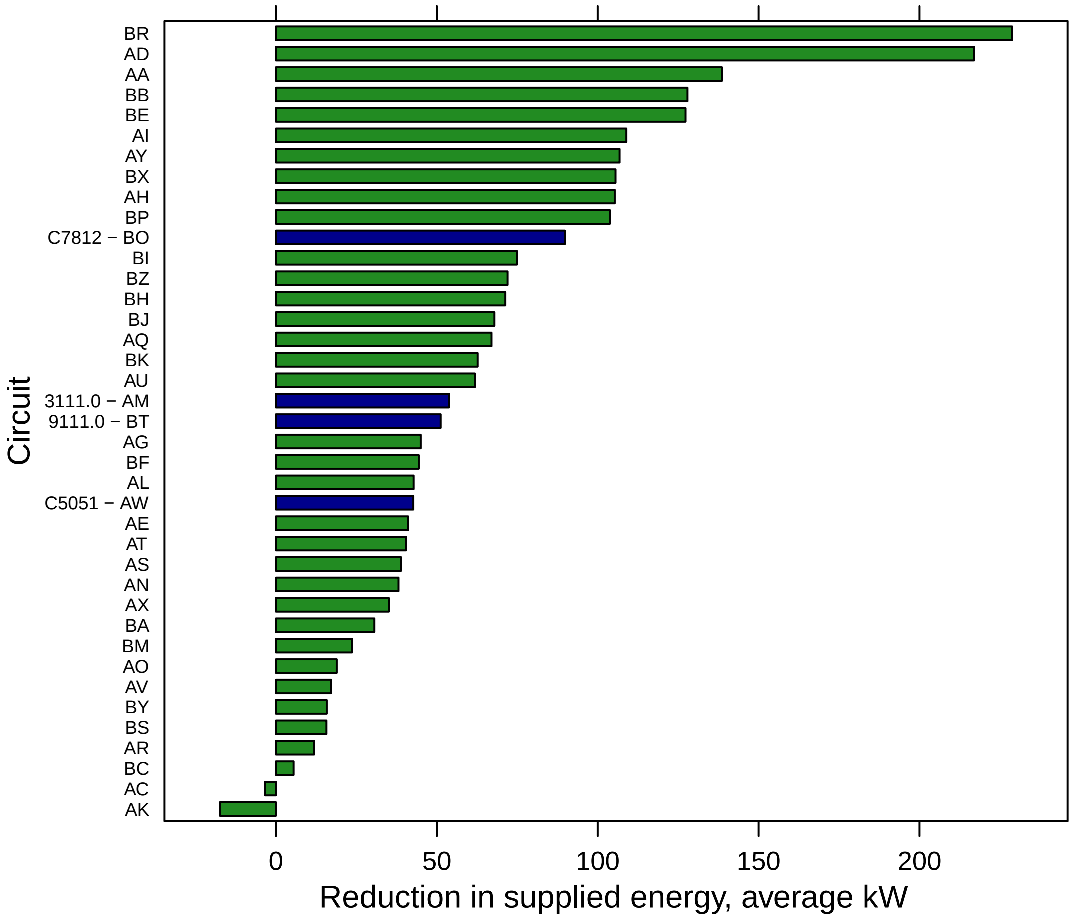


**Figure 3-23**
**Reduction in Average Energy with Voltage Optimization (Average kW)**

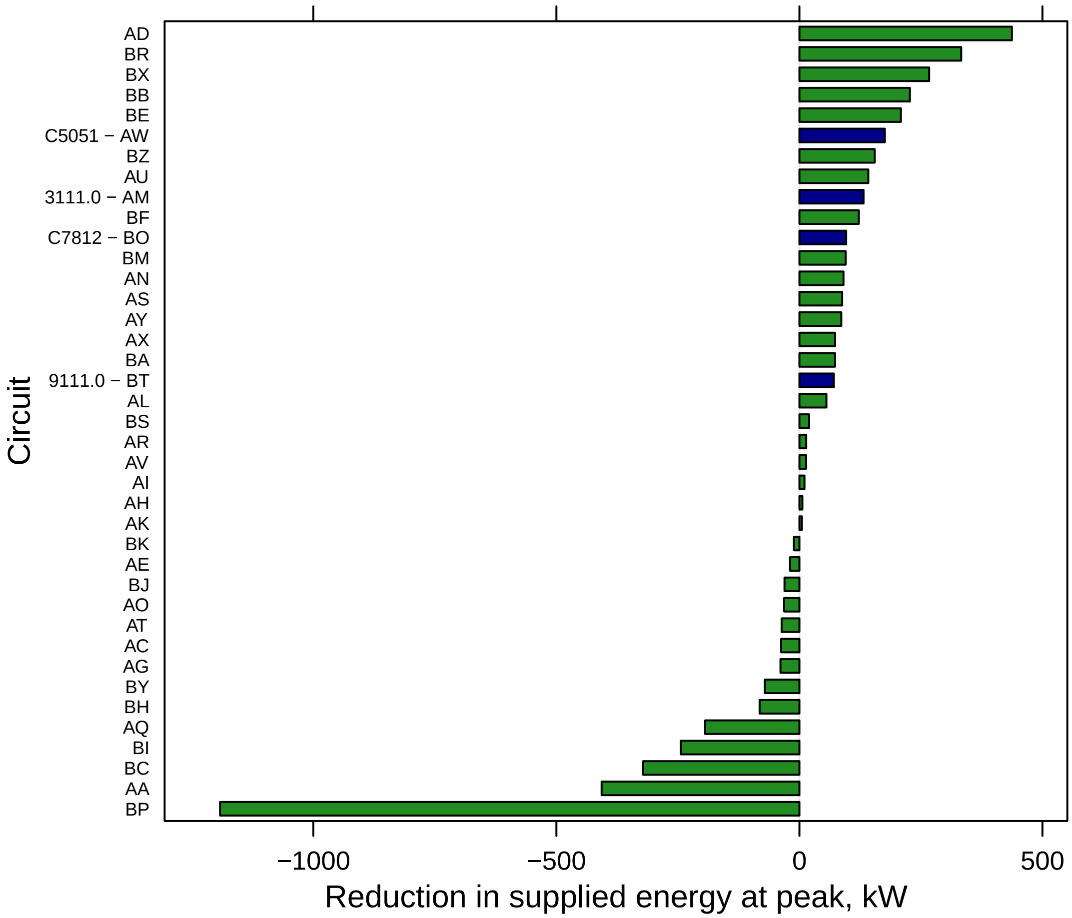


**Figure 3-24**
**Reduction in Peak Loading with Voltage Optimization (kW)**

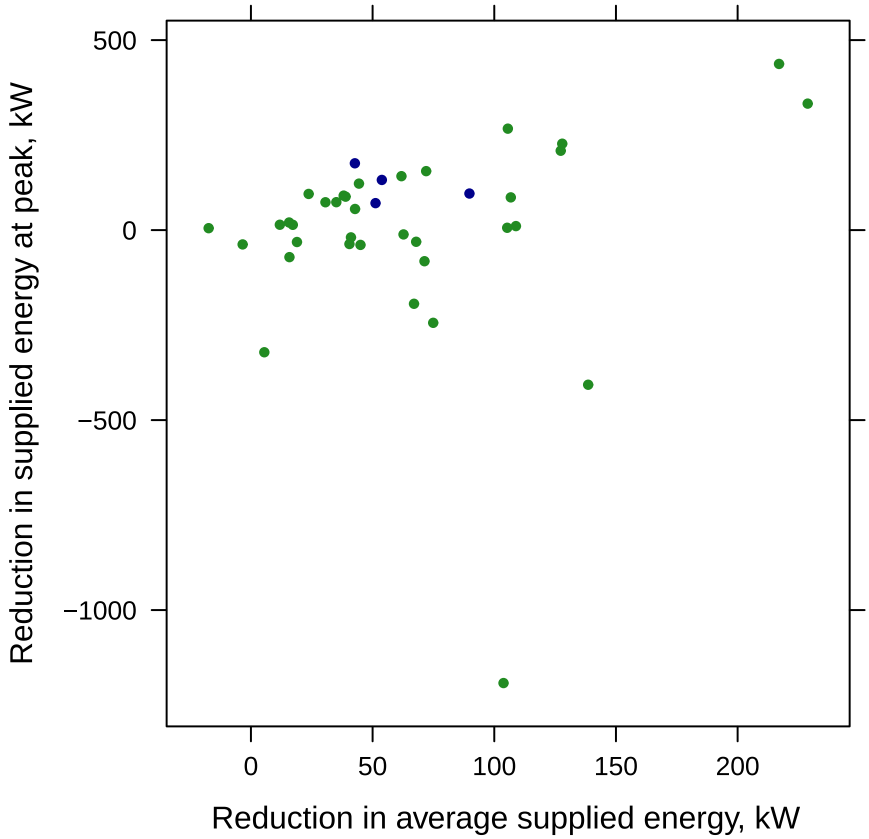


**Figure 3-25**
**Comparison of Reduction in Energy with Reduction in Peak Demand**