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Tacoma Power/AVTA PHEV Demand and Energy Cost Demonstration - Analysis Report

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EXECUTIVE SUMMARY

The U.S. Department of Energy’s Advanced Vehicle Testing Activity (AVTA) is conducting a plug-in hybrid electric vehicle (PHEV) demonstration, and as of the report date, this demonstration includes the testing of more than 250 PHEVs from 12 original equipment manufacturers and PHEV conversion companies in 23 states, Canada, and Finland. The PHEV demonstration includes dynamometer, test track, fleet, and battery testing activities. In addition to these testing activities, AVTA also is evaluating PHEV infrastructure charging impacts. Tacoma Power, an electric utility located in Tacoma, WA, is the first of several sites where AVTA will install instrumentation to better understand onsite PHEV recharging infrastructure requirements and impacts on electricity use and demand at a representative facility. This report provides results from charging of several PHEVs at the Tacoma Power facility as a preliminary assessment of how PHEVs will impact the electricity grid.

Specifically, this study examined the load impact on the electricity grid of charging three of Tacoma Power’s PHEVs. Data collection required measuring attributes such as current, voltage, power, and energy in a real-time environment. Based on the project scope, three PHEVs from the facility car pool were identified for study use. Monitoring full power consumption was deemed impractical due to the large size of the Tacoma Power facility. Instead, a circuit providing power to a section of the facility was identified as a suitable “mimic” for the entire facility, and monitoring of this circuit was conducted. The candidate system needed to be robust, yet flexible enough in meeting the requirements of a simple installation and removal. Based on this and other criteria, the Wireless Energy Monitoring system from Wi LEM USA was used for this study.

Data were collected over a 3-month period for analysis. AVTA examined the data for patterns in demand energy, time-of-day use, and relational behavior between the facility mimic and PHEV activity. The results presented show PHEV charge event history, output power, standby power, facility power, maximum daily power, and a comparison of the maximum daily power to the facility power.

The project scope also required an analysis of cost as it is currently defined for normal residential and commercial service. Monthly and quarterly cost tables were created to support a cost analysis. The tables contain totals for charging and vehicle standby time. Two different utility service plans from Tacoma Power and Salt River Project, respectively, were used in creating cost tables referred to as Base Plan and Time-of-Use Plan. The reason for inclusion of the latter is that the Salt River Project is one of the few U.S. utilities with rates that vary with time of use.

The study showed significant charging and standby power differences between PHEV conversion integrators Hymotion and Manzanita. Additionally, the study illustrated the potential cost impact of standby/hotel loads. After an examination of all data in the 3-month study period, the key finding is that when all three vehicles were being charged, the maximum percent difference between the facility power and PHEV charging power sum added to the facility power was approximately 5%. Therefore, a potential for demand load problems exist if additional PHEVs are added to the facility mimic.

This Tacoma Power-based PHEV demand and energy cost demonstration was instrumented and performed by Electric Transportation Engineering Corporation staff. The Idaho National Laboratory and Electric Transportation Engineering Corporation conduct AVTA for the United States Department of Energy’s Vehicle Technologies Program.

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ACKNOWLEDGMENTS

The authors and the Advanced Vehicle Testing Activity staff thank Tacoma Power staff for their support and cooperation in making this study possible.

ACRONYMS

AVTA	Advanced Vehicle Testing Activity
EMN	energy monitoring node
PHEV	plug-in hybrid electric vehicle
SOC	state of charge

Tacoma Power/AVTA PHEV Demand and Energy Cost Demonstration - Analysis Report

1. INTRODUCTION

The U.S. Department of Energy's Advanced Vehicle Testing Activity (AVTA) is conducting several studies to better understand the impacts of plug-in hybrid electric vehicle (PHEV) charging on the electricity grid. The Tacoma Power-based study, conducted by AVTA, seeks to elucidate the impact of three PHEVs on energy and power demand at a specific facility. Participants in this study include the U.S Department of Energy, the Electric Transportation Engineering Corporation, Idaho National Laboratory, and Tacoma Power. This work was conducted for the U.S Department of Energy's Vehicle Technologies Program.

Individual charging measurements were taken for each PHEV in the study. Additionally, energy and power usage measurements were taken for the facility mimic. All data for the PHEVs and the facility mimic were collected and stored onsite. Each PHEV was assigned a charging stall for its sole use. The vehicles selected were part of the facility vehicle pool and no modifications were made to normal usage. The selected vehicles were identified as PHEV-1 (a Hymotion Prius PHEV conversion), PHEV-2 (a Manzanita Prius PHEV conversion), and PHEV-3 (a second Hymotion Prius PHEV conversion). The Hymotion Prius vehicles have a 5-kWh battery pack and the Manzanita Prius vehicle has a 4.7-kWh battery pack. For the purpose of this study, service panel 2A, which supplies power to Administrative Building 2 – East, was selected as the facility mimic.

In consultation with Tacoma Power engineering staff, monitoring hardware was installed, configured, and tested at the commencement of this study. Data from a test laptop were downloaded on a weekly basis for analysis by AVTA engineers. The analysis documents, on a small scale, PHEV load demand and potential cost impact, and suggest optimal cost and load reduction strategies.

2. METHODOLOGY

In order to obtain the required data, a system was designed that took project resource limitations and objectives into account. Because there are only three PHEVs serving as a representative sample for a fleet of 100 vehicles, a scale representation of a facility mimic in proportion to the sample size was determined. As such, a three-phase facility mimic of either 480 V or 208 V with a minimum load of 100 Amps was deemed sufficient to meet the scale requirements.

In order to collect the required data, it was necessary to identify a data acquisition system capable of acquiring data from different locations and delivering the data to AVTA for analysis. Performance attributes in the evaluation consisted of cost, ease of use, data reliability, ruggedness, and the time needed for installation and configuration. The evaluation also included more subjective attributes such as customer support, product flexibility, and an estimated timeline for a proof of concept.

2.1 System Evaluation

The Wi LEM USA system was evaluated at the eTec engineering center. Product samples were provided along with a field engineer from Wi LEM USA to provide training on operation, configuration, and installation. The Wi LEM USA devices proved capable of measuring the anticipated small loads. A data sheet for the Wi LEM USA system is located in Appendix A.

A second system was also evaluated at the eTec engineering center. Product samples were provided with product literature that covered installation and operation. The evaluation found this system was less than optimal for the small loads that would be part of the Tacoma Power research evaluation

Based on the results of the evaluation, the Wi LEM USA product was adopted as the system platform for this study.

2.2 Wi LEM USA Hardware

The Wi LEM USA hardware operates on a wireless network topology map (see Appendix A). The wireless topology map consists of four elements: (1) single-phase energy monitoring nodes (EMNs); (2) three-phase EMNs; (3) wireless mesh nodes; and (4) a wireless mesh gate. The wireless mesh gate transmits all data acquired from each EMN to a test laptop using a serial cable. Individual stages of the wireless topology net and corresponding data flow are explained in the following subsections.

2.2.1 Single-Phase Energy Monitoring Node

This device measures current, voltage, and power of an individual circuit serving a PHEV charging stall. The EMN consists of three wire leads: one lead for supply voltage, another for ground, and one current transducer clamp. All measured data enter the EMN through the current transducer clamp. The single-phase EMN has a maximum current load of 20 amps, with a full-scale accuracy rating of 99% (the device is shown in Figure 1).

Figure 1. Single-phase energy monitoring node device.

2.2.2 Three-Phase Energy Monitoring Node

This device measures multiple phases at a small facility load center. The three-phase EMN has three current transducer rings, one assigned to each phase of a three-phase circuit. In similar fashion to the single-phase EMN, each current transducer ring must have a corresponding wire termination to measure voltage and current on the assigned phase. Like the single-phase EMN, the three-phase EMN is powered by a series of separate supply wires for each phase (the device is shown in Figure 2).

Figure 2. Three-phase energy monitoring node device.

2.2.3 Wireless Mesh Nodes

The wireless mesh nodes receive data packets from individual EMNs based on an assigned frequency channel. There is one frequency channel for every EMN, with a maximum of 25 channels per node. Each node transmits data on a unidirectional path to either a pickup wireless mesh node or directly to the mesh gate. The wireless signal is a low-power class transmission, typically less than 1 W. Each node contains its own power adapter that is serviced by outlet power (the device is shown in Figure 3).

Figure 3. Wire mesh node device.

2.2.4 Mesh Gate

The mesh gate is connected directly to the test laptop through a serial communications port. Data passes through the mesh gate by using a Modbus Protocol stack. This is accomplished by way of a master and slave ID relationship. Each EMN is assigned a master ID address while the attribute data are assigned a slave ID address. Attribute data selected for this study involve current and voltage measurements. Like the wireless mesh node, the mesh gate has its own power adapter serviced by outlet power (the device is shown in Figure 4).

Figure 4. Mesh gate device.

2.3 Front-End Software

Wi LEM USA provides front-end software for Modbus slave and master ID addressable data types covering all Wi LEM USA products. The output is displayed as a graph on a test screen, along with an associated error status level. Data are converted and displayed as a CSV file at the post-process stage. This platform would have been adopted but the project required the development of a custom front-end software interface.

The front-end software interface is designed to perform four main functions: (1) raw data acquisition, (2) scaling, (3) post-processing of results, and (4) saving the post-process data into a raw text file. All of these activities occurred every 5 minutes using the system clock on the associated test laptop. The front-end software flow chart is located in Appendix A.

2.3.1 Raw Data Acquisition

The front-end software acquires raw data by receiving current and voltage slave ID addresses from each EMN. The raw data are passed through an error check array and indexed to match the system timer of 5-minute increments. Subsequently, the data are converted from hexadecimal format to decimal and integer formats.

2.3.2 Scaling

Each EMN made by Wi LEM USA has a scaling factor based on the rated, full-scale input accuracy of the device. The scaling operation consists of converting every PHEV slave address attribute to decimal form by multiplying its value by a corresponding scaling factor. After the scaling operation, post-processing tabulations are able to take place. Post-processing tabulations are applied to the output power for each PHEV and for the three-phase facility mimic.

2.3.3 Post-Processing

Data are displayed on the screen of the test laptop and are updated in 5-minute intervals. As data are displayed on the screen, they are written to a text file for each PHEV and for the three-phase facility mimic. This operation continues while the error array state remains true. Once it changes state to false, the software aborts while leaving all previously recorded data untouched. A sample screen shot of the front-end software is illustrated in Figure 5.

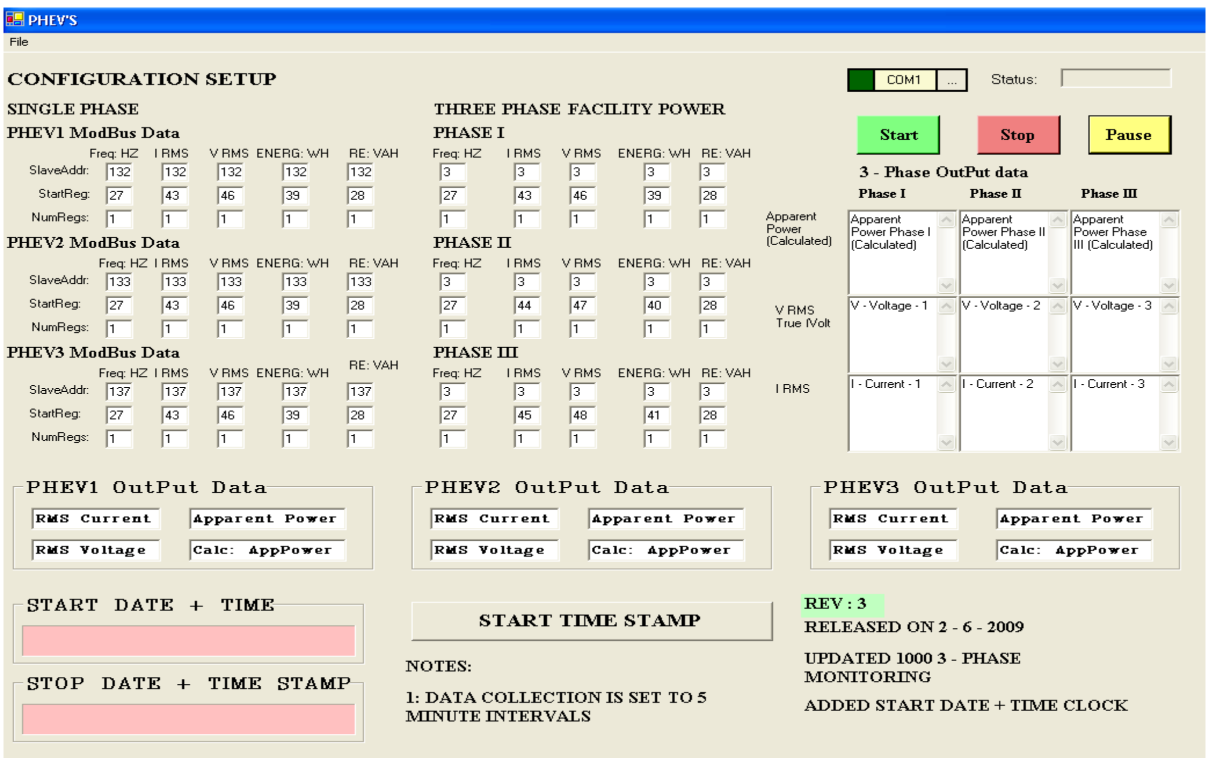

Figure 5. Front-end software screen shot.

2.3.4 Saving the Post-Processing Results

All post-processing data are saved into a text file with an associated time stamp. A separate file exists for each PHEV and for the three-phase facility mimic. The file structure is delivered as a text string in the format of a delimited file. All post-processing results were transferred to an Excel spreadsheet for analysis.

2.4 Proof-of-Concept Electric Transportation Engineering Corporation Site

Once the software was written and all errors addressed, a validation test was conducted at the Electric Transportation Engineering Corporation's PHEV test site. In evaluating the performance of the software and hardware integration, a series of five tests were conducted, requiring a mock exercise of setup and tear down of the entire system. Appendix A, Figure A-5 shows a base plan layout for installation of EMNs, charger locations, and wireless mesh nodes.

Results of the tests showed specific challenges in activating the wireless topology net, along with discovering a problem with the three-phase EMN not measuring all three phases consistently. It was later found the current transducer ring measuring Phase A was susceptible to cage noise. Why and how this happens is unknown. It is believed to be caused by a proximity issue of all three-phase wires being too close to one another. The error fell exclusively on Phase A repeatedly throughout the tests, and the data from Phase A were discarded. Total power was calculated by averaging the power from Phase B and Phase C and multiplying the result by three. It is unknown to what extent this data correction affected the results; however, it was decided that the impact was negligible.

The proof-of-concept test validated the operation of the EMNs and verified a successful deployment of the wireless topology net. Challenges remain in terms of establishing an efficient procedure for installing mesh nodes in support of a robust wireless topology net. Procedures for data collection, formatting, and installation were developed and implemented.

2.5 Pre-Installation at Tacoma Power

Installation at Tacoma Power occurred on April 25, 2009. Prior to installation, assistance from the engineering team at Tacoma Power proved to be extremely valuable. The engineering staff offered information about the building plans, interior photographs of the facility, and advice concerning possible facility mimic candidates. Specific details were provided by the engineering team as an aid in selecting locations for the EMNs and wireless mesh nodes. Tacoma Power also offered the assistance of a qualified electrician.

Using detailed drawings offered by Tacoma Power, a location plan and installation instructions were drafted. The document was developed in consultation with AVTA and Tacoma Power engineering staff. Special arrangements were made by Tacoma Power management concerning the requirements of a power shut-down in support of the three-phase EMN installation.

In meeting the requirements of a successful installation, the engineering staff at Tacoma Power offered several suggestions for overcoming potential noise and wireless signal barriers. A collaborative effort with Tacoma Power produced a sound strategy for installation and setup. Based on this, an estimate of 8 hours for installation was recommended using the service of a qualified electrician. Because of the novelty of the study, AVTA engineering provided support for field installation. The applicable installation drawing is located in Appendix A. Installation/setup instructions for the Tacoma Site are located in Appendix B.

2.5.1 Selection of a Facility Mimic

Based on several conference calls and research on behalf of the Tacoma Power engineering team, a facility mimic was selected as the best scale model of a commercial facility power load. The facility mimic, shown in Figure 6, controls all loads servicing Administration Building 2 – East. The facility mimic is a three-phase, 208-V, 4-wire, delta connection type, with a 100-A service load.

Figure 6. Facility mimic panel.

2.5.2 Placement of Energy Monitoring Nodes in the Vault

The engineering staff provided location photographs for the single-phase circuits supporting PHEV charging stations. Based on information contained in the photos, an installation instruction for EMN placement was created. This instruction is unique to Tacoma Power. Figure 7 shows the location of single-phase PHEV monitoring circuits.

Figure 7. Energy monitoring node location for single-phase monitoring circuits.

2.5.3 Wireless Mesh Node Locations

Tacoma Power engineering staff provided support in determining candidate locations for the wireless mesh nodes. Figure 8 illustrates candidate locations for placing wireless mesh nodes. Figure 9 shows conduit runs for placing wireless mesh nodes in addressing the concrete wall barrier.

Figure 8. Wireless mesh node location.

Figure 9. Conduit runs for the wireless mesh nodes.

2.5.4 Assistance of an Electrician

Using tools available at Tacoma Power, an electrician secured power, terminated wires, and placed the EMNs and wireless mesh nodes. Because of the unique circumstances involved with installation, the electrician's trade knowledge provided alternatives for deployment of the wireless topology net, along with specific issues associated with the three-phase EMN.

2.6 Installation at Tacoma Power

Cooperative efforts with the facility electrician made for a successful installation of all EMNs and wireless mesh nodes. The installation procedure had six steps: (1) equipment inventory and layout, (2) installation of three-phase EMNs, (3) installation of single-phase EMNs, (4) installation of wireless mesh nodes, (5) validation testing of the wireless topology net, and (6) certification for remote logging. Details for each step are defined in greater detail as follows:

1. Equipment inventory and layout

   An accounting for all equipment, including EMNs, wireless mesh nodes, mesh gates, the test laptop, and support for all hardware, took place. Based on consultations with Tacoma Power during the pre-installation phase, it was decided to first install the three-phase EMNs, followed by the single-phase EMNs.

2. Installation of three-phase EMNs

   The three-phase EMNs were installed using a four-wire termination in powering the device. The three-phase EMNs contain one current transducer clamp for each phase line. Like the single-phase EMN, the three-phase EMN transmits data to the mesh gate.

3. Installation of single-phase EMNs

   The single-phase EMNs were installed using three-wire termination for powering the device. The current transducer clamps were placed on a conductor for the assigned PHEV circuit. It is important to note that the EMN sends energy data exclusively from the current transducer ring to the mesh gate. The power lines have no effect on the transmitted data.

4. Installation of wireless mesh nodes

   The wireless mesh nodes were installed using a trial-and-error method to ensure that the signals between wireless mesh nodes and between EMNs and wireless mesh nodes were able to be received. Several of the initial locations did not allow for full signal transmission for extended periods; therefore, different locations were chosen until the transmission levels were acceptable.

5. Validation testing of the wireless topology net

   This step was the most difficult of the installation process. The site conditions required a flexible strategy in placing the wireless mesh nodes. The Tacoma Power electrician provided extension cords, zip ties, and extra wire as needed. As each mesh node was validated by the mesh gate, another node would be installed until all nodes were placed and validated.

6. Certification for remote logging

   Once the wireless topology net was validated and the test laptop was secured in the vault, certification for remote logging could begin. Data were captured using the front-end software described above. The program collects data from the single-phase EMNs and the three-phase EMNs on 5-minute intervals and stores the data on the laptop hard drive. In order to validate the data being taken, assigned vehicles were plugged and unplugged every 5 minutes for a total elapsed time count of 30 minutes. The facility electrician measured the output current for each PHEV and three-phase line of the facility mimic. Based on the results from the electrician's PHEV measurements, a scaling issue arose concerning the EMNs monitoring of the PHEV circuits. The scaling phenomenon was confirmed by an examination of an additional ten readings. Consequently, scaling was taken into account in compiling the results.

3. RESULTS

Data collection for all PHEVs and the three-phase facility mimic was conducted for 3 months, although the months were not immediately consecutive. As data were collected and stored in the test laptop, retrieval of the data was conducted remotely. The raw data were converted and scaled using Excel. An analysis of the results was conducted using Excel and MATLAB. The analysis results of the PHEV data collection, facility data collection, and comparison between the two are discussed in the following subsections.

3.1 Plug-In Hybrid Electric Vehicle Data Collection

The PHEV data cover all charging activity for each PHEV in the study. Specific data elements include current, voltage, and energy, as collected on a 5-minute interval basis throughout the length of the study. This relatively long data collection interval means that the absolute numbers presented are not entirely accurate. The power value at the polling instant is assumed to be constant for the 5-minute interval; this assumption could significantly affect the energy calculated for each interval. However, the overall effect is judged to be negligible. Error correction for the EMNs, charging monitoring equipment on the assigned PHEV circuit, and environmental conditions were taken into account in preparation for reporting all results for this study.

3.1.1 Charge Events

All charge events for each PHEV were captured and the energy associated with each calculated. In discerning real charge activity from standby power, a value of 20 W was selected for the Hymotion PHEVs and 60 W for the Manzanita PHEV as the threshold minimums. The reason for the discrepancy between the two was that the standby power of the Hymotion PHEVs (when connected) was approximately 16 W, while the Manzanita standby power (when connected) was approximately 52 W. Charging will affect the battery state of charge (SOC), where SOC is a percentage based on the batteries' nominal capacity or energy rating. For the sake of this study, a charging event is defined as an addition of sufficient energy to the battery to raise its SOC by 1%. Therefore, any event not containing enough energy to raise the batteries SOC by 1% or if the battery is already at 100% SOC, are not considered charging events.

After a charge event has completed, battery voltage will settle down to a nominal state that is significantly below that of the batteries top-of-charge voltage. If the vehicle is left plugged in for a relatively long period of time or if the vehicle is unplugged and plugged back in, the battery management system may attempt to recharge the battery even though it is fully charged. This will cause the voltage to ramp up quickly, hit top of charge voltage, and go into a constant voltage charge. These constant voltage charge events show up in the data collected for this project; however, because no additional energy (i.e., less than 1% change in SOC) is being added to the battery, these events are not considered charging events.

The charging energy data are summarized in Table 1. It can be seen from the data that there is a large difference in charging energy totals for PHEV-2 among the 3 months of testing. The other two PHEVs experienced much less variation in the amount of charging. From the data, it appears as though PHEV-2 was left unconnected to its charger and the vehicle was not driven for a substantial portion of the test period.

Table 1. Monthly charging summary.

Month	Vehicle	Total Energy (kWh)	Charging Energy (kWh)
1	PHEV-1	32.8	15.3
	PHEV-2	76.0	37.3
	PHEV-3	49.0	33.9
2	PHEV-1	23.9	7.58
	PHEV-2	27.1	8.7
	PHEV-3	32.2	16.9
3	PHEV-1	21.3	6.3
	PHEV-2	45.2	17.8
	PHEV-3	38.5	27.9

Charge event data for months 1, 2, and 3 are summarized in Table 2. There were 16, 27, and 44 charge events for PHEV-1, PHEV-2, and PHEV-3, respectively. The average charging energies were 1.8 kWh, 2.4 kWh, and 1.8 kWh, which correspond to 36%, 50%, and 36% of nominal capacity, respectively. The maximum charging events as a percentage of nominal capacity were 88%, 141%, and 91%, respectively. It is currently unknown why and how the charge event in Month 1 for PHEV-2 exceeded its nominal capacity.

Table 2. Monthly charge event summary

Month	Vehicle	Charge Events	Average Charging Energy (kWh)	Average Charging Energy as Percent of Nominal Capacity	Maximum Monthly Charging Event (%)
1	PHEV-1	6	2.5	51%	88%
	PHEV-2	14	2.7	56%	141%
	PHEV-3	21	1.6	32%	89%
2	PHEV-1	6	1.2	24%	85%
	PHEV-2	3	2.9	62%	78%
	PHEV-3	11	1.5	30%	66%
3	PHEV-1	4	1.6	31%	88%
	PHEV-2	10	1.8	38%	55%
	PHEV-3	12	2.3	47%	91%

The apparent power during Month 1 is shown for each PHEV in Figure 10. Charging activity is clearly identified by a spike in signal amplitude on the graph. Vehicle disconnect is shown by a break in the line graph. A validation between charge events and PHEV power is seen by observing that the number of charge events in a given month matches the number of signal amplitude peaks on a given PHEV power graph. The average apparent powers during charging events in Month 1 for PHEV-1, PHEV-2, and PHEV-3 were 740 W, 1640 W, and 810 W, respectively. The difference in charging power is due to the different batteries installed by the PHEV integrators Hymotion and Manzanita.

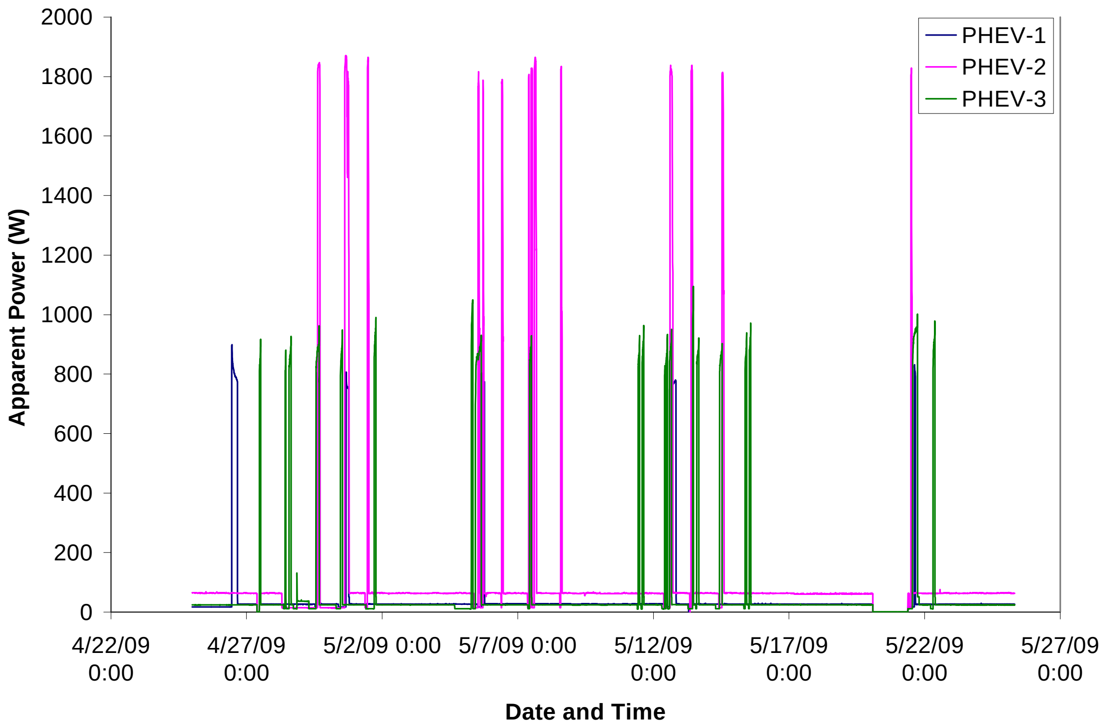

Figure 10. Month 1 apparent power.

The apparent power during Month 2 is shown for each PHEV in Figure 11. The average apparent powers during charging events in Month 2 for PHEV-1, PHEV-2, and PHEV-3 were 640 W, 1500 W, and 770 W, respectively.

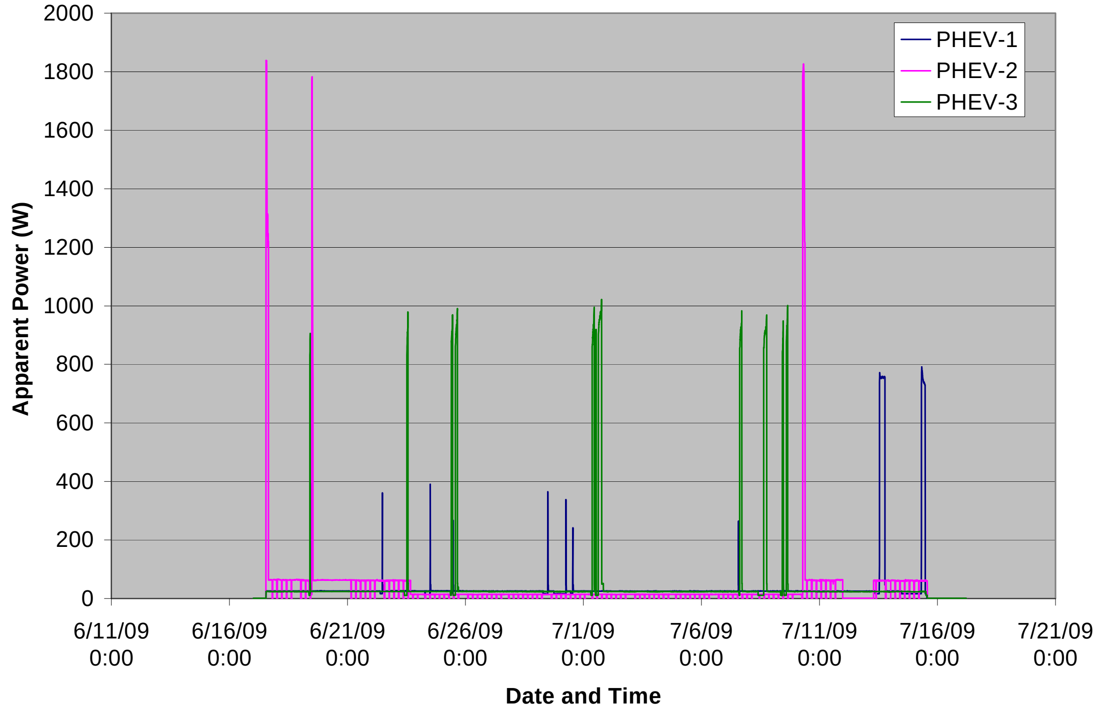

Figure 11. Month 2 apparent power.

The apparent power during Month 3 is shown for each PHEV in Figure 12. The average apparent powers during charging events in Month 3 for PHEV-1, PHEV-2, and PHEV-3 were 630 W, 1300 W, and 620 W, respectively.

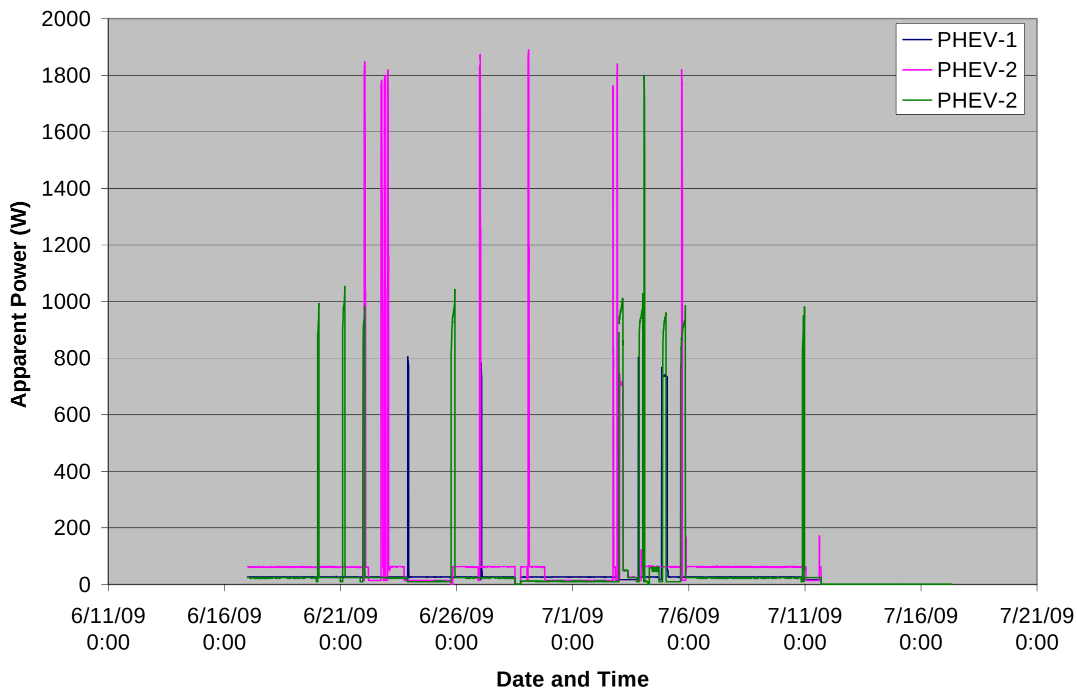

Figure 12. Month 3 apparent power.

3.1.2 Charger and Plug-In Hybrid Electric Vehicle Standby Power

When the PHEVs are not connected to the charger and the power values measured are larger than zero but less than 20 W, the data points are classified as Charger Standby Power. When the PHEVs are connected and the power values are greater than 20 W but fall below the threshold values of 40 W (for Hymotion) and 70 W, the data points are classified as PHEV Standby Power. The Charger Standby Power and PHEV Standby Power data are summarized in Table 3. The data show that the Charger Standby Power values are largely similar, but the PHEV Standby Power values are significantly different for the Hymotion and Manzanita PHEVs. When the Hymotion PHEVs were not connected, the average power draw is 13.7 W; when the Hymotion PHEVs were connected but not charging, the average power draw is 25.3 W. Conversely, when the Manzanita PHEV is not connected, the average power draw is 14.4 W; when the Manzanita PHEV is connected but not charging, the average power draw is 62.2 W. The difference in power draw between the two PHEV types is 36.9 W, for a percent difference of 84.4%.

Table 3. Charger Standby Power and Plug-In Hybrid Electric Vehicle Standby Power summary.

Month	Vehicle	Average Charger Standby Power (W)	Total Charger Standby Power Energy (kWh)	Average PHEV Standby Power (W)	Total PHEV Standby Power Energy (kWh)
1	PHEV-1	17.0	0.9	26.9	16.6
	PHEV-2	14.5	1.1	63.2	37.6
	PHEV-3	10.9	0.7	24.5	14.4
2	PHEV-1	16.2	0.8	25.4	15.5
	PHEV-2	14.2	5.1	62.1	13.3
	PHEV-3	10.9	0.2	24.0	15.1
3	PHEV-1	16.9	0.8	26.7	14.2
	PHEV-2	14.6	2.4	61.2	25.0
	PHEV-3	10.4	1.9	24.1	8.7

3.1.3 Facility Mimic Data Collection

The facility mimic data involved attributes such as current, voltage, and power for each of the three phases. As mentioned previously, the data for Phase A were not captured in a reliable manner. This problem was anticipated based on the evaluation work conducted by AVTA. Therefore, for the purposes of the study, data from Phase A was not included. The remaining Phase B and Phase C were not found to exhibit anomalies and the total power was extrapolated from the other two phases.

Analysis of facility data results is referred to as facility power and daily max power, and the data for the three months are found in Figures 13, 14, and 15. A close examination of the facility power graphs shows instances where data had dropped out. This is due to either the wireless mesh gate or the nodes not operating properly. Because of the small number of data drop instances and, consequently, the short duration of data loss, it was determined that there was negligible impact to the overall results of the study.

The overall pattern on the graphs conforms to typical power consumption during a 5-day work week. The larger peaks represent demand use of office load during the work day. Valleys and smaller peaks represent facility activity during the off hours when demand is lower. In Month 1, the maximum facility power is 72 kW, while the average is 31 kW. In Month 2, the maximum facility power is 83 kW, while the average is 35 kW. In Month 3, the maximum facility power is 116 kW, while the average is 31 kW.

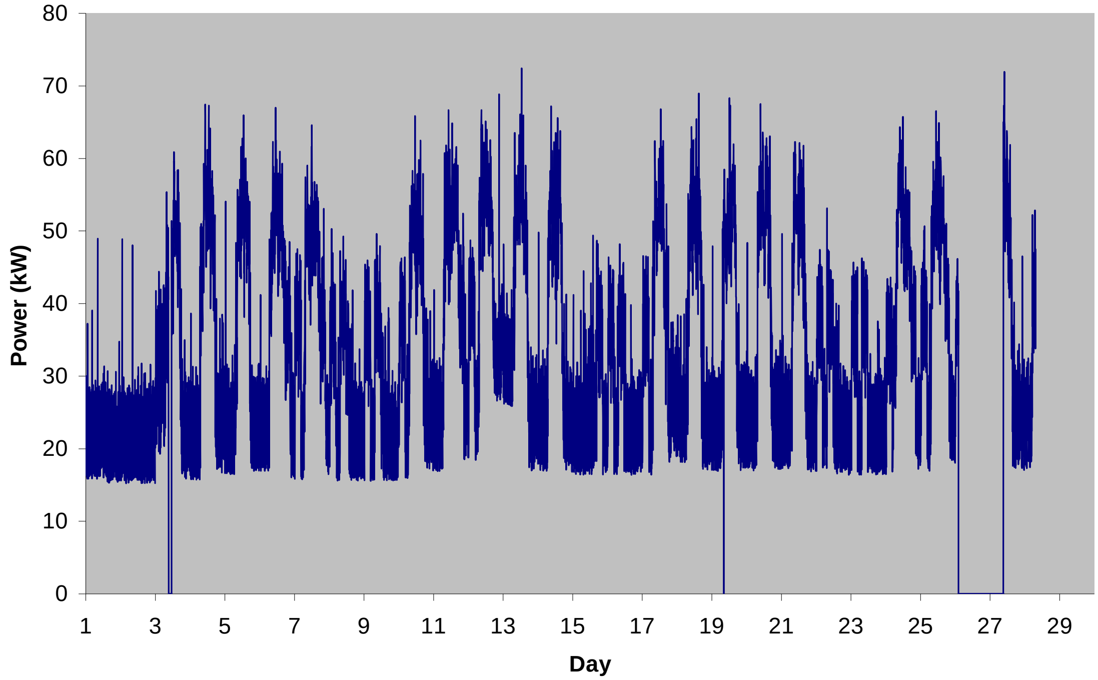

Figure 13. Month 1 facility power.

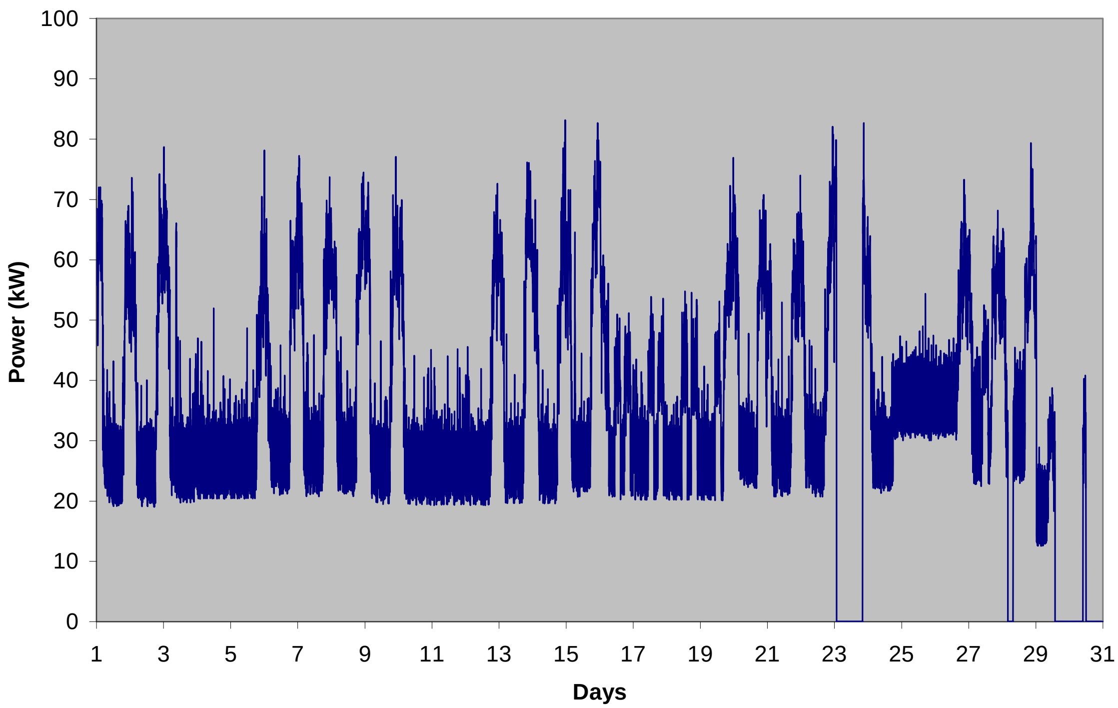

Figure 14. Month 2 facility power.

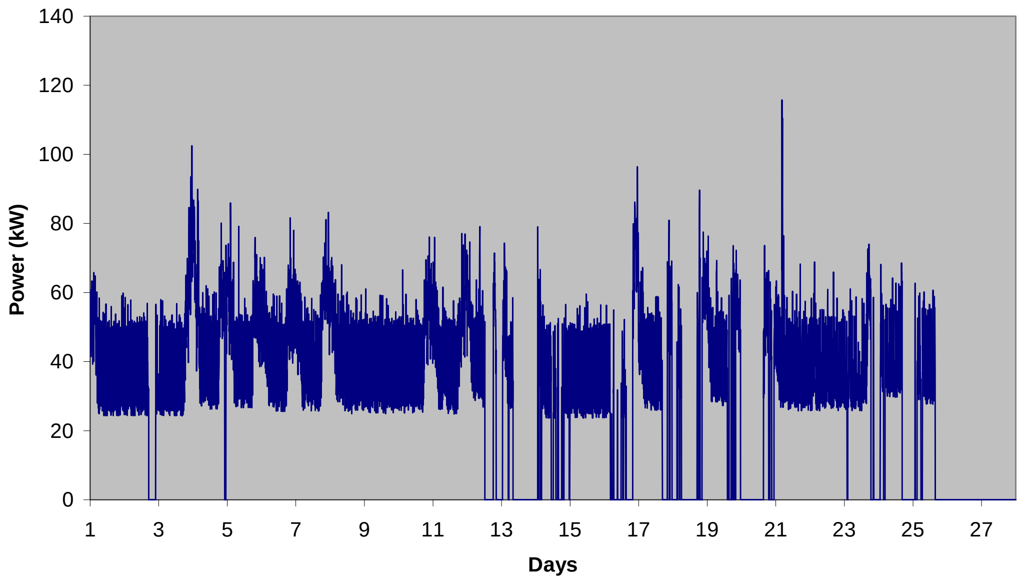

Figure 15. Month 3 facility power.

The facility daily max power is a daily measure of the maximum power for the day in which it was collected. This measure makes no distinction between time-of-day or how long the instantaneous maximum power value lasted on the day it was recorded; however, it is instructive to use these data to measure the effect of adding PHEV charging power, as is done in the following section. Daily max power graphs for Months 1 through 3 can be found in Figures 16, 17, and 18, respectively. The average daily max power values were 61 kW, 70 kW, and 78 kW for Months 1 through 3, respectively.

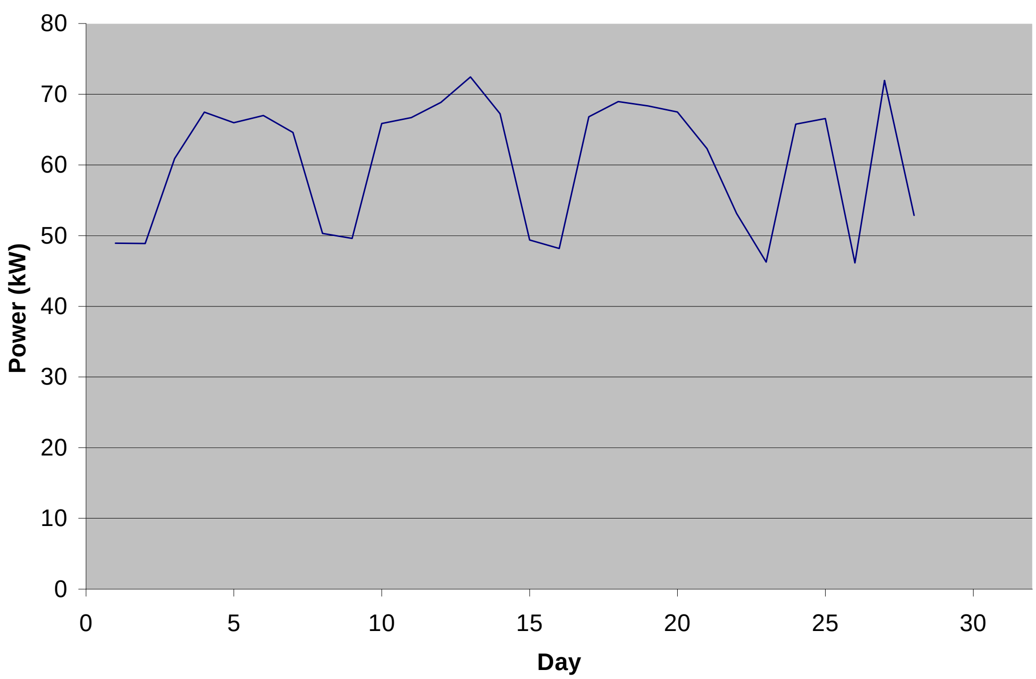

Figure 16. Month 1 facility daily max power.

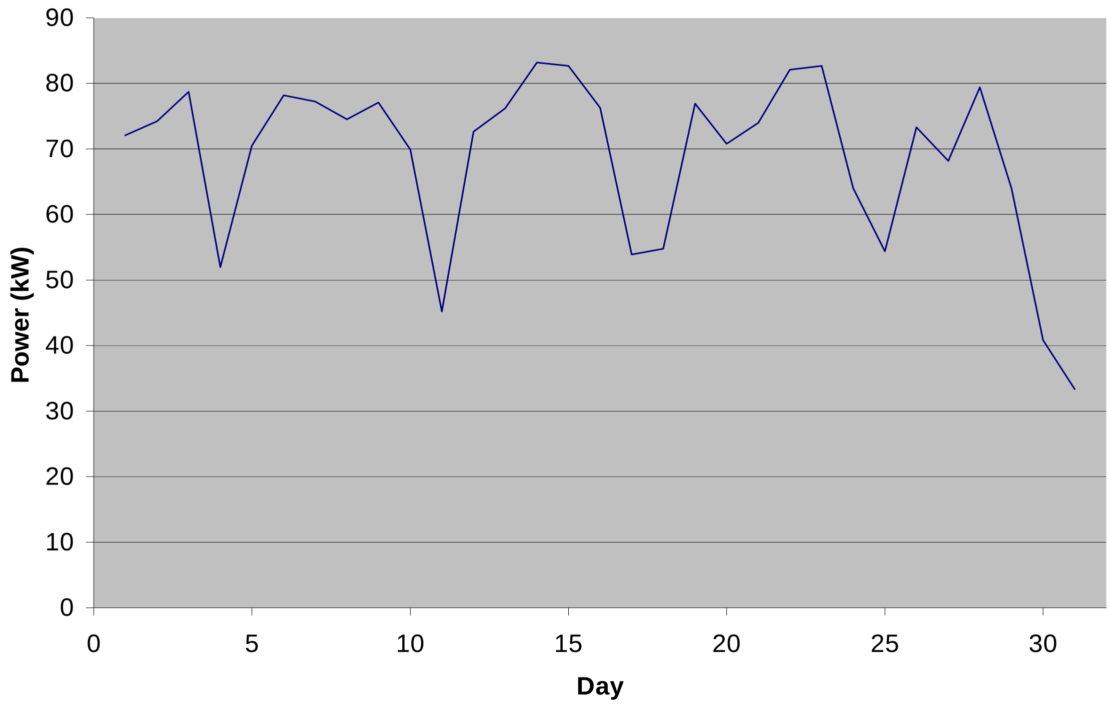

Figure 17. Month 2 facility daily max power.

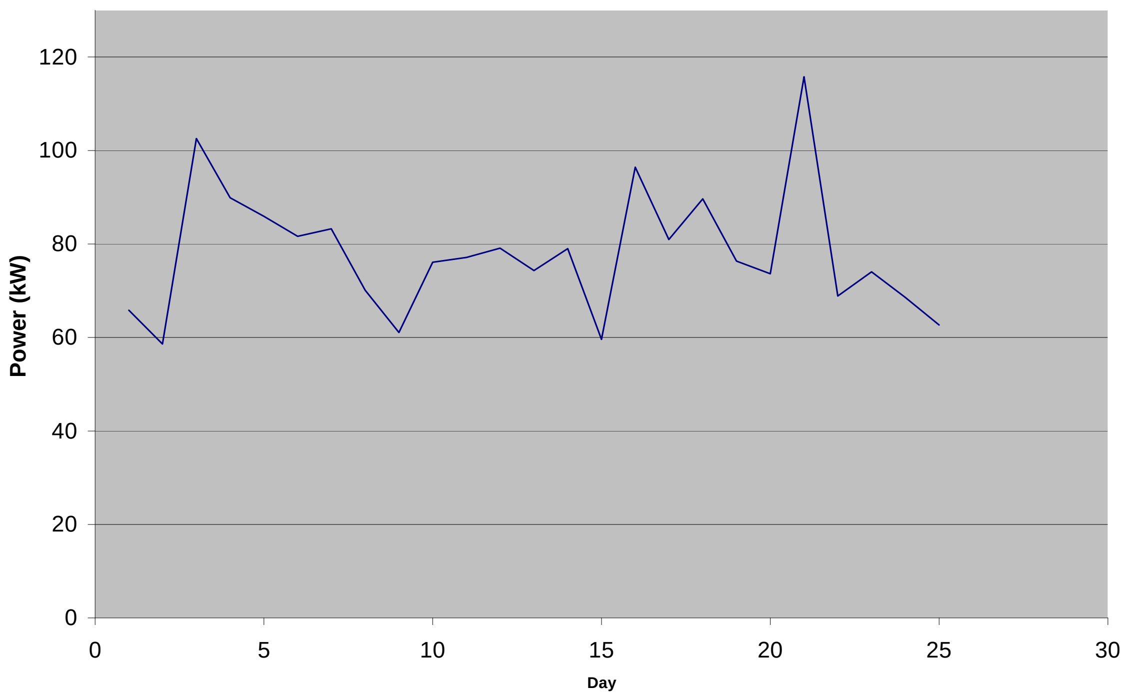

Figure 18. Month 3 facility daily max power.

3.2 Effect of Plug-In Hybrid Electric Vehicle Charging on Facility Demand

In order to gain a better understanding of the loading effect of PHEVs on the facility, comparisons can be made between the sum of all PHEV charging data and the facility demand data. Two such comparisons are presented: one for facility power and another for daily max power. A detailed examination for each is displayed in the following subsections.

3.2.1 Facility Power and Facility Power Plus Plug-In Hybrid Electric Vehicle Power Sum

A comparison of the facility power and facility power plus PHEV power sum as an overlay is used to assist in elucidating the effects of charging on overall power usage. The data for facility power and for facility power plus PHEV power sum were averaged for each time interval for the first test period; this is shown for Month 1 in Figure 19. The minimum difference between facility power and the facility power plus PHEV power sum was 100 W (percent difference of 0.3%), while the maximum difference was 720 W (percent difference of 1.8%). The average difference between the facility power and the facility power plus PHEV power sum was 230 W (percent difference of 0.7%).

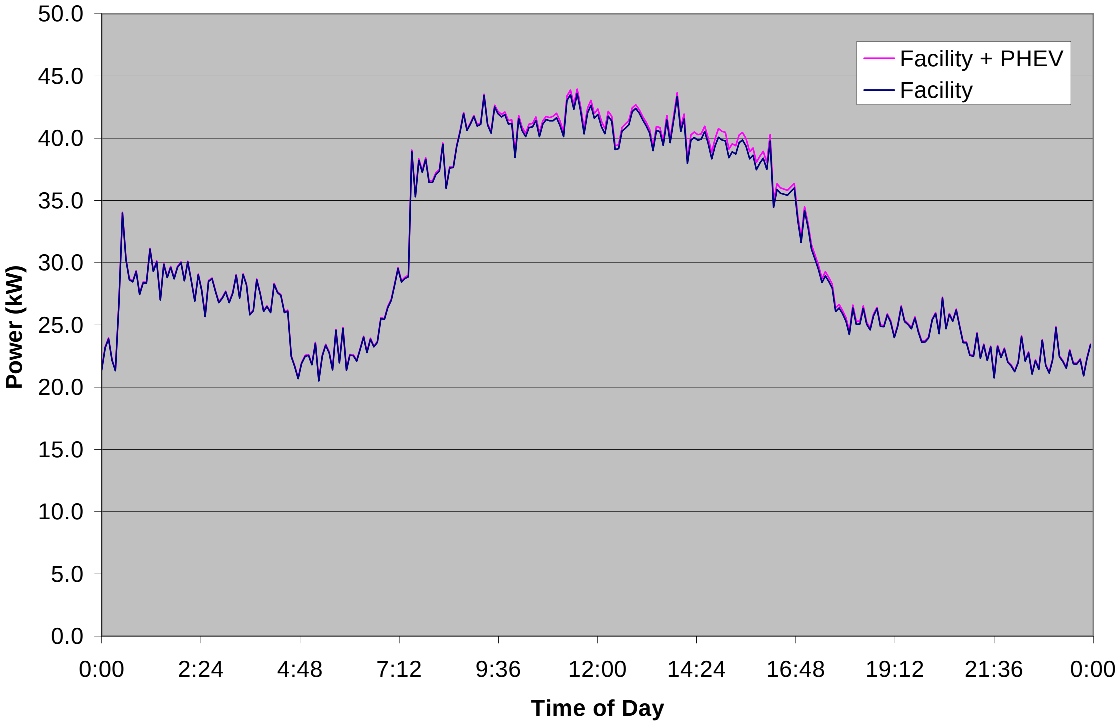

Figure 19. Averaged interval power values for facility plus plug-in hybrid electric vehicle and facility for Month 1.

Data for facility power and for facility power plus PHEV power sum were averaged for each time interval for the second test period; this is shown for Month 2 in Figure 20. The minimum difference between facility power and the facility power plus PHEV power sum was 70 W (percent difference of 0.13%), while the maximum difference was 300 W (percent difference of 1.2%). The average difference between the facility power and the facility power plus PHEV power sum was 120 W (percent difference of 0.4%).

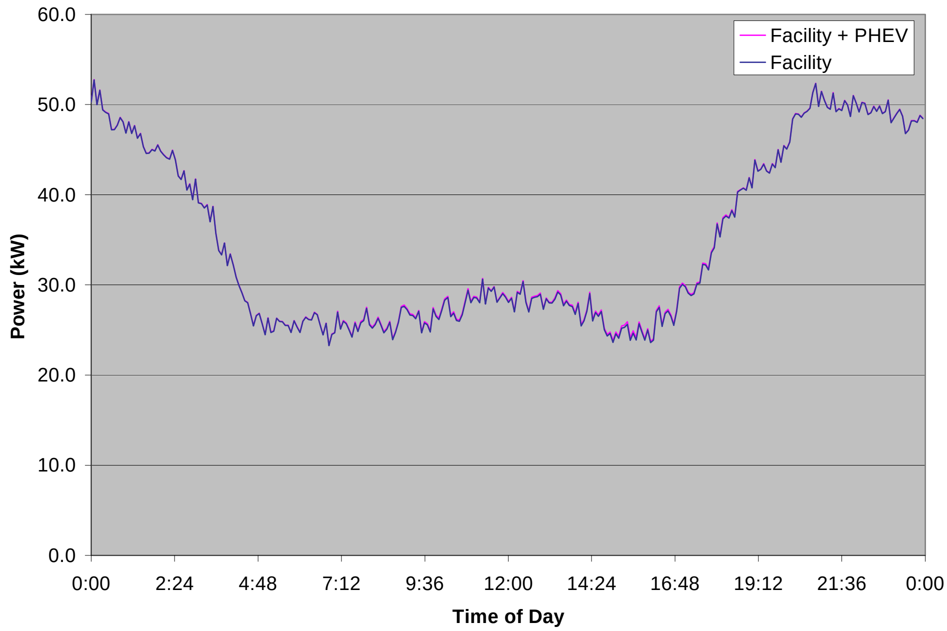

Figure 20. Averaged interval power values for facility plus plug-in hybrid electric vehicle and facility for Month 2.

The data for facility power and for facility power plus PHEV power sum were averaged for each time interval for the third test period; this is shown for Month 3 in Figure 21. The minimum difference between facility power and the facility power plus PHEV power sum was 86 W (percent difference of 0.2%), while the maximum difference was 430 W (percent difference of 1.3%). The average difference between the facility power and the facility power plus PHEV power sum was 170 W (percent difference of 0.4%).

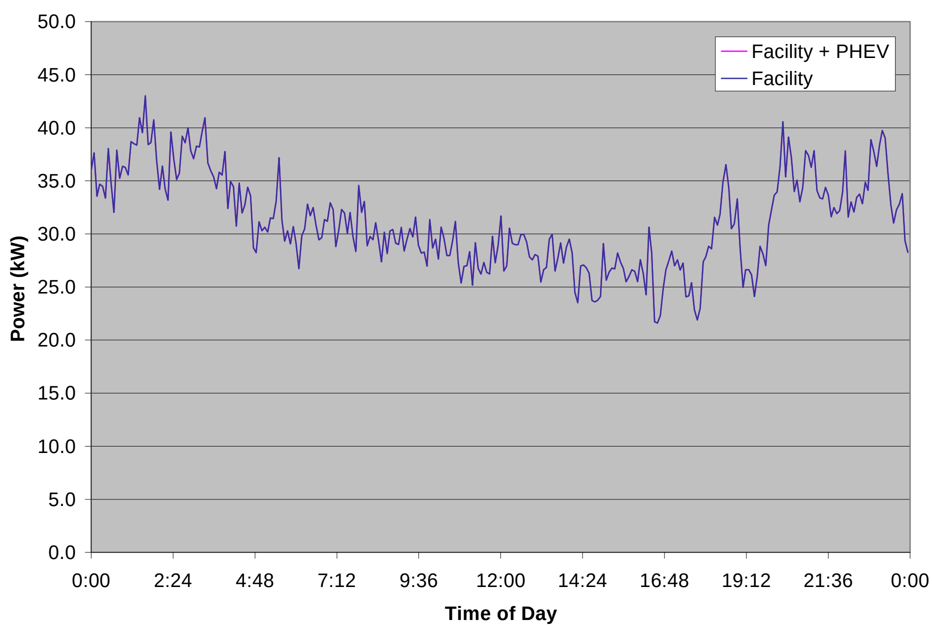

Figure 21. Averaged interval power values for facility plus plug-in hybrid electric vehicle and facility for Month 3.

3.2.2 Facility Daily Max Power and Facility Daily Max Power Plus Plug-In Hybrid Electric Vehicle Sum

A comparison between the facility daily max power and facility daily max power plus PHEV power sum shows the impact of all PHEVs charging on the peak load demand of the facility. This comparison is especially pertinent because it is the anticipated effect of PHEV charging on peak demand that concerns utility companies like Tacoma Power the most. The comparison for Month 1 is shown in Figure 22. The maximum difference between the two is 3.5 kW (percent difference of 4.9%), while the average difference is 320 W (percent difference of 0.5%).

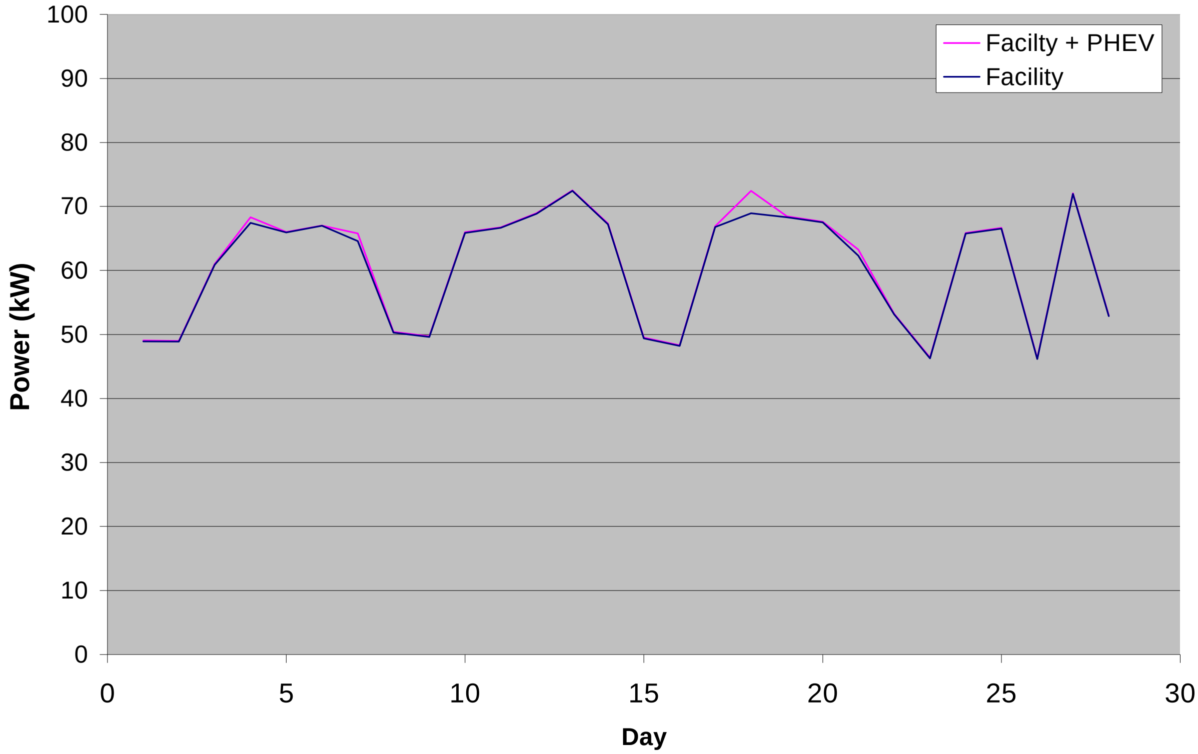

Figure 22. Month 1 comparison between facility daily max power and facility daily max power plus plug-in hybrid electric vehicle sum.

The comparison for Month 2 is shown in Figure 23. The maximum difference between the two is 110 W (percent difference of 0.2%), while the average difference is 70 W (percent difference of 0.1%).

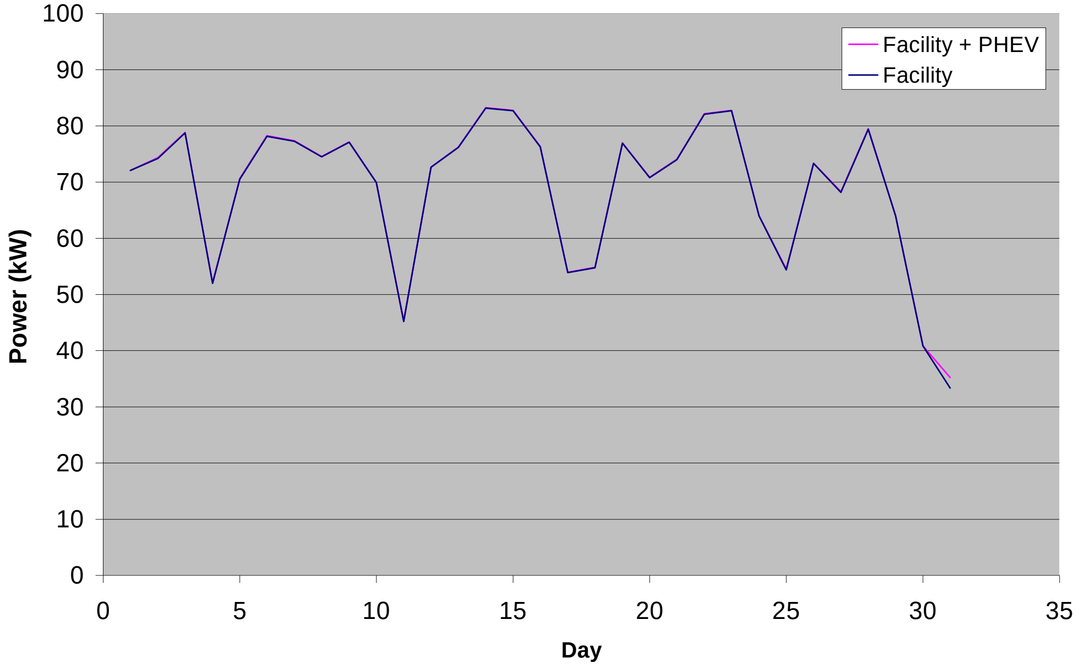

Figure 23. Month 2 comparison between facility daily max power and facility daily max power plus plug-in hybrid electric vehicle sum.

The comparison for Month 3 is shown in Figure 24. The maximum difference between the two is 1.9 kW (percent difference of 2.5%), while the average difference is 260 W (percent difference of 0.3%).

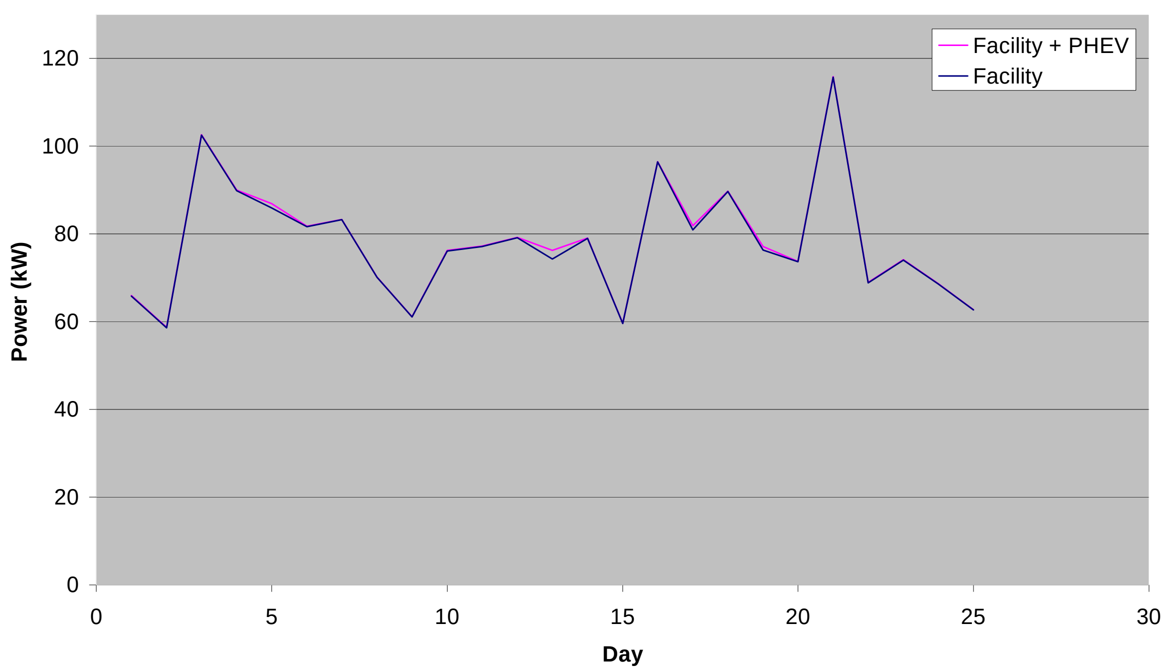

Figure 24. Month 3 comparison between facility daily max power and facility daily max power plus plug-in hybrid electric vehicle sum.

3.2.3 Cost Analysis

The cost impact concerning PHEVs is examined by observing utilization patterns on an appropriate rate structure. In support of this, a summary performance table containing energy consumption data for charging and standby conditions was created for each month. Energy consumption data are then used along with two different rate plans (a flat rate plan and a time-of-use plan) to calculate the costs of the PHEV charging in the project. Rate plans for flat rate and time-of-use plans are exhibited in Appendixes C and D, respectively. Because the study was conducted at Tacoma Power, the flat rate by Tacoma Power was adopted. In order to demonstrate how time-of-use rates could affect PHEV charging costs, the time-of-use rates from Salt River Project, a State of Arizona utility, were selected. A discussion of both rate structures and the resultant costs is included in the following sections.

In calculating costs, the power factor of the PHEV chargers is assumed to be 1, meaning that the apparent power measured is equal to real power. This assumption was made based on discussions with Tacoma Power personnel and is necessary because the electricity rates are provided in $/kWh.

3.2.4 Flat Rate Plan

The cost of energy under this plan is $0.0327 per kWh for any time of day. For the purposes of this study, base monthly charges were stripped along with delivery (per kW) charges, applicable taxes, and fees from the overall cost. Charging and standby data are presented, along with the cost summary in Tables 4 through 6.

Table 4. Cost summary for PHEV-1.

Month	Total Energy (kWh)	Charging Energy (kWh)	Charger Standby Energy (kWh)	PHEV Standby Energy (kWh)
1	32.8	15.3	0.93	16.6
2	23.9	7.58	0.82	15.5
3	21.3	6.3	0.80	14.2
Total Cost	$2.55	$0.95	$0.08	$1.51

Table 5. Cost summary for PHEV-2.

Month	Total Energy (kWh)	Charging Energy (kWh)	Charger Standby Energy (kWh)	PHEV Standby Energy (kWh)
1	76.0	37.3	1.13	37.6
2	27.1	8.7	5.1	13.3
3	45.2	17.8	2.4	25.0
Total Cost	$4.85	$2.09	$0.28	$2.48

Table 6. Cost summary for PHEV-3.

Month	Total Energy (kWh)	Charging Energy (kWh)	Charger Standby Energy (kWh)	PHEV Standby Energy (kWh)
1	49.0	33.9	0.71	14.4
2	32.2	16.9	0.24	15.1
3	38.5	27.9	1.90	8.7
Total Cost	$3.91	$2.57	$0.09	$1.25

3.2.5 Time-of-Use Plan

The cost of energy under this plan varied depending on the time of year, time of day, and whether it was a week day or the weekend. This plan lists three price levels: peak, off peak, and shoulder peak. In the months of May, June, September, and October (Summer), the prices for peak, shoulder peak, and off-peak are $0.1391, $0.0967, and $0.0513, respectively. In the months of July and August (Summer Peak), the prices for peak, shoulder peak, and off peak are $0.1586, $0.1025, and $0.0575, respectively. In the months of November through April (Winter), the prices for peak, shoulder peak, and off peak are $0.1276, $0.0941, and $0.0512, respectively.

In order to ascertain the maximum cost effect of the charging, the Summer Peak rates are used for all three test periods. Similar to the flat rate plan case, monthly service charges, delivery (per kW) charges, and taxes were eliminated from the calculated overall cost. Cost tables for the time of use plan are found in Tables 7 through 15

Table 7. Total PHEV-1 time-of-use rate cost.

Month	Total PHEV-1 Power Cost	PHEV-1 Power Peak Cost	PHEV-1 Power Shoulder Cost	PHEV-1 Off-peak Cost
1	$3.04	$1.37	$0.63	$1.04
2	$2.19	$0.94	$0.49	$0.76
3	$1.70	$0.32	$0.64	$0.74
Total Cost	$6.93	$2.63	$1.76	$2.54

Table 8. PHEV-1 charger standby time-of-use rate cost.

Month	Total PHEV-1 Charger Standby Cost	PHEV-1 Charger Standby Peak Cost	PHEV-1 Charger Standby Shoulder Cost	PHEV-1 Charger Standby Off-peak Cost
1	$0.08	$0.02	$0.02	$0.03
2	$0.07	$0.02	$0.03	$0.02
3	$0.05	$0.03	$0.00	$0.03
Total Cost	$0.20	$0.07	$0.05	$0.08

Table 9. PHEV-1 standby time-of-use rate cost.

Month	Total PHEV-1 Standby Cost	PHEV-1 Standby Peak Cost	PHEV-1 Standby Shoulder Cost	PHEV-1 Standby Off-peak Cost
1	$1.36	$0.38	$0.35	$0.62
2	$1.25	$0.37	$0.30	$0.59
3	$1.11	$0.30	$0.26	$0.56
Total Cost	$3.72	$1.05	$0.91	$1.77

Table 10. Total PHEV-2 time-of-use rate cost.

Month	Total PHEV-2 Power Cost	PHEV-2 Power Peak Cost	PHEV-2 Power Shoulder Cost	PHEV-2 Off-peak Cost
1	$7.33	$3.50	$1.66	$2.16
2	$2.39	$0.82	$0.69	$0.88
3	$3.67	$1.13	$0.82	$1.72
Total Cost	$13.39	$5.45	$3.17	$4.76

Table 11. PHEV-2 charger standby time-of-use rate cost.

Month	Total PHEV-2 Charger Standby Cost	PHEV-2 Charger Standby Peak Cost	PHEV-2 Charger Standby Shoulder Cost	PHEV-2 Charger Standby Off-peak Cost
1	$0.08	$0.01	$0.02	$0.05
2	$0.42	$0.12	$0.11	$0.18
3	$0.18	$0.03	$0.04	$0.10
Total Cost	$0.68	$0.16	$0.17	$0.33

Table 12. PHEV-2 standby time-of-use rate cost.

Month	Total PHEV-2 Standby Cost	PHEV-2 Standby Peak Cost	PHEV-2 Standby Shoulder Cost	PHEV-2 Standby Off-peak Cost
1	$3.11	$0.93	$0.81	$1.36
2	$1.38	$0.33	$0.29	$0.76
3	$2.03	$$0.60	$0.51	$0.92
Total Cost	$6.52	$1.26	$1.61	$3.04

Table 13. Total PHEV-3 time-of-use rate cost.

Month	Total PHEV-3 Power Cost	PHEV-3 Power Peak Cost	PHEV-3 Power Shoulder Cost	PHEV-3 Off-peak Cost
1	$4.40	$1.78	$1.02	$1.60
2	$3.38	$2.04	$0.52	$0.82
3	$3.06	$0.75	$0.85	$1.46
Total Cost	$10.84	$4.57	$2.39	$3.88

Table 14. PHEV-3 charger standby time-of-use rate cost.

Month	Total PHEV-3 Charger Standby Cost	PHEV-3 Charger Standby Peak Cost	PHEV-3 Charger Standby Shoulder Cost	PHEV-3 Charger Standby Off-peak Cost
1	$0.05	$0.01	$0.01	$0.03
2	$0.02	$0.01	$0.01	$0.00
3	$0.14	$0.03	$0.03	$0.08
Total Cost	$0.21	$0.05	$0.05	$0.11

Table 15. PHEV-3 standby time-of-use rate cost.

Month	Total PHEV-3 Standby Cost	PHEV-3 Standby Peak Cost	PHEV-3 Standby Shoulder Cost	PHEV-3 Standby Off-peak Cost
1	$1.19	$0.35	$0.32	$0.52
2	$1.21	$0.32	$0.30	$0.58
3	$0.68	$0.22	$0.18	$0.28
Total Cost	$3.08	$0.89	$0.80	$1.38

The time-of-use plan costs demonstrate that significant savings can be achieved by timing the PHEV charging to off-peak periods. It also can be seen that the Manzanita PHEV is substantially more expensive to charge than the Hymotion PHEVs. However, the small costs calculated for both the flat and time-of-use rates are very small and show that the vehicles were not used to a great extent during the trial. Despite low vehicle usage, it also is clear that costs for electric propulsion are much lower than for gasoline or diesel propulsion.

4. CONCLUSION

This study examined the impact of charging three PHEVs over several months on the power demand of a given facility. The key finding is that when all three vehicles were being charged, the maximum percent difference between facility power and the PHEV charging sum added to the facility power was approximately 5%. For a larger fleet or for a facility with a smaller power demand, this proportion could become significant. Additionally, it is clear from the results of the study that judicious selection of charging times could offer substantial benefits to utilities, even in the absence of vehicle-to-grid technology.

Another point of interest showed the standby time to be a significant factor in terms of energy consumption. Standby energy is power that is consumed by the vehicle or charger after a full state of charge is achieved on the vehicle battery. Cost estimates using two different billing methods, a flat rate and a time-of-use rate confirmed this to be a significant factor, especially if it were applied to a fleet of vehicles. The costs for the situation where the vehicle was connected to the charger but the battery was not receiving energy as a proportion of the total costs were 59%, 51%, and 32% for the flat rate plan and 54%, 49%, and 28% for the time-of-use plan for PHEV-1, PHEV-2, and PHEV-3, respectively.

The study demonstrated a significant difference between the charging of the two types of PHEVs. A large difference between vehicle manufacturers is clearly seen between Manzanita and Hymotion, as it relates to both active charging and standby. When the PHEVs are not connected to the charger, the charger standby energy for the Manzanita is over three times greater than that for the Hymotion vehicles. This may be due to the differences in batteries installed in the vehicle.

Based on an examination of variance between individual PHEV vehicle types used in this study, much can be gained by way of additional studies containing a greater variety of vehicles. An optimized study would include a greater variety of PHEVs and a facility in similar size to the model used at Tacoma Power. The optimized study would be treated as an extrapolated case fashioned around the results of this study. It also was clear from the charging history during the trial that the study PHEVs were not used frequently; any subsequent study would be improved by studying fleet vehicles with a higher usage.

5. APPENDIXES

Appendix A, Data Sheets, Flow Chart, and Drawings

Appendix B, Tacoma Power Installation Instructions

Appendix C, Tacoma Power Rate Schedule G

Appendix D, Salt River Project Time-of-Use Rate

Appendix A

Data Sheets, Flow Chart, and Drawings

Appendix A
Data Sheets, Flow Chart, and Drawings

Application Note

Wi-LEM: Energy Monitoring & Cost Allocation

Reduce the Cost of your Energy Efficiency Projects!

The time of installation is a driving factor for the total energy management project cost, especially in existing buildings. Using a wireless mesh sub-metering network can dramatically reduce time and money and therefore improve the profitability of your project.

Applications

- Cost allocation to specific department or user.
- Energy efficiency project audit: improvement verifications
- Equipments and system efficiency benchmark
- Load management & peak demand

Key Benefits

- Reduce the total hardware cost of your data acquisition chain
- Small size: ideal regardless of the space in your cabinet.
- Reduce the installation time (wireless + split core CT)
- Easy to expand

Case Study: Data-Center.

• Description:
The new generation of "rack-able" servers has become much smaller which allows to increase the power density of each cabinet. It is critical for the data-center facility manager to be able to monitor the electrical load for each server to ensure that the current load does not exceed the breaker capacity and switch off the line. Another consequence is the higher energy consumption. Data-centers are challenged to allocate costs by customers more precisely based on actual consumption rather than space. The ideal scenario would be to equip the building with sub-meters. This would require important installation costs which result in a long duration for return on investment.

• Solution:
The use of a wireless mesh sub-metering network has significant advantages:
- Small size of the sub-meter makes the solution suitable for an existing cabinet (no need for an additional one).
- Easy and Quick Fit reduces the installation cost dramatically and avoids downtime.
- Easy to expand which facilitates the addition of new customers to the data-center (new sub-meter is automatically recognised by the network).

Case Study: Energy Project.

• Description:
The first step in an energy retrofit project is the audit of your site in order to determine which part of the building needs to be monitored. The role of the Energy Service Company (ESCO) is to provide a maximum of measuring points to ensure high accuracy whilst keeping an eye on the budget. In the case of traditional wired sub-meters the total cost of the project was proportional to the number of measurement points. In addition the monitored site can have different configurations which can lead to variable and unpredictable installation costs. After execution of the audit, the ESCO will need to remove the installed sub-meters which will result in additional dismounting costs.

• Solution:
Using a wireless mesh sub-metering network provides considerable benefits:
- Split core current transformers are perfectly adapted for existing installations.
- Wireless communication makes installation and dismounting much faster.
- Easy to expand which allows the ESCO to add new sub-meters if additional measurement points are needed.

LEM

Figure A-1. Wi LEM USA data sheet.

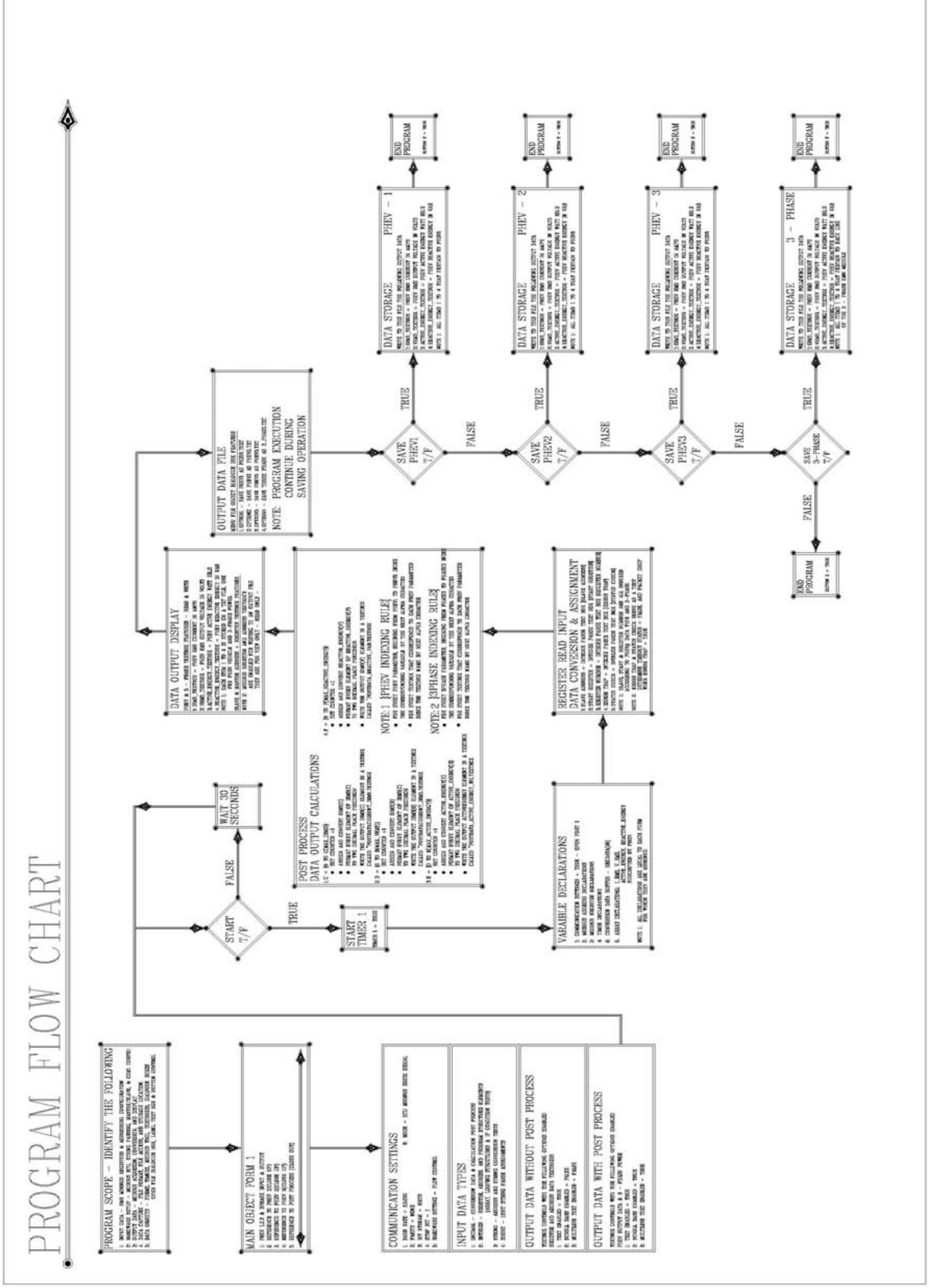

Figure A-2. Front-end software flow chart.

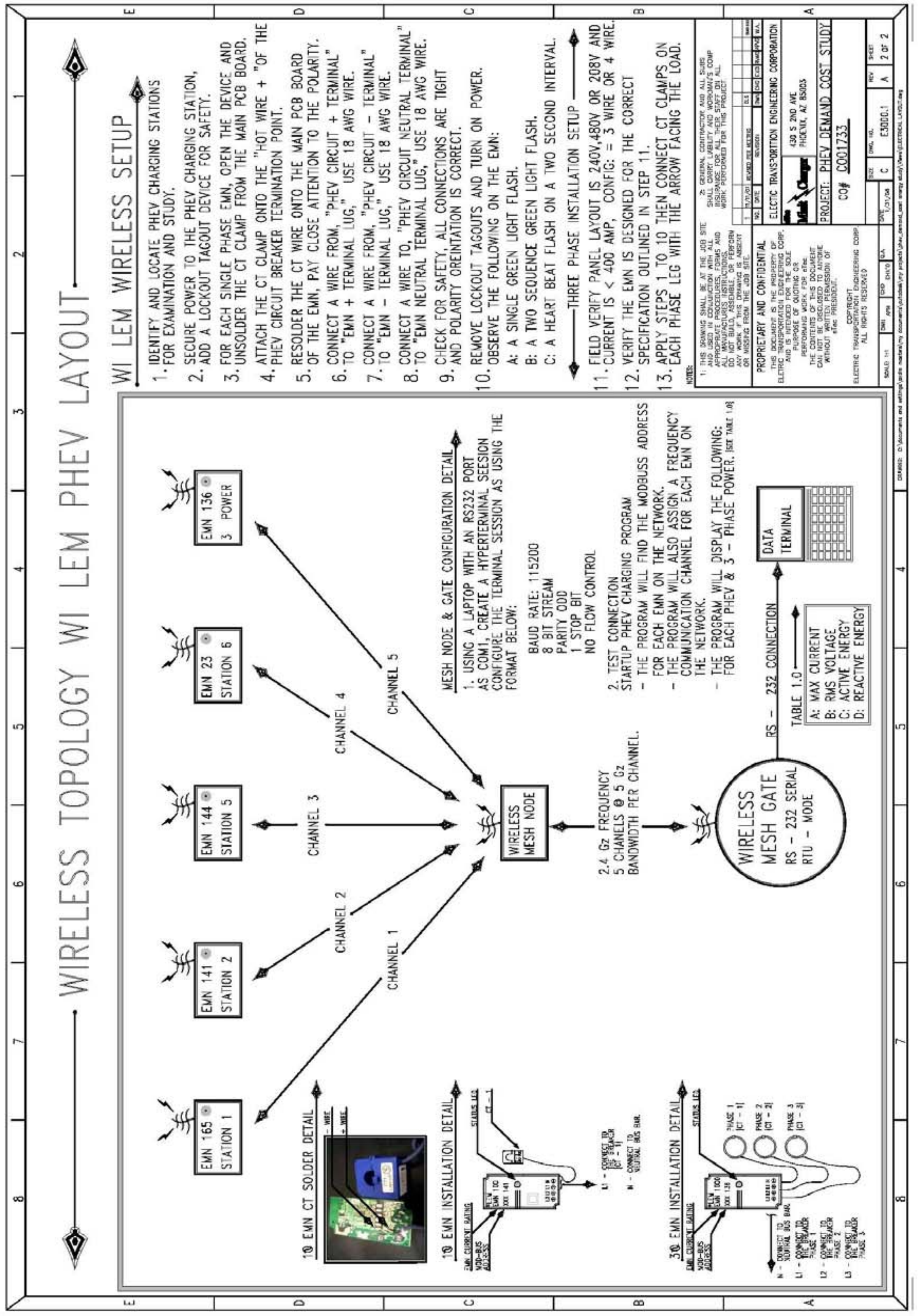

Figure A-3. Wireless topology.

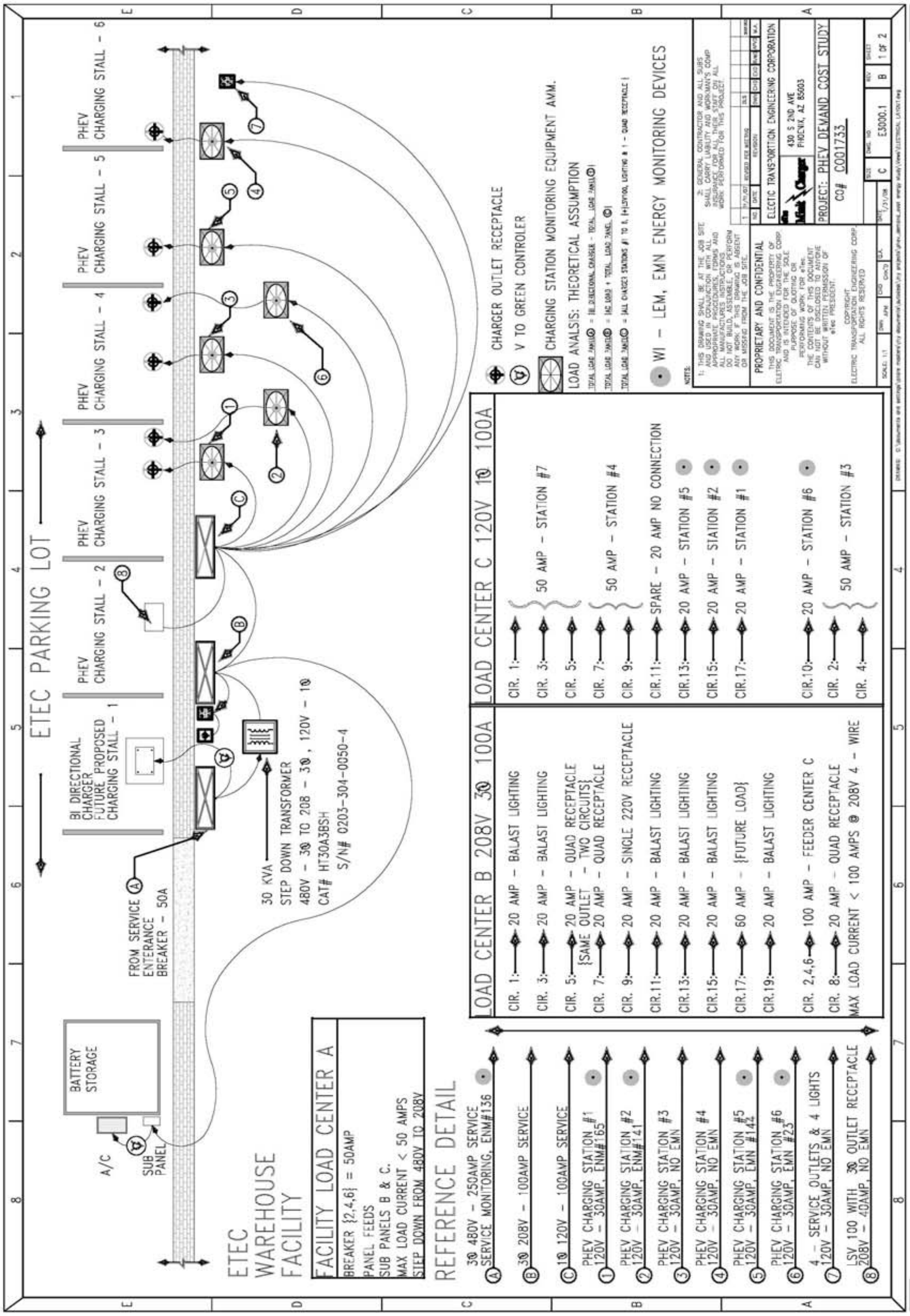

Figure A-4. Electric Transportation Engineering Corporation base drawing.

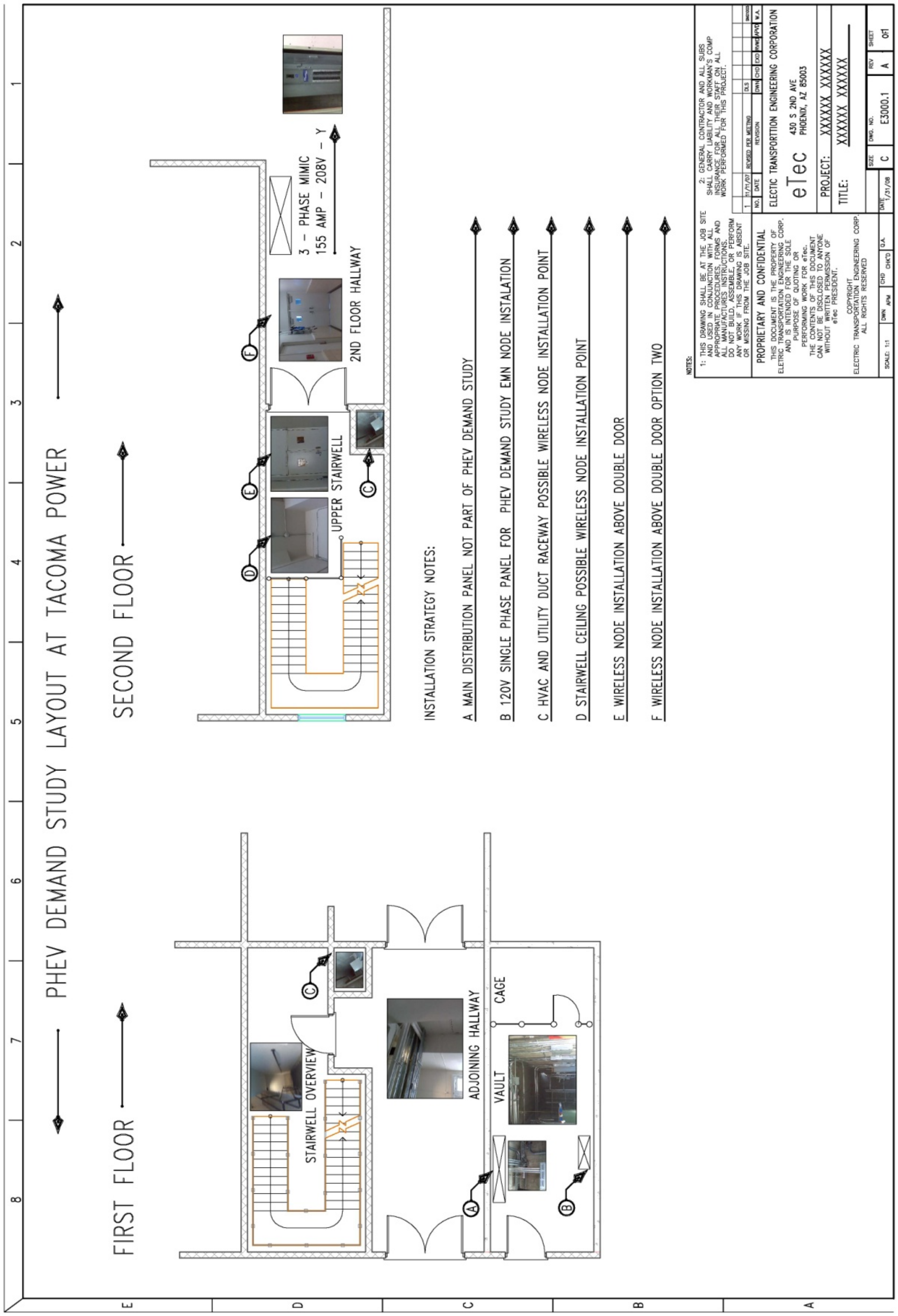

Figure A-5: Tacoma Power installation drawing.

Appendix B

Tacoma Power Installation Instructions

Appendix B
Tacoma Power Installation Instructions

PHEV FLEET OPERATIONS AND INFRASTRUCTURE CHARGING STUDY

WI LEM Installation Guide

Tacoma Power & Light

Part I Site Verification and Hardware EMN install

Step1: Identify and locate circuits for examination.

Step2: De – energize the affected circuit and examine the panel box layout for conduit openings 1" in diameter or larger. Also, observe wire and breaker population keeping in mind the CT clamps, EMN wiring must fit securely in the panel box. It is advisable to install the CT clamps through a 1" diameter conduit opening off the panel box. If there are no available conduit openings on the panel box continue to step 3,4,5 otherwise complete this step and move on to
step 6.

Step3*: Unsolder the CT Clamp from the main processor board in the EMN.

Step4*: Attach the CT clamp onto the HOT wire of the affected circuit at the breaker termination. Make sure the ARROW faces toward the load and not the breaker.

Step5*: Resolder the CT wire onto the main processor board of the EMN. Make sure the polarity is correctly positioned and the board is cleaned up with no flux residue.

Step6: Using 18 awg, connect the RED-HOT wire to the EMN – HOT wire terminal lug. Connect the other end of the EMN's Hot wire to the Hot terminal on the affected circuit panel location.

Step 7: Using 18 awg connect the BLACK – Negative to the EMN's negative terminal lug. Connect the other end to the negative terminal of the affected panel circuit.

Step 8: Using 18 awg connect the WHITE – Neutral wire to the EMN's neutral terminal lug. Connect the other end to the neutral bus bar on the affect circuit location.

Step 9: Verify all wires are placed correctly and connections are tight and firmly established. Place the EMN in a location that is 6" away from the panel box, metallic raceways, conduit, and any metallic surfaces.

Step 10: Turn on power and observe the following on the EMN

A: A single Green Light flashes.

B: A Two sequence Green Light flash.

C: Heart beat flash in a two second intervals.

Step 11: 3 – phase Installation- Verify the following before setup and installation.

A: Verify configuration is set to either 208, or 240 volts, Y configuration with a max current of 200 amp service.

B: Verify the main service is designed as a 4 wire configuration before physical installation of any hardware.

C: Secure Power on the main service and install the EMN to the affected circuit using the same steps as 1 to 9.

D: Clamp a single CT on each Phase leg with the arrow facing the load.

E: Turn on power and repeat step 10.

Part II Mesh Node, Mesh Gate & Raven X Install

Step 12: Attach the Neshnode to a Unistruct rail, or din rail support using black twist ties. Use a location on the power strip for connecting power.

Step 13: Connect the Meshgate to the Test Laptop serial com port using a straight thru serial cable. Use the next available slot on the power strip for connecting power.

Step 14: Connect the Raven X modem to the Test Laptop using a standard yellow Ethernet cable. Observe communication lights illuminate on both ends of the Ethernet cable. Plug the power cable into the next available slot on the power strip. Observe the following activity occurs on the modem.

- Power Light Illuminates: Solid Green
- Network Light Illuminates: Flashing at first followed by a solid green
- Signal Light Illuminates: Flashing at first followed by a solid green
- Service Light Illuminates: Flashing at first followed by a solid green
- Activity Light Illuminates: Flashing during data transfer only
In this case Echo testing to the MTSO.

PHEV FLEET OPERATIONS AND INFRASTRUCTURE CHARGING STUDY

Part IV Test the System

Step 15: Connect laptop power to the next available slot on the power strip. Turn on the laptop and fill in the following:

username: owner
password: 1234

Step 16: Formally install the Phev_STUDY program. Follow all on screen instructions. Notate where the executable file is stored, send a copy to the desktop. Delete shortcut to Excell sheet tasks. This is a diagnostic program used only for testing purposes.

Step 17: Double click on the PHEV_STUDY program Icon. Click the **Start Time Stamp** Button. Observe the following screen information over a 20 minute period.

A: Start Date + Time does not increment

B: Stop Date + Time increments every 5 min.

C: Observe data fills in each drop down box every 5 mins.

Step 18: Verify the save feature works by click File and saving Phev1,2,3 and 3 – Phase Power. Create separate text files on the desktop. Verify data capture for Start and End time stamps occur as a synchronized event.

Step 19: Click Stop on the Phev Program and observe the program terminates with no errors, or hang ups.

Part V Remote Access: (Observation Laptop a Test laptop Client)

Step 20: Using a second laptop with wireless internet enable features on, initiate a remote access action using the following information.

A: Static IP of the Test laptop
"69.29.196.135"
Or
B: Laptop DNS: 605AEFE2.eairlink.com

C: Username: owner

D: Password: 1234

Part VI: System Monitoring (Test Laptop Client Enabled)

Step 21: Observe system activity for 60 minutes using the observation laptop as a remote host computer to the Test laptop. Examine functionality for the following items

A: Save Feature for Phev, and 3 phase power operate correctly with no errors.

B: Transfer of data between one laptop to the other occurs seemingly with no errors.

C: Observe the Start Time and End Time function with no out of sync time differences between Laptop system clocks.

D: Observe LED's on the modem are all green with the activity LED on intermittent flash.

E: Observe LED's on the EMN's, Mesh Nodes and Meshgate operate properly.

Part VII: System Secure

22: Secure the system after all requirements under step 21 are complete with no errors. Do this by initiating the following action items:

A: Break Remote Connection by logging off the remote connection session on the observation laptop side. Observe program control returns to the Test Laptop. At this stage the observation/client laptop is no longer needed.

B: Observe the Test Laptop for 30 minutes. Observe all behavior accociated with its operation and the system overall.

C: Field Verify all monitoring points involving the EMN's. Using a selected vehicle for testing purposes. Begin by removing the vehicle from the charging station and observe the Phev_Study program response. The response may fall within the range of +/- 5 minutes. If the Phev_Study program responds appropriately, take the vehicle for a timed ride about 60 minutes.

D: Plug the vehicle back into the assigned PHEV charging station. Observe charging activity occurs on the PHEV_Study program to within +/- 5min intervals.

Certification for System Release:

If all requirements are met under step 22, the system is ready for self monitoring where all data can be obtained remotely, installation is deemed valid and ready for data collection.

That's It

Appendix C

Tacoma Power Rate Schedule G

Appendix C
Tacoma Power Rate Schedule G

RATE SCHEDULE G
General Service
12.06.215

Availability
For general power use where a demand meter is installed, for standby capacity to customers generating all or a part of their electric power requirements, and for intermittent use. The customer's actual demand as determined by Tacoma Power must exceed 50 kilovolt amperes or total connected load as estimated by Tacoma Power must exceed 65 kilowatts upon initial service energization.

For customers providing all their own transformation from Tacoma Power's distribution system voltage, a discount for transformer investment and maintenance will be provided by reducing the monthly bill by 0.8 percent. For customers metered on the primary side of a transformer, a discount for transformer losses will be provided by reducing the monthly bill by 1 percent. These discount percentages are additive, and not compounded.

Monthly rate
The sum of the following energy, delivery and customer charges:

- **Energy:** All energy measured in kilowatt-hours at $0.032729 per kWh.
- **Delivery:** All kilowatts of Billing Demand delivered at $5.73 per kW.
- **Customer Charge:** $46 per month or any fraction thereof.

Exceptions

- **Within City of Fife:**
  - **Energy:** All energy measured in kilowatt-hours at $0.033856 per kWh.
  - **Delivery:** All kilowatts of Billing Demand delivered at $5.93 per kW.
  - **Customer Charge:** $47.58 per month or any fraction thereof.
- **Within City of Fircrest:**
  - **Energy:** All energy measured in kilowatt-hours at $0.035063 per kWh.
  - **Delivery:** All kilowatts of Billing Demand delivered at $6.14 per kW.
  - **Customer Charge:** $49.28 per month or any fraction thereof.
- **Within City of Lakewood:**
  - **Energy:** All energy measured in kilowatt-hours at $0.035063 per kWh.
  - **Delivery:** All kilowatts of Billing Demand delivered at $6.14 per kW.
  - **Customer Charge:** $49.28 per month or any fraction thereof.
- **Within City of Steilacoom:**

Appendix D

Salt River Project Time-of-Use Rate

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Salt River Project Time-of-Use Rate

SALT RIVER PROJECT AGRICULTURAL IMPROVEMENT AND POWER DISTRICT

E-32

STANDARD PRICE PLAN FOR TIME-OF-USE GENERAL SERVICE

Effective: November 1, 2008
Supersedes: May 1, 2008

AVAILABILITY:
The E-32 Price Plan is subject to equipment availability, as determined in SRP's sole discretion.

APPLICABILITY:
Service under this price plan is applicable to commercial, business, professional, small industrial and recreational facilities, supplied through one point of delivery and measured through one meter.

CHARACTER OF SERVICE:
Sixty hertz alternating current. SRP, in its sole discretion, may provide three-phase or single-phase, at one standard voltage of approximately 120/208; 120/240; 277/480; 2,400/4,160; or 7,200/12,000 volts.

CONDITIONS:

A. On-peak hours from May 1 through October 31 consist of those hours from 2 p.m. to 7 p.m., Monday through Friday, Mountain Standard Time. Shoulder-peak hours consist of those hours from 11 a.m. to 2 p.m. and 7 p.m. to 11 p.m., Monday through Friday, Mountain Standard Time. All other hours are off-peak. On-peak hours from November 1 through April 30 consist of those hours from 5 a.m. to 9 a.m., Monday through Friday, Mountain Standard Time. Shoulder-peak hours consist of those hours from 5 p.m. to 9 p.m., Monday through Friday, Mountain Standard Time. All other hours are off-peak.

B. Metering is at one point and such that kilowatts (kW) and kilowatt-hours (kWh) or kilovolt-amperes (kVA) and kilovolt-ampere-hours (kVAh) can be related to time-of-day.

C. A customer may cancel service under this price plan and elect service under another applicable price plan. Cancellation becomes effective at the end of the billing cycle in which notice is received. The customer may not subsequently elect service under this price plan for at least one year after the effective date of cancellation.

D. A customer requiring additional interconnection, metering, or other equipment beyond what is necessary for SRP to provide basic service applicable under this price plan must pay SRP for the costs of such additional equipment.

PRICE PER METER:

Monthly Service Charge

Billing, Collections	$9.48
Meter Reading	$5.56
	$15.04

Meter

The type of meter will be solely determined by SRP based on customer usage and character of service.

Demand	$4.42
CT/PT	$10.50

Per kW Charges (All kW over 5 kW for the maximum demand measured during the on-peak or shoulder-peak hours)

SUMMER*

Distribution Delivery	$2.93
Transmission Delivery	$1.05
Ancillary Services 1 - 2	$0.07
Total	$4.05

SUMMER PEAK*

Distribution Delivery	$2.93
Transmission Delivery	$1.05
Ancillary Services 1 - 2	$0.07
Total	$4.05

WINTER*

Distribution Delivery	$1.76
Transmission Delivery	$0.55
Ancillary Services 1 - 2	$0.03
Total	$2.34

Per kWh Charges (All kWh)

SUMMER*	On-Peak	Shoulder-Peak	Off-Peak
Distribution Delivery	$0.0435	$0.0264	$0.0000
Transmission Delivery	$0.0159	$0.0122	$0.0000
Ancillary Services 1 - 2	$0.0015	$0.0000	$0.0000
Ancillary Services 3 - 6	$0.0005	$0.0005	$0.0005
System Benefits	$0.0019	$0.0019	$0.0019
Competitive Customer Service	$0.0089	$0.0000	$0.0000
Energy	$0.0264	$0.0152	$0.0084
Fuel and Purchased Power**	$0.0405	$0.0405	$0.0405
Total	$0.1391	$0.0967	$0.0513

SUMMER PEAK*	On-Peak	Shoulder-Peak	Off-Peak
Distribution Delivery	$0.0437	$0.0265	$0.0000
Transmission Delivery	$0.0184	$0.0178	$0.0000
Ancillary Services 1 - 2	$0.0041	$0.0000	$0.0000
Ancillary Services 3 - 6	$0.0005	$0.0005	$0.0005
System Benefits	$0.0019	$0.0019	$0.0019
Competitive Customer Service	$0.0230	$0.0000	$0.0000
Energy	$0.0265	$0.0153	$0.0146
Fuel and Purchased Power**	$0.0405	$0.0405	$0.0405
Total	$0.1586	$0.1025	$0.0575

WINTER*	On-Peak	Shoulder-Peak	Off-Peak
Distribution Delivery	$0.0434	$0.0263	$0.0000
Transmission Delivery	$0.0158	$0.0101	$0.0000
Ancillary Services 1 - 2	$0.0001	$0.0000	$0.0000
Ancillary Services 3 - 6	$0.0005	$0.0005	$0.0005
System Benefits	$0.0019	$0.0019	$0.0019
Competitive Customer Service	$0.0088	$0.0000	$0.0000
Energy	$0.0268	$0.0250	$0.0185
Fuel and Purchased Power**	$0.0303	$0.0303	$0.0303
Total	$0.1276	$0.0941	$0.0512

* Summer is defined as the May, June, September and October billing cycles. Summer Peak is defined as the July and August billing cycles. Winter is defined as the November through April billing cycles.

** SRP may periodically change the price for Fuel and Purchased Power consistent with Adjustment A.