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Utility Management of

Plug-In Electric Vehicle Residential Charging

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Utility Management of
Plug-In Electric Vehicle Residential Charging

by

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Thesis

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Dedication

Dedicated to The City of Austin.

May this work contribute to the City's leadership in promoting and supporting the advancement of Plug-In Electric Vehicles

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Utility Management of

Plug-In Electric Vehicle Residential Charging

Guillermo Hernandez, M.S.E.

The University of Texas at Austin, 2014

SUPERVISOR: Ross Baldick

CO-SUPERVISOR: Michael Webber

The purpose of this study is to identify realistic opportunities and barriers regarding PEV charge management by analyzing real-world PEV data from customers in the Austin Energy service area and evaluating direct, quantifiable economic value benefits as it relates new revenue, cost avoidance, CO_2 reductions, and MW potential for peak shaving. The main objective is to provide business analysis to support the strategic road-map for Austin Energy PEV home charging programs. Three main charge program implementations are considered: Uncontrolled Charging, Time of Use Rates, and One Way Utility Control.

The data used for the analysis includes 45 households with PEVs from Mueller area; 24 were under a Time of Use trial with pricing incentives to charge at night, and 21 receive normal Austin Energy rates. Data analysis shows that 66% of Time of Use trial group successfully shifted PEV load to Off Peak hours (10:00PM to 6:00AM).

The potential of One Way control, based on load availability for interruption, shows that it will not be possible to implement until there are 37,000 PEVs in the Austin Energy area. Uncontrolled Charging represents a risk by increasing load during the residential peak. Time of Use Rates program will incentivize load shifting, reduce wholesale energy costs for Austin Energy while allowing customers to reduce their overall electricity bill.

Table of Contents

List of Tables

List of Figures

Glossary

$/MWh	Dollar per megawatt-hour, cost per unit of energy
4CP	Four Coincident Peak, average coincident peak demand over a four-month period (June, July, August and September)
ACPP	Austin Climate Protection Plan, adopted by the City of Austin in 2007 to build a more sustainable community by 2020
ADR	Automated Demand Response, send signals to cause electrical power-using devices to be turned off
AE	Austin Energy, publicly owned electric utility
AGC	Automatic Generation Control, used for controlling grid frequency
AS	Ancillary Services, A service necessary to support the transmission of energy to Loads while maintaining reliable operation of the Transmission Service Provider's (TSP's) transmission system using Good Utility Practice[a]
CDF	Cumulative Distribution Function, describes the probability that a real-valued random variable X with a given probability distribution will be found at a value less than or equal to x
CO_2	Carbon dioxide
DA	Day-Ahead, the 24-hour period before the start of the Operating Day[a]
DSM	Demand Side Management
EEA	Energy Emergency Alert
EIA	Energy Information Administration
EILS	Emergency Interruptible Load Service
EPA	Environmental Protection Agency

ERCOT	Electric Reliability Council of Texas, ISO representing 85% of Texas electric load
ERS	Emergency Response Service
FERC	Federal Energy Regulatory Commission
Gas-CC	Gas Combined Cycle
Gas-CT	Gas Combustion Turbine
ISO	Indepentent System Operator
kW	kilowatt, unit of instantaneous power
kWh	kilowatt hour, unit of energy
LMP	Locational Marginal Prices
LSE	Load Serving Entity
MW	megawatt, unit of instantaneous power
MWh	megawatt hour, unit of energy
PEV	Plug-In Electric Vehicle
PRC	Physical Responsive Capability
QSE	Qualified Scheduling Entity
RE	Resource Entity
RRS	Responsive Reserves Service
RT	Real Time
RTM	Real Time Market
SCED	Security Constrained Economic Dispatch
ton/MMBTU	Ton per million British thermal units
TOU	Time Of Use

Executive Summary

The primary objective of this work is to provide business analysis to support the strategic road-map for Austin Energy's Plug-In Electric Vehicles (PEV) residential charging programs. Assessment is done by identifying realistic opportunities and barriers regarding PEV charge management by analyzing real-world PEV data from customers in the Austin Energy service area and evaluating direct, quantifiable economic value benefits as it relates new revenue, wholesale cost avoidance in the Energy Reliability Council of Texas (ERCOT) market, CO_2 reductions, and MW potential for peak shaving.

Three main charge management programs are considered:

- Uncontrolled Charging: No utility influence in charging
- Time-Of-Use (TOU) Rates: Incentives to charge during night to reduce peak charging
- One Way Control: Utility actively interrupting charge to reduce wholesale energy cost, provide Ancillary Services, or provide Emergency Response Services.

Behavior from the PEV data analysis is used to assess the programs potential.

Data Analysis Key Points

The data used consisted of 45 customers in the Austin Energy area where 24 of them were under a TOU trial pricing and 21 of them had normal Tier rates. Located in the Mueller community, these customers are early adopters of PEVs who live in 100% green building homes and are assumed to have a culture of progressive energy consumption. The data analysis helps to understand how these customers responded to the TOU incentives.

Both groups consumed the same amount of energy per PEV with a daily average of 5.76 kWh which is about 5840 miles per year. Considering that Mueller is only 3 miles from downtown Austin and there are shopping centers inside the community; the miles traveled from the data analysis are far lower than the national average of 15,000 miles per year and the Texas average of 9,248 miles per year.

Energy consumption, customer cost, and Austin Energy's revenue of an actual implementation over all customers in the Austin Energy service area are expected to be larger than from Mueller customers. Nevertheless, behavior from both groups is used as a relative comparison of implementation of TOU rates.

The analysis shows that house consumption experienced no load shift effect due to the TOU rates. In contrast, PEV charging was successfully shifted by 66% of the TOU group to Off Peak hours (10PM – 6AM). A new household peak created by the PEVs of the TOU group was observed around 4:15 AM as seen in Figure I. The source from the 4:15 AM load is due to PEVs programmed to be charged by Departure Time of 6:00 AM.

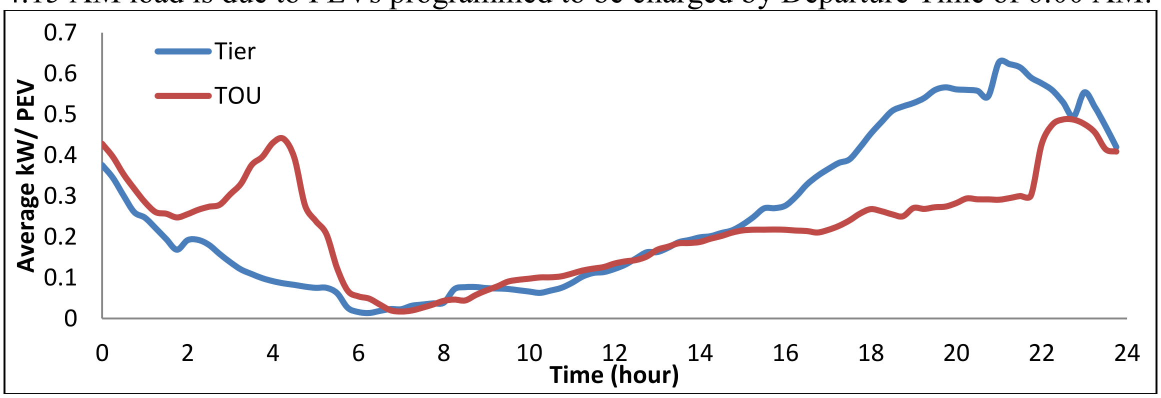


Figure I. Tier and TOU daily average PEV load profile

Load shifting in the TOU group decreased Austin Energy's wholesale energy cost by $14.52/year per PEV. Austin Energy would receive an extra $4.53/year for each household if billed as TOU than from it would from Tier.

Based on a marginal generation analysis, the TOU trial did not have a significant reduction in CO_2 emissions compared to the Tier group. But still both groups represented a decrease in emissions of 64% compared to a new light duty gasoline vehicle from 2013.

If house load remains unchanged, as the data showed; it is possible for a customer to save money under TOU rates just by shifting PEV charging to Off Peak hours.

Charge management program comparison

Uncontrolled Charging average wholesale energy cost is $72.72/year per PEV. This program has no infrastructure cost but increase of PEV adoption will require increased capacity during peak hours and will contribute to Four Coincident Peaks events.

The potential for TOU rates program shows that the incentives can help shifting load to Off Peak hours. Figure II shows the load shifting effect from Uncontrolled Charging to TOU Rates. This program has $62.03/year per PEV wholesale energy cost and 50% less contribution to Four Coincident Peaks events. The cost of a TOU Smart Meter is assumed to be $350 plus a Truck Roll cost of $275 to install each meter.

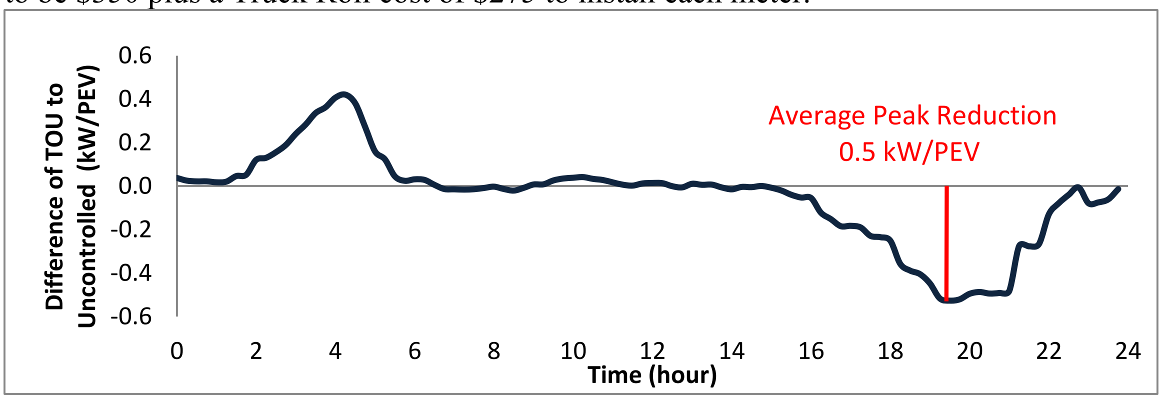


Figure II. Load shifting effect from Tier to TOU

One Way control analysis showed that in order to increase savings during high wholesale energy prices, it is necessary to exponentially increase the number of charge interruption events. This program would require at least 1850 interruptions of 15 minutes each to be able to match the wholesale energy cost of the TOU program.

A statistical analysis shows that the number of PEVs in Austin Energy region is not large enough to represent a reliable resource of 100 kW to provide Ancillary Services or Emergency Response Services. Although actual deployment of these services do not occur 100% of the time, load must be available during the committed time.

Providing Ancillary Services with PEVs would be possible with 37,000 PEVs or more. Providing Emergency Response Services needs at least 75,000 PEVs. These services could be offered into ERCOT programs with much lower PEV numbers if packaged together with other Demand Response devices, such as thermostats.

One Way control infrastructure cost consists of investment in hardware and software, and would have annual operating costs. It would also require increased capacity since after an interruption event, PEV load would create a spike from the vehicles that would normally charge at that time plus the overlap of the vehicles that were interrupted and resume charging. Interruption events of PEV charging can also have a negative impact in the adoption of PEVs at this early stage by increasing range anxiety, introducing uncertainty of charge availability, and affecting Austin Energy's customer service.

The cash flow for each program is presented in Figure III based on energy cost, utility revenue, and infrastructure cost with the following assumptions:

- Annual Growth Rate of PEVs of 25%
- Average miles driven per year 9,248 based on Texas average (TexPIRG)
- Uncontrolled and One Way - Increased capacity cost corresponding to equal annual payments to build a Gas-CT power plant in 2015 for PEV capacity in 2030

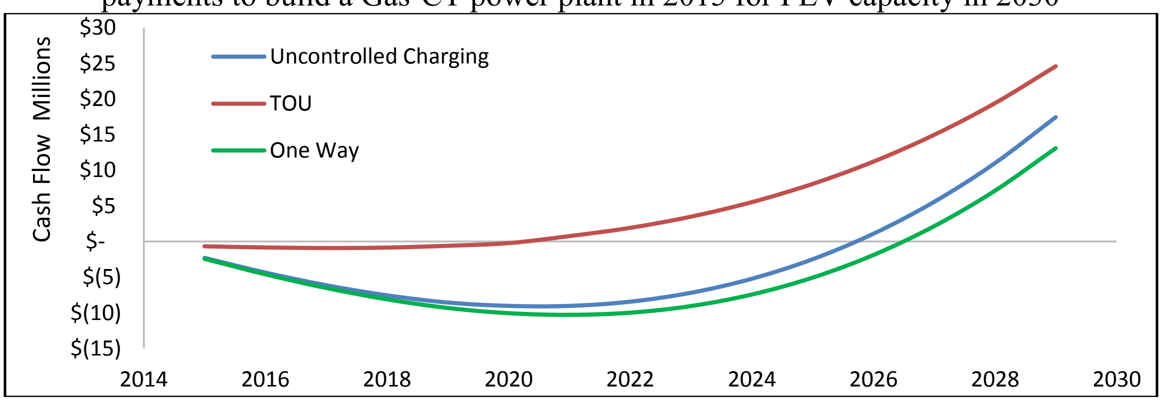


Figure III. Cash Flow for charge programs

Uncontrolled Charging and One Way programs would generate considerable debt to Austin Energy from building a new power plant to match the increased capacity.

The three main programs are also compared on how they align with Austin Energy's mission by addressing the following questions:

- Clean: Contributes to emission reduction in the City of Austin?
- Affordable: Economically viable for Austin Energy and customers?
- Reliable: Promotes load shifting from On Peak to Off Peak
- Excellent Customer Service: Avoids inconvenience for customer?

	Clean	Affordable	Reliable	Excellent Customer Service
Uncontrolled Charging	✓	✓		✓
TOU Rates	✓	✓	✓	✓
One Way	✓		✓	

Table I. Program comparison according to Austin Energy's mission

The program that mostly aligns with Austin Energy's missions is TOU Rates since it is clean, affordable, reliable, and has excellent customer service. It is affordable since it is possible for the customer to save money by shifting PEV charging and it does not generate considerable debt to Austin Energy, it is reliable since it incentivizes load shifting, and it contributes to excellent customer service since it does not represent any major inconvenience to the customer.

The potential of TOU program is the one that contributes the most to Austin Energy's Resource, Generation, and Climate Protection Plan to 2020 by directly addressing to the goal of "Achieve 800 MW savings through energy efficiency and conservation efforts" with possible savings of 5 MW with an adoption forecast of 10,000 PEVs by 2020.

The data analysis gave apparent results of TOU behavior of early PEV adopters in the Mueller community who volunteered for this trial. A 100% implementation of TOU rates program across all PEV customers might not have the same results since there is no way to know how a customer that didn't volunteer for the TOU trial would behave. Regardless, the results show that customers with knowledge of the benefits and willingness to participate on the TOU trial successfully shifted PEV load to Off-Peak hours, decreased wholesale cost of energy, and reduced 4CP contributions.

The proposed recommendation is a combination of Uncontrolled Charging and TOU rates, where customers can voluntarily switch to TOU rates. An implementation strategy should include the following:

- Education to customer about possible economic benefits of TOU rates
- Explanation of grid reliability issues from charging during On-Peak hours
- Expand functionality of austinenergyapp.com that shows energy consumption per day to also include daily energy distribution for TOU customers

Chapter 1: Introduction

1.1 Overview

The rapid increase of Plug-in Electric Vehicle (PEV) penetration raises the need for utilities to evaluate real-time charging control and targeted pricing programs. PEVs represent not only a new load to be serviced, but also a potential to be a grid resource for distributed generation, storage, and support grid reliability.

The purpose of this study is to identify realistic opportunities and barriers regarding PEV charge management by analyzing real-world PEV data from customers in the Austin Energy service area and evaluating direct, quantifiable economic value benefits as it relates new revenue, cost avoidance, CO_2 reductions, and MW potential for peak shaving. The primary objective is to provide business analysis to guide the strategic road-map for Austin Energy PEV home charging programs.

Management of PEVs presents an opportunity to provide several ancillary services such as regulation, reserves, and voltage control [1]. In the electric power system, ancillary services are necessary for maintaining grid reliability, balancing the supply and demand, and supporting the transmission of electric power from seller to purchaser [2].

Several approaches have been studied from the PEV owner perspective determining the possible annual net profit from Vehicle-to-Grid [3]. These approaches assume that the PEV owner has access to a net metering scheme. Other studies focus on the grid operator (PJM, ERCOT, CAISO) market clearing prices for regulatory services assuming direct interaction between PEV owner and grid operator [4].

Looking at the utility level there is an opportunity for the utility to control PEV resources in the specified service area through Demand-Side Management. A regulated area, such as Austin Energy, has the advantages of having a long-term relationship and mandate to serve the needs of each resident within their respective territories.

The scope of this study includes Austin Energy service area and Austin Energy residential customers only. Data used in the analysis comes from Pecan Street Inc. and includes 12 months of 15 minutes interval data points from 45 PEV customers in a contiguous year-long study with data up to December 31st, 2013. Located in the Mueller community, these customers are early adopters of PEVs who live in 100% green building homes and are assumed to have a culture of progressive energy consumption. A group of 24 of the customers were under a time-of-use (TOU) trial with economic incentives, the other 21 customers experienced normal Austin Energy residential Tier rates. Although changes to tariffs (for example, from current rates to TOU rates) or changes in charge management policy (for example, from car owners having complete autonomy over charging to utility-managed charging) could and would be expected to change the charging profile of cars, this study simply uses the measured existing charging profile. Information from the existing charging profile is used to estimate bounds on the maximum potential for changes in rates or management policy to affect, for example, costs to consumers or effects on transmission fees for Austin Energy.

The approach for this study will consist of:

1. defining the charge management programs considered for this study
2. defining quantifiable metrics used to compare the different programs
3. analyzing the current PEV load profiles for the Tier and TOU groups
4. comparing impact of implementing each charge management program in terms of load, emissions, and maximum potentials for the mentioned metrics.

1.2 AUSTIN ENERGY

Austin Energy is the nation's 8th largest publicly owned electric utility. It serves more than 420,000 customer accounts and more than 1 million residents in Greater Austin. Austin Energy missions is to deliver clean, affordable, reliable energy and excellent customer service [5]. Below there is a description of Austin Energy's mission:

Clean - Increase use of renewables and energy efficiency. Reduce CO_2 emissions.

Affordable - Austin Energy must be financeable sound. Cost of electric service must be affordable for all customers.

Reliable - Ensure consistent power quality and reliability requirements. Load shifting to avoid increase of peak demand.

Excellent Customer Service – Provide excellent customer service and assistance

1.2.1 Austin Climate Protection Plan

In 2007 Austin's City Council adopted the Austin Climate Protection Plan (ACPP) with the objective of creating a more sustainable community [6]. Austin Energy developed the Resource, Generation, and Climate Protection Plan to 2020 (Plan) to meet those objectives.

Austin Energy's goals summary for 2020:

- Achieve 800 MW savings through energy efficiency and conservations efforts
- Meet 35% of energy need through the use of renewables
- Establish a CO_2 reduction goal of 20% below 2005 level

Note: Emissions level in 2005 was 5,554,894 Metric Tons of CO_2. A 20% reduction equates to 1,110,979 Metric Tons of CO_2. Emissions level target for 2020 is 4,443,915 Metric Tons

1.3 ERCOT

The Electric Reliability Council of Texas (ERCOT) is the independent system operator (ISO) of about 85% of load in Texas. The function of the ISO is to manage electric power flow assuring balance between load and generation. Each Load Serving Entity (LSE) and Resource Entity (RE) must be represented in ERCOT by a Qualified Scheduling Entity (QSE) which is able to participate in the Day-Ahead and Real-Time Markets (RTM). Therefore ERCOT's function is to ensure balance between supply and demand for energy by supervising scheduling actions done by the QSEs [7].

ERCOT determines Locational Marginal Prices (LMPs) in the RTM by running a Security Constrained Economic Dispatch (SCED) every 5 minutes, with prices determined by averaging the 5 minute runs coinciding with each 15 settlement interval. The 15 minute settlement prices are typically used to determine the value in the real time market. SCED calculates LMPs by taking in consideration QSE's offer curves and constraints in the transmission network.

QSE's can also offer into the Ancillary Services (AS) market using resources in their portfolio. FERC defines AS as those "necessary to support the transmission of electric power from seller to purchaser given the obligations of control areas and transmitting utilities within those control areas to maintain reliable operations of the interconnected transmission system." The main purpose of AS is to ensure reliability in the constant balance at all times between generation and load. Each QSE may self-arrange its Obligation assigned by ERCOT for each of the following Ancillary Services: Regulation Up, Regulation Down, Responsive Reserve, and Non-Spinning Reserve.

Regulation Up and Down are means of compensation for small changes in system frequency. When load is higher than generation, frequency goes down, and when generation is higher than load, frequency goes up. Regulation is deployed as needed every

4 seconds to maintain balance. Regulation responds to Automatic Generation Control (AGC) signals from ERCOT to QSE. Commands are sent every four seconds, but actual response is slower.

Responsive Reserves Service (RRS) provides operating reserves that can begin to be deployed within the first few seconds of a significant decay of system frequency. RRS also acts as a backup for Regulation; therefore it also must be able to begin to respond within three to five seconds both to frequency and ISO signals.

Non-Spinning Reserves can be provided by on-line or off-line generation resources, as well as load resources. Generation must be able to be synchronized and ramped up to the specified output level in within 30 minutes and run for at least one hour. Load must be able to be interrupted within 30 minutes and remain interrupted for at least one hour.

Another type of service that can be provided by a QSE is Emergency Response Service (ERS). The goal of ERS is to decrease the probability of the need for firm load shedding. A QSE may provide ERS-10 or ERS-30 according to the ramp period needed for the resource to respond within 10 and 30 minutes respectively. An Energy Emergency Alert (EEA) occurs when there in not enough Physical Responsive Capability (PRC) which represents the total amount of system capability with high probabilities of responding rapidly to system disturbances. There are three levels of EEA. Level 1 is to maintain 2,300 MW of PRC. Level 2 is to maintain frequency of 60Hz or 1,750 MW of PRC. And Level 3 is to maintain frequency of 59.8 Hz or greater. ERCOT may deploy ERS-10 only during EEA Level 2 or 3 and ERS-30 only during EEA Level 1, 2 or 3.The minimum amount of ERS capacity that may be offered is 100 kW. QSEs may commit to provide ERS at selected contract periods and time periods found in Appendix A. The participating QSE must be able to supply 15-minute interval meter historic data to ERCOT for analysis and approval to participate in ERS.

The ERS program was previously known as Emergency Interruptible Load Service (EILS). In 2/2/2011 there was an EILS deployment that lasted for 28 hours and exhausted some of the available resources. As a consequence of such event, on June 1, 2012 EILS transformed into ERS with new specifications such as lower load offer form 1 MW to 0.1MW and possible contract renewal exhausted. Previous EILS deployments can be found in Appendix A. Notice that although an event like the 2/2/2011 could last several hours, the interruptions would only occur during the contract Business Hours. On average interruption lasts for about 2.5 hours except for 2/2/11 that lasted 28 hours.

In order to recover for transmissions cost, ERCOT has a cost allocation method referred as Four Coincident Peaks (4CP). The 4CP events occur during each 15-minute peak of the months of June, July, August, and September. The four events are averaged and the customer is assigned a cost for transmission based on the percent contribution to the total load average.

1.4 DEMAND-SIDE MANAGEMENT

Demand Side Management (DSM) load shape objectives are used as the basis for the charge management programs. DSM is defined as "the planning, implementation, and monitoring of distribution network utility activities designed to influence customer use of electricity in ways that will produce desired changes in the load shape." DSM includes a deliberate intervention by the utility so as to alter the consumer's demand [8].

Figure 1.1 shows the six general load shape objectives of DSM. Peak clipping, valley filling, and load shifting are classified as load management objectives, strategic conservation and load growth are considered as system planning, and flexible load shape as financial optimization of load supply [9]. The load shape objectives of interest for this study consist of load management.

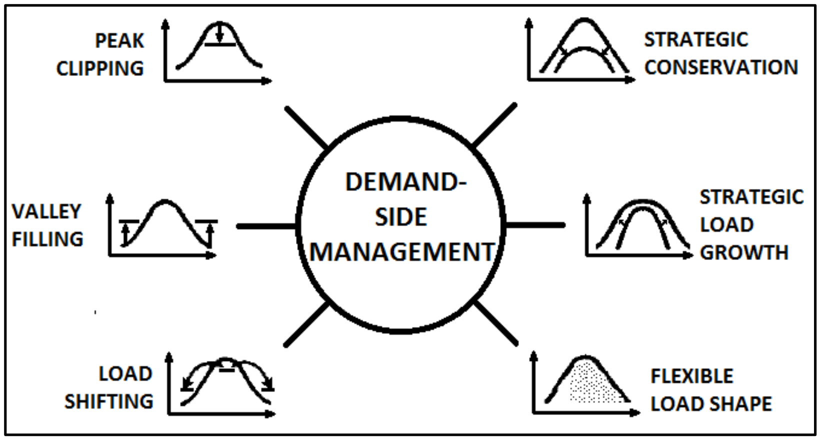


Figure 1.1. Demand Side Management load shape objectives [8]

Peak clipping objective is to reduce load during peak hours, usually during the most probable days of system peak when consumption approaches system capacity. Peak clipping can be accomplished more reliably with utility direct load control, but it is not required. Volunteer programs where control resides within the customers consisting of curtailment during the peak event can also reduce overall energy consumption at peak.

Valley filling promotes the load increase during off-peak hours when system capacity is high and consumption is low. Generally valley filling is incentivized by time of use rates. Energy consumption is increased.

Load shifting involves shifting load from on-peak to off-peak. This requires active participation or control by the customer, and can also be incentivized by time of use rates so the customers shift load to periods that have favorable pricing. The overall energy consumption is not increased or decreased. Instead, the energy consumption is more evenly distributed throughout time.

Implementation of a single load management shape objective may result in a combination of several objectives i.e. peak clipping may also result in load shifting. For example, air conditioning load operates longer after a peak clipping event to account for the increased temperature of the house.

1.5 Plug-In Electric Vehicle Charge Modes

There are two general modes for charging a PEV: immediate and programmable. Immediate means that charge will take place as soon as the PEV is connected to an electric supply and programmable means that start or end time can be programmed by the user. The charge modes of three main PEVs based on the 2013 Owner Manuals are show below:

Chevrolet Volt 2013 [10]

Immediately: The Vehicle starts charging as soon as it is connected to an electrical outlet

Delayed Departure Time: The vehicle estimates the charging start time considering the programmed departure time for the current day of the week.

Delayed Rate and Departure Time: The vehicle estimates the charging start time based on the utility rate schedule and the programmed departure time for the current day of the week.

Nissan Leaf 2013 [11]

Immediate Charge: Charging automatically starts when charge connector is connected to the vehicle

Charging Timer: Gives option to select either start time, end time, or both. If only end time is selected, the system automatically determines when to begin charging.

Tesla Model S 2013 [12]

Immediate Charging: Charging starts when vehicle is plugged-in

Scheduled Charging Sessions: Set specific time when Model S will begin charging

Although the programming settings have some variations, the main observation is that PEVs have the capability to charge at any requested period of time.

Chapter 2: Definition of Charge Management Programs

Three main charge management programs are considered in this study. Each program differs in load management objectives, utility control, and pricing.

2.1 EXISTING UNCONTROLLED CHARGING

This program assumes that the utility does not influence PEV charging. Charging can take place at any time of the day for as long as needed without any restriction. Customers receive Austin Energy's residential Tier rates. No AS or ERS can be provided.

2.2 TIME OF USE RATES

Similar to Uncontrolled Charging, this program assumes that the utility has no active load control over PEV charging. Charging can take place at any time of the day for as long as needed. This program has passive load control by incentivizing load shifting through TOU rates. As mention in section 1.4, the PEV user has the ability to program the PEV charging times. The PEV and the house are billed together though a TOU meter. No AS or ERS can be provided.

2.3 UTILITY MANAGED CHARGING ONE WAY

This program consists of the utility actively sending signals to interrupt PEV load during specific conditions. Control is achieved through an Automated Demand Response (ADR) system with load interruptions of 15 minute and 1 hour intervals. The magnitude of available load for interruption is based on statistical analysis of 95% and 99% availability of PEV charging detailed in section 5.3.

Interruption signals can occur due to the following reasons:

- Avoid high energy cost in wholesale Real Time or Day Ahead ERCOT market
- Deployment of Ancillary Services or Emergency Response Services in ERCOT

One Way control is implemented only in Level 2 charge since an EVSE is required for control. For purpose of this study, all PEVs participating in the One Way program are assumed to be Level 2.

2.3.1 Real Time Prices

The objective of this program is to avoid high energy cost paid by Austin Energy in ERCOT's wholesale market. Interruptions occur when Real Time energy cost ($/MWh) reaches a certain threshold. No AS or ERS can be provided. Since RT prices are determined every 15 minutes, interruption events last a minimum of 15 minutes.

2.3.2 Day Ahead Prices

Just like Real Time, the objective of this program is to minimize cost. The threshold is energy price ($/MWh) in the Day Ahead ERCOT market. No AS or ERS can be provided. Interruptions last a minimum of 1 hour.

2.3.3 Ancillary Services

This program objective is to generate revenue from providing AS. Services considered are Regulation Up and Non-Spinning Reserves with a minimum duration of one hour. Commitment of AS occurs during the hours of high PEV load availability determined by the statistical analysis in section 5.3

2.3.4 Emergency Response Services

Objective of this program is to generate revenue from providing ERS. Load interruption occur when ERCOT sends an Energy Emergency Alert of Level 2. A summary of previous EEA Level 2 events and duration can be found in Appendix A. Notice that even the EEA can last several hours, load interruption would only occur during the committed Business Hours. To determine the possible Business Hours contract period the statistical analysis in section 5.3 is used.

Chapter 3: Definition of Metrics

The different charge management programs are compared using direct, quantifiable economic value benefits as it relates new revenue, cost avoidance, direct utility cost, MW potential for peak shaving, and CO_2 reductions.

3.1 Utility Infrastructure Cost for Charge Programs

The utility cost for infrastructure of each program depends hardware, software, and administrative cost. Table 3.1 shows the utility cost for each program. Table 3.2 shows the cost of building a combustion turbine power plant for increased capacity.

Uncontrolled Charging	
No infrastructure cost	
TOU Rates	
Smart Meter	$350 per PEV
Truck Roll (installation cost)	$275 per PEV
One Way	
Demand Response platform	$20,000 (fixed cost)
Rebate to customer	$85 per PEV
Vendor enrollment	$25 per PEV
Vendor maintenance fee	$15/year per PEV

Table 3.1: Infrastructure cost for charge programs

Combustion Turbine (Peaker)	
Capital Cost	988,000 $/MW
Fixed O&M	14,880 $/MW*year

Table 3.2 Capital and Fixed O&M cost for Combustion Turbine [13]

3.2 AUSTIN ENERGY RATES

Rates used in this study are rates for residential purposes for single-family dwellings and single metered apartments units whose point of delivery is located inside the city limits of Austin as specified in the City of Austin Electric Rate Schedule. Rates are effective since October 1st, 2013. There are two types of rates: tier-rates and tier-time of use rates [14]. Both types of rates can be found on Appendix B.

3.2.1 Rates Seasons

There are two seasons applicable for Austin Energy rates: from October to May and from June to September. For purpose of this study the season of June to September is referred as "Summer" and October to May as "Winter".

3.2.2 Residential Tier Rates

The residential tier rates are divided in five tiers where the energy charges are cumulative. The price is an addition of energy used in the first tier range at the cost of the first tier plus the energy used in consecutive tiers at their respective costs. A sample calculation can be found on Appendix B.

3.2.3 Time of Use Rates

TOU rates are divided in five tiers according to total monthly consumption by adding energy consumed during Off-Peak, Mid-Peak, and On-Peak times at their respective prices. The total monthly consumption sets the tier that is used to charge the customer. A sample calculation can be found on Appendix B.

3.3 ERCOT MARKET PAYOUT

Located in central Texas, Austin Energy is registered as a market participant in ERCOT performing the function of QSE. The ERCOT market payout will depend on several factors: wholesale cost of energy used by PEV at specific times, possible revenue from AS or ERS, and transmission fees cost. Different charge programs are expected to consume energy at different times, have a maximum potential for providing AS or ERS, and a certain contribution percentage in 4CP events. For purpose of this study PEV charging is considered a Load Resource capable of providing AS or ERS by reducing consumption.

3.3.1 Loads in SCED and Day Ahead Market

Real Time and Day Ahead ERCOT prices for Austin Energy settlement point LZ_AEN are the metrics used to compare charge programs. Real Time prices are in 15 minute intervals and Day Ahead in 1 hour intervals for 2013.

3.3.2 Ancillary Services

ERCOT's hourly Market Clearing Price for Capacity for Regulation Up and Non-Spinning Service in 2013 is the metric used to quantify the maximum potentials of the programs.

3.3.3 Emergency Response Services

Contract term, standard time period, and prices in Appendix A are the metric used to quantify potentials of ERS.

3.3.4 Transmission Fees (4CP)

Percentage contribution to 4CP events for each program is the metric used for comparison. The Four Coincident Peaks reported by ERCOT in 2013 are presented in Table 3.3. (AE – City of Austin DBA Austin Energy (TDSP) # 8008717664000)

	June 6/27/2013 17:00	July 7/31/2013 17:00	August 8/07/2013 16:45	September 9/03/2013 16:45	Average 4CP Load	Load Ratio Share
AE	2,475	2,459	2,586	2,535	2,514	3.86%
Total	64,541	65,031	67,335	63,574	65,120	100%

Table 3.3. ERCOT 2013 Four Coincident Peaks

3.4 PEV Adoption Forecast

As of January 2014 there are 785 PEVs in Austin Energy area. The adoption forecast according to the Electric Power Research Institute is show in Figure 3.1.

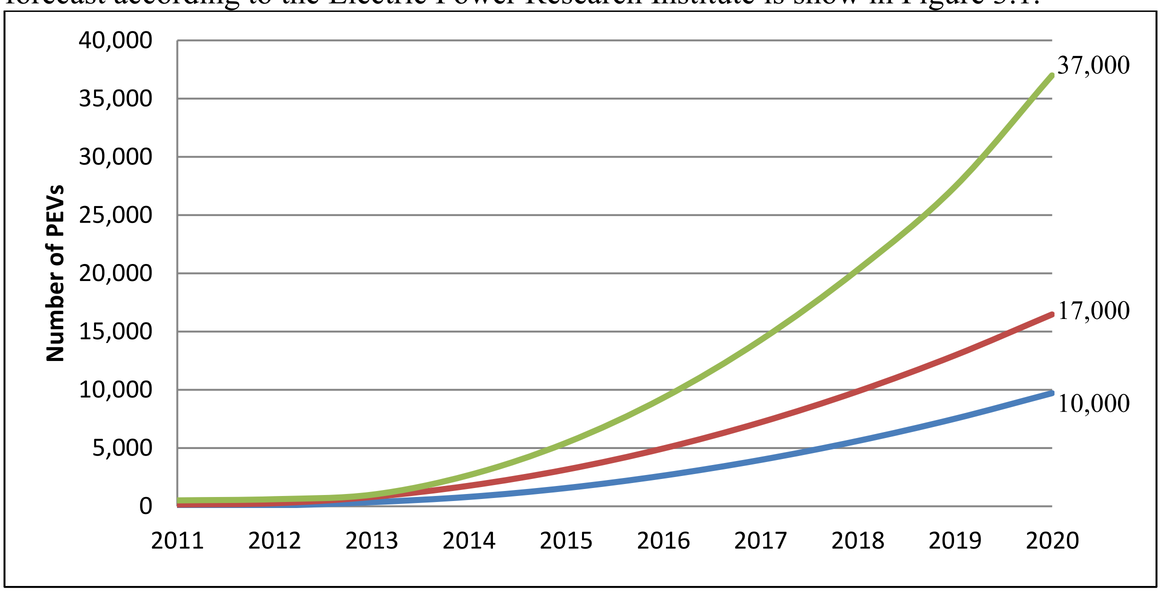


Figure 3.1. PEV Austin Forecast [15].

The forecast has three different projections which will be used to determine an upper and lower bound for peak shaving potential. The 785 PEVs will be used to compare the different programs in present time.

3.5 EMISSIONS

Emissions from PEV depend on the type of source that electricity comes from at the time of charging. At different times of the day there might be different types of generation sources depending on system conditions. An increase in demand would not make all generation sources increase equally; it would only increase the marginal generation at that point in time. Therefore the type of source considered for PEV emissions is ERCOT's marginal generation. In order to compare emissions from PEV and conventional gasoline vehicles a common metric of per mile is used.

3.5.1 ERCOT Marginal Generation

The data for this analysis comes from ERCOT's generation mix from 2013 with 15 minute intervals. The methodology consists of comparing the generation values by fuel type from interval to interval and determining which technology is moving in response to the change in demand. The following assumptions are made:

- If RT price is less than $0/MW then Wind is marginal
- If RT price is higher than $50/MW then Natural Gas is marginal
- If Natural Gas generation is increasing, regardless of price, Natural Gas is marginal
- Otherwise the generation with the highest increase is considered marginal
- For Natural Gas, the source with higher generation between Gas-CT or Gas-CC is used

This approach generates rather a rough estimate since there might be times that two sources are marginal but it is used mainly to compare the emission contribution of PEV load at different times of the day.

The main marginal generation sources are 48% Gas-CC, 21% Gas-CT, 18% Wind, and 6% Coal. Natural Gas is marginal mainly during day time and Wind is marginal during night time.

3.5.2 CO_2 Emissions by Source

The kilograms of CO_2 per kWh by source are summarized in Table 3.4. These values are obtained using CO_2 emissions factors (ton/MMBTU) from EIA [16] and assumed heat rates for different type of sources from ERCOT 2012 State of Market Report [17]. Sources with zero emissions mean that no hydrocarbon fuel is burned. Emission values only account for direct fuel consumption. Life cycle emissions are not considered since this study focuses on understanding the interaction of PEV load and increase in demand at different times of the day.

Source	kg of CO_2/kWh
Coal	0.950
Gas-CT	0.609
Gas-CC	0.406
Nuclear	0
Wind	0

Table 3.4. CO_2 Emissions from ERCOT main generation sources

The generation sources in Table 3.3 represent 99.6% of ERCOT's generation mix. Other sources like biomass, solar, and hydro represent 0.4% and do not play a significant role in marginal generation.

3.5.3 CO_2 Emissions per mile from PEV and Gasoline Vehicles

PEV emissions per mile are calculated using electricity source emissions from Table 3.5 and EPA Fuel Economy average of 360 Wh/mile. Gasoline emissions value obtained from light-duty automotive technology EPA average for new vehicles in 2013 [18].

Source	CO_2 kg/mile
Coal	0.342
Gas-CT	0.219
Gas-CC	0.146
Nuclear	0
Wind	0
Gasoline	0.370

Table 3.5. CO_2 Emissions per mile from different sources

The fuel source with most emissions per mile is motor gasoline, followed by coal, and natural gas. Even in a worst case scenario where all energy comes from coal, a PEV will have fewer emissions than a new 2013 gasoline vehicle.

Chapter 4: Data Analysis

The data set used for this analysis comes from Pecan Street Inc. The set includes data with 15 minute interval measurements for home electricity consumption as well as PEV consumption of Austin Energy customers. It consists of 45 homes with one PEV each; 24 of these customers participated in a TOU trial. The group of customers that received the normal Tier rates is referred as "Tier" and the group under the TOU trial as "TOU".

4.1 Home Load Profiles

The average annual daily load profile per house of Tier and TOU groups is shown in Figure 4.1. The profile includes house load as well as PEV charging. The TOU trial group differs from the "traditional" load profile by reducing consumption at peak hours and by introducing a small peak at 4:00 AM. During the Off-Peak period from 3:15 AM to 6:00 AM the TOU load is higher than Tier.

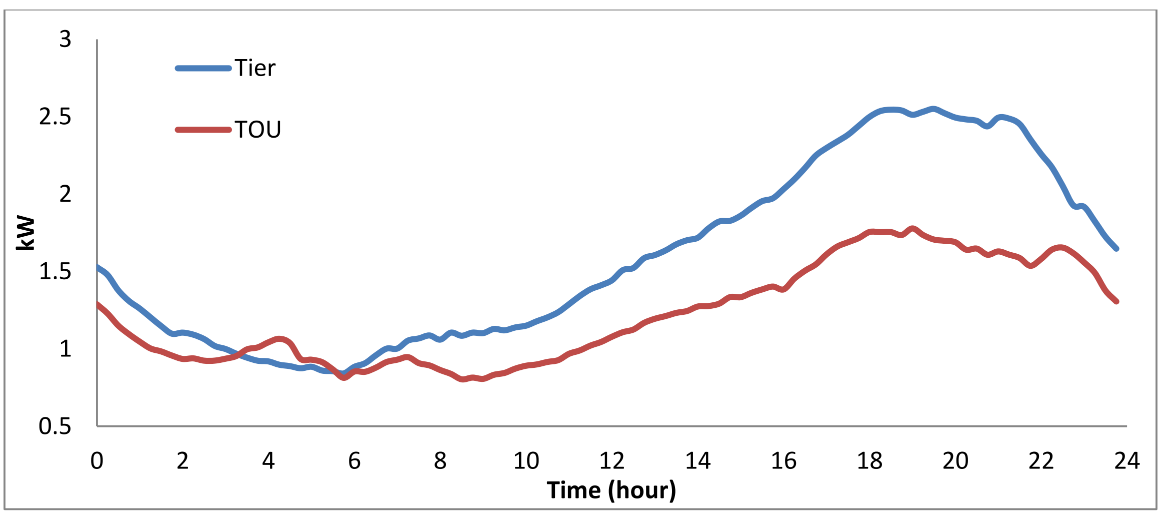


Figure 4.1. House average daily profile

The introduction of PEV charging and incentives to charge at night has apparently created a change in the overall house load from Tier profile to TOU profile.

Now considering only house load without PEV charging Figure 4.2 presents profiles of both groups. In this case they have similar load shapes but different magnitudes. The magnitude of the house load is directly affected by season by having higher load during summer and lower during winter.

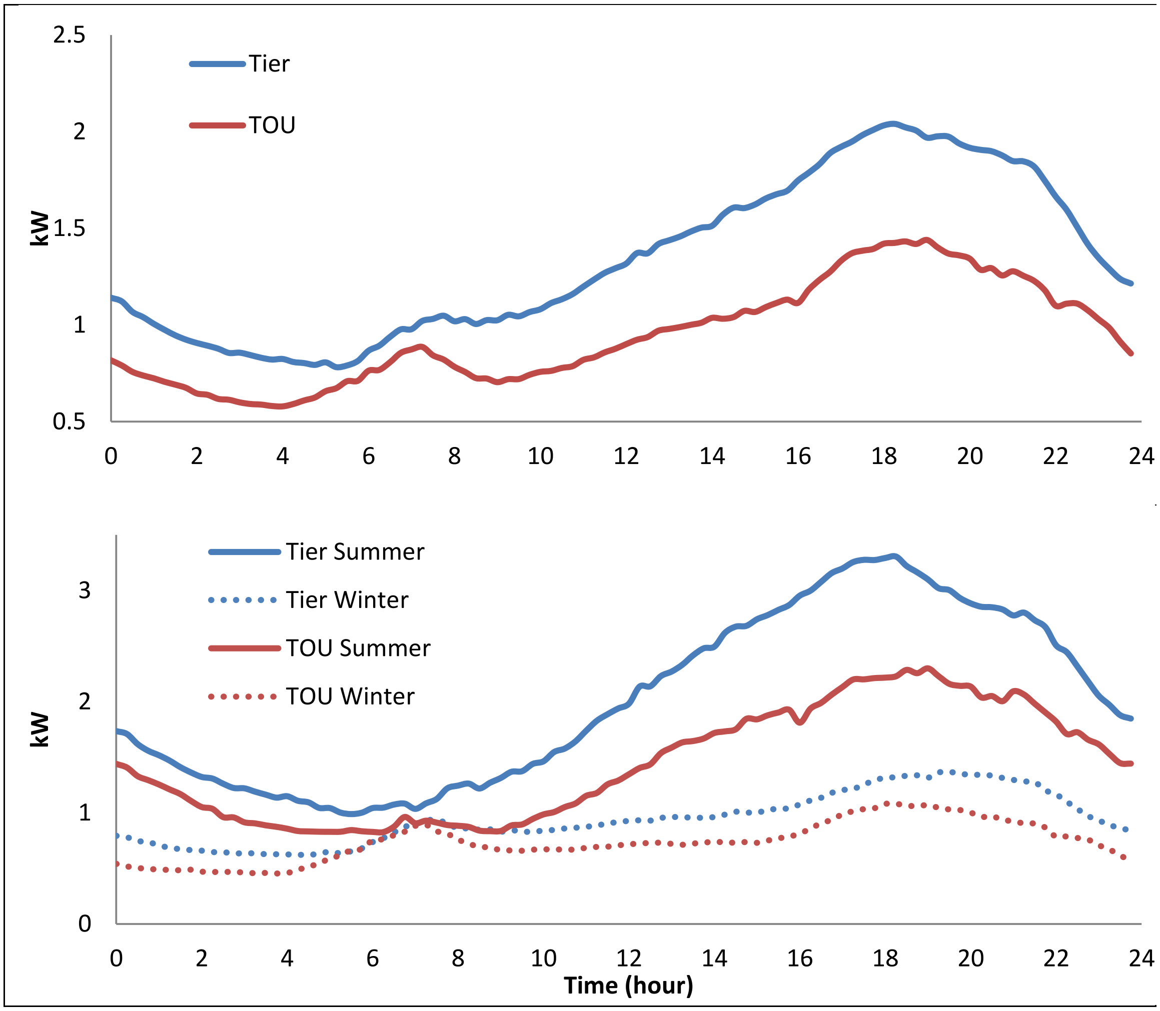


Figure 4.2. Annual and seasonal house daily load profile

On average, customers under the TOU trial used less energy per day in both winter and summer seasons as seen in Figure 4.3. Energy consumption is presented in Wh/sqft per day in order to take in consideration house size. Noting that other factors such as insulation, window to wall ratio, year of construction, etc. affect energy consumption; it is not clear why one group is lower than the other with the available data. Rather notice that both Tier and TOU energy consumption was higher by 105% and 83% in summer than winter.

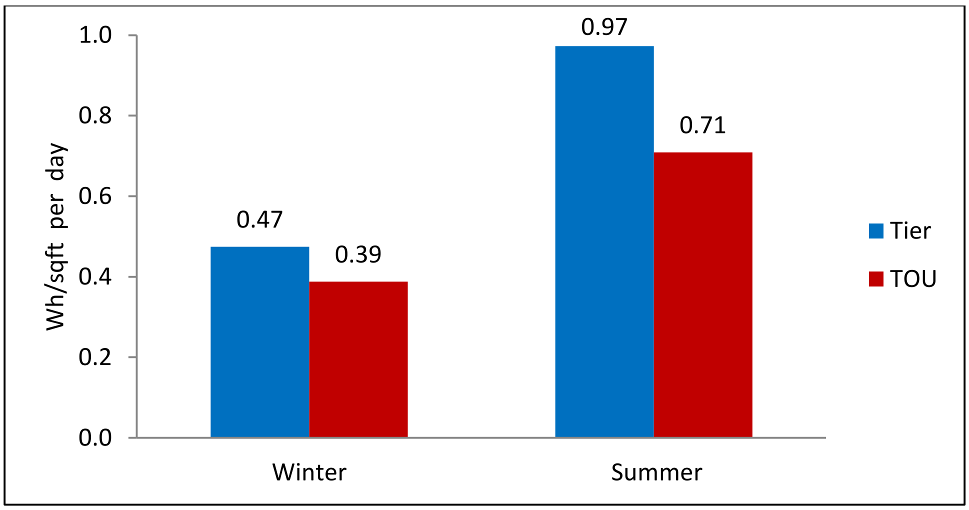


Figure 4.3. Average daily energy consumption per sqft.

Both groups presented essentially the same energy distribution during On, Mid, and Off Peak hours. Figure 4.4 shows the percent consumption distribution. This consumption only considers house load and does not include PEV charging.

Since there is no information about the TOU group energy usage before the trial, it is not clear if the TOU rates would decrease energy consumption. But rather notice that the TOU trial did not create a considerable load shift in house consumption compared to the Tier group.

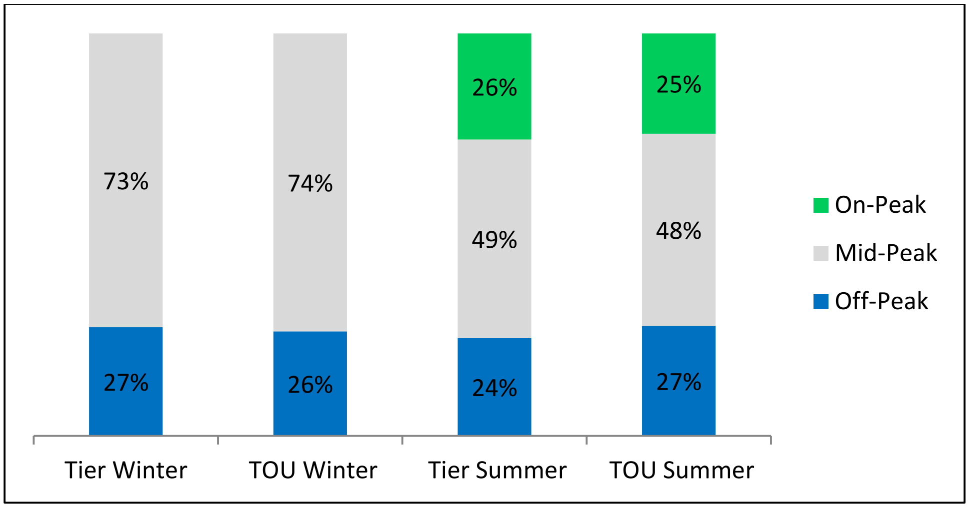
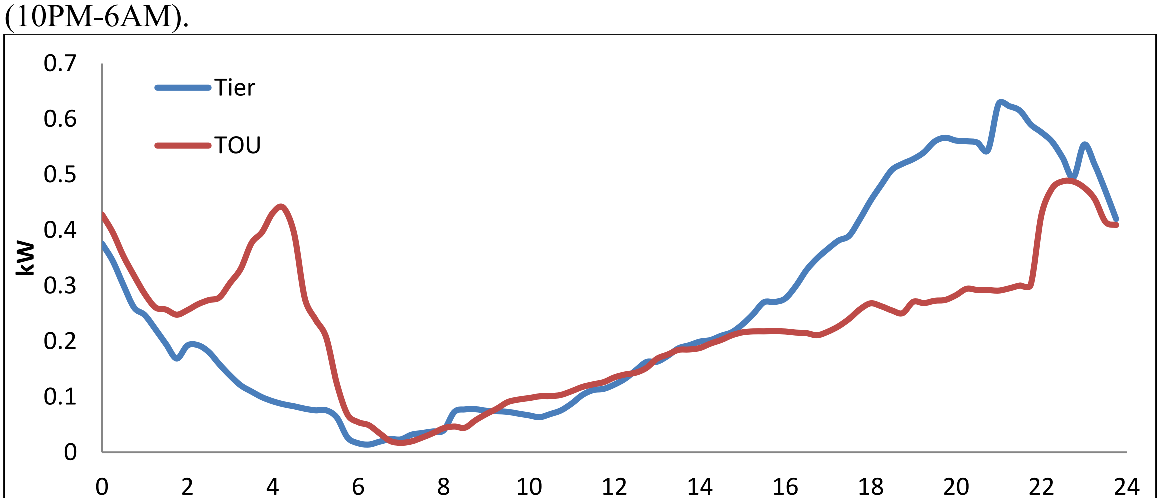


Figure 4.4. Percent house energy consumption distribution.

4.2 PEV Load Profiles

Figure 4.5 shows average daily load per PEV with annual, summer, and winter profiles. In this case, magnitude and peak match for both seasons, meaning there is no direct difference from seasonal change.

There is a load shifting effect due to the TOU trial. Customers under TOU trial avoid charging during peak hours (6AM-10PM) and increase load during Off-Peak hours (10PM-6AM).



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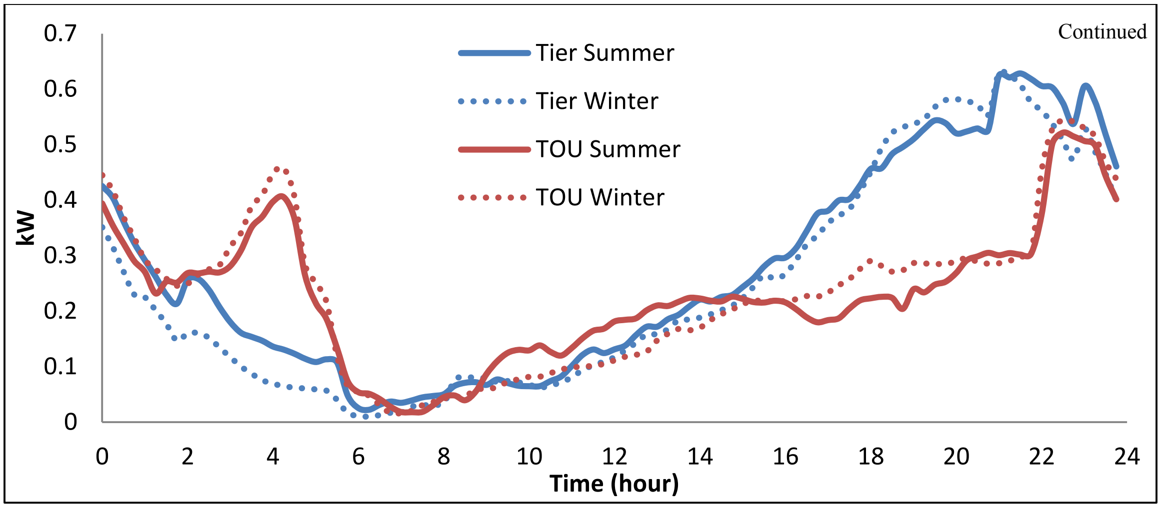


Figure 4.5: Annual and seasonal PEV daily load profile

. The Tier profile gradually increases from 6:00AM until peaking at 9: 00PM and then gradually decreaeses apporacing to zero at 6:00AM The Tier profile has one peak and one valley similar to house consumption.

The TOU profile has two peaks at 4:15AM and 10:00PM which indicates that there is a combination of several behaviors. In order to identify the source of these peaks, the TOU group was divided into three equal parts of 8 PEVs each.

- TOU A: Direct contribution to 4:15AM peak
- TOU B: Direct contribution to 10:00PM peak
- TOU C: No direct contribution to any peak

TOU A shows a linear increase at early AM and a sudden drop to zero at 6:00AM which suggests that the PEV was programmed to be charged by departure time of 6:00AM. TOU B shows a step increase exactly at 10:00PM which suggests that customers started charging right at the beginning of the Off Peak period. TOU C is very similar to the Tier profile with a gradual load increase and decrease.

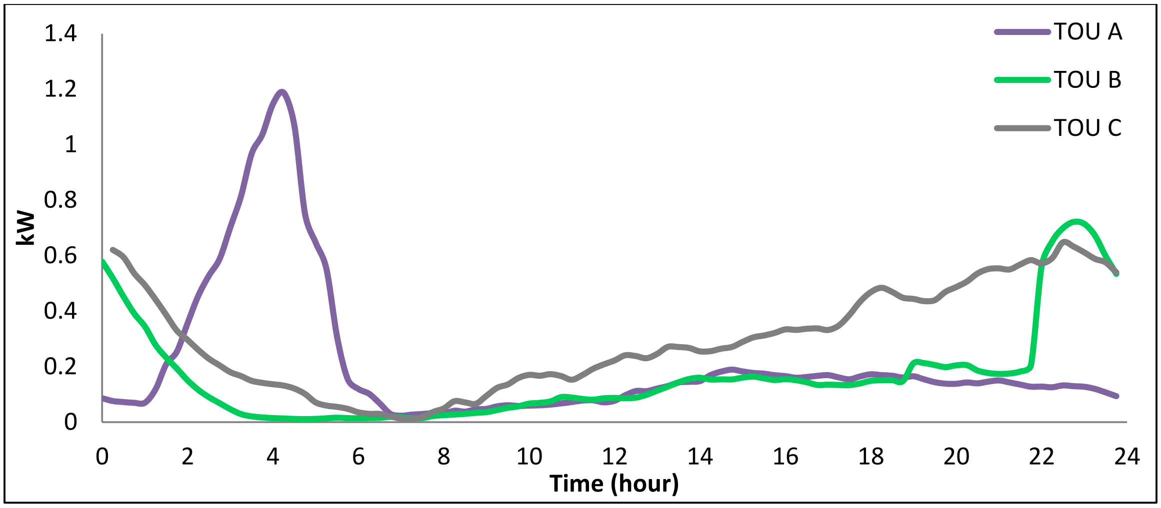


Figure 4.6. TOU Groups

The peak at 10:00PM comes from both TOU B and C, whereas the peak at 4:15AM comes almost entirely from TOU A.

From this profile it can be concluded that the TOU trial had almost no effect in TOU C. In contrast, TOU A and B show that the majority of charging happened during Off Peak hours. The TOU incentives effectively shifted load from On-Peak to Off-Peak hours in two thirds of the TOU customers decreasing overall load during On Peak.

In average both groups used about the same energy per day for PEV charging with an average of 5.76 kWh per day. With only 10% increase and 6% decrease for Tier and TOU respectively from winter to summer. Although these values depend on several factors such as distance driven, car temperature etc.; there is not a significant seasonal change compared with the 105% and 83% increase in house load. The enrgy consumed equates to about 16 miles per day.

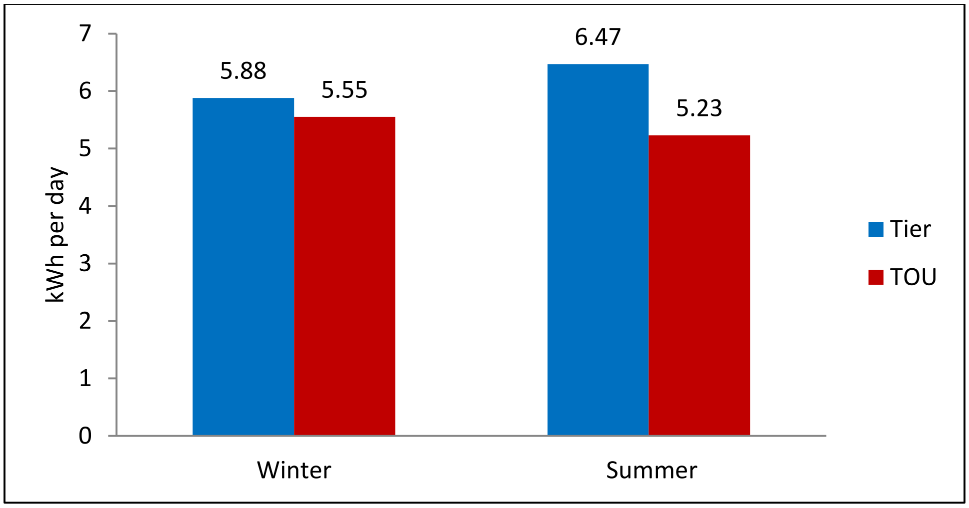


Figure 4.7. Average daily energy consumption per PEV.

PEV under TOU trial were charged about half of the time during Off-Peak hours, while Tier only about one third. Exact percentages can be found in Figure 4.8. In both seasons the TOU group charged less during On/Mid-Peak hours and more during Off Peak.

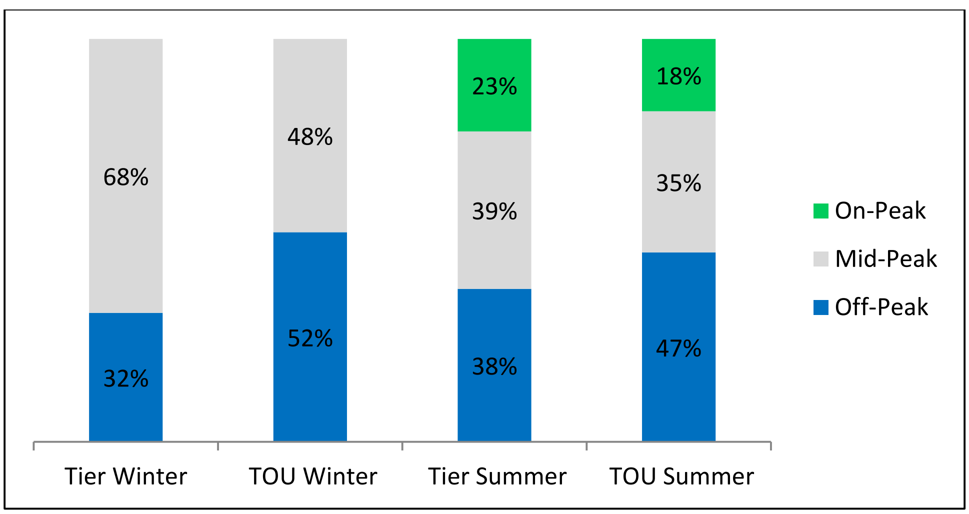


Figure 4.8. Percent PEV energy consumption distribution.

4.2.1 Emissions

PEV emissions are calculated using the marginal generation analysis from Chapter 3 and PEV load at each 15 minute interval. Results are shown in Table 4.1. There was not a significant change in emission from Tier to TOU, only a 6% reduction. Although PEV load is present during all hours of the day, Tier load is higher during peak hours, which implies that most energy comes from Natural Gas. Instead TOU load is higher during Off-Peak hours, which means energy comes from Wind but still mainly from Natural Gas which make both groups almost equal. Nevertheless, PEV emissions were about 64% lower than a gasoline vehicle for same miles driven.

Emissions	Tier	TOU	Gasoline
kg of CO_2	804	752	2161

Table 4.1. Annual CO_2 Emissions per vehicle

4.2.2 Charge frequency profiles

The histogram for charge duration considering all charges combined for the 45 PEVs during 2013 is presented in Figure 4.9. The average charge duration is 2.25 hours.

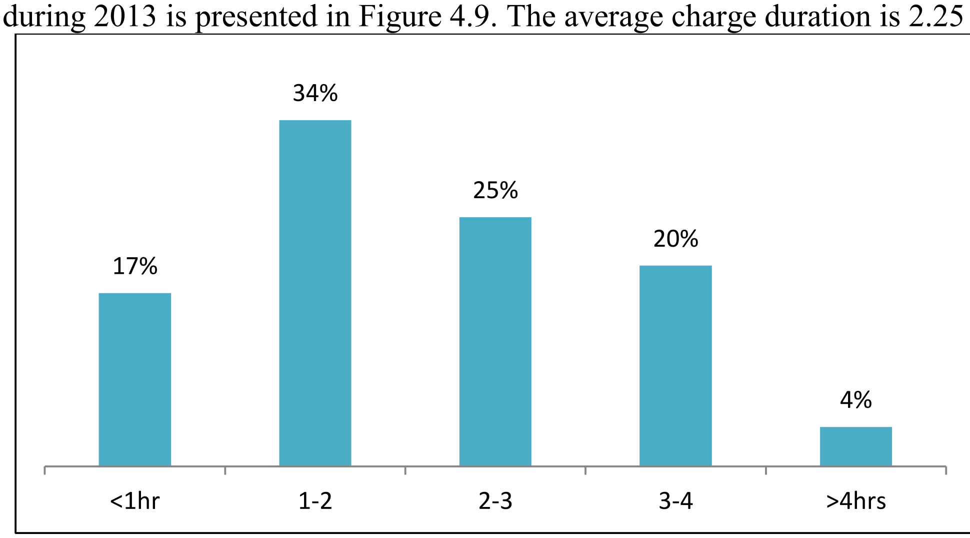


Figure 4.9. Charge duration distribution

4.3 ERCOT Market Payout

4.3.1 Real Time and Day Ahead Cost

The charging events from the Tier and TOU groups were used to calculate an average annual wholesale cost per PEV using Real Time and Day Ahead prices for 2013. In average PEVs under the TOU group had less annual wholesale cost with both prices.

	Tier	TOU
Real Time	$75.83	$61.31
Day Ahead	$73.03	$62.61

Table 4.2. Annual average cost per PEV in ERCOT wholesale market

Incentivizing charge during Off Peak hours reduced the cost paid by Austin Energy in the ERCOT wholesale market by 19% and 14% in RT and DA markets.

4.3.2 Transmission Fees (4CP)

The Tier group contribution to 4CP load was almost double than the TOU group. There is not a consistent relationship in magnitude contribution for any of the groups but in general TOU contributions are smaller.

kW	June 6/27/2013 17:00	July 7/31/2013 17:00	August 8/07/2013 16:45	September 9/03/2013 16:45	Average 4CP Load(kW)	Average 4CP per PEV (kW)
Tier	7.465	0.208	4.803	20.273	8.18725	0.3898
TOU	9.609	0.015	3.441	6.673	4.93450	0.2056
All	17.074	0.223	8.244	26.946	13.1217	0.2693

Table 4.3. Four Coincident Peak contribution from Tier and TOU

During the all the 4CP events, a higher percentage of PEVs from the Tier group were charging than from the TOU group.

	June 6/27/2013 17:00	July 7/31/2013 17:00	August 8/07/2013 16:45	September 9/03/2013 16:45
% of 21 Tier PEVs	14%	5%	15%	24%
% of 24 TOU PEVs	13%	0%	4%	8%

Table 4.4. Percentage of PEV charging during 4CP events

4.4 TIER RATES VS TIME OF USE RATES

4.4.1 Effect of All Study Households move to Time of Use Rates

Using Austin Energy rates, the possible electricity revenue from all households in the study was calculated as if all of them were billed with Tier rates and then with TOU rates. Table 4.5 presents the summation of all 45 households yearly bill with either rates.

	Tier	TOU
2013 Annual Bills	$61,356	$61,560

Table 4.5. Total annual revenue from bills if charged as Tier and Time of Use

There is a $204 difference, which means in average Austin Energy would get $4.53 per customer more if all are charged with TOU rates. Actual customer savings or cost per year distribution if billed as TOU is shown in Figure 4.10. There is an even distribution where about half would save and half would spend more:

- 22 (13 of them under TOU trial) customers would save if billed as TOU.
- 23 (11 of them under TOU trial) customers would spend more if billed as TOU.

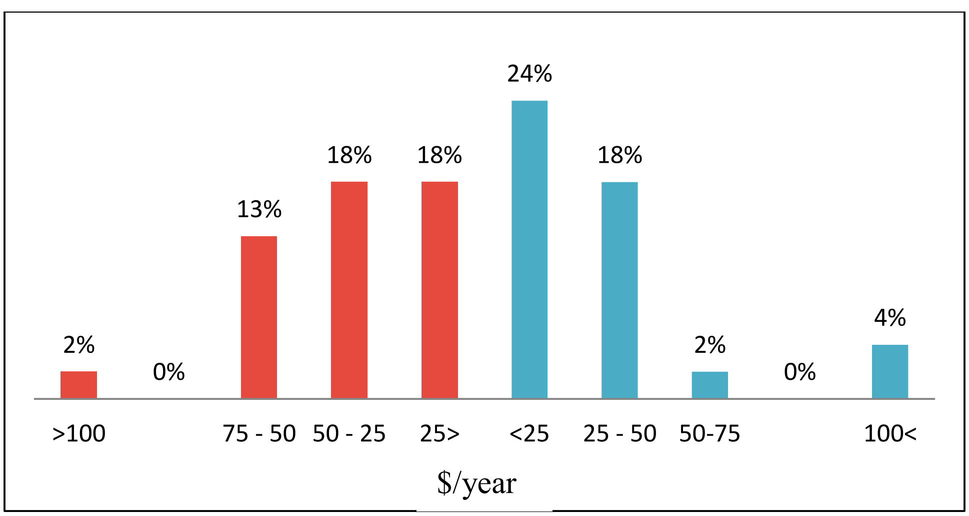


Figure 4.10 Cost (red) and Savings (blue) per year if billed as TOU

4.4.2 House profiles with most and least benefit from TOU rates

The most and least benefit house annual profiles are shown in Figure 4.11.

- Household 4957 (Tier) would save $122 if billed as TOU ($2555 – $2433)
- Household 5357 (TOU) would spend $149 if billed as TOU ($3588 – $3737)

Household 5357 is mainly affected by having a high load exactly at On/Mid Peak hours and having another peak from 4:00AM to 9:00AM which incidentally is not from PEV charging. As it happens PEV load is close to ideal where the majority of the charging starts after 10:00PM. In contrast, Household 4957 has a PEV load which occurs mainly during On/Mid Peak hours but still would be the most benefited from TOU rates.

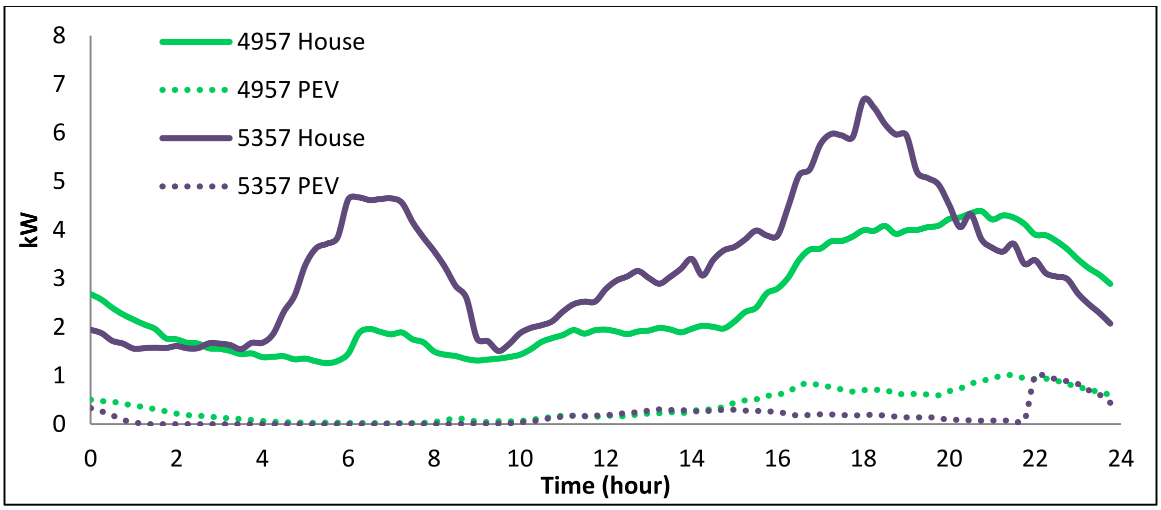


Figure 4.11. House and PEV profile with most and least benefit from TOU

If billed as TOU, a household from the Tier group that had no incentive to shift load to Off-Peak hours would be the most benefited and a household under the TOU trial that had incentive would be the least benefited.

Note: The PEV profile is averaged over the whole year. Although charging took place at 3.3 kW level, the average decreases the apparent kW value in the graph.

4.4.3 PEV profiles with best and worst behavior for TOU rates

The best and worst PEV profiles for TOU rates are shown in Figure 4.12.

- Household 6139 (TOU) would save $44 if billed as TOU ($998 - $954)
- Household 7510 (Tier) would spend $49 if billed as TOU ($1450 - $1499)

Household 6139 PEV load profile is ideal by having close to 100% of charging taking place during Off-Peak hours. The fact that PEV load occurs from 2:00AM to 6:00AM indicates that the charging has been programmed to be completed by departure time of 6:00AM.

In contrast, Household 7510 PEV load occurs mainly during On/Mid Peak hours. There is almost no charge from midnight to 7:00AM which indicates that there is no programming at all involved.

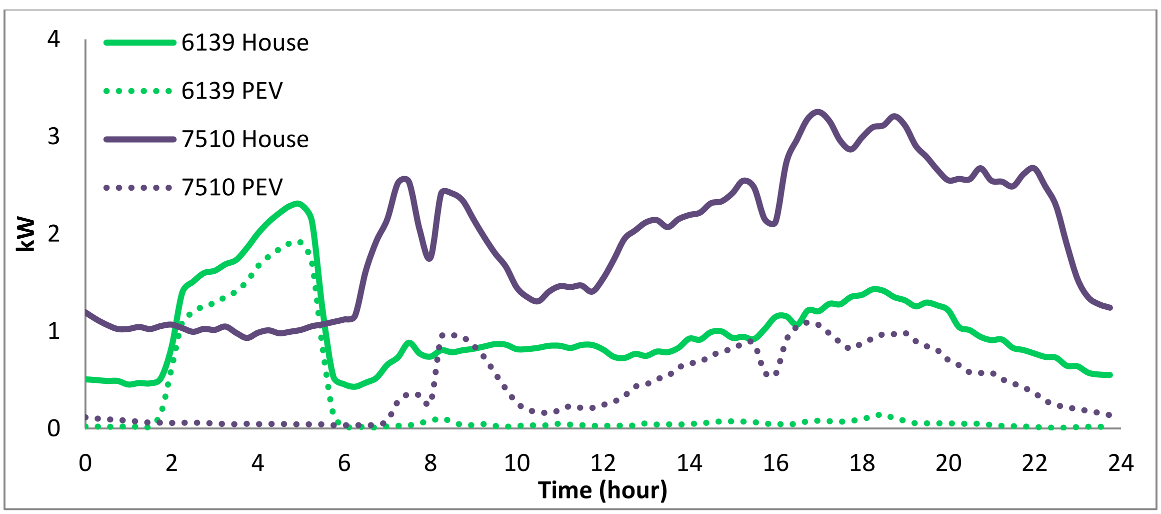
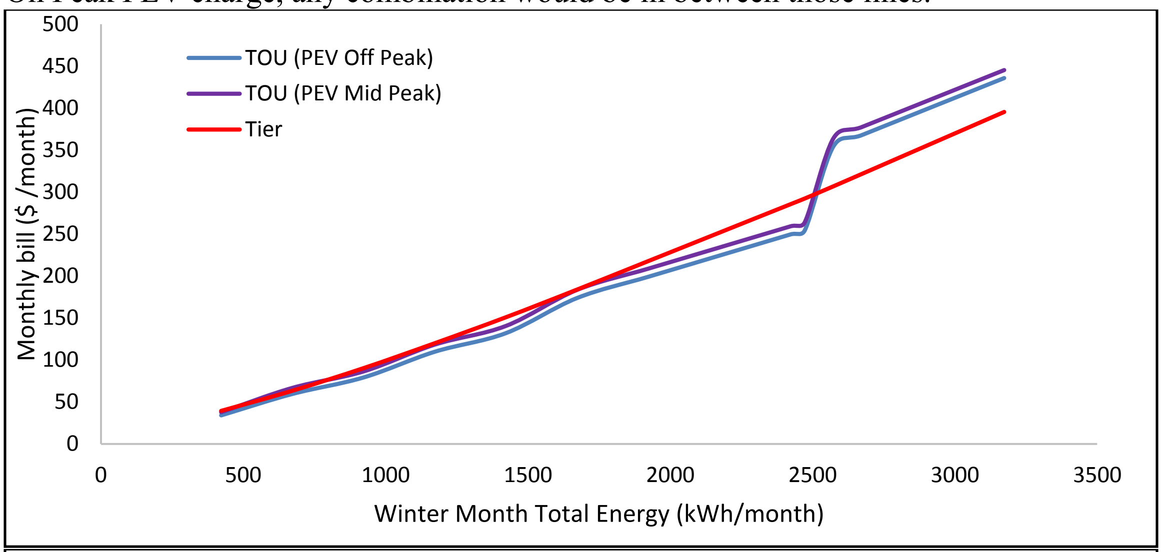


Figure 4.12. House and PEV profile with best and worst PEV behavior for TOU rates.

4.4.4 Austin Energy Tier and TOU Rates Analysis

The following analysis is used to compare the effect of shifting PEV charging between Off Peak and On Peak hours. House load On, Mid, and Off Peak percentage distribution is taken from section 4.1.An average PEV consumption of 5.76 kWh per day is assumed from section 4.2. Figure 4.13 shows the montly bill cost with Tier and TOU rates. The TOU lines in the graph create a boundary between 100% Off Peak and 100% On Peak PEV charge, any combination would be in between those lines.



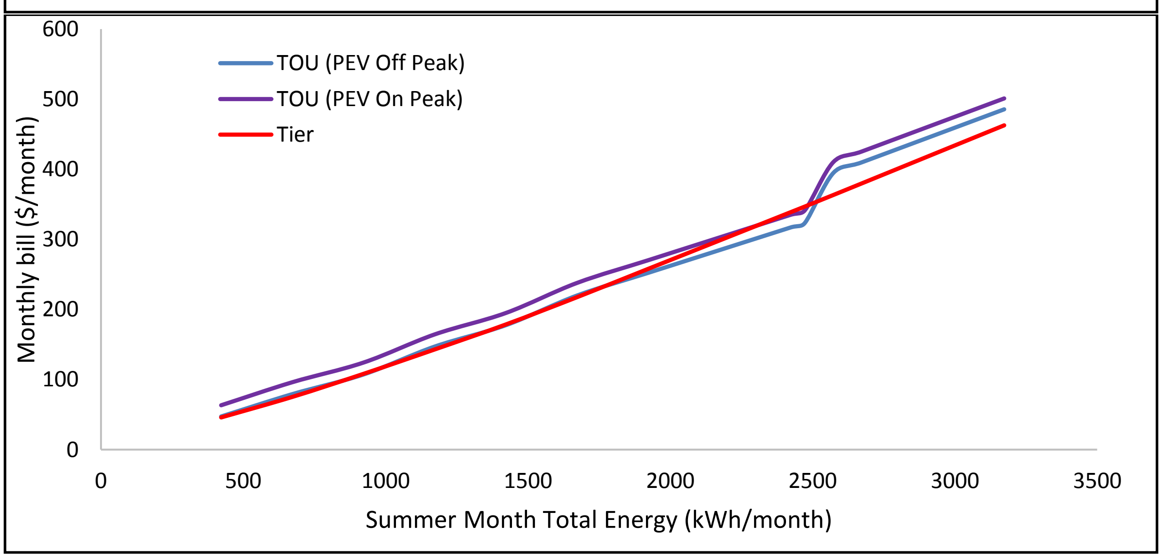


Figure 4.13 Montly bill cost with Tier and TOU rates.

As seen in Figure 4.13 Tier and TOU costs are similar for both seasons until total house consumption is 2500 kWh/month or higher, then TOU rates are always more expensive than Tier regardless PEV load shifting.

The annual TOU cost compared to Tier is presented in Figure 4.14. Positive values mean that the cost is higher than it would be with Tier rates and negative mean that it would be lower. As the figure shows, shifting all PEV charging to Off Peak could save money to the customer under TOU rates. If all PEV charging takes place during On Peak, then it would be more expensive except for some situations. After 2500 kWh per month, TOU is always more expensive than Tier.

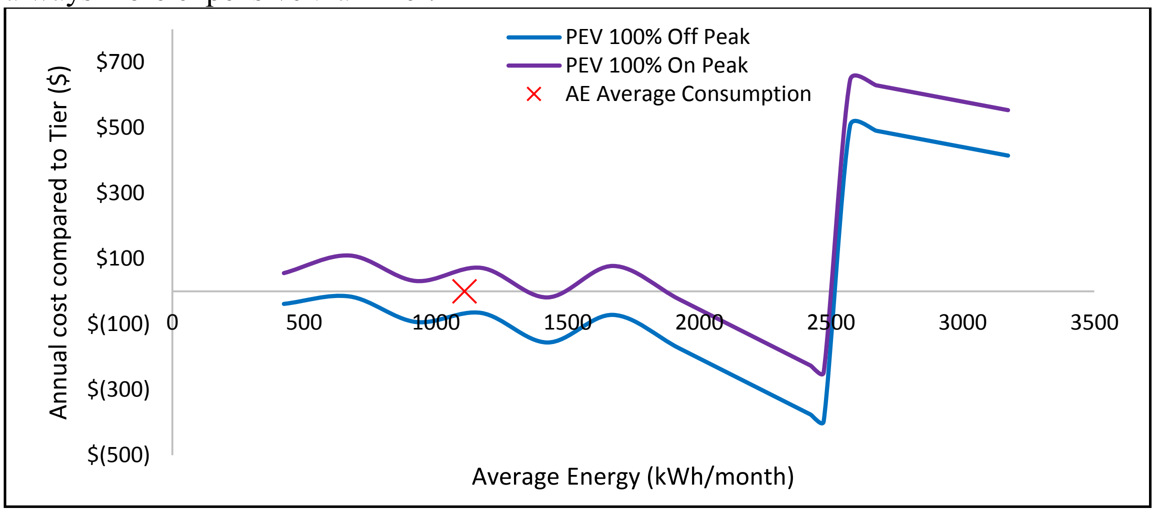


Figure 4.14. Annual TOU cost compared to Tier rates

The main point of this rate analysis is to show that it is possible to save money under TOU rates by shifting PEV charging to Off Peak hours. When energy consumption is more than twice the average residential kWh per month, TOU is more expensive.

4.5 Data Analysis key points

Season effect

- House load is affected by season
- PEV load is not significantly affected by season

TOU trial

- TOU trial had a load shift effect on PEV load
- There is not a significant change in emissions from Tier to TOU
- Two main charge programming identified: Departure Time by 6:00 AM and Start Charge at 10:00 PM

PEV charging

- Average charge duration is 2.25 hours
- Average consumption is 5.76 kWh/day which is about 16 miles per day
- Average annual miles is 5840, far lower than Texas and national average
- Most customers charged at 3.3 kW Level 2 (except for 2 Nissan Leafs at 6 kW)
- There is a 64% reduction in CO_2 emissions from Gasoline to PEV

Billing and ERCOT Payout

- It is possible to save money under TOU rates by charging PEV during Off Peak
- Austin Energy would receive similar revenue for either billing method
- Austin Energy would have less wholesale energy purchase cost if PEV load behaves like TOU
- TOU group had about half the contribution to 4CP events compared to Tier

Chapter 5: Program Implementation

The following analysis consist of understanding the potential and possible results of implementing each charge management program. This analysis is based on the results from the data in Chapter 4 and the PEV adoption forecast. After analyzing the potentials a comparison of the programs is presented addressing the metrics mentioned in Chapter 3, Austin Energy's Mission, and Austin Energy goals for the Climate Protection Plan to 2020.

5.1 Uncontrolled Charging

In the case where there is no control or load shifting incentives, the behavior from the Tier group is expected to continue. Considering the highest point of the Tier profile, which is at 9:00 PM, and the PEV adoption forecast, Figure 5.1 is presented. This figure shows the capacity needed to support PEV load at its highest point.

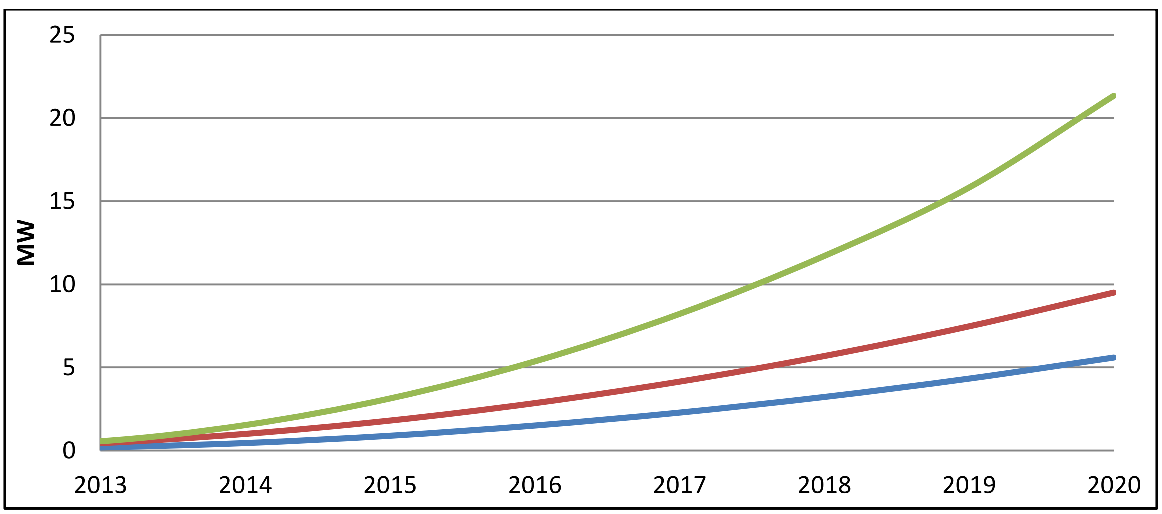


Figure 5.1 Uncontrolled Charging capacity requirement

This program has no cost to the utility in terms of infrastructure or implementation. If left uncontrolled, PEV charging will increase the residential peak load, which could have cost in terms of generation, transmission or distribution expansion.

5.2 TOU Potential

Implementation of TOU rates program would have an effect of peak shaving but would create a new residential peak. Assuming that if implemented, the current 785 PEV users would behave exactly like the TOU trial customers. The difference from TOU to Tier profile is show in Figure 5.2, where positive values mean increase in new load and negative values mean decrease in existing load. An increase of 330 kW of capacity at 4:15AM would be needed and 413 kW would be avoided at 7:30 PM.

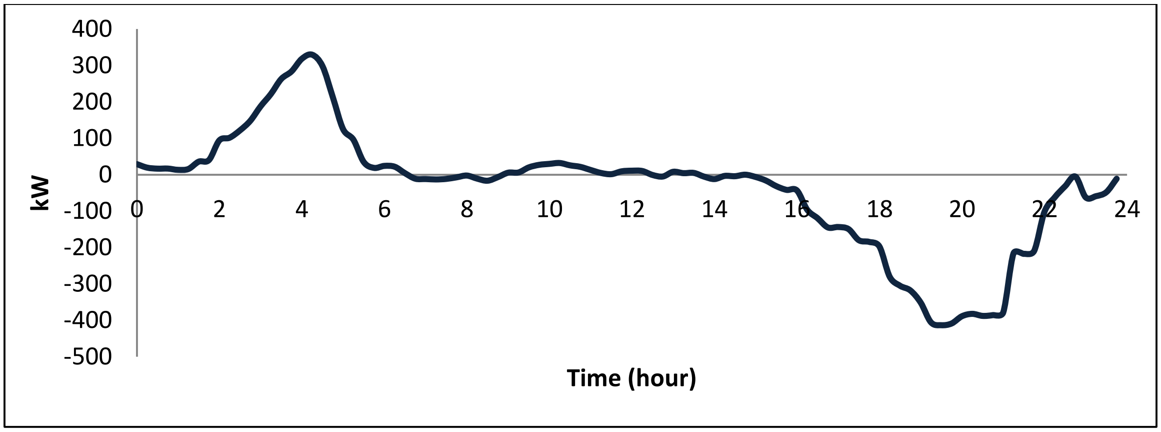


Figure 5.2. Difference from TOU to Tier profile.

Using the PEV adoption forecast the possible capacity needed at 4:00AM and load avoided at 9:00PM is show in Figure 5.3.

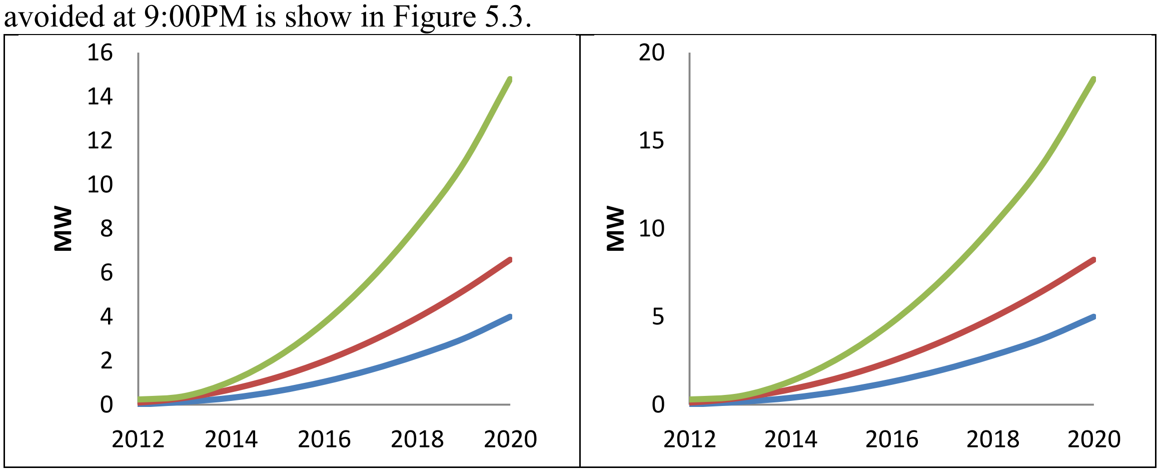


Figure 5.3. New capacity needed at 4:15AM (left) and load avoided at 9:00PM (right)

5.3 One Way Control Potential

5.3.1 Average Energy Cost without any Interruptions

The average profile of the Tier group is used as the assumed daily PEV load. The annual energy cost without any interruption is shown in Table 5.1; also as a point of comparison, the cost of the TOU average profile is included. Notice that the TOU profile cost is about $10 lower than the Tier cost.

	Annual Real Time Energy Cost	Annual Day Ahead Energy Cost
Average Tier Profile	$72	$75
Average TOU Profile	$62	$64
Savings with TOU	$10	$11

Table 5.1. Annual Energy Cost of Average Tier and TOU Profiles

5.3.2 Real Time Prices

As mention in section 2.3.1, the objective of this program is to avoid high energy costs in the ERCOT Real Time wholesale market. Interruptions occur when the price of energy is higher than a specified threshold.

For example: The average Real Time price of energy in 2013 was 32.3 $/MWh. It is decided that if the price of energy is higher than 32.3 $/MWh, PEV charging is interrupted and restored until the price is lower than the specified threshold. A total of 8954 interruptions of 15 minute each would occur which represent an equivalent of 93.3 days. The annual cost per PEV would be $56.60 which represent savings of $16.12 per PEV

Table 5.2 shows a tabulation of Real Time Annual Cost per PEV, threshold, interruptions, cumulative interrupted time, and savings. It can be observed that to increase the amount of savings, the number of interruptions increases exponentially.

RT Annual Cost per PEV	Threshold ($/MWh)	Interruptions (15 min each)	Longest Int.	Cumulative interrupted time	Savings
$72.70	---	0	---	---	$0
$62.70	**46.7**	**1850**	**6.25 hrs.**	**19 days**	**$10**
$56.60	32.3	8954	1.3 days	93 days	$16
$52.20	27.0	14328	2.7 days	171 days	$20

Table 5.2. RT-Cost, threshold, interruptions, cumulative interrupted time, and savings

Since the values of this program change with the specified threshold, the approach is to analyze the 46.7 $/MWh threshold which equals the annual savings of the TOU profile of $10.00. With this threshold, 80% of the 1850 interruptions would last less than 1 hour. About 67% of the interruption events would occur between 1:00 PM and 6:00 PM.

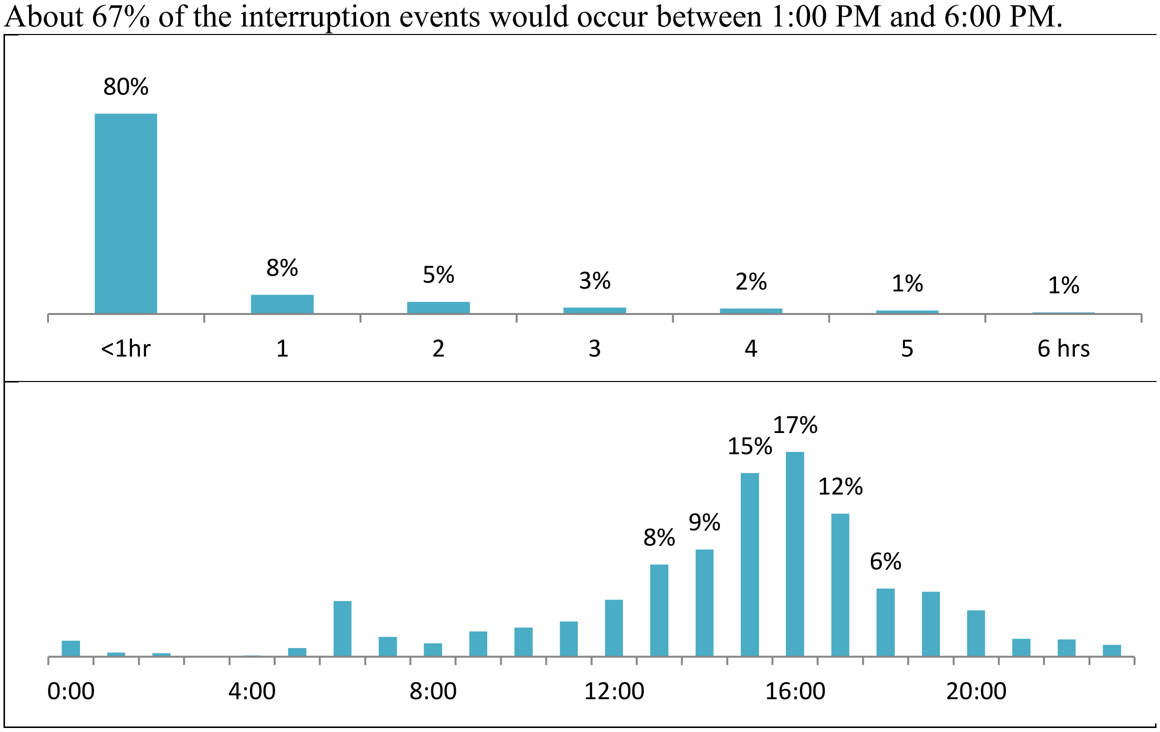


Figure 5.4. RT Histogram of interruption length and frequency during time of the day

The average profile using One Way control for Real Time prices with a threshold of 46.7 $/MWh would be similar in shape to the Uncontrolled Charging. There is not a considerable load shift effect, but the profile exhibits some spikes.

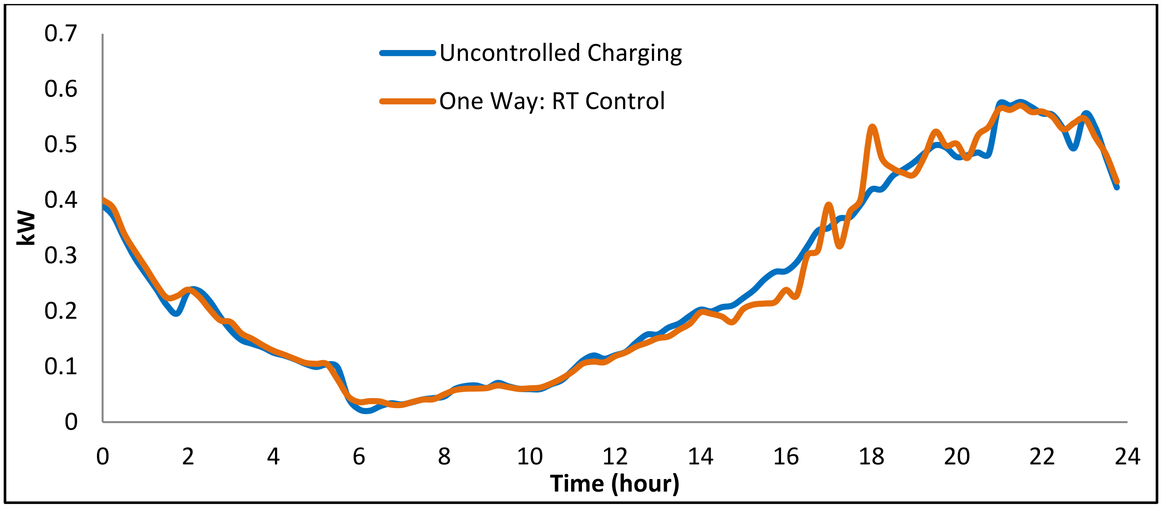


Figure 5.5. RT – Average daily load profile per PEV

The spikes in the profile are created from the vehicles that would normally charge at that time plus the overlap of the vehicles that were interrupted and resumed charging. While avoiding high energy cost, interruptions occur during all 4CP events, so there is no contribution to 4CP events.

5.3.3 Day Ahead Prices

Similar to the previous section, the objective of this program is to avoid high energy cost in the Day-Ahead energy market. Table 5.3 shows a tabulation of Day Ahead Annual Cost per PEV, thresholds, interruptions, cumulative interrupted time, and savings. It can be observed that similarly to Real Time Prices; in order to increase the amount of savings, the number of interruptions increases exponentially.

DA Annual Cost per PEV	Threshold ($/MWh)	Interruptions (1 hr. each)	Longest Int.	Cumulative interrupted time	Savings
$75.53	---	0	---	---	$0
$64.53	**36.7**	**2301**	**1.8 days**	**96 days**	**$11**
$55.53	28.9	4750	3.9 days	198 days	$20

Table 5.3. RT-Cost, threshold, interruptions, cumulative interrupted time, and savings

Taking the same approach as comparing the possible savings using DA program to the savings of the TOU profile Figure 5.6 is presented. With a threshold of 36.4 $/MWh, only 21% of the 2301 interruptions would last less than 1 hour. This means that 79% would last two hours or more. About 66% of the interruption events would occur between 1:00 PM and 6:00 PM.

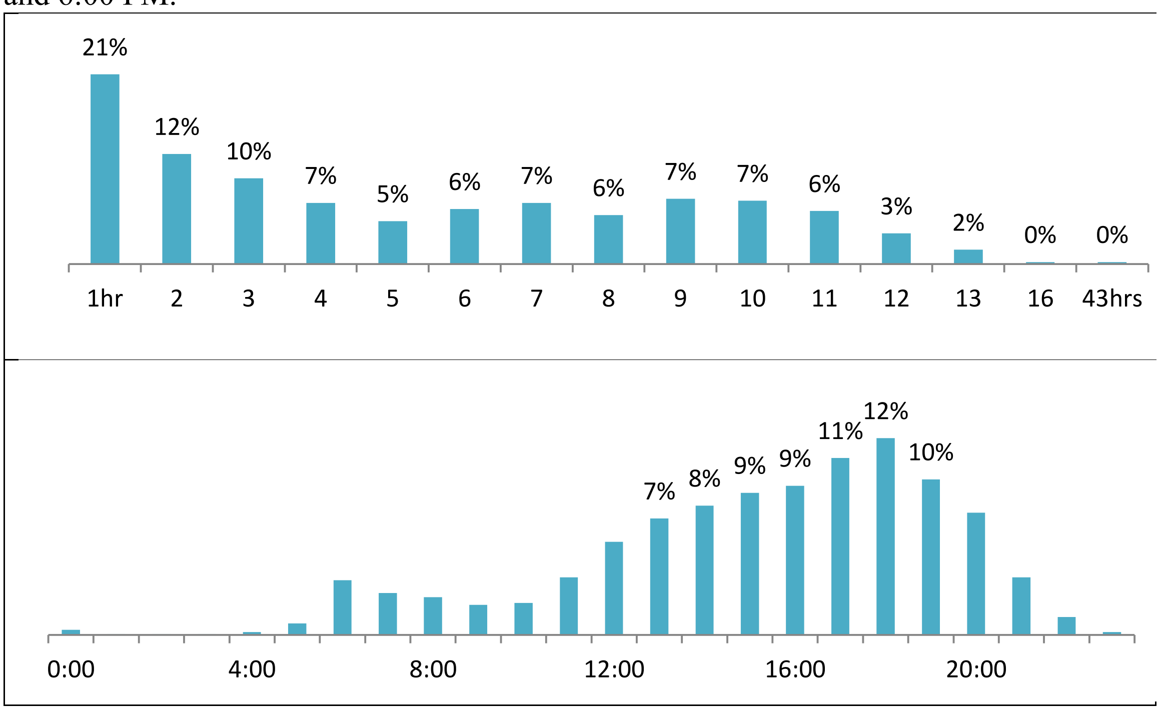


Figure 5.6. DA-Histogram of interruption length and frequency during time of the day

The average profile using One Way control for Day Ahead prices with a threshold of 36.7 $/MWh would be considerable different than the Uncontrolled Charging profile. It is noticeable that the Day Ahead control avoids high prices during On Peak hours and shifts most of the load to 8:00 PM or later.

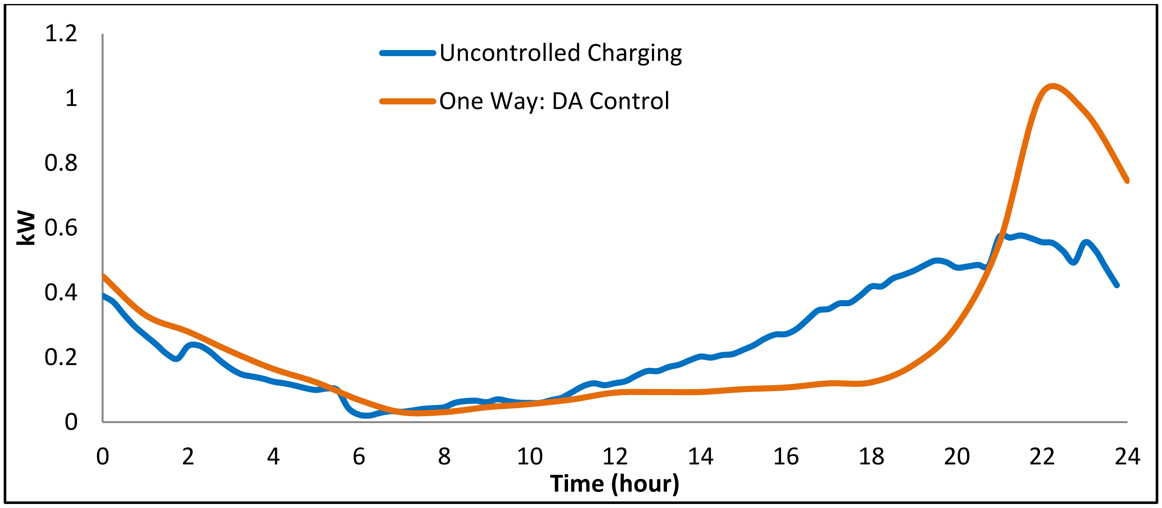


Figure 5.7. DA – Average daily profile per PEV

This program had no contribution to 4CP events. Although DA program has a load shifting effect that is of interest to the utility, implementation of this control requires a significant amount of interruptions (2301 hours interrupted). Remember that this threshold was chosen to achieve same amount of savings as the implementation of TOU incentives.

Both RT and DA programs had no contribution to 4CP events. RT does not achieve the desired load shifting effect. In contrast DA control successfully shifted the load, but at a high price of large amount of interruptions. It might be more feasible to implement RT control than DA control since it requires less and shorter interruptions.

5.3.4 Load Availability for AS or ERS

ERCOT has a minimum commitment requirement of 100 kW for each Ancillary Service offer and ERS. In case of committing ERS, the load must be available during the committed Business Hours specified in Appendix A. In case of committing AS, the QSE must make an offer every day in the Day Ahead market specifying the first and last hour of the offer. Penalizations can occur if the load is not available when requested by ERCOT.

In order to determine the number of PEVs needed to provide each service at possible times, a statistical analysis was performed using the charging events of the Tier group in 2013. The Cumulative Distribution Function (CDF) for each time interval is used to assign a percentage of load availability at any given day. The CDF describes the probability of a given quantity to be found at a value less than or equal than the specified quantity. Figure 5.8 shows the 785 population load mean and the percent availability.

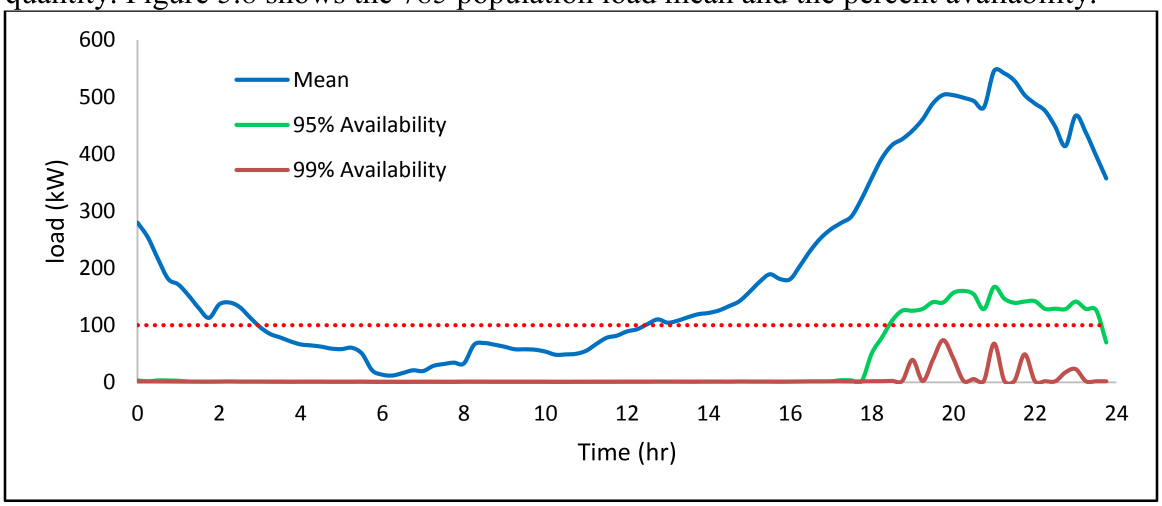


Figure 5.8. Population mean and availability

The percent availability curves indicate the amount of PEV load that is present 95% and 99% of the time. In order words, 95% availability means load is present 346 days per year with a value equal or greater than the specified value.

5.3.5 Potential to Provide Ancillary Services

The current population of 785 PEVs would be able to provide 100 kW for AS commitment 95% of the time from 7:00 PM to 11:00 PM. There is a risk of being deployed and not be able to provide 100 kW if deployment occurs during the 5% of the time that load is not available.

In order to minimize risk, 99% availability might be desired. Figure 5.9 shows the number of PEVs needed for 99% availability of 100 kW. Based on the PEV adoption forecast from section 3.4, it might not be until 2020 that 99% availability of 100 kW would be possible for the hours of 7:00 PM, 8:00 PM, and 9:00 PM; notice this is considering the highest adoption forecast.

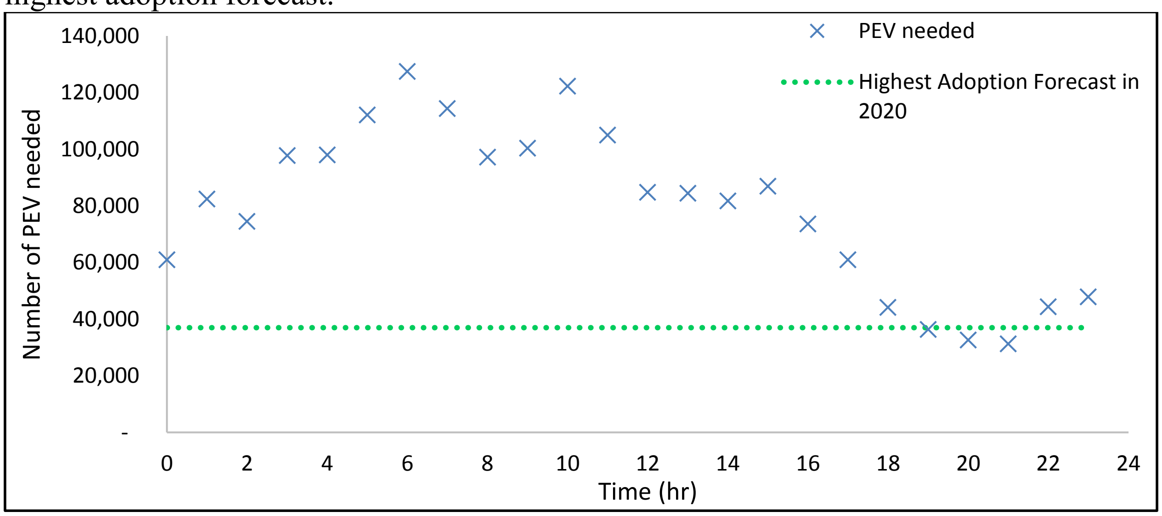


Figure 5.9. Number of PEVs needed for 99% availability of 100 kW

5.3.6 Potential to Provide Emergency Response Services

In order to be able to offer ERS, the load must be available during the whole Business Hours period. Table 5.4 presents the amount of PEVs needed to be able to offer 100 kW for each period at the expected availability.

Availability	BH1 (8:00 AM – 1:00 PM)	BH2 (1:00 PM – 4:00 PM)	BH3 (4:00 PM – 8:00 PM)
99 %	120,000	87,500	75,000
95 %	119,400	85,000	73,000

Table 5.4. Business Hours periods and PEV needed to offer 100 kW

With the current population of 785 PEVs it is not possible to offer any period of ERS. Even considering the highest adoption forecast of 37,000 PEVs by 2020, it would not be possible to offer at any ERS period.

It is important to note that these services could be offered into ERCOT programs with much lower numbers if packaged together with other devices, such as thermostats. It is most likely that this is in fact how that would occur. It is still useful to see how many PEVs are required if it was only PEV load, but should be noted that Austin Energy most likely would combine PEVs with other devices, which means any amount could be included.

5.4 Programs Comparison

The following section includes several assessment of the charge management programs in different categories. Firs possible cash flows assuming two values for annual miles driven, next advantages and disadvantages of each program based on the metrics of Chapter 3. Then a comparison of how each program addresses Austin Energy’s Mission. Last, a comparison of how the programs fit into the Austin Climate Protection Plan to 2020.

The cash flow for each program is presented in Figure 5.10 based on energy cost, utility revenue, and infrastructure cost with the following assumptions:

- 5840 annual miles driven per year based on data analysis from Mueller customers
- Uncontrolled and One Way RT - Increased capacity cost corresponding to equal annual payments to build a Gas-CT power plant in 2015 for PEV capacity in 2030

The cash flow is only positive for the TOU program. Notice that this analysis includes a low average of miles driven per year, therefore low energy consumption.

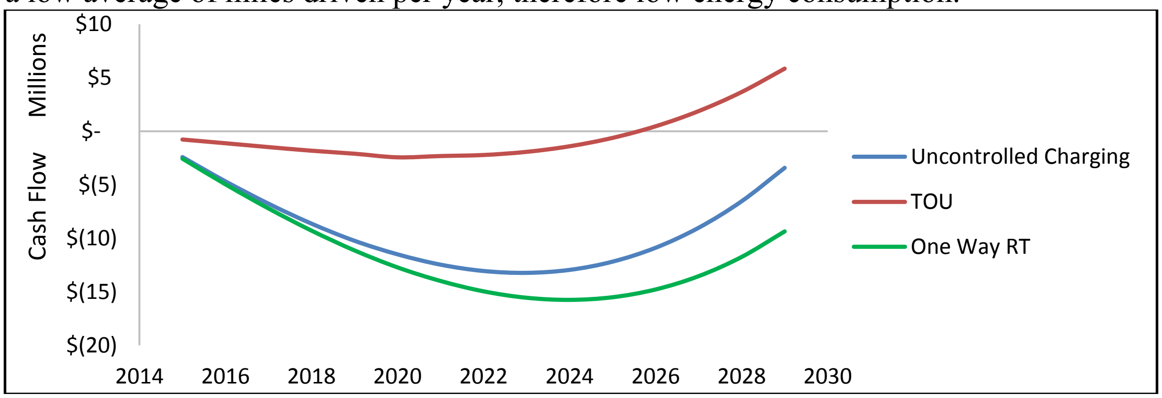


Figure 5.10. Cash Flow based on Mueller customers annual miles driven

Now considering 9,248 miles driven per year based on Texas average (TexPIRG) all cash flows end positive, although Uncontrolled and One Way RT programs generate considerable debt to Austin Energy from building a power plant. Notice how increase of miles driven, therefore energy consumption and revenue, make a positive cash flow.

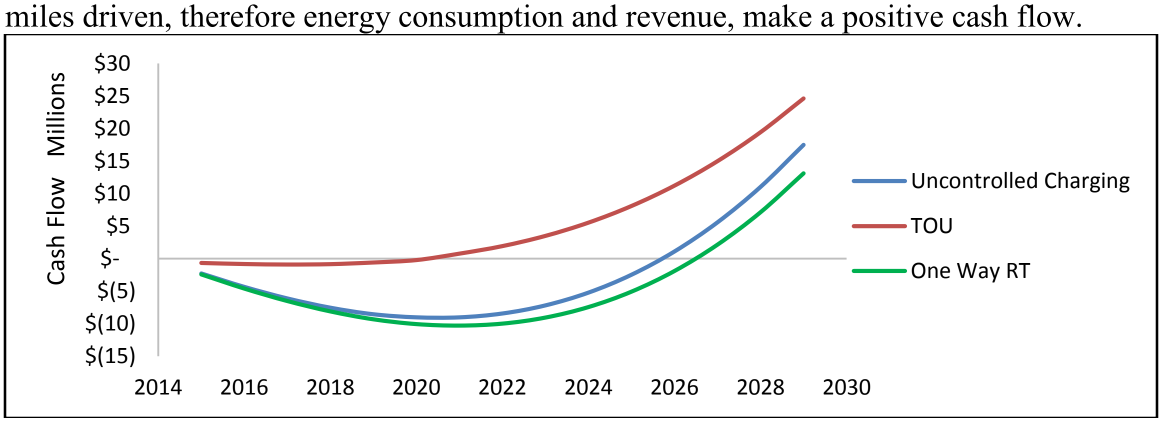


Figure 5.11 Cash Flow based on Texas average annual miles driven

The advantages and disadvantages of each program potential are presented in Table 5.5.

Program	Advantages	Disadvantages
Uncontrolled Charging	No infrastructure cost	High energy wholesale market cost Highest 4CP contribution Contribution to residential peak
TOU Rates	Load shifting effect Low energy wholesale market cost Low 4CP contribution	TOU Smart Meter cost New Peak at 4:15AM
One Way RT	Savings in RT wholesale market Short interruptions No 4CP contribution	Highest Capital Cost Contribution to residential peak
One Way DA	Savings in DA wholesale market Load shifting effect No 4CP contribution	Highest Capital Cost Very large number of long interruptions
One Way AS	Synergy with existing DR thermostat program	Highest Capital cost

Table 5.5. Advantages and disadvantages of program implementation

The criteria to assess how each program addresses Austin Energy Mission is based on the following questions:

- Clean: Contributes to emission reduction in the City of Austin?
- Affordable: Economically viable for Austin Energy and customers?
- Reliable: Promotes load shifting from On Peak to Off Peak?
- Excellent Customer Service: Avoids inconvenience for customer?

	Clean	Affordable	Reliable	Excellent Customer Service
Uncontrolled Charging	✓	✓		✓
TOU Rates	✓	✓	✓	✓
One Way	✓		✓	

Table 5.6 Program Comparison according to Austin Energy's Mission

In order to assess and quantify how the programs fit into the Austin Climate Protection Plan only Uncontrolled Charging, TOU Rates, and One Way RT are compared. One Way RT is assumed to give same results as Uncontrolled since they have similar load shape. One Way DA, AS, and ERS are not feasible to implement by 2020.

Austin Energy goals for 2020:

Achieve 800 MW savings through energy efficiency and conservations efforts

Uncontrolled Charging and RT control would increase the capacity required during On Peak period while TOU Rates would shift load to Off Peak period. The amount of MW of increased capacity and possible savings are summarized in Table 5.7

	Low / High 2020 Forecast
Uncontrolled/RT Increased Capacity	5.0 / 18.5 MW
TOU Rates Savings	4.0 / 14.8 MW

Table 5.7. Increased and Saved Capacity

Meet 35% of energy need through the use of renewables

Neither charge management program directly addresses the use of renewables since PEV load comes directly from ERCOT's marginal generation which is outside of Austin Energy's control. Increase of renewables for PEV charging would require programs outside the scope of this study such as Residential Solar Rebates and direct power transfer from solar panels to PEV battery.

Establish a CO2 reduction goal of 20% below 2005 level

The emission reduction goal of 20% below 2005 level requires a total reduction of 1,110,979 Metric Tons of CO_2. Although PEVs will not directly reduce emissions from Austin Energy generation, there will be an indirect emission reduction by offsetting emission from gasoline vehicles. Table 5.8 gives a range of the possible emission reduction and relative percentage of the 20% for Uncontrolled/RT and TOU Rates programs.

	Low / High 2020 Forecast (CO_2 tons reduced)	Emissions reduction percentage
Uncontrolled/RT	13,570 / 50,209 tons	1.22 / 4.52%
TOU Rates	14,090 / 52,133 tons	1.27 / 4.69%

Table 5.8 Emission reduction in 2020

There is not a significant contribution from PEVs to the emission reduction goal. Moreover there is not major difference from one program to the other.

Based on the previous comparison, only the TOU Rates program would make a significant contribution to the goal of 800 MW savings by 2020.

Chapter 6: Conclusion

PEVs can have different effects on the residential load depending on the time of the day that they are being charged with impacts such as: demand increase, emissions from type of generation source, and cost of energy. As an electric utility, Austin Energy has the opportunity to manage PEV charging in order to mitigate possible negative effects.

Three main charge management programs were defined in Chapter 2: Uncontrolled charging, implementation of TOU rates, and One Way direct utility control. Then metrics to compare these programs were defined in Chapter 3 that include: direct utility cost, revenue from rates, ERCOT market payout, PEV adoption, and CO_2 emissions.

Load profiles for Tier and TOU were analyzed in Chapter 4 using real data from 45 customers in the Austin Energy area in the Mueller community where 24 of them were under a TOU trial pricing and 21 of them had normal tier rates.

The data analysis shows that TOU rates effectively created a load shift effect. The house consumption experienced no time shift; so the only load that was shifted by the TOU rates was the PEV charge. A new residential peak around 4:15 AM was observed. In contrast with house load, PEV charge did not significantly change from season to season.

The TOU trial group only had a limited reduction in CO_2 emissions compared to the Tier group. But still both groups represented a decrease in emissions of 64% compared to a new light duty gasoline vehicle from 2013.

The analysis showed that it is possible for the customer to save money under TOU rates by shifting PEV charging to Off Peak hours, which also decreases wholesale cost for Austin Energy. In general there is not significant change in AE revenue from customers switching from current Tier rates to TOU rates.

The charge management programs implementation was analyzed in Chapter 5. Uncontrolled Charging has no infrastructure cost but future increase of PEV adoption will require increased capacity during peak hours and will have contributions to 4CP events.

The potential for TOU rates program shows that the incentives can help to shift load to Off Peak hours. This program has low wholesale energy cost and low contribution to 4CP events.

One Way RT and DA control analysis showed that in order to increase savings during high wholesale energy cost, it is necessary to exponentially increase the number of interruption events. Implementation of this RT control might be more feasible since it requires less and shorter interruptions than DA control. Nevertheless both programs would require a significant amount of interruptions to be able to decrease wholesale energy cost as much as the TOU program.

The number of PEVs in Austin Energy region is not large enough to represent a reliable resource of 100 kW for AS or ERS. Although actual deployment of AS or ERS do not occur 100% of the time, load must be available and willing to participate 100% of the committed time. Implementation of One Way AS might be possible after 2020 assuming there will be 37,000 PEVs.

One Way control would also require investment in DR hardware and software, and have annual operating costs. Interruption events of PEV charging can also have a negative impact in the adoption of PEVs at this early stage by increasing range anxiety, introducing uncertainty of charge availability, and affecting Austin Energy’s customer service.

The program that mostly aligns with Austin Energy's missions is TOU Rates since it is clean, affordable, reliable, and has excellent customer service. It is affordable since it is possible to save money by shifting PEV charging, it is reliable since it incentivizes load shifting, and it contributes to excellent customer service since it does not represent any major inconvenience to the customer.

The data analysis gave apparent results of TOU behavior in early PEV adopters who volunteered for this trial. A 100% implementation of TOU rates program across all PEV customers might not have the same results since there is no way to know how a customer that didn't volunteer for the TOU trial would behave. Regardless, the results show that customers with knowledge of the benefits and willingness to participate on the TOU trial successfully shifted PEV load to Off-Peak hours, decreased wholesale cost of energy, and reduced 4CP contributions.

The proposed course of action is a combination of Uncontrolled Charging and TOU rates, where customers can voluntarily switch to TOU rates. An implementation strategy should include the following:

- Education to customer about possible economic benefits of TOU rates
- Explanation of grid reliability issues from charging during On-Peak hours
- Expand functionality of austinenergyapp.com that shows energy consumption per day to also include daily energy distribution for TOU customers

Appendix A ERCOT ERS Period and Price

STANDING ERS TIME PERIODS

Time Period Name	Time Period Hours
Business Hours 1	8:00:00a.m. to 1:00:00p.m. Monday through Friday except ERCOT Holidays
Business Hours 2	1:00:00p.m. to 4:00:00p.m. Monday through Friday except ERCOT Holidays
Business Hours 3	4:00:00p.m. to 8:00:00p.m. Monday through Friday except ERCOT Holidays.
Non-Business Hours	All other hours

Table A.1 Standing ERS Time Periods

(All times are Central Prevailing Time)

ERS STANDARD CONTRACT TERMS

Terms
February 1 through May 31
June 1 through September 30
October 1 through January 31

Table A.2 ERS Standard Contract Terms

ERS CLEARING PRICE PROCUREMENT RESULTS OF 2013

Term/Period	Jan1-Jan31		Feb 1–May 31		Jun 1 –Sep30		Oct 1-Dec 31	
ERS	10	30	10	30	10	30	10	30
Business Hours 1	$8.22	$8.10	$8.10	$7.81	$10.21	$11.00	$8.01	$8.00
Business Hours 2	$8.77	$9.20	$8.71	$8.60	$12.07	$12.00	$8.37	$8.50
Business Hours 3	$9.06	$9.50	$8.82	$8.90	$12.60	$14.00	$8.44	$8.80
Non-Business Hours	$8.15	$8.20	$8.04	$7.80	$10.13	$11.00	$7.98	$8.00

Table A.3 ERS Clearing Price Procurement Results of 2013

Price in dollars per MWh

EILS DEPLOYMENTS SINCE 2006

Day	Date	Time	Type of Deployment	Season	Period	Length
Mon	4/17/06	15:34	EECP Step 2 Systemwide	Spring	BH2	2 hrs.
Tue	2/26/08	18:49	EECP Step 2 Systemwide	Winter	BH3	3 hrs.
Wed	2/2/11	5:20	EEA Level 2A Systemwide	Winter	NBH	28 hrs.
Thu	8/4/11	14:32	EEA Level 2A Systemwide	Summer	BH2	2.5 hrs.

Table A.4 EILS Deployments Since 2006

Emergency Electric Curtailment Plan (EECP)

Emergency Energy Alert (EEA)

Appendix B Austin Energy's Residential Rates [13]

RESIDENTIAL TIER RATES

Energy Charges (kWk)	October to May (¢/kWh)	June to September (¢/kWh)
First 0-500	1.8	3.3
From 501-1000	5.6	8.0
From 1001-1500	7.2	9.1
From 1501-2500	8.4	11.0
From 2501-plus	9.6	11.4
Customer charge per month	$10.00	

Table B.1 Residential Tier Rates

TIME-OF-USE PERIODS

October through May	
Off-Peak	10:00 P.M.–6:00 A.M. Everyday
Mid-Peak	6:00 A.M.–10:00 A.M. Everyday
On-Peak	None

June through September	
Off-Peak	10:00 P.M.–6:00 A.M. Everyday
Mid-Peak	6:00 A.M.–2:00P.M. and 8:00 P.M.–10:00 P.M. Monday–Friday 6:00 A.M. – 10:00 P.M. Saturday – Sunday
On-Peak	2:00 P.M. – 8:00 P.M. Monday – Friday

Table B.2 Time Of Use Periods

TIME-OF-USE TIER-RATES

Total Monthly (kWh)	Period	October to May (¢/kWh)	June to September (¢/kWh)
0-500	Off –Peak	-0.924	0.493
	Mid-Peak	1.201	5.040
	On-Peak	0.000	9.761
501-1000	Off –Peak	-0.427	1.188
	Mid-Peak	3.673	6.218
	On-Peak	0.000	11.003
1001-1500	Off –Peak	-0.014	2.182
	Mid-Peak	4.891	7.134
	On-Peak	0.000	12.196
1501-2500	Off –Peak	0.692	2.679
	Mid-Peak	6.282	7.934
	On-Peak	0.000	13.031
2501 plus	Off –Peak	4.170	6.158
	Mid-Peak	9.761	9.512
	On-Peak	0.000	14.979
Customer charge per month $12.00			

Table B.3 Residential Tier Rates

FIXED COST FOR TIER AND TOU RATES

Power Supply Adjustment	3.709 ¢/kWh
Community Benefic Charges	0.665 ¢/kWh
Regulatory Charge	0.794 ¢/kWh

Table B.4 Fixed Cost for Tier and TOU Rates

EXAMPLE CALCULATION

For simplicity of calculation assume a house with a constant load of 1kW in June 2013.

Daily energy consumption	1kW x 24 hr = 24kWh per day
Month consumption	24 kWh x 31 days = 744 kWh

Table B.5 Energy consumption for example calculation

Tier Calculation

Energy Charges (kWh)	**Energy (kWh)**	**Price (¢/kWh)**	**Cost ($)**
First 0-500	500	3.3	16.5
From 501-1000	244	8.0	19.52
Power Supply Adjustment	744	3.709	27.59
Community Benefit Charges	744	0.665	4.95
Regulatory Charge	744	0.794	5.91
Customer Charge per month			10.00
Total			**$ 84.47**

Table B.6 Tier Calculation

TOU Calculation

June 2013	Weekday (23 days)	Weekend (8 days)	Total (hours)
On Peak	6	0	138
Mid Peak	10	16	358
Off-Peak	8	8	248

Table B.7 Total hours of TOU periods in June 2013

Energy Charges (kWh)	Energy (kWh)	Price (¢/kWh)	Cost ($)
On-Peak	138	1.1.003	15.18
Mid-Peak	358	6.218	22.26
Off-Peak	248	0.188	2.95
Power Supply Adjustment	744	3.709	27.59
Community Benefit Charges	744	0.665	4.95
Regulatory Charge	744	0.794	5.91
Customer Charge per month			12.00
Total			**$ 90.84**

Table B.8 TOU calculation

Note actual house load is not expected to be a constant load. The main purpose of these examples is to illustrate how Tier and TOU bills are calculated.

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