EVTC

Electric Vehicle Transportation Center

EV Workplace Charging Energy Use and Cost Case Study

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1 Summary

Efforts to increase the availability of plug-in electric vehicle (PEV) charging stations have focused on expanding public charging stations, promoting charging at the workplace and using charging stations as a shopping incentive for retail stores. This report examines the costs and energy uses to provide the charging service. Rapidly charging a PEV requires expensive electric equipment and can lead to high operating costs due to electrical demand charges. This project presents results from a detailed case study for 5 PEV chargers where the charger electricity costs are a part of a facilities electric bill. Also presented are options for minimizing the electrical demand costs of the facility. These results show that electrical charging costs can be minimized if the workplace chargers are operated using a building energy management system (EMS) to control electricity use. In addition, the equipment costs will need to be capitalized through station use from multiple vehicles. Otherwise workplace charging can be costly.

2 Introduction

Workplace charging provides a convenient location for employee's to charge their vehicle while those vehicles are parked for extended periods of time. The purpose of this paper is to investigate the cost and energy use of PEV charging in the workplace. A previous study investigated the life-cycle costs associated with workplace charging when the charging unit is connected to a dedicated utility meter and found that costs can be similar or less expensive than charging at home[1]. This report presents results from a case study where the charger electricity costs are a part of a facilities electric bill. Also presented are options for minimizing the electrical demand costs of the facility due to charging. Results from these two studies show that charging costs are similar only when the workplace chargers are operated in a manner that minimizes electrical demand costs.

The case study also presents the development of a simple energy management system (EMS) that can lend itself to reducing or eliminating the portion of the electric bill associated with charger electrical demand. This EMS system has the two goals of minimizing the facility electricity demand and maximizing workplace charger availability. If EV chargers are not controlled, higher than expected utility demand costs can occur. To control these costs, a simple control scheme has been developed where the charging station is turned off or controlled when the historical monthly peak is expected to be exceeded.

The electric utility rates at the Florida Solar Energy Center (FSEC) are based on a commercial rate provided by Florida Power and Light. The rate class is referred to as General Service Demand and includes a rate charge of $0.05/kWh and a demand charge of approximately $10.50/kW/month. The maximum average power, known as the monthly peak demand, is calculated based on the maximum power averaged over a 30-minute interval that occurs once during the monthly billing period.

The presented case study looked at five charging stations located at FSEC in Cocoa, Florida. These stations were instrumented with energy meters and monitored for over a year. This data was collected beginning in early 2015 and has provided an understanding of the impact a PEV charging station would have on the facility energy use and operational cost. The PEV charging stations installed were a 45 kW DC Level 2 charging station and a dual-plug 6 kW AC Level 2 charging station for the public and two non-public 6 kW workplace AC Level 2 charging stations for employee use. These stations are described in detail in the next sections. An energy management system monitored the facility's electric utility meter and controlled the non-public workplace charging stations to avoid increased electric utility bills due to electrical demand charges. These results are presented in the following sections.

3 Charging Stations Description, Data and Analysis

Electric vehicle supply equipment (EVSE), aka EV charging stations, come in several forms. PEVs come equipped with an AC Level 1 charging cable which charges the vehicle traction battery slowly, at just over 1 kW of power. Publically available EVSEs can charge the vehicle more quickly, typically providing about 6 kW of power. This power level corresponds to an AC Level 2 EVSE as standardized by the Society of Automotive Engineers[2]. High speed EVSEs also exist where a PEV can be charged in under an hour. Referred to as DC fast chargers, these charging stations require upwards of 25 kW of electrical power. DC fast chargers with power levels below 40 kW are known as DC Level 1 while those with a higher power rating are referred to as DC Level 2 chargers.

This section presents the public and private charging station descriptions, the data taken and the analysis of the data for the five stations at FSEC. The analysis for the public stations is presented first followed by the private or employee stations. The private or employee stations includes the description of the EMS and the demand management reduction systems that were employed.

3.1 Public Charging Stations

FSEC was fortunate to receive a donation from Nissan North America when they donated a DC fast charger as part of their campaign to provide more public charging stations for their customers. This station was installed in December 2014. The Signet FC50K-CC 45 kW DC fast charger has 2 plugs, a CHAdeMO and SAE Combo connector that allows all U.S. PEVs the ability to quick charge if the vehicle is so equipped. Only one vehicle may be actively charged at any given time.

As part of this installation, an AC Level 2 public charging station was also included to provide charging for those vehicles not equipped with fast charging capability. A ChargePoint CT-4021GW single pedestal, dual-plug unit operates at 208 volts with two dedicated 30 amp breakers and provides 6 kW of charging capability per plug. Both of these stations are publically available and include payment systems which manage the charging session and payment processing (see Figure 1).

The public charging stations include payment systems which collect and record the revenue. Charging stations that do collect revenue will typically include recurring operating costs for the payment system. The DC fast charger is connected to the Green Lots payment network while the AC Level 2 chargers are connected to the Charge Point network. The fees for these networks are discussed in Table 2.

The public charging stations have been used regularly since their installation, albeit at a low level of use. Records collected from the network providers indicate that each calendar month these charging stations draw between 5 to 12 users and are used between 9 and 32 times per month. Monthly energy use ranges from 92 to 375 kWhs and revenue collected ranges from $16 to $60 (See Figure 2).

Figure 1. FSEC Public Dual AC Level 2 (left) and DC Fast (right) Charging Stations

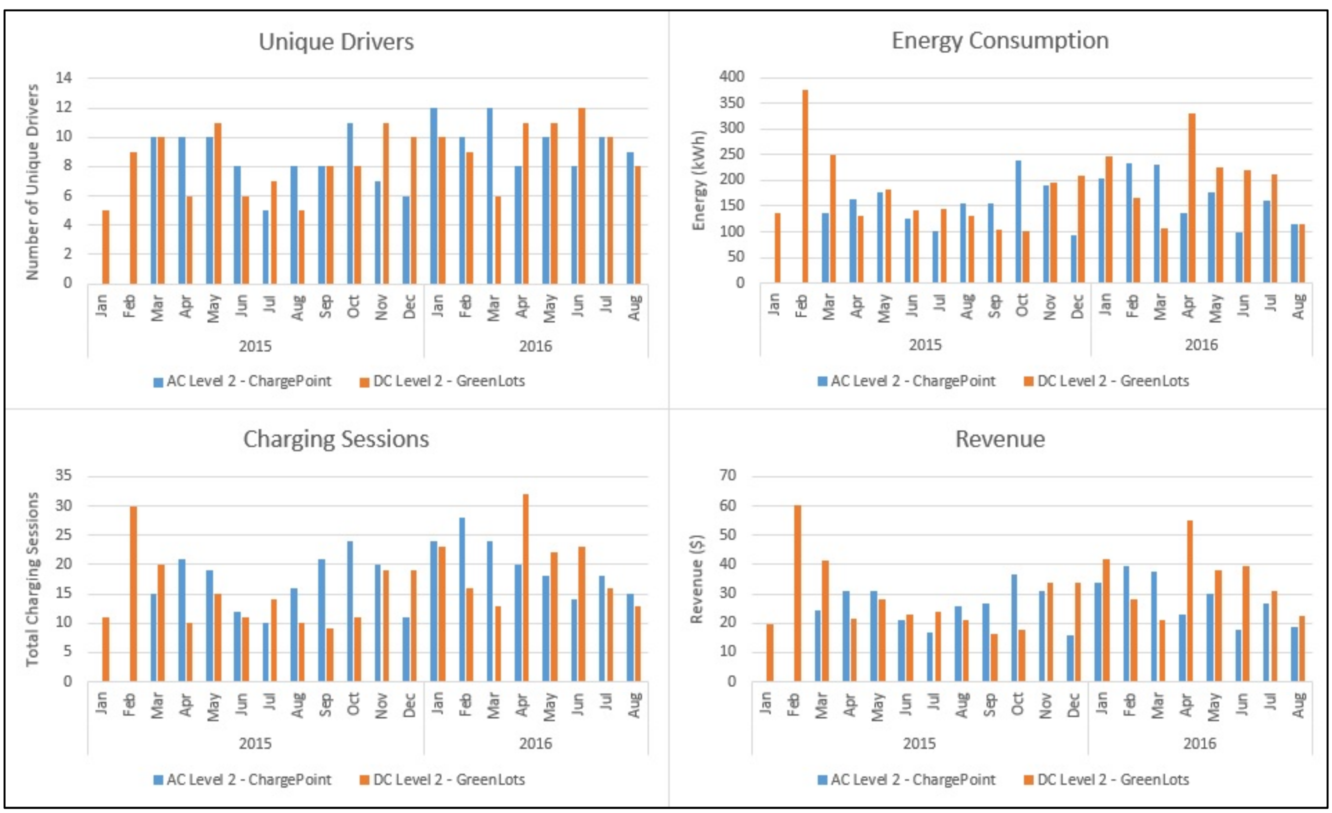

Figure 2. Public Charging Station Statistics

The five charging stations at FSEC are not connected to dedicated electric utility meters and electricity costs associated with PEV charging are included in the total facility monthly electric bill. This type of application can hide the true operating costs since the impact on electricity costs can be hidden in the single monthly utility bill.

To measure total facility energy use, the electric utility company installed a switch closure mechanism where each measured switch closure is equivalent to 72 watt-hours of energy consumption. The measured facility energy data not only provides an indication of the facility energy use but can also be used to study the impact of commercial electric utility demand costs. The demand charge is taken as the highest monthly demand (kW) over a 30-minute period for the month. At FESC, a new peak demand is determined each month. Figure 3 shows a one-day typical facility peak event for July and November. The timing of the July peak demand event occurred before 8 A.M. prior to employee arrivals, thus, charging had no effect on facility peak power demand. In the winter example, charging is added to the facility peak demand.

Workplace charging stations are typically available 100% of the time for employee use. In the Figure 3 example, the grey line represents the scheduled availability of the workplace charging stations. If the charging stations were active during the peak period like the November day, then the facility peak demand would increase by 12 kW and electricity demand would add an additional $126/month (12 kW * $10.50/kW/month).

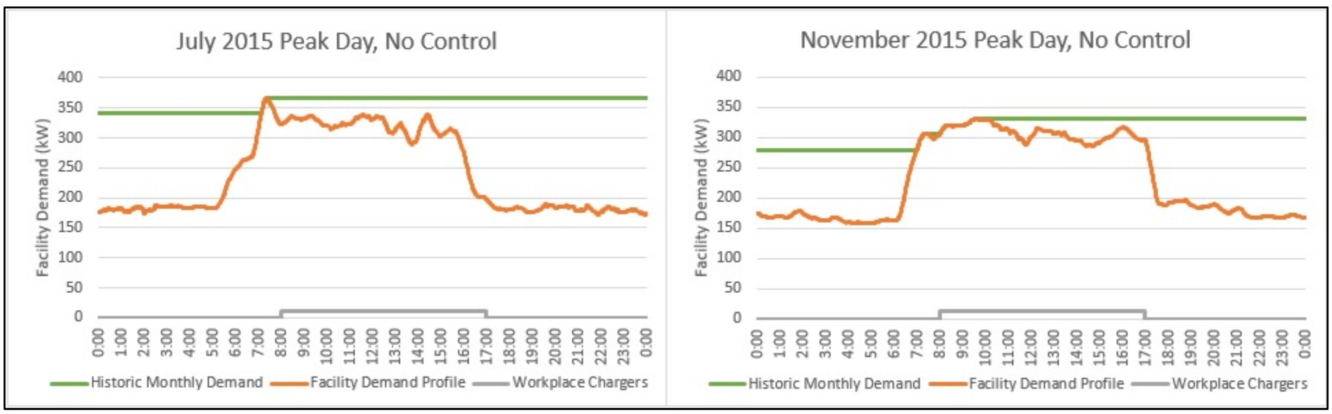

Figure 3. Example summer and winter facility peak event

Understanding when charging stations are used, how long they are active and how their use may impact a facility electricity bill is necessary when developing methods to minimize facility electricity costs. Shown in Figure 4 is the total facility electric demand profile for two days in early 2015. Each of these days occurred within the same month's electric utility billing period. The total facility electric demand corresponds to the left Y-axis while the electric demand for all charging stations corresponds to the right Y-axis. They are at different scales.

The total facility instantaneous measured power demand (orange line) and the calculated facility power as if the DC fast charger were not installed (light green line) are presented for discussion. The DC fast charger instantaneous power draw (blue line) and the average power draw over a 30-minute electric utility demand window (red line) are also shown. The dark green line represents the workplace chargers. The black line is the public AC Level 2 chargers which were not in use in either of these figures. From Figure 4, on February 24, 2015, the facility peak reached 278.4 kW, which can partly be traced to the coincident use of the DC Level 2 charger. Later in that same billing period on March 5, 2015, the building load (without DC fast charger active) was measured at 255 kW. Therefore, the impact the DC fast charger had on the electric utility meter was an additional 23.4 kW of demand over what would have been the peak without the DC fast charger (Additional cost = $245.70).

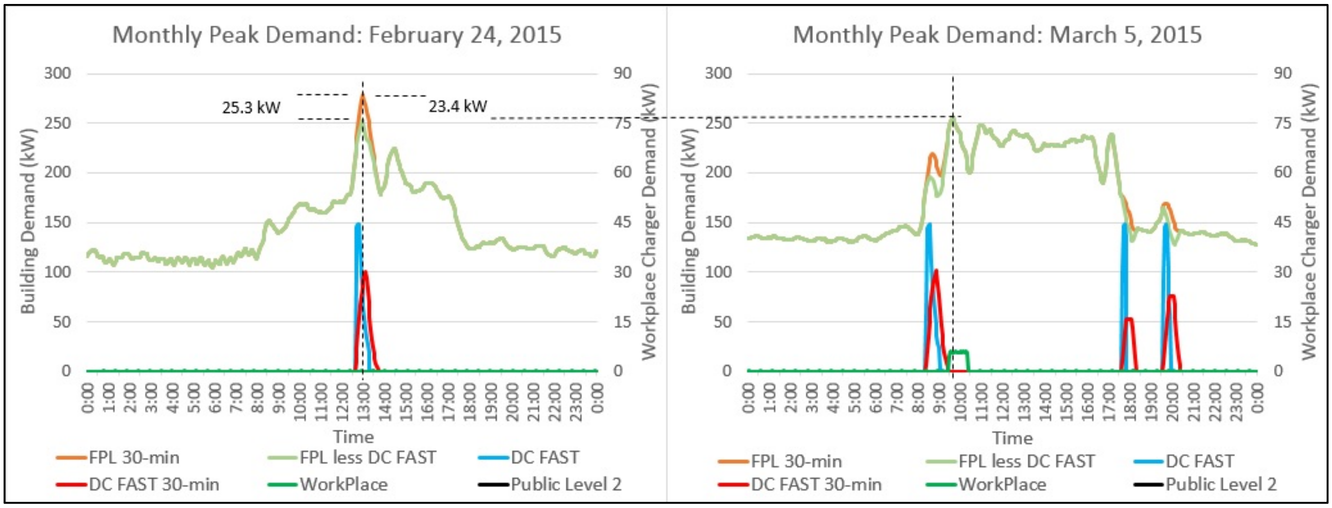

Figure 4. FSEC Facility and Workplace Charger Electric Profile, Feb 24, 2015

Another daily example, shown in Figure 5, is presented for June 1, 2015. On this day, the FSEC electric utility bill registered the peak electric demand for that month. All charging stations were active as some time during the day, however only the public AC Level 2 charging station operated concurrently with the time of peak demand which increased the facility electricity demand by 6 kW. The point here is that the operation of the charging stations must coincide with the one time during the month that the facility encounters the peak power draw, otherwise these charging stations will not add to the building's monthly peak electric demand. Concurrent operation of the charging stations with the time of the monthly peak demand is a random time event. If the charging stations are operated throughout the day on a daily basis, the probability of the charging stations adding to the monthly peak demand greatly increases.

The measured electricity costs associated with the public charging stations are shown in Table 1. The DC fast charger and Public AC Level 2 chargers measured monthly energy use corresponds to the monthly utility billing cycle which is regularly read on about the 7th of each month. Analysis of facility energy use provides the impact each of these charging stations have on facility peak demand and charging session costs. For each charging station type, which were sub-metered for energy use, the utility electric demand is determined by subtracting the public charging station energy use (one at a time) from the total facility energy use and then calculating the monthly peak demand with and without the charging stations. The difference between these calculations is the utility electric demand associated with each charging station type. Cost was then determined using FSECs commercial electric utility rate of approximately $0.05/kWh during this time frame. Note that Florida's residential electricity rates are upwards of $0.12/kWh if employees charged at home.

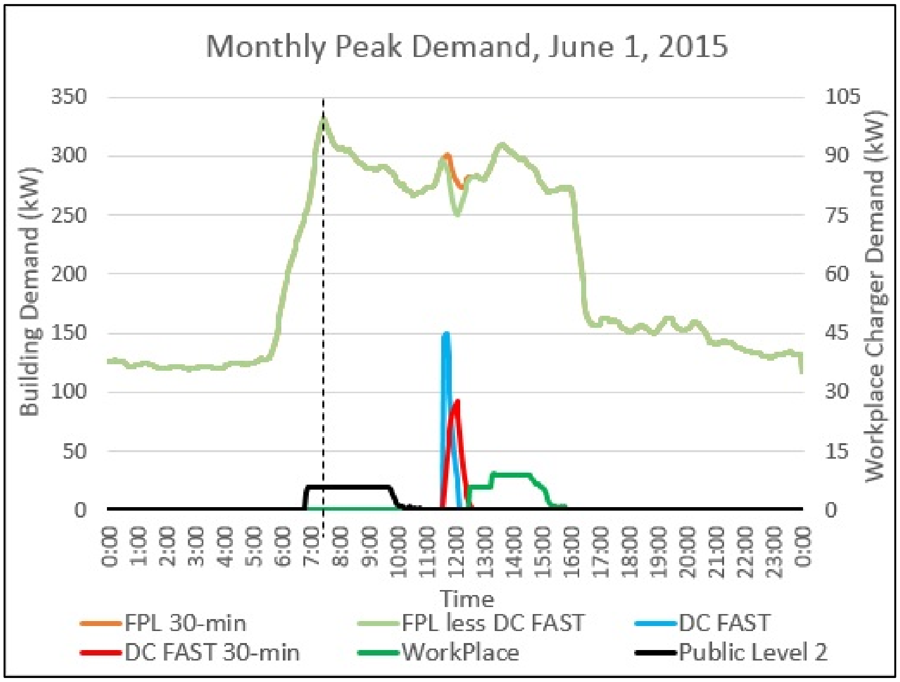

Figure 5. FSEC Facility and Workplace Charger Electric Profile, Jun 1, 2015

Table 1. Public Charging Station Electricity Costs

Month (2015)	Public DC Fast Charger				Public AC Level 2 Chargers			
	Sessions (#)	Energy (kWh)	Demand (kW)	Cost/Session ($)	Sessions (#)	Energy (kWh)	Demand (kW)	Cost/Session ($)
Feb	25	359	23.4	10.65	Not measured			
Mar	20	232	2.1	1.72	Not measured			
Apr	10	123	0.0	0.63	25	210	0	0.43
May	17	224	0.0	0.68	11	102	5.7	5.98
June	8	114	0.0	0.74	10	110	0	0.57
July	15	170	0.0	0.58	12	123	0	0.53
Aug	10	146	0.0	0.75	16	144	0	0.48
Sep	7	62	0.0	0.46	22	203	0	0.48
Oct	15	156	0.0	0.54	21	205	0	0.51
Nov	18	168	0.0	0.48	22	199	0	0.47
Dec	21	231	0.0	0.57	8	92	0	0.59
Jan	20	216	0.0	0.54	28	224	0	0.40
Feb	17	162	0.0	0.48	23	223	0	0.49
Mar	17	170	0.0	0.50	28	227	2.4	1.30
Apr	28	283	0.0	0.51	17	112	0	0.33
May	25	305	4.4	2.54	15	195	0	0.65
June	20	205	0.0	0.51	13	92	0	0.35

Charging costs for electricity over the 17 month period were minimal since these charging stations only added to the peak demand 4 times (see shaded values in Table 1). The cost per session shows what each vehicle owner would have to pay on average to cover the cost of electricity. For months where public charging stations did not impact facility electricity demand costs, the average electricity cost per session is about $0.53 corresponding to an average energy use per session of about 10.3 kWh.

These results show that operating costs for charging stations can be low if demand charges can be reduced or minimized. For charging stations operating on dedicated electric utility meters, reducing or eliminating demand charges is not likely since electric utility rate structures would typically include monthly peak demand as an added cost to the electricity bill. For utility companies with a time-of-day rate, the demand charges would be included in a dedicated meter's PEV rate structure during the day, but would most likely be lower at night to incentivize consumers to charge during off-peak periods.

When charging stations are installed at an existing facility, and utilize the existing facility electric utility meter, the operating costs can potentially be lowered by operating in a manner that avoids the electrical demand charge. For example, the facility electric utility meter could be monitored and when the facility is nearing the peak power demand for the month, the charging stations could be disabled. A simple EMS system for workplace chargers would then provide a low-cost solution for mitigating electricity cost.

Mitigating electricity cost is one aspect of workplace charging station operation that can be controlled by the facility operator. Networking and processing fees will also add to the operating costs, and if the charging stations are not used regularly these fees can outweigh the collected revenue. Equipment and installation costs for these public charging stations are shown in Table 2 below. The DC fast charger was donated by Nissan North America and the AC Level 2 charging stations were purchased through the installation contractor. Costs associated with the installation include electrical, trenching, concrete pad and bollards. Additionally, the added cost of parking space identification and local lighting (see Figure 1) were provided by this facility and are not included in these data.

Table 2. Public Workplace Charging Station Equipment and Operating Costs

Charging Station Type	Equipment	Maintenance	Network Fee's	Transaction Fee's	Total Fee's	Annual Electricity	Annual Revenue
DC Fast Charger	$25,000	TBD	--	10% or $0.50	$92	$161	$358
AC Level 2 Charger	$8,108	TBD	$560	10%	$597	$129	$374
Installation	$23,629	TBD					

The measured annual electricity and revenue for the FSEC public charging station for the period July 2015 through June 2016 are shown in Table 2. Since these are relatively new stations, information on maintenance is unavailable, hence a placeholder is included in the table. Since these stations collect payment for electricity use, each of the vendors require network and/or payment processing fees. One vendor requires an annual network fee of $280/year/port while the other does not. Per session transaction fees are collected by both vendors with one having a minimum fee of $0.50. The energy required to charge a Nissan Leaf varies but averages to about 10 kWh per charge. At $0.15/kWh this translates to an average cost of $1.50 per session. One vendor would charge the station owner a payment processing fee of $0.15 per session while the other would charge $0.50. These network fees must be considered as part of the annual operating cost.

These costs would be typical of those costs used to develop a business model for public charging stations. When charging stations are used less often, about once per day as shown in Table 1, the station owner will not break even on the equipment cost. If a station owner were to attempt to profit from these stations then the fees charged to consumers would need to be higher than the consumer might be willing to spend.

3.2 Private or Employee Charging Stations

This report section examines the two FSEC workplace charging stations. These stations are equipped with demand reduction technologies. The Electric Vehicle Laboratory at FSEC operates these two non-public AC Level 2 charging stations. One is relatively inexpensive to purchase and is manufactured by Clipper Creek (the CS-40 charging station is shown in Figure 6). The station is also equipped with a 30 amp, 208 VAC electrical breaker and a switch closure input that interrupts operation when the contacts are closed. The switch is connected to a low-cost building energy management system (EMS) used to mitigate the impact PEV charging stations may have on building electrical peak demand.

Figure 6. AC Level 2 with closure switch

The second is a more advanced "smart" charging station is (see Figure 7). It is a prototype manufactured by AeroVironment which was further customized by Grid-2-Home and has an Ethernet based system. The charging station includes a wireless connection to a gateway which connects to a central server over Ethernet. The communication protocol uses the Smart Energy Profile 2.0 communication standard (SEP 2.0). The central server sends commands to the gateway, which relays the commands to the charging station.

Figure 7. Smart EV Charging

This smart charger can be easily integrated into a commercial building EMS which manages HVAC, lighting and fire and security systems. These EMS systems could also manage workplace chargers, dedicated electrical outlets for EV charging or even EV charger scheduling and may be optimized to avoid paying additional demand charges. The first component needed is a miniature microprocessor used to control the end-use equipment. This equipment will also need to communicate with a central system, the building EMS or other control software.

A simple EMS was deployed at FSEC to manage the operation of the workplace chargers. The EMS system monitors the building electric meter in real time. As part of the EMS, the electric utility company installed a pulse output circuit on the facility electric energy meter which provides a switch closure for every 72 watt-hours of energy consumed. These pulses are read by a microprocessor and reported to a central server. The central server monitors the building energy use and determines when the building's electric meter is "peaking" with regard to the monthly maximum power demand. At the time of peak demand, the central server sends commands to each workplace charging station to momentarily turn off until such time as the building demand lowers below the current monthly maximum demand. This system is represented in Figure 8.

The two workplace chargers use different methods to control electrical energy consumed by each device. The Clipper Creek model uses a simple switch closure to disable charging while the external switch is closed. The prototype AeroVironment charger was modified to use the Smart Energy Profile (SEP) 2.0 application protocol. The IEEE 2030.5-2013 SEP 2.0 application protocol[6] is an international standard specification which defines the mechanisms for exchanging application messages. This EMS system is simple in design where the facility electric utility meter is monitored real-time for building energy use. This data is transferred to a central server where decisions can be made to allow the charging stations to operate normally or to disable the stations for the period of peak demand. To avoid unauthorized use, the workplace charging stations are software deactivated between the weekday hours of 7:30 PM and 7:00 AM and during the weekends. This off schedule can be overridden if an employee reserves the workplace charging stations after normal working hours. This avoids a problem with the public accessing the equipment and allows employees to fully utilize the workplace chargers.

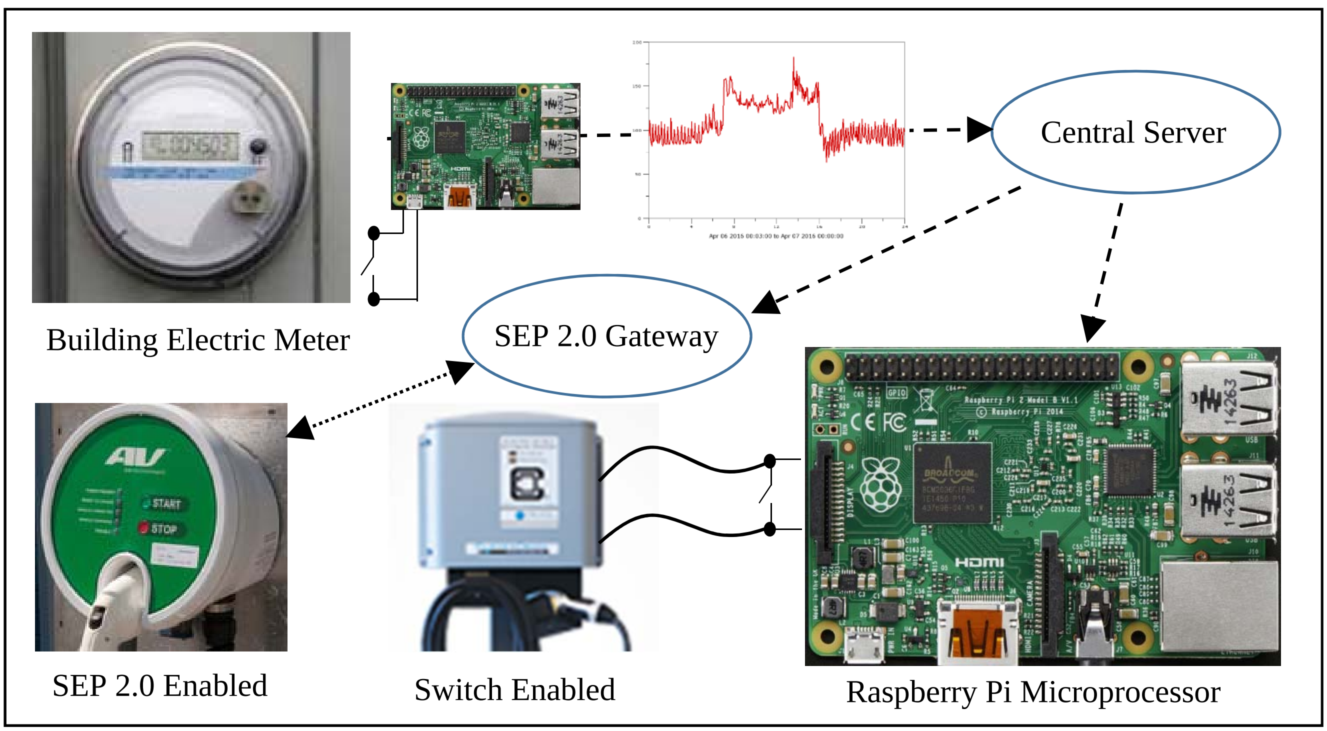

Figure 8. FSEC Energy Management System

The first control strategy implemented to minimize workplace charger electricity demand was to turn off the charging stations only if the instantaneous facility demand exceeded the highest measured electrical peak demand for the current month (i.e., the historic monthly demand). Operation of the EMS is shown graphically in Figure 9. The real-time facility energy meter (yellow trace) is measured every minute as 72 watt-hour per pulse. The maximum peak demand (green line) during the current month is continually calculated and reset each month on the approximate day the electric utility meter is scanned by the utility. As a reference point, the historic monthly peak demand starts out on this day at 70 pulses or 302.4 kW (70 pulses/minute x 0.072 kWh/pulse x 60 minutes/hour). The 30-minute running average of the facility energy meter (red line) represents how the local electric utility company determines demand charges. The orange line represents the measured energy consumed by the workplace chargers (0.005 kWh/pulse) while the magenta and purple lines represent the EMS control signals for the AeroVironment (0%-100%) and Clipper Creek (0/1 or on/off) chargers, respectively. On this day, as the building demand exceeds the historic monthly demand the EMS sends a signal to turn off both workplace chargers at just after 10 A.M. See Appendix A for a more detailed description of the EMS controller. The control strategy represented by this figure is that the workplace chargers are off when the 30-minute demand (red) exceeds the historic monthly demand (green). When the 30-minute demand signal falls below the historic monthly demand, the workplace chargers are enabled (before 10 A.M., ~10:20 A.M., 10:40 A.M., etc.).

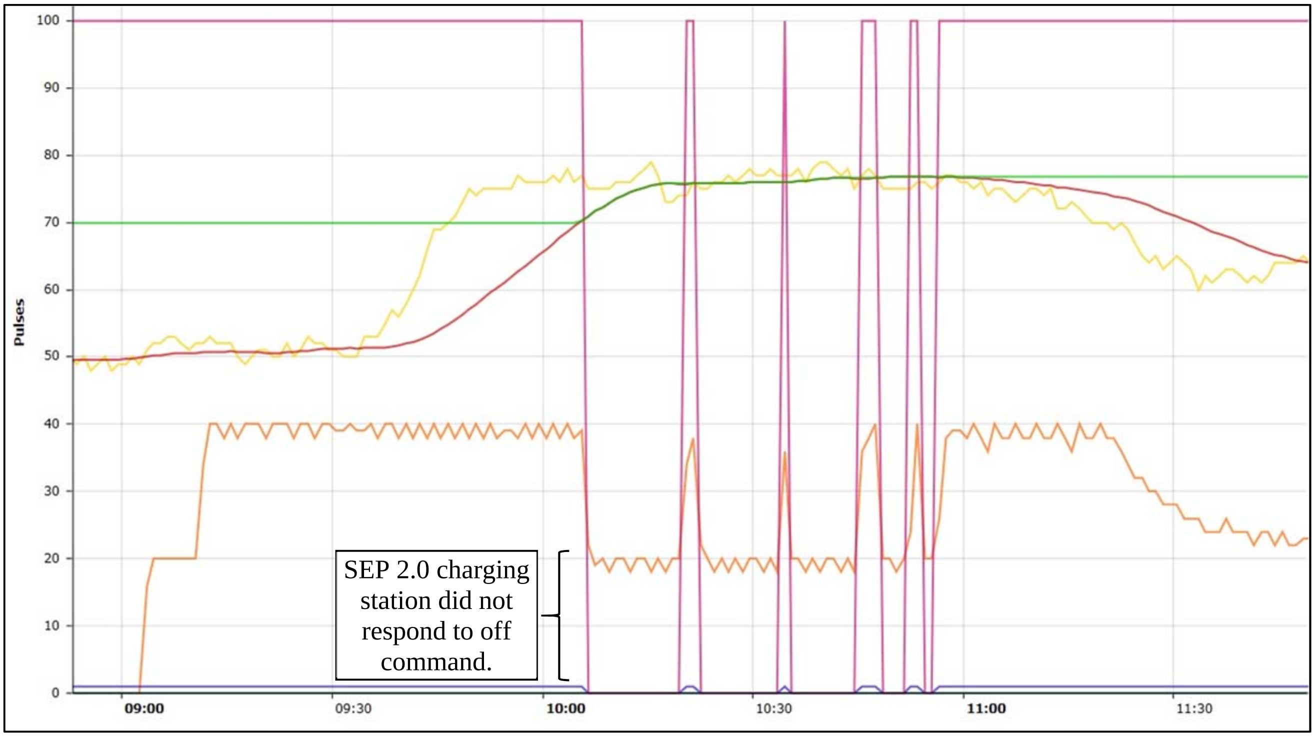

Figure 9. EMS Real-Time Monitoring – Mar 28, 2016

The problem with this control method is that the chargers can be used anytime and the historic monthly demand can be greater than the current demand. This means that if a demand event occurs, the power supplied to the workplace chargers is included in the 30-minute average and will be included in the new facility monthly peak demand (if the peak event occurs within 30-minutes after exceeding the historical monthly demand). For this facility, the workplace chargers must be off 30-minutes before the maximum facility peak time to completely eliminate the demand costs associated with workplace chargers. Any operation of the workplace chargers within the utility company's demand "window", in this case a 30-minute window, will increase the facility's monthly electricity cost.

Figure 10. Active Workplace Charger Control again shows the peak day in November where the green line represents the historic monthly peak demand as previously described. If the facility 30-minute demand includes an ideal workplace charger control scenario where the chargers are off during the peak event, then the November facility peak demand would be 12 kW lower than previously measured. Also note that the time available for workplace charging has diminished from 9 hours to 6.5 hours.

This is an ideal example of a control technique since the building energy profile was known and charging station operation could easily be selected to provide no additional demand (kW) cost to the facility electric bill. Choosing a control methodology to accurately predict when to disable the charging stations is more difficult and is presented in the next section.

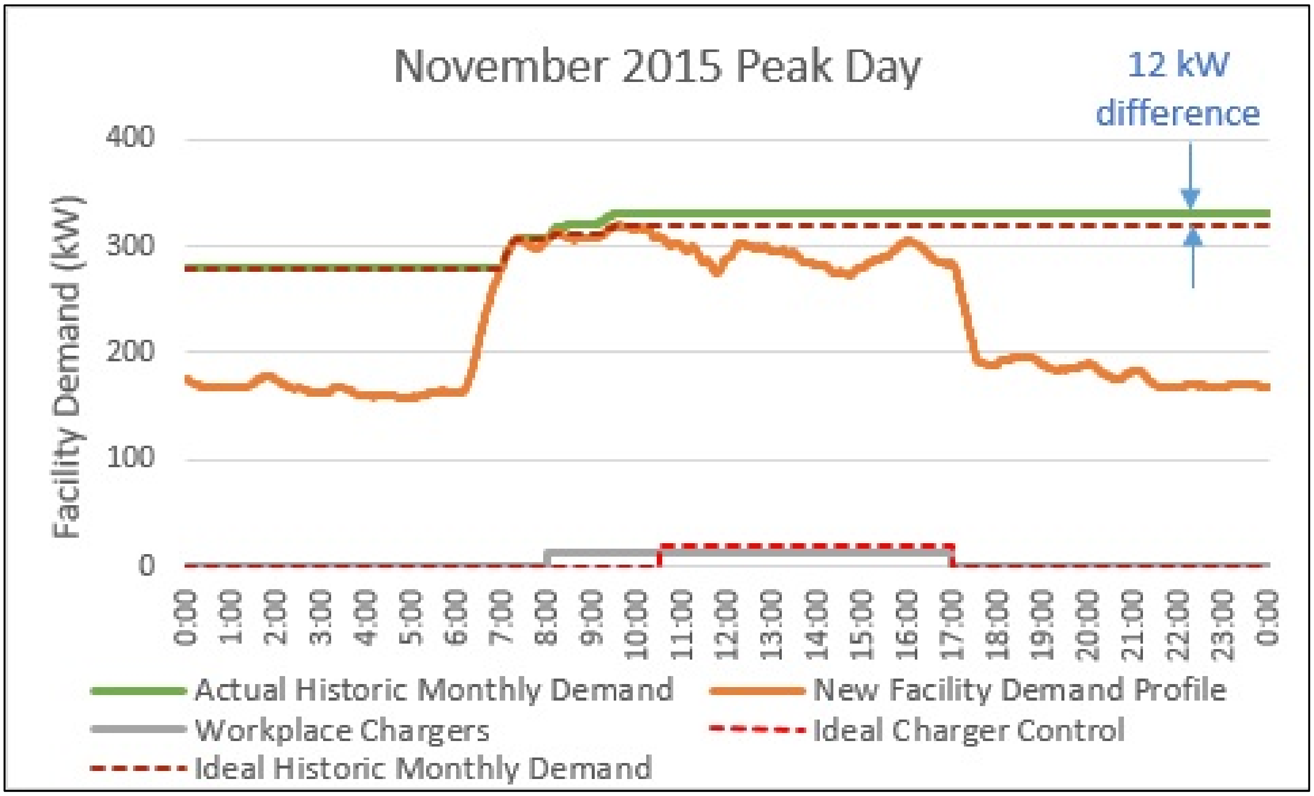

Figure 10. Active Workplace Charger Control

4 Charging Station Demand Control Optimization

A simple EMS system can be developed to reducing or eliminating the portion of the electric bill associated with utility electrical demand. The one developed herein has set two simple goals.

- Minimize facility electricity demand, and
- Maximize workplace charger availability.

If a simple control scheme is used where the charging station is turned off only when the historical monthly peak is exceeded, unexpectedly high utility demand costs can occur since the charging station is active just prior to the peak event. For this reason, a more sophisticated control algorithm is needed. The control algorithm design was implemented by analyzing the following control techniques:

- No control – workplace chargers would not be controlled
- Exceeding peak – workplace chargers would be turned off when the facility 30-minute demand was equal to or greater than the historic monthly demand
- Imminent Peak – the workplace chargers would be turned off when the facility 30-minute demand was within X kW of the historic monthly demand where X = the current power draw of the workplace chargers in kW
- Aggressive Rate-of-Change – workplace chargers would be turned off when the rate-of-change of the 30-minute demand predicted a peak event in the near future
- Combined algorithm – workplace chargers would be turned off when a combination of the above control techniques anticipated a peak demand event

The analysis used historic measured facility energy use to create a realistic facility baseline energy profile. The measured energy use was adjusted for charging station operation by subtracting charging station measured energy from the measured facility energy use. This gives a normal baseline energy profile which allows for 12 kW of charging station operation scheduled from 8 A.M. to 5 P.M. (normal facility operating hours) to represent 2 AC Level 2 workplace chargers operating continuously (see Figure 10).

The first objective was to determine the extent to which the workplace chargers would add to the monthly electric utility bill. The control methodology where charging stations would not be controlled is implemented by simply scheduling the workplace chargers to be on during the day, adding that energy use to the baseline data and then comparing the new calculated monthly electric demand to the baseline data. The results in Table 3 show that during winter months the workplace chargers are expected to add an additional 12 kW to the electric utility bill monthly demand. This result is not unexpected since it involves the absence of a HVAC increased summer peak. After review of the measured facility energy use, the additional demand charges are usually not present during summer months since the facility typically exhibits the peak earlier than 8 A.M. during HVAC system startup. The HVAC system uses an early start predictive algorithm to pre-cool the building prior to occupancy. This algorithm would start the HVAC system early, which occurs before the employees arrive at work (see Figure 3), so that the building interior air temperature was at the cooling set point temperature at 8 A.M.

The next objective was to test the remaining control techniques to see which scenario caused the greatest reduction in monthly peak demand. Waiting for facility electricity use to exceed the historic monthly peak demand before turning off the charging stations provided only a moderate reduction in monthly peak demand since the charging stations were active just prior to the peak event and therefore still added to the monthly peak demand. This control technique is only active a few times during the month and therefore provides a high charger availability rate of 99.4%. A more proactive approach was to turn off the charging stations when a demand event was imminent and within 12 kW of the historic peak demand. This technique further reduced facility peak demand but did not eliminate it entirely. Charger availability is also reduced since the charging stations are inactive anytime the facility electrical demand approaches the historic peak demand. These results are shown in Table 3.

For a utility company with a monthly peak based on a 30-minute interval, the charging stations must be off for at least 30 minutes prior to the peak event. Thus, intelligent control of these charging events requires a predictive algorithm. For this reason, the rate-of-change of the peak demand signal was used to predict the future facility demand. The rate-of-change of the 30-minute demand is multiplied by the number of minutes into the future the prediction is to occur and then added to the current 30-minute average demand. If this prediction exceeds the historic peak demand the workplace chargers are disabled. Using this control methodology the facility monthly demand impact is greatly reduced and charging station availability is still high at 97.1%.

Table 3. Charging Station Control Optimization Results

Month	Facility Maximum Peak Demand (kW)	Control Algorithm Impact on Facility Electric Peak (kW)				
		No Control	Exceeding Peak	Immanent Peak	Aggressive Rate-of-Change	Immanent + AROC
May	330.9	0.0	0.0	0.0	0.0	0.0
June	337.8	4.0	2.1	0.0	0.0	0.0
July	366.0	0.0	0.0	0.0	0.0	0.0
Aug	355.8	0.0	0.0	0.0	0.0	0.0
Sep	353.8	0.0	0.0	0.0	0.0	0.0
Oct	337.5	12.0	7.9	6.3	0.7	0.7
Nov	319.7	12.0	6.2	0.0	4.4	0.0
Dec	328.6	12.0	11.2	8.8	2.0	2.0
Jan	287.6	12.0	9.1	7.5	0.7	0.0
Feb	280.6	12.0	7.2	4.8	0.4	0.4
Mar	325.1	12.0	4.8	0.0	1.5	0.0
Charger Availability:		100.0%	99.4%	96.4%	97.1%	95.6%

The final control technique uses a combination of the imminent peak and aggressive rate-of-change control strategies. If either is true, the workplace chargers are disabled. This combined control method provides a much greater reduction in facility peak demand than the previous techniques and still maintains a 95.6% charger availability rating.

The following mathematical relationships can be programmed into any EMS system to provide a custom workplace charger control algorithm.

Exceeding peak: $If\ P_{historic} - P_{30-min,\ t} \leq 0\ ,\ P_{charger} = 0$

Imminent peak: $If\ P_{historic} - P_{30-min,\ t} \leq X,\ P_{charger} = 0$

Aggressive rate-of-change: $\Delta P_{demand} = \left(P_{30-min,\ t} - P_{30-min,\ t-1}\right)$

$$P_{predicted} = (\Delta P_{demand} \times \tau) + P_{30-min,\ t}$$

$$If\ P_{predicted} \geq P_{historic}\ ,\ P_{charger} = 0$$

Where:

$P_{historic}$ = maximum facility demand during the current month, kW

$P_{30-min,\ t}$ = integrated facility demand at time t over the previous 30-minute electric demand window, kW

$P_{charger}$ = workplace charger electric power demand, kW

X = maximum workplace charger power or other threshold used to disable chargers, kW

ΔP_{demand} = difference in workplace charger electric power demand from time t to time t-1, kW

$P_{predicted}$ = predicted facility electric power demand at a future time τ, kW

Note is made that different building demand profiles may call for a different combination of equations to minimize facility electricity costs. What works for this facility may not work for others.

The control technique analysis results were compared to evaluate the impact each new technique had on charger availability and facility peak demand. Figure 11 represents a comparison of two of the control methodologies used in this analysis. The original control methodology (exceeding peak) is compared to results of the new methodology where a new facility electrical demand peak is predicted based on the facility's real-time electric meter measurements (aggressive rate-of-change). If the facility energy use is increasing, for example between 6 A.M. and 7 A.M., the rate-of-change (red line) provides an indication of what the new facility peak would be (thin red line), in this case 15-minutes into the future. Using this predictive algorithm, the workplace chargers can be disabled early enough that the portion of the electric bill associated with the workplace charger electrical demand would not dramatically increase electricity cost.

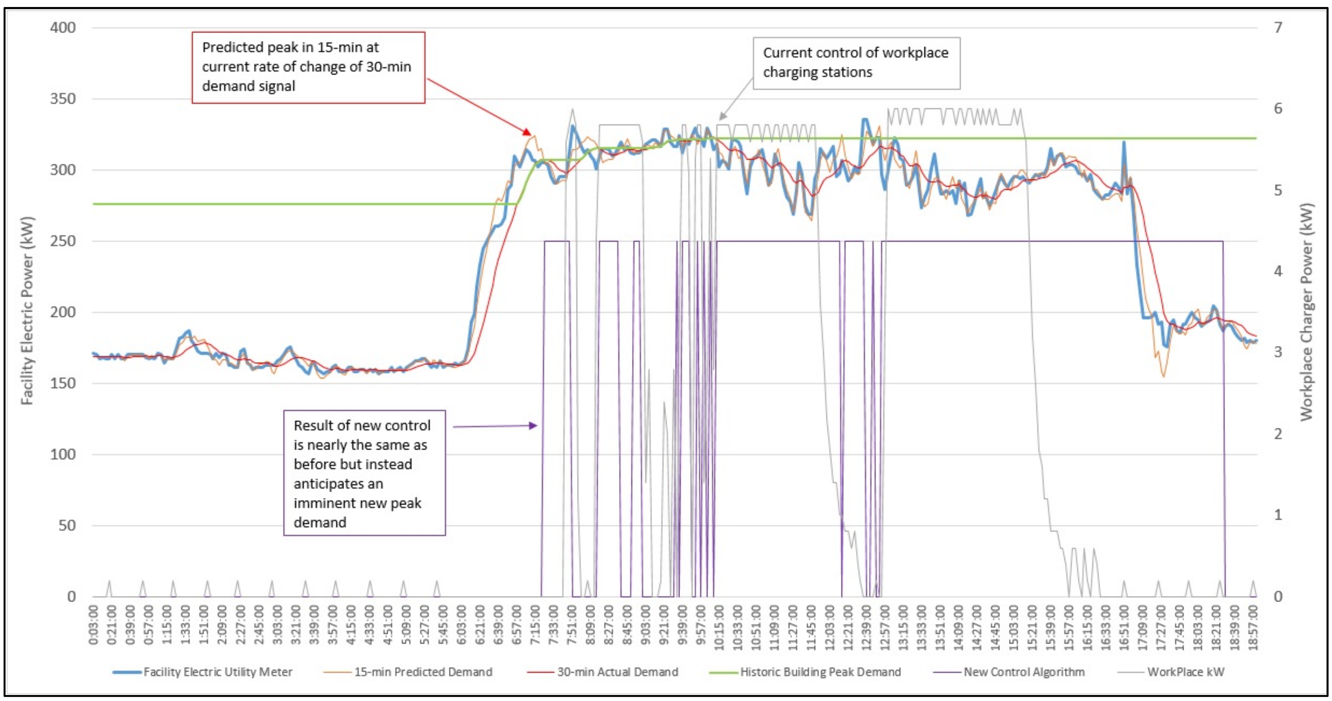

Figure 11. Charging Station Control Algorithm Optimization Analysis (November 7, 2015)

The Clipper Creek workplace charger has been operational since March of 2014. The prototype Aerovironment SEP charger was installed on May 7, 2015. The FSEC EMS system was operational beginning August 2015 using a simplified algorithm which disabled workplace chargers if the 30-minute average peak demand exceeded the historic monthly peak demand. This algorithm was improved in early May 2016 to include the aggressive rate-of-change of the 30-minute demand control strategy. Communications with the SEP charging station were intermittent at times and required that the gateway be power cycled to again allow proper communication. For this reason, the utility electric demand costs associated with the workplace chargers could not be completely eliminated. The gateway was subsequently plugged into an electrical outlet timer (Aug 2016) in an attempt to avoid additional communication problems.

The workplace chargers have been used regularly for the past 17 months with increased use in 2016. Each charging station draws approximately 6 kW of power and require 12 kWs when both stations are active. During the 2015 calendar year, the workplace chargers were used about once per day. Due to the limited use, the chargers avoided adding to the facility peak demand during some months. Of note is that when a charging station is not used often, for example in April 2015, the cost to charge each vehicle is quite high if added demand costs occur. When the charging station is used more regularly, electricity costs fall dramatically since demand costs are spread over a greater number of vehicles.

Table 4. Workplace Charging Station Electricity Costs

Month (2015)	Workplace AC Level 2 Chargers			
	Sessions (#)	Energy (kWh)	Demand (kW)	Cost/Session ($)
Feb	22	280	1.9	1.58
Mar	15	204	0.0	0.72
Apr	4	68	5.9	16.58
May	14	276	0.0	1.03
June	31	320	0.0	0.54
July	31	371	0.0	0.62
Aug	19	246	1.3	1.39
Sep	9	129	0.0	0.76
Oct	41	529	0.0	0.67
Nov	26	390	5.7	3.12
Dec	25	382	0.0	0.79
Jan	48	596	4.0	1.46
Feb	43	728	5.2	2.08
Mar	51	809	6.3	2.08
Apr	67	1039	4.7	1.50
May	57	865	1.2	0.98
June	68	1052	0.0	0.78

5 Conclusions

Workplace and retail store optional EV charging can help promote the use of electric vehicles while supplying an employee incentive or retail stores can draw in customers that would not otherwise frequent their establishment. These concepts are easy to understand, however, there are costs associated with the purchase, operation, and maintenance of the charging equipment. The results from this study shows that an active building energy control methodology can be used to minimize charger operating costs when the EV charger is part of the facility energy use (does not have a separate utility meter). Using these control methods, higher charging rates are possible without adversely affecting operating costs.

6 Acknowledgments

This report was funded through a grant from the U.S. Department of Transportation's University Transportation Centers Program under the Research and Innovative Technology Administration.

7 References

1. IEEE Standard 2030.5-2013 – IEEE Adoption of Smart Energy Profile 2.0 Application Protocol Standard. IEEE Communications Society. Institute of Electrical and Electronics Engineers.
2. Raustad, R., "Cost Analysis of Workplace Charging for Electric Vehicles", Florida Solar Energy Center, FSEC-CR-2030-16.

APPENDIX A – Overview of FSEC EVSE Energy Management System

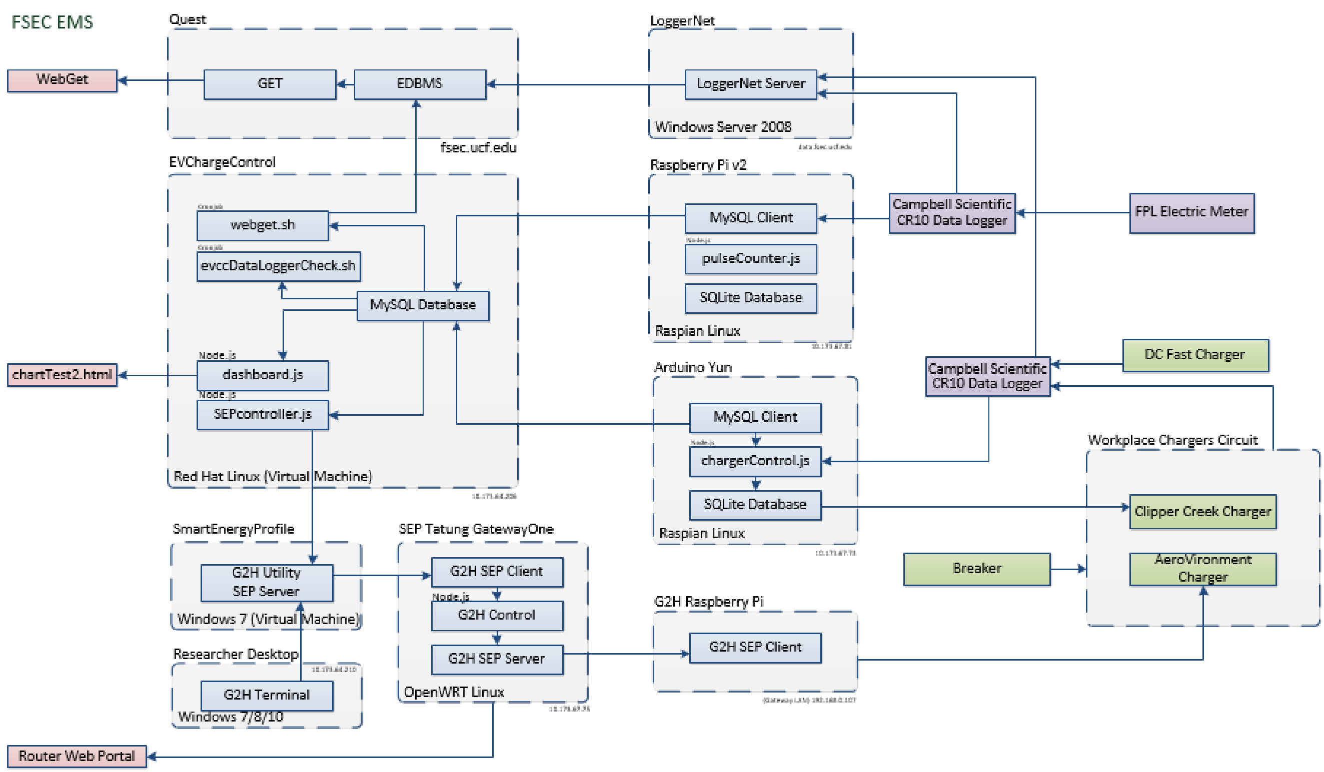

Figure A.1. FSEC EMS System Architecture

A brief description of the energy management system used to control workplace charging is as follows. Starting at the lower right of Figure A.1, the workplace charging stations are shown as a Clipper Creek and AeroVironment. These stations are connected to dedicated 30 amp single-pole breakers on a 208 VAC electrical service.

AeroVironment

Grid-2-Home modified the AeroVironment (AV) charger to include SEP 2.0 communication capability (bottom center of figure) and this unit is currently in the prototype stage. The SEP client in the charging station wirelessly communicates with the server side of the SEP Gateway which is located inside the facility. The gateway client is then networked to the main SEP server in the FSEC computer room. Grid-2-Home also provided a desktop terminal program that can communicate with the main SEP server, for example to act as a utility company sending demand response commands to the charging station.

Clipper Creek

A less sophisticated system is used to monitor and control the Clipper Creek charging station. This charging station employs a switch closure mechanism to disable the charger. An Arduino Yun microprocessor is connected to the Clipper Creek switch closure input via a transistor activated reed relay.

FSEC EMS System

The Arduino Yun microprocessor monitors the power meter connected to the workplace chargers. A Raspberry Pi microprocessor is also deployed to monitor the facility electric utility meter. In parallel, dedicated data loggers made by Campbell Scientific are also deployed to monitor facility and charging station electrical energy use independently. Each of these microprocessors store collected data in ring format. Finally, an EVSE controller is deployed to monitor the facility power meter data and disable the charging stations when necessary. The main database is located on this server and retains 1-minute data over the course of the project. A java script program, SEPController.js, makes the necessary decisions and sends disable commands either to the SEP server or the Arduino Yun microprocessor to control the workplace chargers. The final building blocks shown in the schematic are in-house software to store and analyze field collected data (denoted as LoggerNet and EDBMS) and are used to graphically report data for this and other research projects.

Actual operation of the EMS system was shown in Figure 9. This data is presented as pulses and not to scale. The yellow line is the facility electric meter (1 pulse = 4.32 kW) reading at 1-minute intervals. This data is averaged over a 30-minute window and presented as the red line to represent the facility peak demand as interpreted by the utility company. The green line is simply the maximum 30-minute demand recorded each month. The maximum 30-minute demand is reset on the 7th of each month to roughly correspond to the electric utility billing cycle. The orange line is the power meter data collected from the workplace charging stations (1 pulse = 0.3 kW). Finally the magenta line at the top of the figure and the purple line at the bottom of the figure are control signals for the AeroVironment (AV, 0-100%) and Clipper Creek (0/1 or on-off) charging stations. These stations are controlled in unison and either on or off. No modulation is attempted for the AV charging station.

On this day a PEV capable of charging at 6 kW plugged in just after 9 AM and a second 6 kW capable PEV plugged in shortly thereafter. The charging stations are active since the 30-minute facility peak demand (red) is well below the historic monthly facility demand (green). As facility resources increase energy consumption the total facility power increases as does the 30-minute peak demand. As the 30-minute facility peak demand exceeds the historic facility peak demand the workplace charging stations are disabled. The goal is to disable the workplace chargers 30 minutes prior to setting the maximum demand such that the workplace chargers have no impact on facility demand. The algorithm used is a simple test for when instantaneous demand exceeds the historic threshold. This method does not anticipate an imminent peak event and only disables the charges after the beginning of such an event. Also in Figure 9, although the control system requires both PEV charging stations to be disabled, only one of the two workplace chargers are disabled. The prototype AV gateway failed to respond to the disable commands and only the Clipper Creek unit responded. This issue was an ongoing problem throughout the project. If the AV gateway were power cycled, the system would respond appropriately for some time until the unit required another power cycle to reset the system. The manufacturer was contacted, however, since this was a prototype unit no resolution was found. As a corrective action, an electrical outlet timer was installed at the Gateway power plug to power cycle the unit each day at 4 A.M. No other communication failures have been noted since that time (Aug. 29, 2016).