A Report On: An Optimized EV Charging Algorithm Using Control Horizon Method

William Mollenkopf
October 02, 2015

Abstract:

The paper I researched is titled: "An Optimized EV Charging Algorithm Using Control Horizon Method" by Chang-Jin Boo, Bong-Woon Ko, Ho-Chan Kim. It was written in the Advanced Science and Technology Letters Vol.58 (Electrical Engineering 2014) and can be found on pages pp.113-116.

The paper proposes an optimized electric vehicle charging algorithm using control horizon method. Model predictive control with linear programming is used for control. Simulation results show that the reduction of energy cost and peak power can be obtained using the proposed algorithm.

The research paper originates from Korea, and this report is on not only on the paper itself, but also some background information as well in order to help explain the core concepts of the paper, and how it can be applied to the world we live in here in America.

1. Introduction

As of this writing, for the most part Electric Vehicle (EV) charging is performed either at the car owner's home, or at fairly sparse locations. Whereas refueling a gasoline powered vehicle is far easier to do when a person is "out on the town" due to the number of locations where it is available.

One of the biggest hurdles to increase electric vehicle adoption is that it is difficult to maintain a relatively charged battery for some. Especially those who have to travel fairly long distances (~30 minutes to an hour) on a daily basis.

So then the question becomes: "Why aren't there more EV charging stations in the first place?" One of the reasons is that currently implementing an EV charger at locations near or at businesses would cause a surge in power consumption that could cause a business' peak to become even more than usual.

Peak charges are usually very expensive compared to their usual flat fee charges and the paper I researched uses a control horizon method to help prevent EV chargers from consuming past an overall peak point.

Originally I had found this paper a year ago, likely very shortly after it was published, when I was tasked at my job for finding a solution of how to prevent an EV charger from going over the peak since the cost of the peak itself is so extreme. (The peak demand cost per kW fee can be roughly 50x more than the typical flat fee for consumption and is added as an additional charge to the consumption fee itself.

As for some related work to this paper, the task I was assigned at work includes networking a series of embedded systems (such as Raspberry Pi and Arduino YUN systems) and have them report on the consumption of the building power, as well as the individual EV chargers. And to devise a way for the embedded system to send a “kill signal” or “limiting signal” in which the EV chargers would either stop charging a vehicle, or charge at a lower rate. Considerations also needed to be made in order to possibly charge customers using the EV charger a fee during peak hours, or an additional fee if one is already imposed for typical charging.

My personal interest in the horizon method paper stems from a broad idea of being able to incorporate a world where businesses can easily implement EV chargers at their business as means of advertisement, and/or incentive for customers to spend time at their business rather than elsewhere. It also has the benefit of more electric vehicle adoption, and hopefully be able to decrease fuel costs for everyone (electric or gas powered) through means of essentially cheaper competition with widespread EV chargers.

2. Background Information (in regards to the paper)

One of the things that needs to be elaborated on is load shedding, but before load shedding can be elaborated on, billing peaks need to be explained first in order to truly grasp the importance and value of load shedding.

A typical consumer is usually charged a flat fee, and a slightly higher fee for consumption over a certain amount. While this could be used to explain load shedding, the margins are typically too small to explain much meaning behind them. However, a business is actually charged (typically) a very different bill than consumers are.
For example, one of the businesses that I’m aware of recieves a bill similar to this:

Meter reading - Meter [redacted]

Current reading	08191
Previous reading	- 07540
kWh constant	× 240
kWh used	**156240**
Demand reading	1.49
kW constant	× 240.00
Demand kW	**358**

Energy usage

	Last Year	This Year
kWh this month	160800	156240
Service days	32	32
kWh per day	5025	4882

****The electric service amount includes the following charges:**

Customer charge:	$19.48
Fuel: ($0.031300 per kWh)	$4,890.31
Non-fuel: ($0.020360 per kWh)	$3,181.05
Demand: ($10.61 per kW)	$3,798.38

Enroll now in FPL Budget Billing by paying $10,590.38 in 1 payment by the due date instead of $13,055.80. Your bill will be about the same each month & stabilized year-round. Learn more at FPL.com/bb

Amount of your last bill		12,552.49
Payment received - Thank you		12,552.49CR
Balance before new charges		$0.00
New charges (Rate: GSD-1 GENERAL SERVICE DEMAND)		
Electric service amount	11,889.22**	
Storm charge	101.55	
Gross receipts tax	307.46	
Franchise charge	757.57	
Total new charges		$13,055.80
Total amount you owe		**$13,055.80**

- Payment received after **November 30, 2015** is considered **LATE**; a late payment charge of **0.395830%** will apply.

Fig. 1. a typical medium-sized business bill

In Fig. 1. take note of the 1.49 demand reading. This is the the the max kW demand that occurred for that month. Even an amount that small can lead to a nearly $4,000 additional fee on an electric bill. Adding several electric vehicle chargers would drastically increase this charge.

In terms of the bill provided, the peak is calculated based on a 30 minute sliding window that slides every 15 seconds. Which means that every 15 seconds, a calculation is made in regards to how much kW was used and is used to determine a peak for that month (based on which peak was the maximum for that month).

In order to avoid going over a peak, a task known as “load shedding” can be performed to avoid going over a peak value. This can be done by either switching off something that consumes electricity (such as some outdoor lighting equipment, or additional air condition units that may not be needed to run at all times) -- or in in a more relevant example: EV chargers connected to the buildings power source. Load shedding can also be performed other ways such as turning on the air conditioning prior to when employees arrive to the office place in order to place less demand and stress on the air condition unit all at once when a sudden surge of employees arrive. But in terms of EV chargers load shedding can be done by simply modifying the amount the EV charger is allowed to charge (electricity it may draw into the car) or to completely shut off an EV charger altogether to avoid going over a peak.

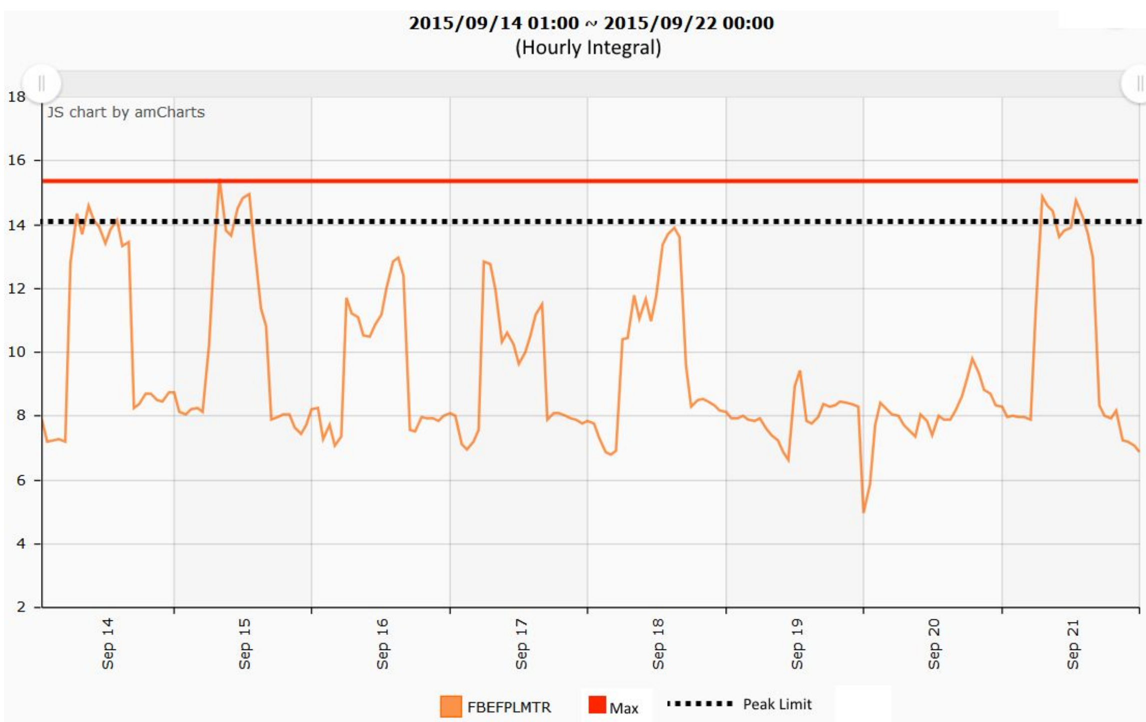

Fig. 2. hourly integral of consumption for the same business from the bill provided.

As with Fig. 2. if load shedding were implemented to stay below the 14 mark, then the nearly $4,000 additional charge would have been completely avoided.

3. Main Focus

The research paper uses their control horizon method proposed in order to switch off an EV charger whenever the power consumption is predicted to reach a certain amount during a 15 minute interval to perform load shedding.

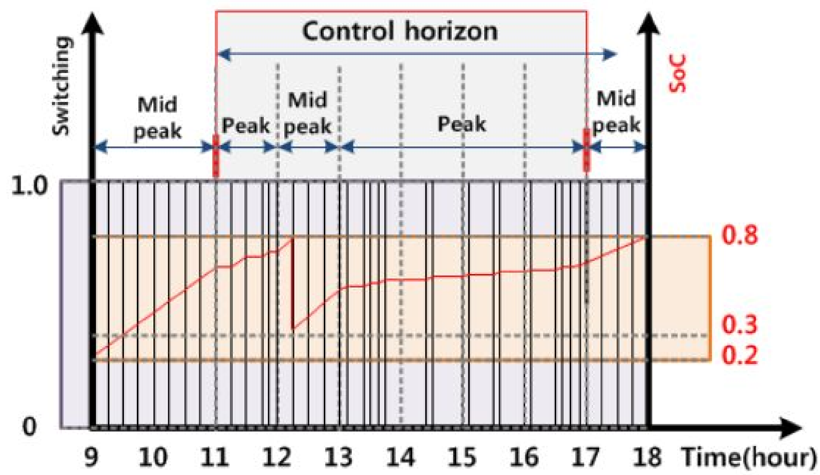

Fig. 3. Control Horizon Method

Fig. 3. displays an example of their control horizon method in action. It uses Model Predictive Control (MPC) and Linear Programming (LP) to create a prediction every 15 minutes. So if you consider the time being at 12, the data of what actually occurred previous to that would be consider historical data. And the interval of 12 and 12:15 would be the prediction of where the consumption will end up. The prediction shows that it will reach a peak and so the decision is made to shut off the EV chargers. Between the times of 12:15 and 12:30 you can see that the red line makes a drastic dip and the prediction is made again. Now that the consumption is so low in terms of peak, the prediction is made that it will rise again and is allowed to do so since it is still far under the peak.

4. Results

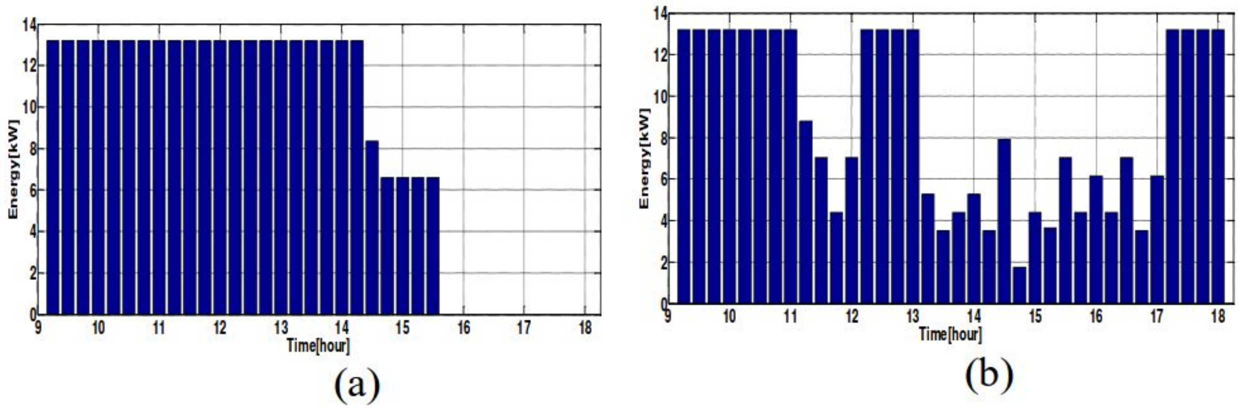

Fig. 4. Energy rate of: (a) On/off and (b) MPC and LP

Their computer simulation testing results showed a 4.7% energy savings versus an On/off method for controlling the EV chargers (as demonstrated by Fig. 4). While this doesn't seem like the most promising amount of savings ever, the paper states that more research is needed and that better computer simulations are need as well. There is most certainly a savings versus the On/off method but perhaps the more important aspect to take away from this paper is that it can help businesses implement EV chargers without the fear of them interfering with their peaks and costing them exorbitant amounts of money.

5. Conclusion

The paper proposed a control horizon method using model predictive control and linear programming. Their method could possibly be implemented in order to reduce peaks and conserve electricity here in the US. Their MPC constraints are implemented with linear programming in order to create prediction based intervals to allow for the ability to predict when a peak may soon be reached so that load shedding can be performed. They also state that future work is needed once simulations are "more mature".

6. References and Relevant Literature

Chang-Jin Boo, Bong-Woon Ko, Ho-Chan Kim. "An Optimized EV Charging Algorithm Using Control Horizon Method." in Advanced Science and Technology Letters Vol.58 (Electrical Engineering 2014), pp.113-116 <http://onlinepresent.org/proceedings/vol58_2014/24.pdf>

Frank Stern, Navigant. "Peak Demand and Time- Differentiated Energy Savings" <http://www.nrel.gov/extranet/ump/docs/peak_impact_061812.docx>

Brayden Automation Corp <http://energysentry.com/prod%20docs/educational%20literature/How%20does%20Peak%20Demand%20Occur.pdf>

EG Energy Controls Ltd. “Load Shedding, Demand Control, …” <http://www.egenergy.com/peak-demand-management>

Duke Energy “Understanding Demand and Consumption.” <http://www.think-energy.net/KWvsKWH.htm>

Plugin Recharge. “Plugin...Recharge!: UCF's New Solar…” <http://www.pluginrecharge.com/2010/05/ucfs-new-solar-powered-charging-station.html>

Simon Property Group. “Welcome To Waterford Lakes Town Center…” <http://www.simon.com/mall/waterford-lakes-town-center>

Wikipedia. “PID Controller” <https://en.wikipedia.org/wiki/PID_controller>

Government Technology. “Minnesota Cities Plan for Electric Vehicles” <http://www.govtech.com/transportation/Minnesota-Cities-Plan-for-Electric-Vehicles.html>