Capstone Proposal is a Classification Algorithm for Residential Ownership of EV's and their Charger Type

I. Problem Statement

Electric vehicles (EV's) are fundamentally more efficient than vehicles powered by internal combustion engines (ICE's), and hence have a lower Carbon Footprint. For example, the efficiency of an ICE might be 21%, while that of an electric motor is closer to 90%. The thermal efficiency of a modern gas-fired combined-cycle power plant can exceed 55%, and transmission losses typically aggregate less than 10%. This arithmetic demonstrates that the carbon footprint of an EV can be half that of an ICE vehicle. Moreover, EV's can be re-fueled with SolarPV energy during the day, and Wind Energy at night (when the wind often is strongest, and vehicles are normally at home). In this manner, EV's can be almost carbon free in terms of their fuel consumption, which is a major benefit as GHG emissions from transportation are now the largest category: moreover the US, as Tesla is demonstrating already, can provide a constructive model for other countries around the globe to follow.

Longer term, EV's are widely considered to be the platform for Autonomous Vehicles, which are expected to confer many benefits on society. Numerous players (including Apple, Google, Tesla and the leading automobile manufacturers worldwide) have, or are actively planning, multi-billion dollar investments in electric and autonomous vehicles. In recent years, many electric utilities have faced fundamental pressures from significant losses of sales due to the growth of Distributed Energy generation, including due to the growth of PV solar energy. This dilemma has been referred to somewhat controversially as "*The Utility Death Spiral*": as fixed costs are amortized over a shrinking customer base, electricity price increases are required that further accelerate customer defections. However, the widely expected rapid growth in electric vehicle ownership has been anticipated to reduce or entirely reverse that trend. EV's have therefore been declared the prospective "savior" of electric utilities.

The good news is that there is sufficient excess capacity in power generation and long-distance transmission lines that the capital expenditures required in these two areas are each modest. However, for local distribution it is a quite different matter. In terms of context, the peak energy consumption of a single household might typically occur in the Summer (due to a high air-conditioning load), attaining a level of 3 kilowatt hours (kwh). Residential load levels tend not to fluctuate too widely, and the peak load for many residences may be less than twice the average load. This has worked well, because beyond 64% of capacity, such transformers would tend to overheat, and the remaining life of the transformer may be thereby materially shortened. Thankfully, these high levels of capacity utilization have historically occurred only rarely, and so the system has worked well.

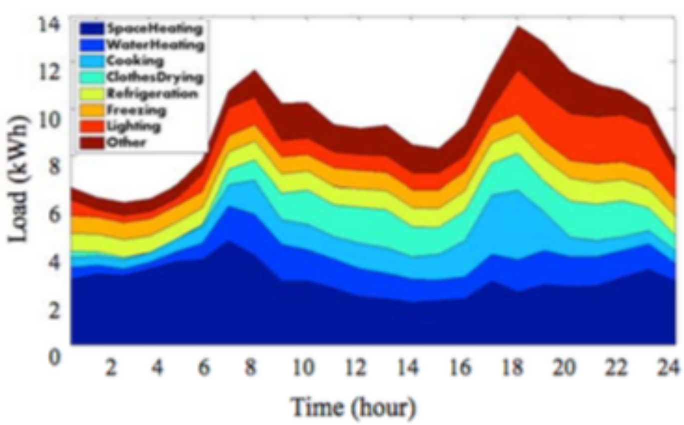


Fig. 1. Hourly winter load seen by a 25kVA distribution transformer, serving five homes.

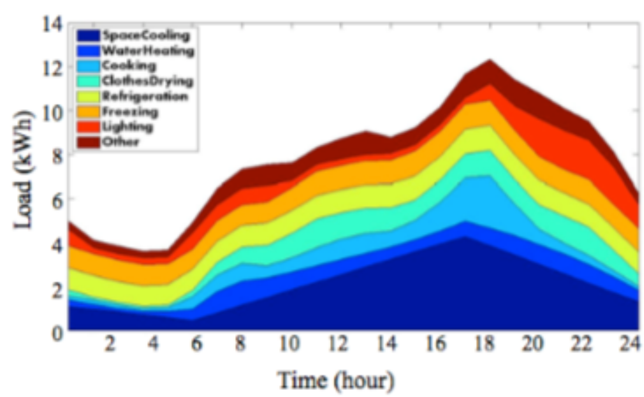


Fig.2. Hourly summer load seen by a 25kVA distribution transformer, serving five homes.

However, a rather technical and not especially intuitive problem arises. Somewhat unusually to a non-specialist, these transformers typically have been designed to operate at maximum efficiency of just 33% of their nominal capacity. The normal life of a transformer might be 20-40 years. However, once the usage load exceeds 64%, overheating tends to occur, and the ageing of a transformer can be accelerated in a highly non-linear manner.

In situations of high overload (which might mean 100% or more of nominal capacity), the life of a transformer might be reduced to just a few hours, or a brown-out may occur as a protective fuse is tripped. The problem here is that while historically such high rates of load have been rare, with EV charging they can be easily achieved, and the consequences even now, with still very low EV penetration rates, are already being felt, as outlined below.

Distribution Transformer Losses

- **Typical 25 KVA Transformer**
  - At 130% Loading
    - Core Losses 51 watts
    - Winding Losses 781 watts
  - At 100% Loading
    - Core Losses 51 watts
    - Winding Losses 462 watts
  - At 30% Loading
    - Core Losses 51 watts
    - Winding Losses 41 watts

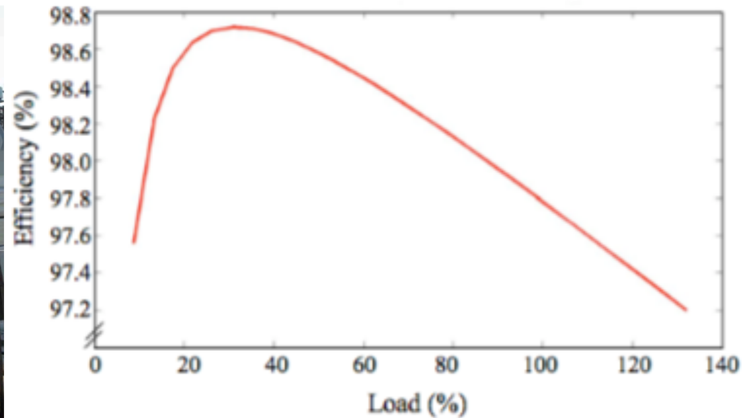
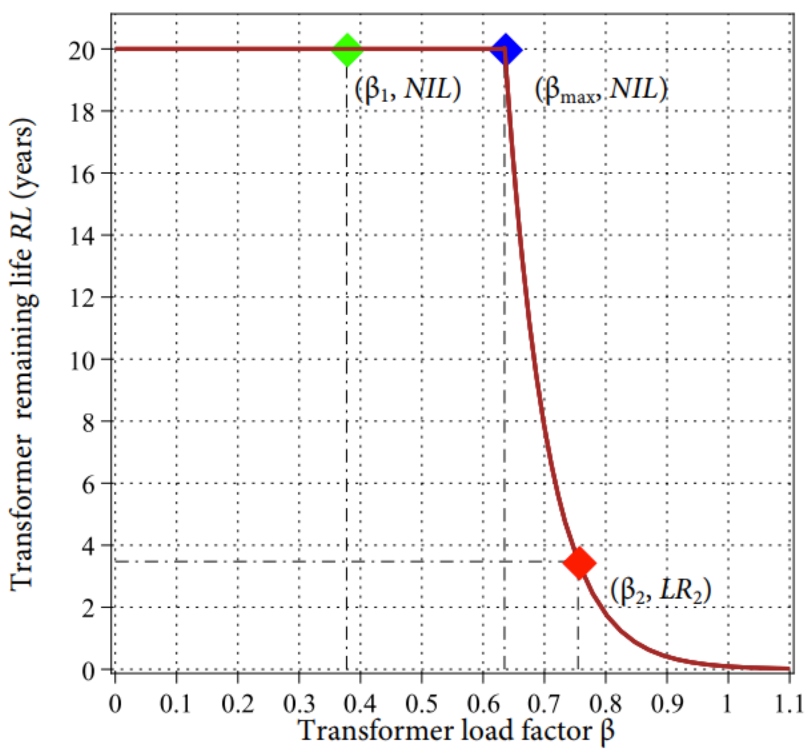


Fig. 3. Transformer efficiency curve.



At 0.64 Load Factor (and below), each hour is equivalent to 1 hour (corresponding to a 20-year remaining life).
At 0.70 Load Factor, each hour is now equivalent to 2.65 hours.
At 0.75 Load Factor, each hour is now equivalent to 5.65 hours.
At 0.80 Load factor, each hour is now equivalent to 11.67 hours.
At 0.85 Load factor, each hour is now equivalent to 23.3 hours.
At 0.90 Load factor, each hour is now equivalent to 38.9 hours. At 0.95 Load factor, each hour is now equivalent to 70.0 hours.

NB: The above exponentially increasing factors are not inconsistent with the statement made elsewhere that *"transformer overloading can shorten the remaining life by as much as 10,000-times"*.

II. EV Charging Rates and the Potential for Transformer Overload

The hourly power consumption of a so-called Level 1 charger (aka a "*Trickle Charger*") is c.2kwh. These were popular and sufficient for the early EV models with their relatively small (25-40 kwh capacity) batteries. However, in the last few years high performance vehicles with much larger (eg 85 kwh) batteries have become very popular. Indeed, even in conservative Norway, the Tesla's are now outselling all other models. The trickle Chargers are generally insufficient for EV's with large batteries, as charging from empty to full could take a matter of days, which is clearly impractical. A Level 2 charger normally charges at an hourly rate of 6 kwh (and these chargers receive a Federal subsidy), but also at an optional 11 kwh rate. Importantly, the latter higher rate can be achieved with a standard 240 volt residential electrical outlet for a drier or a stove. Indeed, a Tesla Model S is delivered with a charger of exactly this 11 kwh-rate capacity included. And someone who can afford to purchase a high performance EV and receives the charger free as part of the deal, may not be concerned about foregoing a government subsidy available for the lower 6 kwh-rate Level 2 charger.

Regarding Local Distribution infrastructure, groups of 4-10 residences are typically served by cylindrical pole-mounted transformers, which are sized according to various traditional rules of thumb.

In the approach outlined below, based on historical or expected usage for each household a peak rate is estimated for each household, and these are then summed and discounted by a so-called "diversity factor", which reflects the expectation (*normally* perfectly sound) that the respective peaks are unlikely to occur at the same time. Examples of such factors are set forth below:

Number of Customers	1	2	3	4	5	6	7	8	9	10
Diversity Factor	100%	90%	75%	65%	63%	62%	61%	61%	61%	61%
Number of Customers	11	12	13	14	15	16	17	18	19	20
Diversity Factor	60%	59%	58%	58%	57%	57%	56%	54%	54%	54%

[So suppose we have five residences supported by a standard 25 kVa transformer, the peak load would ordinarily be 15/25, or a comfortable 60%, with zero age acceleration. However, add a single Level 2 charger to that peak load, and the new peak would be 22 kwh, or a transformer life shortening 88%.] *see reference 12*

	Summer Peak	Winter Peak
KW for 1200 Square Foot home	13	15
KW for 4 X 1200 sq. ft. homes	52	60
Appling the 4 home diversification factor i.e. x .65	33.8	39
select a 25 kVA transformer with x 1.4 and 1.6 overload factor	35	40

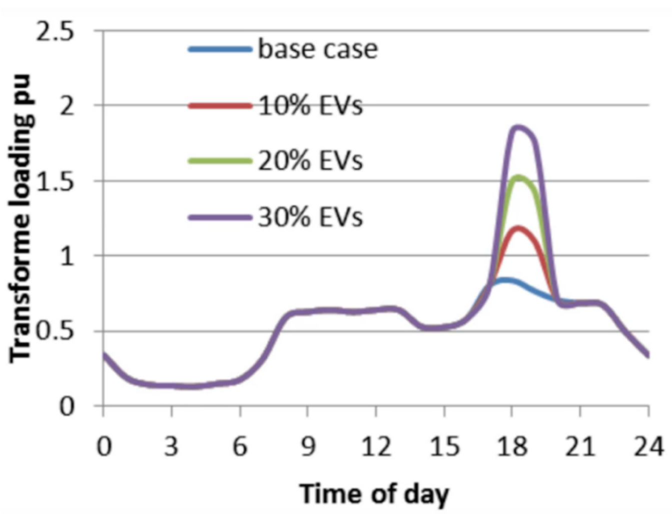
As one author has saliently commented "*The additional load of almost 10 kW that a single Level 2 charger consumes concurring with the coincident evening peak load could push even conservatively sized distribution transformers over their nameplate rating. The consequence is that distribution transformers will operate in overload conditions on a regular basis, reducing efficiency, driving up temperature and reducing the life of the transformer. Two Level 2 chargers fed from the same transformer and powered on after an evening commute will skew the diversity factor closer to 1 and could lead to equipment failure unless asset monitoring is in place.*

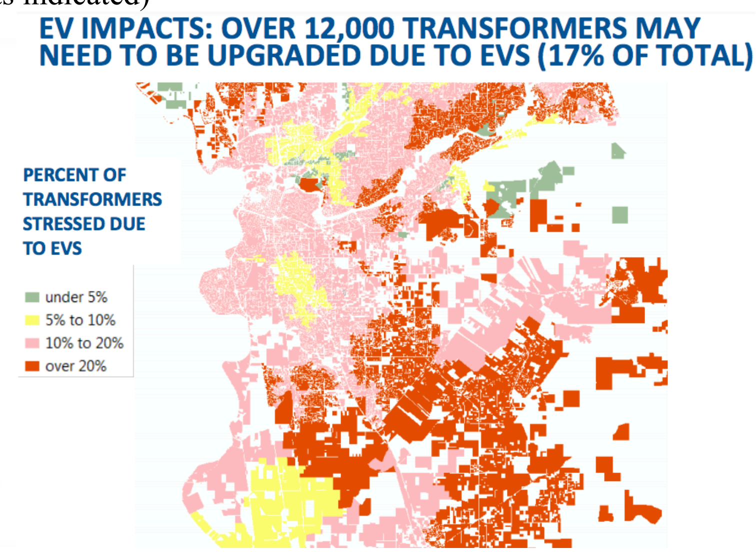
And from a different source, but a rather similar perspective: *"Local distribution grids are not built to accommodate the huge spikes in demand where electric cars will be particularly prevalent. Transformers, which connect every home and business to the power grid, are the most vulnerable and affected elements of the system.*

Add more than one electric car to the same local transformer (charge clustering) and overloading is more likely to occur. This causes damage to the electrical equipment which reduces the lifespan and can result in outages and added costs. The risk of overloading local transformers is particularly high during peak hours. Studies suggest that higher penetration of EVs can increase transformers' loss-of-life factor, by up to 10,000 times. As an example, the Sacramento Municipality Utility District has recognized 17% of their transformers need replacing as a result of EV-related overloads, at an average estimated cost of $7,400 per transformer."

Moreover, there is extensive evidence of so-called clustering of EV's, both in terms of their location (for example due to income and demographic concentrations), and the times that their owners choose to charge. So in a prosperous area we might find two EV's supported by the same transformer. Now the peak load has jumped to 29 kwh, representing a 116% load on the transformer at which, depending on ambient temperatures, a marked shortening of the remaining average life, or even ultimately a brown-out, could occur.

Left: *The charging demand from just two EV's can exceed the peak for all other power demands:*
(pu stands for "per unit", and can exceed unity as indicated)





Right: *In areas where EV ownership is more common (eg SMUD), residential transformers are already stressed.*

Two factors make this situation especially problematic. First, the transformers are not equipped with sensors of any kind, so there is no warning of overheating which is likely to result in accelerated ageing. Second, electric utilities typically do not know which residences own EV's. For example, SCE in Southern California reportedly knows the locations of only 40% of the EV's within its territory. Since the replacement cost of a transformer is $7,500, a brown-out is a very expensive way of discovering an EV location.

The above portrayal of problems are not mere conjectures. In the Sacramento area, which has a high concentration of EV ownership, thousands of such transformers have already been thermally stressed (see RHS figure above). Moreover, anecdotes of brown-out's triggered by EV charging are becoming common. There seem to be at least two consequences. First, if the relevant transformers are not upgraded in a manner to pre-empt their lives being shortened, then the local distribution cost component might rise to more than $0.10/kwh, and the profitability of EV charging could be impaired. Second, there may be reputational damage incurred, as all 5-7 households served by that transformer would have suffered from the adverse consequences of the brown-out. Moreover, as such brown-out's become increasingly common in line with projected EV adoption levels, there could be delays in obtaining new transformers, and even in installing them, as qualified work crews become overburdened with such jobs. In the long term, there could be an accelerating movement to rooftop solar with battery storage (think Tesla Powerwall), as a way for homeowners to become more independent of a conspicuously unreliable grid. In the alternative, there could be a backlash against EV owners for the inconvenience and costs imposed on their neighbors, and the adoption of EV's could be markedly slowed. This would be unfortunate for electric utilities in terms of a lost growth opportunity, and also for those people concerned about long-run Climate Change.

. The broader issue here is that anticipating and pro-actively resolving these issues, while not a trivial matter, when done properly can be achieved at a tiny fraction of the cost of replacing prematurely-aged transformers. A "*Time-Of-Use*" (TOU) plan is an obvious way for a utility to shift load away from Peak hours. The peak price for EV charging may be set as high as 40-50 cents/kwh, while a starting at midnight a *Super Off-Peak* rate of below 10 cents/kwh with a $15/month supplement (as implemented by SDGE) might be considered. However, it is now well documented that the designation of such Off-Peak periods can induce a mini-peak of its own, as EV chargers set their timers to charge at exactly the same hour, namely the onset of the Off-Peak period.

A fundamental challenge remains because even as sophisticated a company as SCE in Southern California (with a multitude of advisors) reportedly knows the locations of only 40% of its EV owners, since installers of charging systems are under no obligation to notify the relevant utility. Of course, a utility can make highly attractive offers targeted at EV owners to help surface the locations of such owners, and hence the local transformers that may need to be upgraded. However, SCE does seem to have pursued exactly these types of initiatives, and it still left in this uncomfortable predicament with a high degree of uncertainty. One problem here may be a pattern of so-called "satisficing" behavior. EV owners tend to be relatively wealthy and also perhaps busy people: they may not feel compelled to take advantage of such special offers because they simply have higher priorities elsewhere. In fact, the difference in cost between charging at Peak hours and Off-peak may be less than $5, and so some may continue charge during Peak hours simply for reasons of convenience. However, the replacement cost of a transformer at $7,500 is a very different order of magnitude, and so the utility is burdened with an unpleasant liability that appears hard to control.

III. Managed Charging

The standard approach among the academic community to addressing the "*Last Mile*" challenge has been so-called "*Managed Charging*", pursuant to which EV chargers cede control to a third-party agent of the exact timing and charging rate, subject to their EV being suitably charged by the morning. This is of course a very sensible approach, which would allow the overall charging profile to be greatly smoothed out in a highly beneficial manner. Moreover, sudden bursts in generation from Wind Energy could be advantageously accommodated. More broadly, Wind Energy is notoriously volatile, and requires highly inefficient back-up from low-efficiency simple-cycle gas turbines ramping up and down, with a carbon footprint that can actually exceed that of a coal-fired power plant. Charging intermittently can obviate the need for such a costly back-up, and its benefits are widely appreciated. There have been over the last ten years numerous academic papers on this topic of *Managed Charging*, with increasingly sophisticated refinements. Moreover, two companies eMotorWerks and Fleetcarma (www.emotorwerks.com and www.fleetcarma.com) were launched specifically to offer *Managed Charging* to EV owners. However, the unfortunate truth is that *Managed Charging* has not yet been widely adopted, and both of these companies were, after reportedly struggling to survive for some time, acquired by much larger companies with deeper pockets and longer time horizons.

Moreover, electric utilities may be cautious to let such companies become too powerful, as their interests may not be congruent with those of the utilities. For example, eMotorWerk on their website advertises *"Charge up to 13*x *faster with a JuiceBox! Powerful and portable, our smart EV charging stations make it easy to charge at home and on the go".* This type of fast charging would likely exacerbate the *Last Mile* problem, and could burden utilities with large costs. Nowhere does eMotorWerks explicitly mention that its algorithms even take into account local distribution networks, and anyway, utilities may not wish to share this confidential information until matters get clarified. For example, might electric utilities wish to avoid possible conflicts of interest and provide the *Managed Charging* themselves, if they could attract the (expensive?) technical talent to get the job done? One may note that most of the utilities that have associated with eMotorWerks already have AMI-type Smart Meters capable of two-way communication, and may therefore be well-positioned to implement a form of *Managed Charging* on their own in the future.

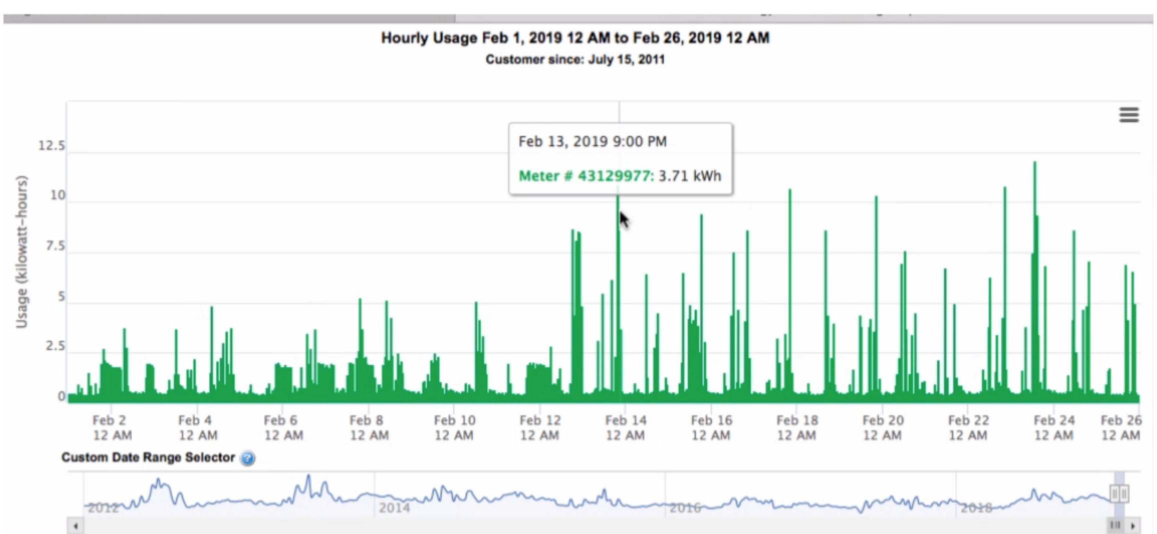
As a somewhat broad generalization, most individuals (especially in America?) seem to like to make their own decisions. They do not seem eager to pay for an expensive specialized two-way communications meter that does not actually offer them lower electricity rates in return (although a generous array of credits and other benefits are currently offered to defray the initial cost). So even though in California wholesale electricity prices in the middle of the night are demonstrably on average only half the level at the onset of PG&E's EV Off-Peak period, EV owners gain no benefit from deferring their charging to this later time (although an intermediary such as eMotorWerks might instead benefit by simply purchasing power in the wholesale or real-time market, and reselling it at a profit). Moreover, the cost of clusters of EV chargers choosing to charge at the onset of the Off-Peak period is that a mini-load-peak is created, which may expensively shorten the lives of the nearby pole-mounted local distribution transformers.

In addition, it seems that much of the age-acceleration of transformers that occurred in Sacramento was due to mere Level 1 chargers, which may operate for most of the night and so the anticipated "cool-down" period built into the design of the transformers is effectively eliminated. While *Managed Charging* should avoid immediate damage to the transformers, the more fundamental point here is that it may be somewhat wishful thinking on the part of the electric utilities that such a large increase in total power demand can be accommodated without any incremental infrastructure investments.

IV. An Intermediate Algorithmic Approach

The algorithmic approach described here is in not as optimal as *Managed Charging* could be. Rather, the goal is to informationally assist an electric utility in acting in sensible ways in the context of an imperfect world, and to minimize potentially avoidable costs. This starts with the surprising fact that most utilities do not know which of their customers have EV's, and which of their local distribution transformers are most likely to be thermally degraded, with a consequent expensive shortening of their remaining life. Specifically, more than a dozen sensible measures were enumerated that would appear to be constructive in avoiding unnecessary costs, whose confluence could easily render EV charging unprofitable for an electric utility. In the long term, *Managed Charging* would be better, but its prospects are quite uncertain.

A Case Study: Corn Belt Energy : the chart below shows the hourly kwh consumption of a fellow data scientist who lives in Illinois and in February acquired a Tesla and a more powerful Level 2 charger, having owned a Honda EV with a smaller battery before. The electricity provider is Corn Belt Energy, a not-for-profit co-op, which is the sixth largest utility in Illinois, with more than 30,000 households and 34,000 Automated Meter Reading ("AMR") type meters, which record electricity consumption on an hourly basis, as indicated in the chart below. A simple visual inspection suggests the date of the acquisition was around February 13th, as after this date the daily peaks now regularly exceed 5kwh, while this was a rarity with just a single occurrence before.



Nationwide, a statistical analysis of 2017 data reveals that there are over 300 utilities with more relevant meters (one-way AMR, and two-way AMI, or Smart Meters) than Corn Belt. Perhaps the takeaway from the foregoing is that although there is much dismay among utility analysts that Smart Meters (type AMI, with two-way communication) are not as common as would be ideal, nevertheless if For the goal is the pro-active detection of EV's, and the inference of whether they are charging at Level 1 or Level 2, the AMR data may well be sufficient. The key issue is to detect EV's, and most specifically clusters of Level 2 EV chargers, before the cumulative thermal load of the cluster severely shortens the remaining life of nearby pole-mounted transformers, with an associated cost of thousands of dollars per transformer. Data for five other larger Illinois electric utilities is set forth below (as extracted from an EIA database, for which a separate Jupyter Notebook is available):

utility	state	grid	amr	ami	smeters
Commonwealth Edison Co	IL	PJM	0	3394474	3394474
Ameren Illinois Company	IL	MISO	441222	615409	1056631
MidAmerican Energy Co	IL	MISO	74043	0	74043
City of Springfield - (IL)	IL	MISO	59912	0	59912
City of Naperville - (IL)	IL	PJM	0	53398	53398
Corn Belt Energy Corporation	IL	MISO	33778	0	33778

Con Ed Case Study: the importance of the AMR/AMI distinction is especially clear for Con Ed, which has relatively few genuine Smart Meters, but more than a million AMR meters. Con Ed might think "an algorithm" is not feasible, because *Managed Charging* requires two-way communication. But Con Ed could use the *Intermediate Approach* above to identify the small percent of households with EV's, and then give them a discounted deal on a Smart Meter. That way every new Smart Meter could be profitable, rather than a cost burden.

V. Getting Ahead of the Game: The Benefits of EV Discovery via an Algorithm using hourly meter readings

Of course, the above problem would largely disappear if the utility knew the identity of an EV owner 95% of the time. The nearby local distribution transformers could simply be pre-emptively upgraded in an orderly manner, and the utility could then look forward to decades of enhanced sales with only relatively low incremental costs. In this context, we believe that with a relatively high degree of confidence, EV ownership can be reliably deduced from hourly metering records retained by the utility.

Potential Approaches to Classification

Approach 1: a standard *Time-Series-Classification* (TSC) approach, which employs one of a variety of distance metrics for classification. These are well-described at the website hosted by the University of East Anglia in the United Kingdom: see www.timeseriesclassicication.com . These standard approaches may fail to use relevant external data (see point 2. below). *Data*: The data will be hourly metering records routinely collected by standard AMR meters (NOT smart Meters). A list of 300 electric utilities with such records has been created in a separate Jupyter Notebook that processes EIA excel sheets. An initial csv file has been obtained from one electric utility, and a request for additional records has been submitted along with initial analysis and commentary. A dozen utilities with whom this author has some personal contacts may also be potentially targeted. Actually getting the information may however take a while.

Approach 2: a more tailored approach which is premised on a number of qualitative questions as to what features we might reasonably expect to see in the hourly metering records. These include, for example:

1. An increase in the monthly total power consumption of approximately 333 kwh, for an EV driver who drives 1,000 miles each month (regardless whether the charger is of Type 1 or Type 2)

2. A lower increase (eg 165 kwh) where the battery is smaller (as for a Honda) and is regularly used up, and an ICE is then used for the balance of the trip.
3. A series of spikes of c.7kwh between 6pm and 6am, corresponding to charging with a Level 2 charger, mostly in consecutive hours, within a sequence of 2-5 hours
4. A sequence of modest spikes of 2 kwh between 6pm and 6am, for a Level 1 charger, in consecutive sequences lasting 4-9 hours,
5. Possibly a higher standard deviation of hourly kwh consumption for a level 2 charger, since after charging has been completed, there may be a large drop in power consumption.
6. Where the owner has a Time-Of-Use (TOU) tariff scheme (which currently is generally NOT the case), an increase in consumption of 2 kwh for a Level 1 charger, and 7 kwh for a level 2 charger at the onset of the designated Off-Peak period, which varies by season.
7. Numerous other insights, to be developed (including autocorrelation and moving average-based).

There are many different approaches possible here. One is to have three or five classifiers, each using a different feature (similar to the features outlined above). The Classifiers can then vote in an *ensemble* manner, with the majority vote prevailing. Or we could have a logistic regression approach, with the independent variables being a selection of the statistically significant features outlined above.

Approach 3: A Bayesian Approach, constrained by third party records, such as ownership of different types of EV's by zip code, or correlating EV ownership with available income and demographic information available by zip code. One of the fundamental challenges with EV charging is Clustering (geographically by ownership, and temporally for charging).

Approach 4: So far the focus has been exclusively on Classification, but a more fundamental question is given a collection of different residential households (normally 5-10) served by a single pole-mounted local distribution transformer, what is the likelihood of that transformer being prematurely aged. This can be explored through Monte Carlo type simulation, including some of the models put forth by CalTech in the *Statistical Inference* section. This could be combined with #3 above. The fundamental point is that the accelerated ageing of transformers (and actual brown-out's) seem to be occurring already, but the models put forth by electric utilities suggest that this could only be a problem in the distant future.

Approach 5 (Clustering): in Classification problems, normally the labels are a given, but here they are not. This is because the whereabouts of MOST of the EV's is typically unknown: the purported "*Not EV*" class can therefore be expected to contain in fact most of the EV's. One possible way to proceed is to construct a series of twenty or more metrics that are intuitively relevant to classifying EV ownership, and then clustering based on these metrics. If we observe a high degree of EV ownership within a particular cluster, then that may be the "EV Cluster", and the non-EV's should be investigated using a combination of attractive Special Offers and other records (including DMV and federal charger tax credit records).