Optimum Load Shaping

Charging Electric Vehicles and Batteries with Renewable Energy Sources

A Technical Paper prepared for SCTE by

Frank Sandoval
Principal
Pajarito Technologies LLC
1650 Gaylord St, Denver CO 80206
+1-720-338-1988
frank@pajaritotech.com

Dr. Robert F. Cruickshank III
CTO
GRIDIoT® by RCA
132 Cruickshank Rd #269, Big Indian, NY 12410
+1-703-568-8379
rfciii@cruickshank.org

Laurie Asperas Valayer
CSO
GRIDIoT® by RCA
16 Wincott Dr, Melville, NY 11747
+1-631-335-9197
asperasvalayer@gmail.com

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1. Introduction

Traditionally, electric utilities forecast electricity consumption, aka load, and then generate enough power to supply demand at any point in time. But the world is changing, and this model is becoming tenuous at best, and perhaps will be wholly insufficient to meet our needs for low-cost reliable power. The grid is aging and becoming less reliable as evidenced by recent years' California wildfires and the February 2021 Texas Power Crisis. As the need to reduce carbon emissions is becoming more urgent, significant amounts of distributed power generation from solar and wind are coming online, and demand is increasing with the penetration of electric vehicles (EVs).

These changes present opportunities for innovation, and one area of activity attempts to shift the demand for energy (via load shaping) to the most efficient, cheapest, and cleanest sources of energy supply during the daily cycle. As significant consumers of electricity, cable companies have much to gain by adopting load shaping strategies for facilities, fleets, customers, and the outside plant.

Several working groups within the SCTE have been exploring technologies that could aid in actively shaping electrical loads. A specific use case is the battery-backed EV charging station. Cable fleets of tens of thousands vehicles will become electrified and there is ample motivation to drive down the anticipated costs of EV charging. Using utility-provided Optimum Load Shaping (OLS) signals—based on pricing, low carbon generation, and weather—each charger may be controlled to time its charging periods to ensure the least cost.

Other examples of load shaping include the orchestration of loads within a micro-grid that powers a cable facility. In this scenario, a micro-grid controller may obtain OLS signals and other data to drive algorithms that optimize the load within its domain, using solar, battery, fuel cell, and building management assets.

The outside plant consumes most of the electricity in a cable operation, and there are interesting concepts to leverage batteries, renewable generation, and consume energy in proportion to RF bandwidth powering.

2. Limits to Supply

Since electricity became available in 1882, the grid was simply assumed to grow to meet demand. The one-way model of energy generation, transmission, and distribution has generally been taken for granted, and as cities and towns grew—and more and more appliances and devices were powered up—electricity suppliers simply worked to satisfy all new demands. There are natural limits to this approach, and we've hit them.

2.1. Diverse Generation

The Public Utility Regulatory Policies Act of 1978 complicated the traditional one-way model of the grid by allowing non-utility generators to market their power to utilities. Energy supplies and pricing became more dynamic, and the sourcing and movement of electricity became more complex and less reliably predictable.

More recently, Distributed Energy Resources (DER), such as industrial, community, and household solar, wind, and emerging battery systems add vastly more energy generation sources, deeper into the distribution system, further complicating pricing and management systems. Repurposing the same infrastructure developed for stable one-way generation and transmission to a highly dynamic bi-directional system has worked remarkably well, it reminds one of how cable networks were fortuitously able to accommodate Data traffic overlaid upon infrastructure developed for broadcast TV. However, the grid was not designed for the uses its being asked to serve. Renewable generation fluctuates with the weather, complicating forecasting of fossil fuel generation. Regulations, financing models, distribution systems, management and maintenance systems, and infrastructure—all struggle to adapt without the benefit of a modern intentional design or purpose-built systems.

2.2. Carbon Pollution

Politics aside, carbon pollution appears to be a present and growing threat that communities and governments around the globe are reacting to. Utilities are adopting external or internal mandates to de-carbonize and, in many regions, vigorous efforts are currently underway to replace fossil fuel generation with less carbon-intensive alternatives.

While energy suppliers strive to replace and surpass current fossil fuel capacity, we consider ways to shape and blunt the growth of demand. If the rate of demand growth slows, then the rate of replacement of carbon intensive fuels by renewables accelerates, helping suppliers reach carbon targets more quickly.

2.3. Inefficiencies

As engineers, we might feel offended by how inefficient we've been with fossil generation. As shown in Figure 1, fully 2/3 of the energy released from burning fossil fuels is wasted as heat! Simply put, 2/3 of the carbon we've released into the atmosphere by electrical generation has served humanity not one bit of good. We can—and of course should—do better.

In Figure 1, line widths are proportional to flows. Given total usage of 100 quadrillion BTUs, all numbers on the chart denote approximate percentages, e.g., at left, solar power provided for 1% of U.S. Energy use, and at right, 33% of all energy provided for useful work and 67% was rejected as waste heat—via smokestacks, heat exchangers, and tailpipes.

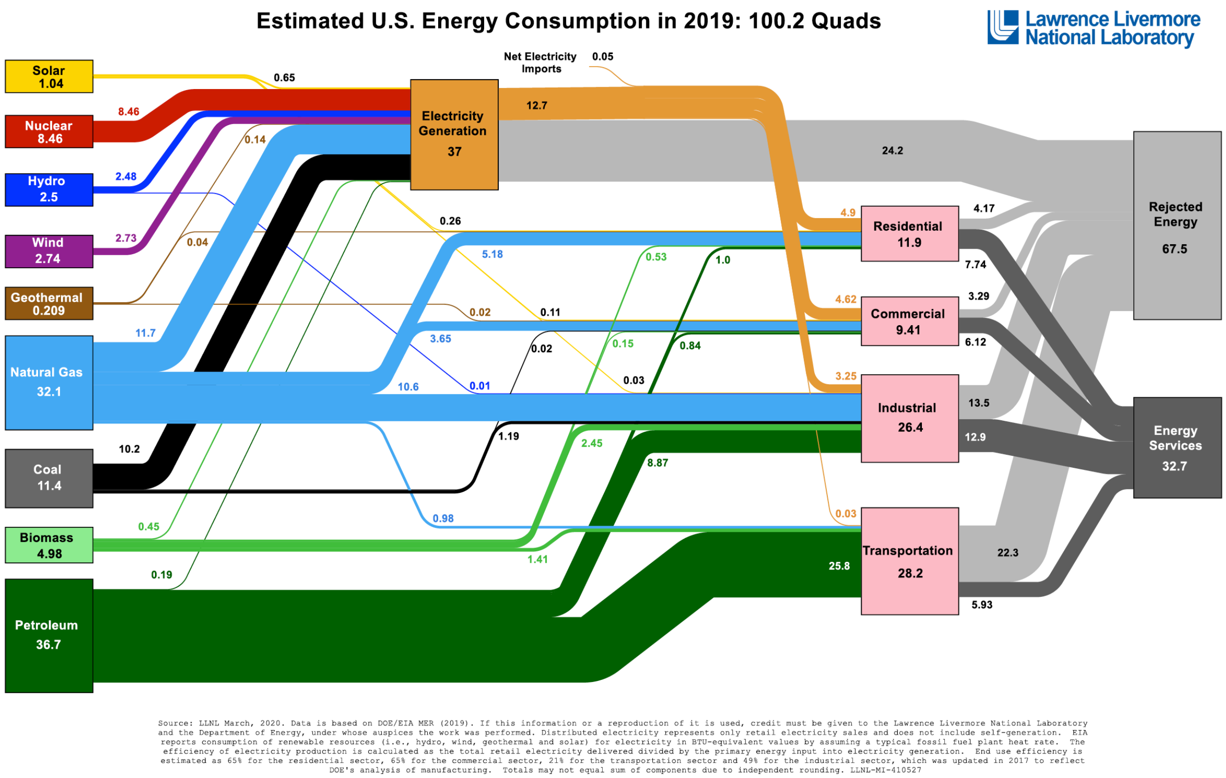


Figure 1 - U.S. Energy Consumption

2.4. Aging Infrastructure

A failed C hook, purchased circa WWII for half a dollar, caused the Camp Fire in California in 2018, the most destructive fire in the state's history to that point, causing $16.8B in damages and 85 lost lives. Images illustrative of Pacific Gas and Electric's failing infrastructure, responsible for starting the fire, are shown in Figure 2.

Figure 2 - PG&E Failing Infrastructure

The mean life expectancy of grid equipment is 65 years, yet, on average, equipment is in service in the field 68 years, with components as old as 108 years!

This leads to an inherently fragile and costly grid that will require time and money to rebuild and repair. Diminishing the maximum capacity that the grid is meant to support will lessen the overall costs and time required to retrofit.

2.5. Severe Weather

Recent history and unexpected trends indicate more frequent and severe weather events that can overwhelm the grid. The unprecedented cold in Texas earlier this year led to catastrophic grid failures. Increasing drought and heat, especially along the West coast is spiking demand for air conditioning.

A cruel irony of higher temperatures is that it makes fossil generation less efficient—the necessary cooling and condensation of water vapor is less effective leading to a higher ratio of fuel to kilowatt-hours (kWh) generated.

2.6. Electrification

Most car manufacturers have by now made it clear that Internal Combustion Engine (ICE) vehicles will be as quaint as horse drawn buggies in a few decades. Electric Vehicles (EV) alone will cause an estimated 25% surge in electricity demand, growth that today's infrastructure is simply incapable of handling.

Other factors will lead to increased electrical demand, for example rising temps will induce increased use of air conditioning. Continued efforts to reach carbon neutrality will necessitate transitions to electric heating, cooling, and cooking.

Figure 3 reminds us of the many of today's sources of fossil fuel consumption by transportation and buildings; these all will transition to electricity over time.

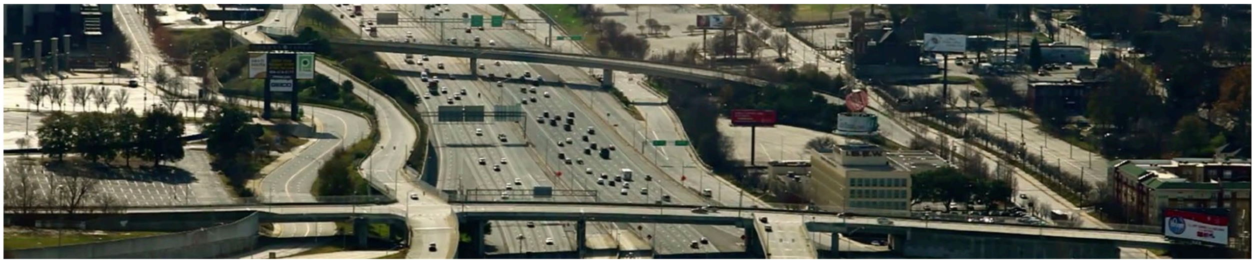


Figure 3 - Energy Consumers

2.7. Cyber threats

Increasingly, various elements of our national infrastructure, such as recently publicized ransomware attacks on fuel lines and meat processors, are under attack via software hacks. There are known instances of successful infiltrations of energy grids. While it appears intruders have to date not exploited such attacks to great effect, there is risk that that they could by activating current breaches or introducing others. Our ability to more fully monitor our energy infrastructure, effectively distribute generation, and dynamically respond to adverse conditions, whether natural or man-made, are signature elements of future grids. Mitigation strategies include shifting or curtailing loads by switching to local generation or postponing demand when the grid is attacked or otherwise failing.

3. Limit Demand

All of the stressors on supply described above require tremendous costs and years of effort to address, and fortuitously all of them can be mitigated to some extent by controlling the amount and timing of demand.

As noted, the general paradigm in electricity services has been that supply chases demand that grows unconstrained by any overt controls—and that electricity costs are so low that it presents very little impediment to growth in demand. The obvious upside of low costs and reliable access is accelerated economic growth and minimally constrained personal use. The obvious downsides are waste, pollution, and over-investment in fuel and infrastructure.

We consider here ways to diminish the rate of growth of electrical consumption, if not one day decreasing the absolute amount of electricity consumed.

There are two categories of demand side control:

- Lowering absolute consumption
- Time-shifting consumption

3.1. Frugality

There will always be people who are sensitive to wasteful consumption and don't particularly mind trimming their own use by turning down the thermostat in winter and hanging their laundry out to dry—but let's face it, most folks will opt first for convenience and comfort. Making it easy for people to lead more efficient lives will probably require seamless technologies and higher prices.

We mention this simply to acknowledge that we all might become more energy aware but concede that this will not likely be sufficient to eliminate all supply issues.

3.2. Pricing

Electricity has been relatively inexpensive since it was first made available 140 years ago. Most homeowners are not enthusiastic about seeking reduction in their consumption as it represents such a small percentage of monthly budget. Renewables are proving to be less expensive than coal and natural gas, and we may find ourselves paying even less for electricity over the long term. In the short term however, a carbon tax or other price signal might be introduced to spur transition to a net carbon neutral economy.

3.3. Building and Device Efficiency

Energy Star appliances, LED light bulbs, strict building codes, improved materials, better batteries, and many other improvements in all of the thousands of technologies we rely upon have had significant impacts on our overall energy footprint. Recall the cable voluntary agreement to deploy energy efficient set-top boxes. Many fossil fuel generation plants have not been build as the result of inexorable improvements in our material culture.

But these gains are significantly offset by other energy-hungry advancements. The growth of mobile and other personal devices, crypto-mining, expanding air-conditioning, and many other factors erode the gains produced by efficiencies.

3.4. Utility Incentives

For some time, various mechanisms have been developed to help utilities avoid brownouts and blackouts by encouraging customers—typically large facilities such as factories—to reduce or avoid consumption during times of expected peak load. Imagine a heat wave during which a utility forecasts a supply deficit in the late afternoon, as some businesses are still operating but many people are coming home and cranking up the AC. This utility may have pricing agreements with energy consumers to encourage strategies such as peak-shaving and load shedding to help avoid grid failures.

Time of use pricing seeks to encourage consumption in periods during the day when prices are low. To succeed, accurate and timely accounting of energy consumption must be collected and reported. This is a form of time-shifting demand, as opposed to lowering absolute demand.

Time-of-use pricing leads us to consider Transactive Energy models. Such systems promise to create highly efficient markets as producers and consumers use real-time and dynamic pricing to balance supplies and demand. Such systems are technically and operationally complex and have yet to be widely deployed.

While certainly valuable, given the scale of supply challenges, these strategies have not proven to be entirely sufficient to mitigate supply shortages or disruptions.

3.5. Direct Controls

A number of strategies have been developed to allow utilities to directly control system loads. You might have seen or even enrolled in a program that allows your electricity provider to manage your home's thermostat. Such programs are bespoke to address specific targets for a specific provider.

The Automated Demand Response (ADR) protocol has been standardized to spur adoption of such systems by enabling interoperability between utilities that issue control messages and the devices and management systems that respond to them. While this lowers technological barriers it doesn't necessarily lead to mass scalability. Business and product development of ADR programs remain time consuming and costly in order to meet specific goals of specific utilities.

4. Optimum Load Shaping

A close cousin to ADR, Optimum Load Shaping (OLS) provides a mechanism that may encourage time-shifting of energy consumption on a massive scale. The control signal is not a specific on/off command or a retail price signal, but simply a table of values that represent the optimal percentage of a day's electrical load that should be consumed within a given period, typically an hour. The set of values describe a curvilinear shape, and are intended to accordingly shape the load on the system.

The Optimum Load Shape protocol has been standardized by SCTE and published as ANSI SCTE 267 2021. The specification was developed within the SCTE micro-grid working group and specifically addresses the cable industry's emerging EV fleet and battery charging systems, however, the protocol can be applied to any flexible load.

4.1. Theoretical background

The economic value of flexible load shaping has been studied, using various data sets and modeling strategies. A study of related literature and a description of a simulation of the Texas ERCOT system, using historical data, is provided by [Cruickshank].

A key element of the simulation methodology is the Unit Commitment Model, used within the Generic Algebraic Modeling System (GAMS), and expressed in Figure 4.

The mathematical formulation of the Unit Commitment model constructed in GAMS consisted of a cost-optimization objective function based on production costs:

$$\min \left\{ \sum_{t=1}^{n} \left\{ \sum_{i=1}^{N} v_i c_i(p_i) \right\} \right\}, v_i \in \{0,1\} \tag{11}$$

which was constrained by the need to match supply and demand in each time period:

$$\sum_{i=1}^{N} p_i = d \tag{12}$$

where:

n was the number of time intervals in each optimization step

N was the total number of generators

v_i was the binary variable indicating whether a generator is committed (1) or not (0)

c_i was the operating cost of generator i ($US/MW)

p_i was the power generation of generator i (MW)

d was the system demand (MW)

Figure 4 - Unit Commit Model [Cruickshank]

Simulations were run to 1) calculate the cost and carbon emissions of meeting all load through traditional fossil-fueled generation, 2) calculate the cost and carbon of an optimally flat fossil-fueled generation scenario, and 3) to overlay renewable generation onto the flat fossil-fueled scenario. Flat constant-output fossil-fueled generation is more efficient than variable output, as it eliminates the inefficiencies of starting and stopping generators, ramping generators up and down, and running at less than ideal capacity, i.e. less than maximum efficiency. Flat fossil-fueled generation does not, however, meet demand that exceeds that static supply, hence renewables and storage are overlaid onto that scenario to create an Optimum Load Shape.

The result of the third simulation indicates that costs and carbon emissions can be significantly reduced if fossil-fueled generation is held flat and load follows the shape produced by overlaying renewables.

4.2. Architecture

The OLS system follows the common client-server pattern, using the term Producer instead of server, and Consumer instead of client; an OLS producer makes available OLS signals, and any number of consumers may acquire the signals as shown in Figure 5.

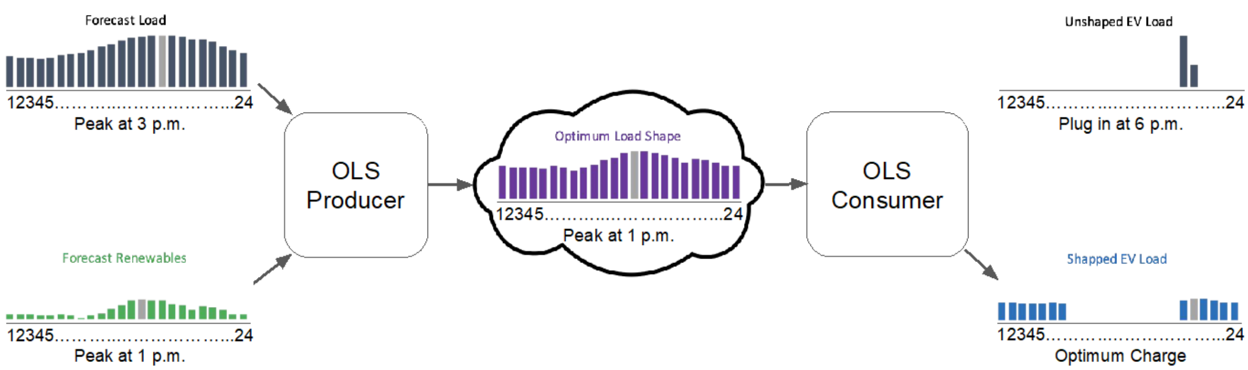


Figure 5 - OLS Architecture

An OLS signal is a datagram that simply contains a table of timestamped values. Timestamps represent the start of a period sometime in the future, typically the top of an hour of the day following the generation of the signal, and as mentioned above, the values represent the percentage of daily use that should ideally be consumed for that period.

The producer of the signal may use any algorithm to create the signal, incorporating input such as fossil fuel generation costs, availability of renewables with weather forecast, machine learning inputs from historical usage data and anything else those crafty nerds can make use of. In its simplest form, the signal can be made available to everyone within a service area—since the shape applies to the supply-side and does not target specific users.

The left side of the diagram in Figure 5 illustrates a strategy to optimize the use of renewables by flattening fossil fuel generation and overlaying the forecast renewable generation. The closer the aggregate load matches this shape, the more efficiently the mix of renewable and fossil fuel generation will be.

Consumers of OLS are not concerned about why the signal takes the shape it takes; they simply respond as best they can to the signal. Some electrical consumers, say the lighting of a retail store, cannot time-shift, but many others, say a battery or thermostat, often have flexibility to determine the times at which to pull power from the grid.

Each consumer autonomously decides how best to respond to OLS signals, if at all. For example, an EV charging system may define flexibility constraints, such as blocking certain hours during the day in which a car will be in use and not available for charging—and a specific hour, say 7 am, by which the car must be fully charged. Given these constraints, the OLS consumer can strive to match the OLS shape as best it can. This still can produce dramatical results, for example, avoiding load spikes at the close of the workday by smoothing the load across a population of EVs.

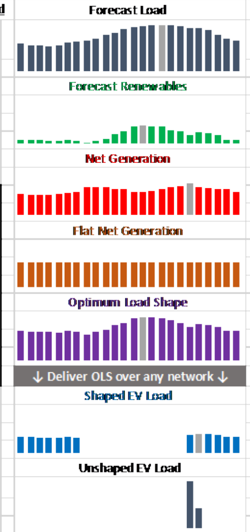
The right side of the diagram in Figure 5 illustrates examples of unshaped load (at top) and shaped load (at bottom). Figure 6 provides a more detailed analysis of the concepts in Figure 5 and depicts ~20% savings at far right.

	Supply-side: Two forecasts [GWh] feed Optimum Load Shape (OLS) Producer					Demand-side: OLS Consumers modulate load			Electricity Price and Cost		
	Forecast Load	- Forecast Renewables	= Net Generation	→ Flat Net Generation	→ Optimum Load Shape	→ EV Optimum Load Shape	→ Shaped EV Load	Unshaped EV Load	Retail ¢/kWh	Shaped ¢/h	Unshaped ¢/h
Midnight	36.1	6.0	30.1	35.2	3.7%	7.3%	0.73	-	15.1	11.1	0.0
1	34.6	5.8	28.8	35.2	3.6%	7.3%	0.73	-	14.4	10.5	0.0
2	33.7	5.4	28.3	35.2	3.6%	7.2%	0.72	-	14.2	10.2	0.0
3	33.4	4.6	28.8	35.2	3.5%	7.1%	0.71	-	14.4	10.2	0.0
4	34.7	4.3	30.4	35.2	3.5%	7.0%	0.70	-	15.2	10.7	0.0
5	37.5	6.7	30.8	35.2	3.7%	7.5%	0.75	-	15.4	11.5	0.0
6	38.2	4.6	33.6	35.2	3.5%	7.1%	0.71	-	16.8	11.9	0.0
7	40.0	0.4	39.6	35.2	3.2%				19.8	0.0	0.0
8	43.2	4.5	38.7	35.2	3.5%				19.4	0.0	0.0
9	47.0	7.8	39.2	35.2	3.8%				19.6	0.0	0.0
10	50.7	14.2	36.5	35.2	4.4%				18.2	0.0	0.0
11	53.8	18.0	35.8	35.2	4.7%				17.9	0.0	0.0
Noon	56.5	23.6	32.9	35.2	5.2%				16.5	0.0	0.0
13	58.4	25.0	33.4	35.2	5.3%				16.7	0.0	0.0
14	59.7	24.7	35.0	35.2	5.3%				17.5	0.0	0.0
15	60.2	23.5	36.7	35.2	5.2%				18.4	0.0	0.0
16	59.7	20.0	39.7	35.2	4.9%				19.9	0.0	0.0
17	58.0	17.8	40.3	35.2	4.7%				20.1	0.0	0.0
18	55.9	11.6	44.4	35.2	4.1%	8.3%	0.83	7.00	22.2	18.5	155.3
19	55.0	16.7	38.3	35.2	4.6%	9.2%	0.92	3.00	19.1	17.7	57.4
20	52.3	14.8	37.4	35.2	4.4%	8.9%	0.89	-	18.7	16.7	0.0
21	47.5	11.5	36.1	35.2	4.1%	8.3%	0.83	-	18.0	15.0	0.0
22	43.0	6.2	36.7	35.2	3.7%	7.4%	0.74	-	18.4	13.5	0.0
23	39.5	6.0	33.6	35.2	3.6%	7.3%	0.73	-	16.8	12.3	0.0
Totals →	1,128.7	283.6	845.1	845.1	100%	100%	10.00	10.00	Cost→	$ 1.70	$ 2.13
	GWh	GWh	GWh	GWh	Unitless	Unitless	kWh	kWh	Savings→	$ 0.43	$ 157.03
										per/day	per/year

Deliver Optimum Load Shape over any network

The vehicle is in use and unavailable for charging from 0700 - 1800 hours.

The charger takes unavailability into consideration and autonomously adjusts the Optimum Load Shape that it received from the supply-side.



Assumptions & notes:
1. Data are illustrative of load for the serving area of the Electric Reliability Council of Texas, and represent ~10% of U.S. nationwide electricity usage on a hot peak summer day.
2. Model can be similarly applied to any vertically integrated serving area, e.g., for micro and nanogrids. Modeling wholesale markets and on-site combined heat & power (CHP) is TBD.
3. In power systems, generation = load. In optimization, loads from electric vehicles (EVs), facility batteries, and smart devices are modulated , i.e., shifted forward & backward in time.
4. The OLS is normalized between zero and one by dividing the generation at each time step by the sum of generation over the simulation horizon, in this case 1-day.
5. The unshaped EV Level 2 charger draws 7 kW for 1.43 hours = ~10 kWh of energy for ~100 miles of travel. No opt-in or two-way communications is required; OLS can be broadcast.

Figure 6 - EV Charging Example Detail

4.3. Protocol

The ANSI SCTE 267 2021 standard defines the Data Model for an OLS signal in YANG format. YANG is a human and machine-readable schema language designed to model hierarchical data structures. YANG can be converted via software tools, or by hand, into various transport and encoding formats, such as REST and Protobuf.

The standard provides an HTTP REST OpenAPI specification of an API based on the Data Model. REST is arguably the most common protocol in use today to support client-server architectures.

Human and machine-readable assets are available on Github at:
https://github.com/cablelabs/scte-ols

There could be many non-exclusive paradigms for communicating OLS signals, including pull, push, and notifications.

The lightweight specification of the payload and non-normative guidance on transport/encoding formats is intentional and encourages innovation. Both OLS producers and consumers are expected to iteratively develop and improve algorithms to generate and respond to signals, based on learnings in the field.

4.4. Monitoring

The OLS specification currently provides no definitions for how OLS consumers expose their behavior in response to OLS signals. This greatly simplifies the entire platform, compared for instance to Transactive Energy models. While one might expect that OLS consumers will more aggressively adopt OLS if given new incentives, which be performance based, these business issues are not explicitly addressed in the current standard.

Additional definitions could be developed and standardized to support monitoring of OLS consumers. For now, we expect the market to innovate and discover where then real needs lie. In the meantime, when OLS is used with increasingly popular dynamic electricity rates and existing back office, interval metering, and billing infrastructures— lower cost of operations electricity bills are the result.

4.5. Use Case: Cable EV Fleet Charging

The initial use cases that led to the development of OLS within the SCTE micro-grid working group are concerned with lowering costs, increasing network reliability, and enhancing operations during the transition of cable fleets from internal combustion engines to EVs. In the absence of load controls, local load spikes may occur when numbers of EVs stop service for the day and attempt to recharge at the same time. Such spikes can easily overwhelm a local grid endpoint, such as a transformer, leading to expensive and time-consuming upgrades to the distribution grid. Such software-based mitigations are called 'non-wired solutions' in the utility industry and are highly prized as they avoid capital outlays.

With OLS, the EV charging load can be shaped to follow renewables and smoothed out over several hours, as described above. This provides cable operators more flexibility in when to recharge fleets and could lower overall costs where Time-of-Use dynamic pricing or other incentives are provided by utilities.

Figure 5 illustrates an example where pricing follows expected load. In this particular example, load shifting can reduce OLS consumer costs by approximately 20%.

The effort to create the OLS standard benefited from having specific use cases identified, but the resulting standard has applicability to any scenario in which a load can be shifted in time.

The authors have built a web-based API that provides SCTE-compliant OLS signals for nearly 22,000 grid transmission interconnection regions across the US. The OLS signals reduce the cost of purchasing electricity. Broadband providers may consume an OLS and further target and optimize to specific sub-regions or consumers. For example, a micro-grid controller might consume a regional OLS and subsequently pass further-optimized OLS signals to sub-components like battery walls, EV charging systems, building management systems, thermostats, and other flexible loads.

5. Conclusion

ANSI/SCTE 267 2021, Optimum Load Shaping, is intended to benefit the cable industry in lowering energy costs and improving operations. It's meant to directly address the transition of the fleet of service vehicles to EV and can also provide value by being applied in many other use cases, including many beyond the cable industry.

Besides cost reductions and operations improvements for cable operators the benefits of OLS include:

- Reduce fossil fuel utilization
  - Improve efficiency by reducing peaks, starts/stops, up/down ramping
  - Reduce fuel costs, water consumption, pollution
- Accelerate transition to low-carbon economy
- Reduce investments in electrical infrastructure
  - Provide non-wires solutions to local congestion
- Lower costs to electrical consumers where time of use or other incentives are offered
- Improve Service Continuity for cable operators as grid failures are reduced

Abbreviations

ADR	automated demand response
EV	electric vehicle
HTTP	Hypertext Transfer Protocol
ICE	internal combustion engine
kWh	kilowatt hour
OLS	Optimum Load Shape
Protobuf	protocol buffer
REST	representational state transfer
SCTE	Society of Cable Telecommunications Engineers
YANG	Yet Another Next Generation [Model]

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OLS Blog, https://optimumloadshape.com/

