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SCTE · ISBE
Society of Cable Telecommunications Engineers
International Society of Broadband Experts

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International Society of Broadband Experts™
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From the Editors

Welcome to the second volume issue one of the *Journal of Energy Management*, a publication of collected papers by the Society of Cable Telecommunications Engineers (SCTE) and its global arm, the International Society of Broadband Experts (ISBE).

This April 2017 edition of the Journal focuses on cost saving opportunities for critical facilities by way of a benchmarking tool analysis and second paper examining climate management approaches and use of fiber to impact positive energy change. Finally, a utility sector, multi-year strategic plan report (as it pertains to road mapping and availability of commercial power) has been included.

In support of Energy 2020, the Energy Management Subcommittee is looking to the future of the program with an analysis of what we have done, the goals we have before us and the gaps that need to be addressed in support of the industry achieving the goals of the muti-year program.

We would like to thank the individuals who contributed to this issue of *the Journal of Energy Management*, especially the authors, peer reviewers, and the SCTE/ISBE publications and marketing staff. We hope that the selected papers spark innovative ideas to further our collaboration to mature the industry's operational practices, standards and technology solutions to help everyone meet the Energy 2020 goals.

In closing, if there is any editorial information or topics that you would like us to consider for the next issue of SCTE/ISBE *Journal of Energy Management*, please contact Derek DiGiacomo ddigiacomo@scte.org.

SCTE/ISBE Journal of Energy Management Senior Editors,

Simpson Cumba

SCTE Energy Management Subcommittee Chair

Derek DiGiacomo

Senior Director, Energy Management Programs and Business Continuity

Benchmarking Assessment Tool

A Technical Paper prepared for SCTE/ISBE by

Mike Leighton, Master’s Candidate, Villanova University, SCTE/ISBE Member
800 Lancaster Avenue
Villanova, Pennsylvania

Ava Calvano, Master’s Candidate, Villanova University, SCTE/ISBE Member
800 Lancaster Avenue
Villanova, Pennsylvania

Albert Phan, Master’s Candidate, Villanova University, SCTE/ISBE Member
800 Lancaster Avenue
Villanova, Pennsylvania

Aileen Gallagher, Master’s Candidate, Villanova University, SCTE/ISBE Member
800 Lancaster Avenue
Villanova, Pennsylvania

Jessica Silva, Master’s Candidate, Villanova University, SCTE/ISBE Member
800 Lancaster Avenue
Villanova, Pennsylvania

Sajid Hossain, Master’s Candidate, Villanova University, SCTE/ISBE Member
800 Lancaster Avenue
Villanova, Pennsylvania

Project Leader: Lindsey Walaski
Faculty Advisor: Professor Schmidt

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1. Executive Summary

The cable telecommunication industry is an untapped resource for energy conservation and efficiency efforts. These facilities utilize large amounts of equipment, operate for long durations, and provide services that have growing market demand. As such, there are tremendous opportunities to reduce energy usage, specifically within the headend and hub facilities. Because there are not many resources for energy management for this industry, the goal of this project is to develop a diagnostic tool to benchmark energy use within these facilities and measure improvements towards energy reductions through a partnership with the Society of Cable Telecommunications Engineers and the Villanova University Resilient Innovation through Sustainable Engineering program. This tool will also be used to share information on best practices and ultimately track progress towards SCTE's *Energy 2020* goals.

Comcast served as the pilot for developing the tool. Site visits were conducted at three Comcast facilities to present a full range of size and services of hub and headend facilities. Comcast also shared raw electricity data from the meters and inventories for their information technology (IT) equipment. This data was narrowed down and formatted to showcase the relevant metrics to indicate the facility's energy performance, including total electricity consumption in kilowatt hours (kWh), instantaneous real power in kilowatt (kW), greenhouse gas emissions in pounds, and the average power usage effectiveness (PUE), among others. The data for these metrics was then formatted to show changes on a monthly basis. The equipment inventory was then categorized based on the type of unit to determine the real power for different types of equipment.

These metrics were developed as a decision making tool for operating managers. Among the trends of the data, the most indicative was the power draw of the equipment types. This indicated the routers and chassis were the highest energy consumers within the IT equipment and presented the biggest opportunity for equipment modernization and energy efficient procurement strategies. These metrics also calculated the dynamic PUE, showing the changes over time as operating conditions within the facilities change. This is an informative metric to track, as it is able to show the opportunities for cooling need reductions.

Based on the metrics developed, the diagnostic tool is a valuable resource to start an energy management system. This tool showcases energy performance, while providing the operating managers with condensed metrics to make maintenance and energy related decisions. The tool is also designed to generate these metrics autonomously to streamline the integration of use. By benchmarking the energy data, the operating managers can begin the cyclical process of supporting energy management, assessing performance, and evaluating results.

2. Background

Energy is increasingly becoming a concern for organizations. Beyond growing concerns for grid dependency, fuel price volatility, and climate change, energy can represent a significant operational expense. Therefore, minimizing energy consumption is an opportunity ripe for improving an organization's bottom line.

The Society of Cable Telecommunications Engineers (SCTE), an industry trade group for technical cable telecommunications professionals, is addressing these energy concerns in the cable telecommunications industry with an inter-organizational energy management program titled *Energy 2020*. This initiative comes as part of an industry-wide push toward sustainability as well as a reduction of operational costs. Under business-as-usual practices, the cable industry's energy costs are expected to increase to $4 billion USD per year by 2020. Furthermore, energy efficiency can enable optimal capacity growth while maintaining operations in the facilities. In *Energy 2020*, SCTE has established the following program goals to be achieved by the year 2020:

- Reducing power consumption 20% on a unit basis,
- Reducing energy costs by 25% on a unit basis,
- Reducing grid dependency by 10%, and
- Optimizing the footprint of technical facilities & data centers by 20%.

Through Villanova University's Resilient Innovation through Sustainable Engineering (RISE) program, SCTE and a team of graduate students in the Sustainable Engineering program are developing a tool to benchmark and assess energy consumption of cable telecommunications facilities. Although there are numerous tools of this sort already available for data centers, cable telecommunications facilities need a more industry-specific approach. The overall project objective is to provide hub and head end operators with more knowledge of their energy usage and equipment to achieve the *Energy 2020* program goals. Additionally, the tool will help generate collaboration among operators to share best management practices and measure progress toward energy reduction. The tool will also enable a focus on cross-operator performance comparisons to help spread best practices for these facilities, which are also less common than data center practices. Lastly, the tool will also allow SCTE to gather data to measure progress and develop goals beyond the initial 2020 target year.

3. Methodology

3.1. Stage I - Benchmarking Study

Following the mid-September kick-off meeting, the Villanova Team began a three-week independent research period. Team members reviewed relevant background material such as the *Energy 2020* goals, the SCTE Standards for Energy Management, and various other resources prepared by industry authorities like Energy Star and the National Renewable Energy Laboratory. Since resources made specifically for hub and headend applications were scarce, data center resources often served as a close substitute, particularly while researching best management practices.

In addition to industry standards and best management practices, team members also performed independent web searches for existing energy benchmarking tools. Five publicly available tools were identified and studied as potential models (overviews of existing tools can be found in Appendix B Overview of Existing Tools):

1. The PECO Smart Business E-Audit
2. The 42U Data Center Energy Efficiency Savings Calculator
3. The Sustainable Energy Authority of Ireland's Energy Bill Tracker Tool
4. The Sustainable Energy Authority of Ireland's Significant Energy Users Tool
5. The Sustainable Endowments Institute Green Revolving Investment Tracking System

During the research period, team members had the opportunity to attend the SCTE Cable-Tec Expo in Philadelphia and the SCTE Plenary Session in Denver. These experiences gave the Villanova team the opportunity to verify information uncovered during the desk study and gain preliminary feedback on this tool through discussions with practiced cable professionals. Shortly thereafter, the Villanova Team met to consolidate resources, synthesize research results, and discuss lessons learned at the Expo and Plenary Session.

3.2. Stage II - Site Visits

The project charter specified that the Villanova Team would focus on three specific facilities in order to develop and preliminarily test the tool. In October, three edge facilities were selected for study. The sites were intentionally selected to represent the full range of physical sizes and service levels found among typical edge facilities. The mid-sized hub was designated “Site A,” the large headend as “Site B,” and the small-sized hub, “Site C.” All three were located in Delaware and owned and operated by Comcast.

The Villanova Team coordinated with SCTE and Comcast to arrange a tour of each facility. During the tour, team members familiarized themselves with the facilities’ equipment, infrastructure, operation, and management. Photos from all three site visits can be found in

Appendix E Site Visit Photos.

3.3. Stage III - Data Collection and Analysis

Following the site visits, Comcast was able to share excel-based datasets for all three facilities with the Villanova Team. The datasets included both meter-derived energy use data and equipment inventories. Given Comcast’s robust data collection, it was assumed this application would be a best case scenario of available data.

The team chose to begin the data analysis by thoroughly processing the data for the smallest facility, Site C. Once the refined Site C data had established the operational foundation for the tool, data from Sites B and A could be analyzed and incorporated.

The meter-derived energy use data spanned from February to October of 2016, with nearly six months of continuous meter readings at one-minute intervals. In total, the dataset covered thirty-nine distinct energy metrics. It was decided that such a massive quantity of data would ultimately detract from the usability of the SCTE benchmarking tool. After collaborative review, the Villanova Team selected those key metrics that appeared the most relevant to SCTE’s *Energy 2020* goals and the most indicative of energy performance:

- Real Energy Consumption (kWh)
- Total Instantaneous Real Power (kW)
- Total Power Factor
- Total Real Power Max Demand (kW)

These four metrics were further processed to produce three additional metrics of interest: daytime power demand, nighttime power demand, and the difference between maximum and instantaneous power demand for each interval. Finally, monthly averages were calculated for each of these seven key metrics.

For the inventory dataset, the team began by eliminating all equipment entries that did not consume power - those labeled as “passive,” “pending development,” and “not powered.” An internet search was then performed for each powered device to determine its equipment classification (e.g. modem, router, chassis, modulator, etc.). Together with the provided nameplate specifications, these equipment classifications allowed the team to explore disparities in power demand between different types of devices. Finally, Comcast supplied a conversion factor of 0.46 to be applied to the nameplate specifications and account for a more accurate power draw.

3.4. Stage IV - Tool Development

As specified in the project charter, Microsoft Excel was chosen as the platform for the final energy benchmarking tool due to its ubiquity, its easy-to-use interface, and its compatibility with most other computational software.

Therefore, the final benchmarking tool was developed in the form of an Excel worksheet with built-in formulas and instructions. The worksheet designates columns for time intervals, the key energy metrics discussed in the previous section, device IDs, nameplate specifications, and equipment classifications. Once energy data is imported, the worksheet automatically calculates monthly averages and an estimate of the facility’s power usage effectiveness (PUE). The Villanova Team also included an addendum to the worksheet to allow the user to evaluate the financial impacts of potential facility improvements, described Appendix A Financial Analysis. For a final deliverable, the worksheet generates a graphical representation of key energy use trends and an approximate breakdown of energy use by equipment type.

4. Results

With the amount of data available from Comcast across the three sites, the team was able to use the tool to format the data and better understand the energy performance of each site. By breaking down each site’s data by month and daytime versus nighttime demand, as well as creating an inventory by equipment type, the team could build a better picture surrounding the real time energy demands of the sites. This is especially useful in better understanding and improving energy efficiency. Additionally, sections about total cost and greenhouse gas (GHG) emissions help make both the sustainability and financial case for energy usage improvements. The team then formatted the data by year and the results were as follows:

4.1. Site A – Large

2016 Data (January - October)

- Sum of Total Energy Consumption: 2,080,660 kWh
- Average of Total Instantaneous Real Power: 298.14 kW
- Average of ΔMax and Instantaneous Demand: 62.87 kW
- Average of Nighttime Demand: 298.90 kW
- Average of Daytime Demand: 297.36 kW
- Total Energy Cost: $161,385.86
- Total GHG Emissions: 3,252,187 lbs

2015 Data (February - December)

- Sum of Total Energy Consumption: 1,875,005 kWh
- Average of Total Instantaneous Real Power: 308.80 kW
- Average of ΔMax and Instantaneous Demand: 49.74 kW
- Average of Nighttime Demand: 308.38 kW
- Average of Daytime Demand: 309.02 kW

- Total Energy Cost: $145.434.30
- Total GHG Emissions: 2,930,737 lbs

4.2. Site B - Medium

2016 Data (January - October)

- Sum of Total Energy Consumption: 285,439 kWh
- Average of Total Instantaneous Real Power: 41.53 kW
- Average of ΔMax and Instantaneous Demand: 26.64 kW
- Average of Nighttime Demand: 41.42 kW
- Average of Daytime Demand: 41.63 kW
- Total Energy Cost: $22,140.00
- Total GHG Emissions: 446,157 lbs
- Average PUE: 2.790

2015 Data (February - December)

- Sum of Total Energy Consumption: 324,931 kWh
- Average of Total Instantaneous Real Power: 43.72 kW
- Average of ΔMax and Instantaneous Demand: 22.76 kW
- Average of Nighttime Demand: 43.65 kW
- Average of Daytime Demand: 43.72 kW
- Total Energy Cost: $25,203.18
- Total GHG Emissions: 507,885 lbs
- Average PUE: 2.935

4.3. Site C – Small

2016 Data (January - October)

- Sum of Total Energy Consumption: 177,502 kWh
- Average of Total Instantaneous Real Power: 31.35 kW
- Average of ΔMax and Instantaneous Demand: 4.56 kW
- Average of Nighttime Demand: 31.33 kW
- Average of Daytime Demand: 31.36 kW
- Total Energy Cost: $13,875.65
- Total GHG Emissions: 277,435 lbs
- Average PUE: 2.035

The graphical representation of this data for Site B can be seen in Figure 1. Once energy conservation measures are implemented, the impacts to the energy consumption would be very clear in this type of representation.

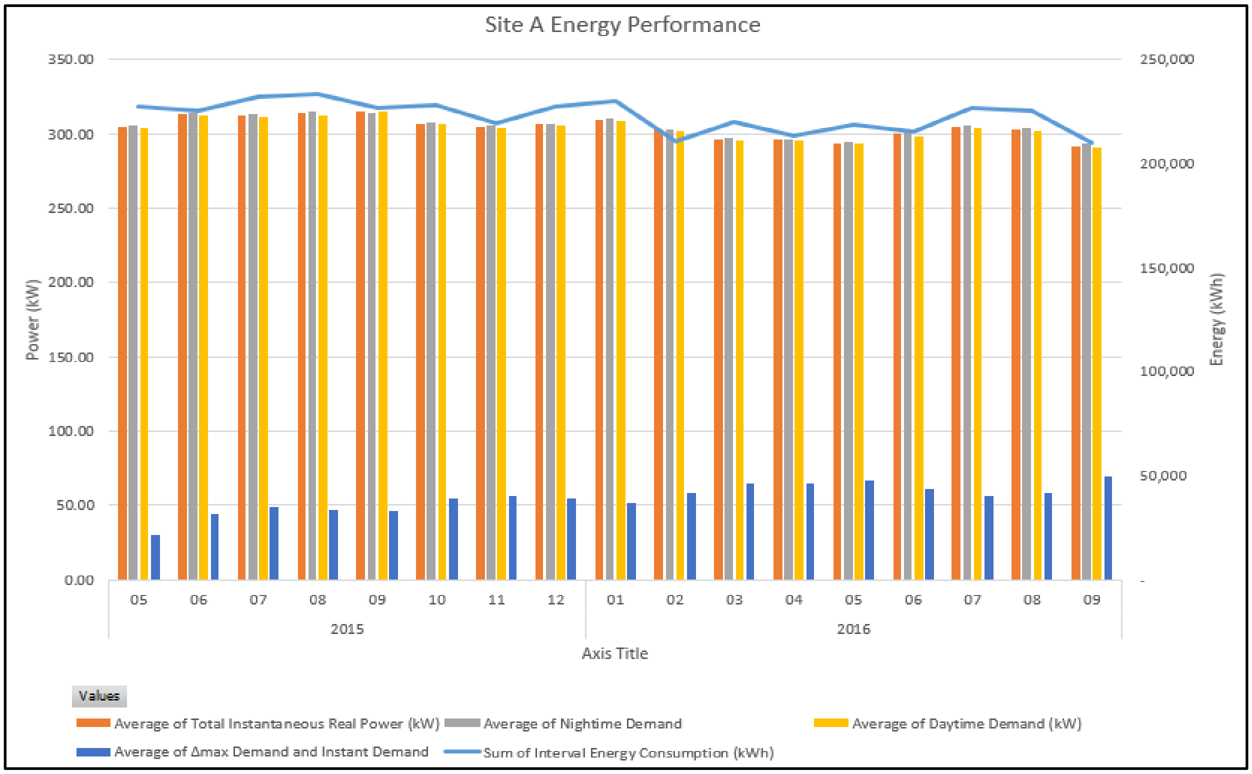

Figure 1 - Site A Energy Performance

After performing an equipment inventory across the three sites, the largest consumer of electricity were routers, based on nameplate energy usage, which accounted for ~54% of observed energy consumption at each site. However, the team did not have access to separate IT load versus Heating/Cooling/Lighting loads. For future benchmarking, this would be extremely helpful since these loads present a good opportunity for energy reductions.

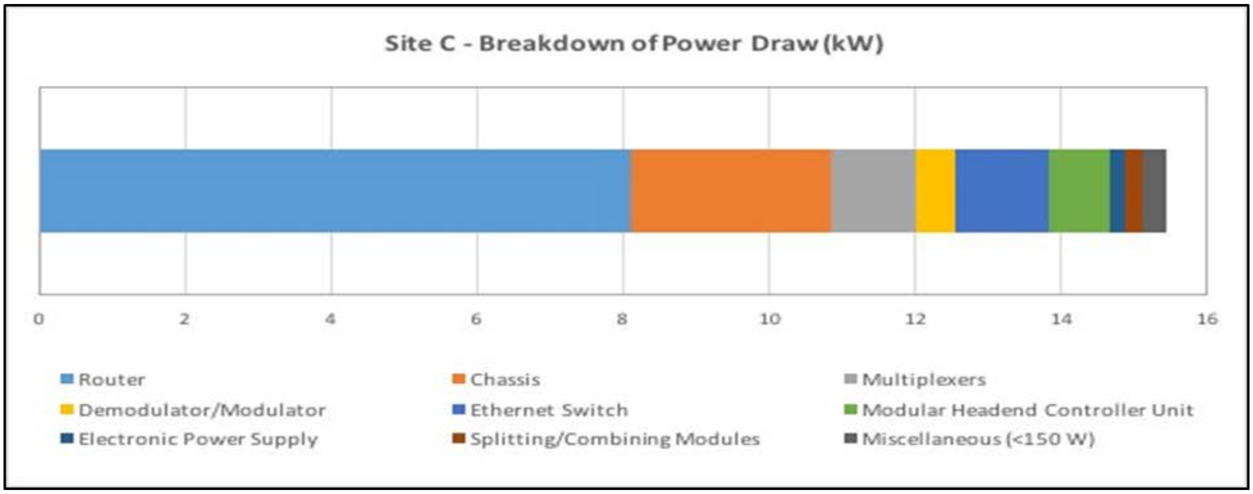

Figure 2 - Site C Equipment Breakdown

Looking at average PUE, by month, there is a correlation between Average Monthly Temperature for each location and PUE load, as shown in Figure 3. The chart below uses temperature data[1] for Wilmington, DE and the corresponding PUE load at the Site A Hub facility. The team believes that this data strengthens the case for cooling improvements and clearly indicates the seasonal impacts on energy performance.

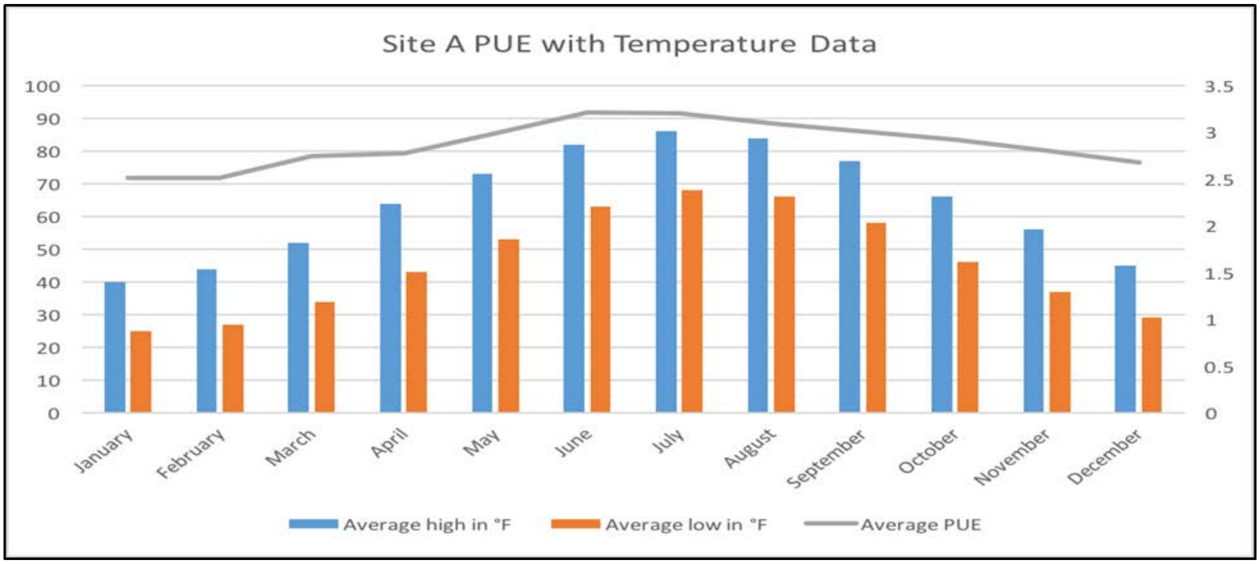

Figure 3 - Site A PUE versus Temperature Data

When examining the Nighttime versus Daytime loads, there is not a significant difference in loading for hub sites. This is to be expected at these sites, given the operating hours are 24 hours per day. However, there may be a difference among smaller sites and the demand during different times of day should still be tracked.

One of the goals in creating the tool was to identify and explain any significant differences in energy consumption, including equipment changes. As further data is collected, tracking the maximum power demand along with PUE will be helpful in understanding the changing needs of the facilities.

5. STEEP Analysis

A truly sustainable project will reduce negative impacts and strengthen positive impacts in five key dimensions - socially, technologically, economically, environmentally, and politically. The Villanova University Sustainable Engineering Program refers to this sort of whole-system project appraisal as a "STEEP Analysis," in which STEEP is an acronym for the five key dimensions. As part of its final deliverable, the Villanova Team performed a high-level, qualitative evaluation of the SCTE project using the STEEP framework. The results are presented in tabular format in Figure 4.

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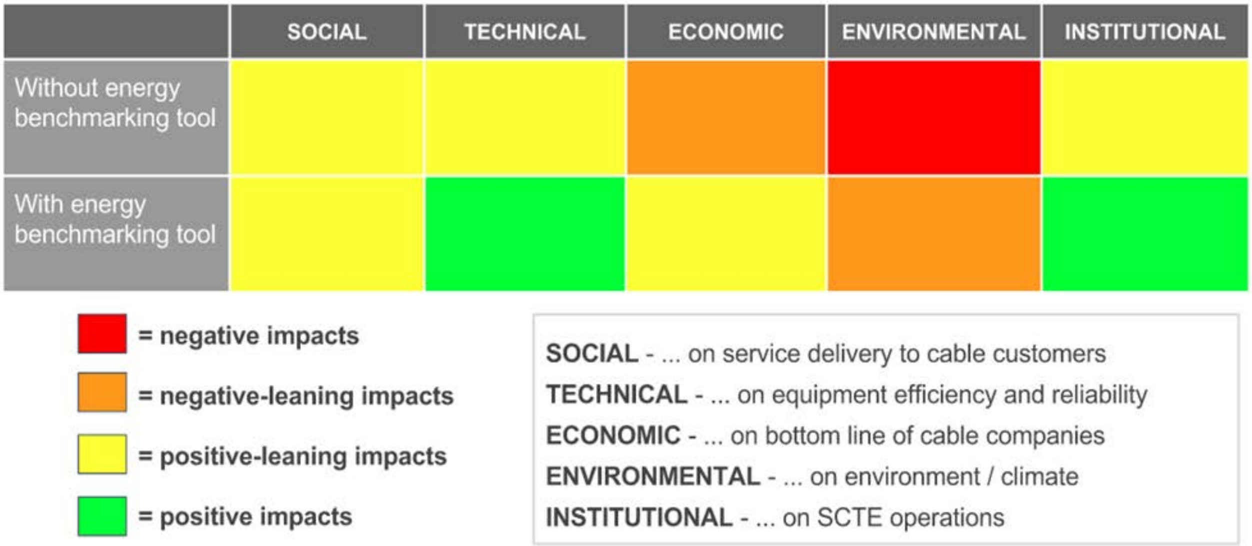
[1] Source: U.S. Climate Data (http://www.usclimatedata.com/climate/wilmington/delaware/united-states/usde0055)



	SOCIAL	TECHNICAL	ECONOMIC	ENVIRONMENTAL	INSTITUTIONAL
Without energy benchmarking tool	🟨	🟨	🟧	🟥	🟨
With energy benchmarking tool	🟨	🟩	🟨	🟧	🟩

🟥 = negative impacts

🟧 = negative-leaning impacts

🟨 = positive-leaning impacts

🟩 = positive impacts

SOCIAL - ... on service delivery to cable customers
TECHNICAL - ... on equipment efficiency and reliability
ECONOMIC - ... on bottom line of cable companies
ENVIRONMENTAL - ... on environment / climate
INSTITUTIONAL - ... on SCTE operations

Figure 4 - STEEP Analysis

The STEEP analysis compares two scenarios: (1) cable service provision *without* implementation of the SCTE Energy Benchmarking Tool, and (2) cable service provision *with* implementation of the SCTE Energy Benchmarking Tool. Each key dimension was qualitatively rated using a color key. A red cell signifies that, overall, impacts are negative within a particular dimension. Conversely, a green cell indicates that impacts in that dimension are positive. An orange cell signifies that impacts are mostly neutral but perhaps "negative-leaning," whereas a yellow cell signifies that impacts are mostly neutral but perhaps "positive-leaning." The ratings were based on the team's collective understanding of the cable industry and an optimistic projection of the tool's efficacy, and should not be interpreted as data-based or definitive.

To simplify the assessment, the social dimension rating was specifically based on impacts on cable customers. Cable service provision was rated as a positive-leaning impact for customers, regardless of whether the energy benchmarking tool had been implemented. In other words, implementation of the tool is not expected to impact customers in any significant way, negatively or positively.

The rating for the technical dimension was based on hypothesized impacts on equipment efficiency and reliability. Since edge facility equipment already undergoes periodic upgrades for improved efficiency and reliability due to cost and capacity concerns, the scenario without the tool was rated as positive-leaning. However, if the energy benchmarking tool were implemented, it would be reasonable to expect an increase in these upgrades, since the provided energy use metrics would give further incentive for procuring efficient and reliable equipment. Implementation of the tool is therefore expected to bring technical impacts from yellow to green.

The economic dimension was rated based on the bottom-line profit for SCTE's member companies. Without the energy benchmarking tool, cable companies are losing money on exorbitant and inefficient energy use at their edge facilities. With the energy benchmarking tool, cable companies will be better positioned to cut these expensive energy losses in the long-term, as long as they are willing to invest in some preliminary capital costs. Based on this reasoning, the impacts in the economic dimension are expected to move from negative-leaning to positive-leaning with the introduction of the energy benchmarking tool.

The environmental dimension was broadly defined as the natural environment and the climate. The high energy demand of the cable industry's edge facilities impacts the stability of the global climate by relying on fossil fuel combustion and the subsequent release of greenhouse gases to the atmosphere. Without the energy benchmarking tool, impacts on the environment are rated as decisively negative. However, those impacts are curbed - though not eliminated - with the introduction of the energy benchmarking tool and the subsequent reduction in energy use. It is unlikely that energy reductions at edge facilities will be substantial enough to characterize cable provision as a positive impact on the environment, but it could certainly help the industry transition from "negative" to "negative-leaning."

The political dimension was rebranded as the "institutional" dimension for the purpose of this analysis. The rating of the institutional dimension was based on the tool's expected impact on SCTE operations. SCTE is already a positive influence in the cable industry, as demonstrated by its advancement of the *Energy 2020* goals. However, implementation of their own energy benchmarking tool would magnify that influence, and could significantly empower SCTE in the achievement of the *Energy 2020* goals. For that reason, the energy benchmarking tool can be expected to elevate SCTE operations from positive-leaning to decisively positive in impact.

In conclusion, the STEEP analysis of the SCTE project suggests that implementation of the energy benchmarking tool could improve impacts across the board without sacrificing service to cable customers.

6. Conclusions

There is tremendous value in measuring and benchmarking energy usage. From both a holistic and scientific approach, collecting data and then using the benchmarking tool can help companies in the cable telecommunications industry better anticipate their needs and make future improvements. Use of the tool can help justify equipment upgrades and help flag any inconsistencies in the data. By also guiding facilities to meet SCTE's *Energy 2020* goals, benchmarking energy use will have a dual impact by improving energy use in the field and within the energy industry.

7. Next Steps

For Comcast, we recommend continuing to track the electricity data, including the metrics specified above within the normal data collection strategies. This will allow the facilities to establish a baseline of energy usage, measure the impacts of improvements, and continually monitor the energy performance of their facilities.

For SCTE, we recommend engaging with smaller facilities to apply this diagnostic tool to address any improvements and increase the effectiveness of the tool. We also recommend coordinating a survey among the partner cable companies to determine the various needs and resources available and the existing level of data collection.

For SCTE, we recommend developing a standard on data collection strategies and energy benchmarking as a long term strategy. This standard would define the data points, frequency of collection, tracking resources (such as this diagnostic tool), and the proper metering instruments. (Suggested metrics are included in Appendix D Data Collection Standards). There is a large variability of data collection efforts based on the size of the facility. Larger facilities such as Comcast already have the infrastructure in place to gather this data, and the operators can easily add the recommended metrics to the existing data collection system. However, smaller facilities may just be getting started with their data collection system and need as many resources as they can. As such, a standard can have a more universal impact across the partner companies and fulfilling the various needs of the different sized facilities.

8. Abbreviations and Definitions

8.1. Abbreviations

IT	information technology
kW	kilowatt
kWh	kilowatt hour
PUE	power usage effectiveness
RISE	Resilient Innovation through Sustainable Engineering
SCTE	Society of Cable Telecommunications Engineers
STEEP	social technical economic environmental political

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Appendix A Financial Analysis

One of the biggest obstacles to implementing facility improvements is simply not knowing how much the upgrades will cost. New equipment is assumed to be expensive, but how expensive? Facility owners may be aware that both local and national financial incentives exist, but may be unaware of the degree to which they would offset costs. The tool developed by our team seeks to simplify decisions by organizing the relevant information in a clear format.

Primary Inputs

The first tab requires the user to supply basic operational information to set a baseline for comparison. The user should review the company's utility bill to obtain the total rates for both consumption (per kWh) and demand (per kW), which represent the costs incurred by the company's total electricity need and peak usage rate, respectively. Note that rates may be broken out further into 'delivery' and 'supply' charges, and the user should be sure to include both when calculating the total rate. The user should also enter energy usage information by system (e.g., servers, heating/cooling, etc.) as available. This tab also requires the user to indicate geographic location (default is NJ/DE/PA), which enables a better estimate of emission avoidance savings, as well as the company's tax rate and discount rate, which enables an accurate payback period calculation.

Project Information

There are two tabs built into the template for the evaluation of two unique projects. The user should start with the third section, 'Project Inputs,' and fill out the anticipated investment horizon for the project and depreciation timeline for the equipment involved. (Break project into multiple tabs if pieces of equipment have different depreciation timelines.) The equipment cost should be listed net of any manufacturer's rebates only - additional rebates should be listed separately on the line below. There are a variety of sources for rebates to incentivize upgrades to more efficient equipment, provided at the regional, state, and federal[2] level, as well as by some utility companies. The user should also obtain a quote for the installation of the new equipment.

The last three user inputs are the monthly demand reduction, annual operating costs, and annual energy savings associated with the installation of the new equipment. The user should estimate these figures as best as possible, and list all assumptions in the designated section. With this information complete, the user can then get an estimate of the project's net present value (NPV), payback period, and internal rate of return (IRR), three metrics that will ease corporate decision-making about the project's merit. (In this example, the company would be wise to undertake the project because it has a positive NPV.) The estimated annual avoided greenhouse gas emissions is also a useful selling point for the potential project.

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[2] More information on federal incentives can be found at http://www.nrel.gov/docs/fy07osti/40467.pdf.

Appendix B Overview of Existing Tools

10. The PECO Smart Business E-Audit

Given basic information about a facility, such as building age, square footage, operating hours, equipment inventories, billing rates, and weather conditions, the *Smart Business E-Audit* can produce an approximate breakdown of total energy costs by use (e.g. lighting, heating, cooling, etc.). The output is provided in both tabular and graphical form.

	Base Facility
	Average Efficiency
Indoor Lighting	$4,104
Outdoor Lighting	$0
Cooling	$2,490
Refrigeration	$0
Heating	$1,143
Cooking	$0
Water Heating	$104
Miscellaneous	$1,073
Annual Total	**$8,913**

Figure 5 – Graphical Output of the PECO Smart Buisness E-Audit

11. The 42U Data Center Energy Efficiency Savings Calculator

This tool was specifically designed for data centers, but could easily be applied to edge facilities like hubs and headends. Given the IT power load and the total facility load, the tool calculates the facility's PUE and its reciprocal, DCIE (Data Center Infrastructure Efficiency). The tool also allows one to set a "desired PUE level" and easily compare the subsequent cost savings.

Current Efficiency Level

Total IT Load: 2,000.00 kW

Total Facility Load: 4,000.00 kW

Desired Efficiency Level

Desired IT Load: 2,000.00 kW

Desired Facility Load: 2,400.00 kW

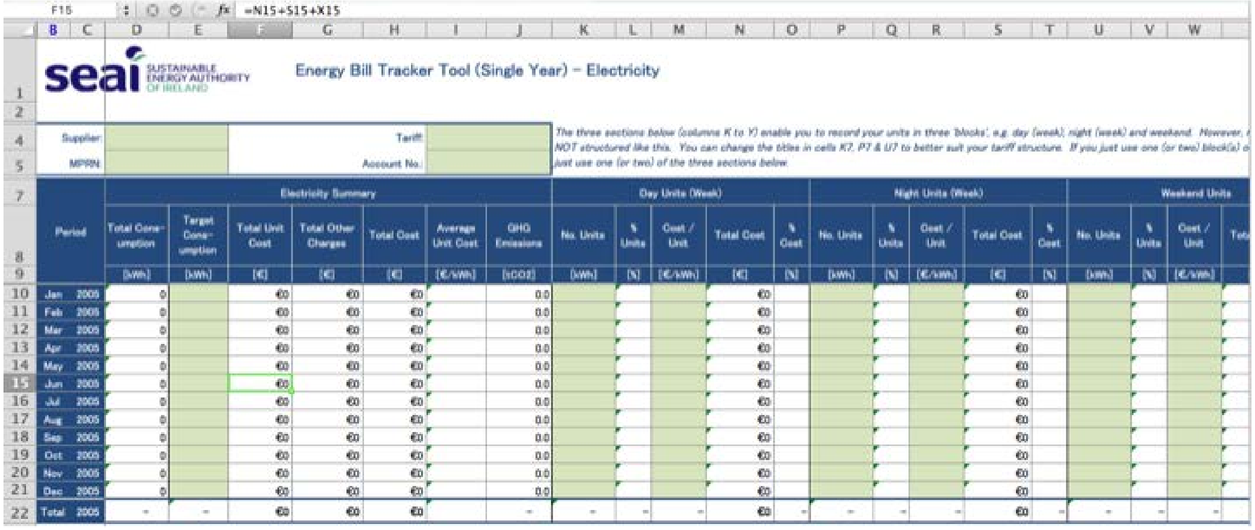
Less kW/h Use	Less Power Cost
1 Year Savings	1 Year Savings
14,016,000.00	$1,286,668.80
5 Year Savings	5 Year Savings
70,080,000.00	$6,433,344.00
10 Year Savings	10 Year Savings
140,160,000.00	$12,866,688.00

Figure 6 - Visual output of the 42U Data Center Energy Efficiency Savings Calculator

12. The Sustainable Energy Authority of Ireland's *Energy Bill Tracker Tool*

The SEIA's *Energy Bill Tracker Tool* is an open-source, Microsoft Excel-based tool.

When various energy metrics and financial parameters are entered in the inputs worksheet, a separate outputs worksheet automatically produces color-coded graphs that plot a facility's energy use and expenditure trends.



Energy Bill Tracker Tool (Single Year) – Electricity

Supplier:

MPRN:

Tariff:

Account No.:

The three sections below (columns K to Y) enable you to record your units in three 'blocks', e.g. day (week), night (week) and weekend. However,
NOT structured like this. You can change the titles in cells K7, P7 & U7 to better suit your tariff structure. If you just use one (or two) block(s)
just use one (or two) of the three sections below.

	Electricity Summary							Day Units (Week)					Night Units (Week)					Weekend Units			
Period	Total Consumption	Target Consumption	Total Unit Cost	Total Other Charges	Total Cost	Average Unit Cost	GHG Emissions	No. Units	% Units	Cost / Unit	Total Cost	% Cost	No. Units	% Units	Cost / Unit	Total Cost	% Cost	No. Units	% Units	Cost / Unit	Tot
	[kWh]	[kWh]	[€]	[€]	[€]	[€/kWh]	[tCO2]	[kWh]	[%]	[€/kWh]	[€]	[%]	[kWh]	[%]	[€/kWh]	[€]	[%]	[kWh]	[%]	[€/kWh]	
Jan 2005	0		€0	€0	€0		0.0				€0					€0					
Feb 2005	0		€0	€0	€0		0.0				€0					€0					
Mar 2005	0		€0	€0	€0		0.0				€0					€0					
Apr 2005	0		€0	€0	€0		0.0				€0					€0					
May 2005	0		€0	€0	€0		0.0				€0					€0					
Jun 2005	0		€0	€0	€0		0.0				€0					€0					
Jul 2005	0		€0	€0	€0		0.0				€0					€0					
Aug 2005	0		€0	€0	€0		0.0				€0					€0					
Sep 2005	0		€0	€0	€0		0.0				€0					€0					
Oct 2005	0		€0	€0	€0		0.0				€0					€0					
Nov 2005	0		€0	€0	€0		0.0				€0					€0					
Dec 2005	0		€0	€0	€0		0.0				€0					€0					
Total 2005	-	-	€0	€0	€0		-	-	-	-	€0	-	-	-	-	€0	-	-	-	-	

Figure 7 - Inputs worksheet for the SEAI's Energy Bill Tracker Tool

13. The Sustainable Energy Authority of Ireland's *Significant Energy Users Tool*

Like the *Energy Bill Tracker Tool*, the *Significant Energy Users Tool* is open source and based in Microsoft Excel. Once provided with the requested equipment specifications, this tool provides summary tables that highlight which devices in a facility consume the most energy, and when.

Energy Type	[€]	Unit
Average Electricity Price		per kWh
Average Thermal Energy (gas/LPG/oil) Price		per kWh
Average Fleet Diesel Price		per Litre
Average Fleet Petrol Price		per Litre

Electricity				
Significant Electricity User	Consumption		Cost	
	[kWh]	[% of Billed Consumption]	[€]	[% of Billed Cost]
Lighting	0		€0	
HVAC	0		€0	
ICT	0		€0	
Refrigeration	0		€0	
Motors & Drives	0		€0	
Compressed Air	0		€0	
Other Electrical Equipment	0		€0	
Total (Significant Energy Users)	0		€0	
Unaccounted for Shortfall (Excess)	0		€0	
Total Billed Amount in Year		-		-

Thermal Energy				
Significant Fuel User	Consumption		Cost	
	[kWh]	[% of Billed Consumption]	[€]	[% of Billed Cost]
Boilers	0		€0	
Other Thermal	0		€0	
Total (Significant Energy Users)	0		€0	
Unaccounted for Shortfall (Excess)	0		€0	
Total Billed Amount in Year		-		-

Figure 8 - Output tables for the SEAI's Significant Energy Users Tool

14. The Sustainable Endowments Institute Green Revolving Investment Tracking System

The GRITS tool is an online-based resource to track the impacts of energy efficiency projects, including the energy, greenhouse gas emissions, and cost savings. The tool also keeps a library of projects to track the data on a project and facility level.

Annual Tracking Data

DATE	ENERGY PRICE ($/MMBTU)	ENERGY SAVED (MMBTU)	ANNUAL FINANCIAL SAVINGS ($)
2013-03-06	0.0000	0	(46,000)
2013-06-30	35.1685	131	5,097
2014-06-30	51.5805	682	36,700

RESOURCE	PRICE ($)	SAVED (ANNUAL BASIS)	ANNUAL FINANCIAL SAVINGS ($)
Maintenance (Other)	30.0000 /hrs	50 hrs	1,500
Electricity (Energy)	0.1760 /kWh	200,000 kWh	35,200

Figure 9 - Input tables for the Sustainable Endowments Institute GRITS

Appendix C Best Management Practices

The Hub and Headend facilities are the largest energy consumers in the “cable facility supply chain”, representing 73-83% of the total energy usage. The utility costs are expected to grow over the next several years to $4 billion per year, and is why energy improvement strategies that could potentially address asset underutilization and power load on equipment are worth investing in for companies who maintain these facilities.

Better Equipment Utilization and Management of Assets:

Before getting started on the energy improvements within the hub and headend facilities, managers should review the location of the energy meter for monthly energy consumption readings, which should be installed at the UPS, and should not include major equipment such as cooling equipment. Major equipment that does not make up part of the IT energy load should be sub-metered so that IT energy load is properly identified.

One of the major issues the hub and headend facilities experience is the underutilization of equipment, particularly IT equipment. On average, servers at these facilities operate at less than 10% utilization. One approach the operations managers could consider, is upgrading to running multiple applications per one server through the use of virtual servers (software), which would utilize more of the capability of the one physical server.

Another problem that contributes toward the underutilization of the facilities, is the lack of a maintenance program, enforcing all equipment to be reviewed regularly. This would help identify equipment that is not being properly utilized or is no longer necessary and can be made obsolete. An assessment should be developed to review equipment as frequently as deemed necessary (i.e, annually or semi-annually), and also when new equipment is implemented so that old servers and equipment no longer providing value are disposed of. During the assessment, servers that are identified as being minimally used, but still necessary, should also be evaluated to merge applications from multiple servers into one server, which would further reduce power consumption of unnecessary equipment, and maximize on the output that the one server can provide.

As the on-site equipment becomes more efficiently used, addressing the ever-growing future need of more storage becomes a challenge that also can no longer be put off. However, there are solutions utilizing storage resource management tools and efficient storage hardware devices to use less storage capacity, which would result in less energy need, to meet the ever-growing data collection necessity. Some management tools include deduplication and tiering storage, utilizing software to review data and delete copies of the same files, which are often generated in multiples, and moving old stored data that may no longer be as necessary from high-speed to slower drives. Less energy-intense storage equipment that could also assist with reducing future energy needs are lower speed drives and solid state drives.

Sometimes energy efficiency changes can be as simple as modifying the arrangement of the equipment. If not properly placed already, changing the orientation of server rows can help minimize energy losses from the hot and cold air being drawn in/vented out, which would improve the airflow of server equipment. IT equipment intakes cold air from the front and releases hot air through the back of the server. Therefore, when servers are lined up in rows, the front faces of the servers should always be facing each other, and the backs of the servers should also be facing. This will avoid having the front face of the server drawing in the hot air being released from the back of another server.

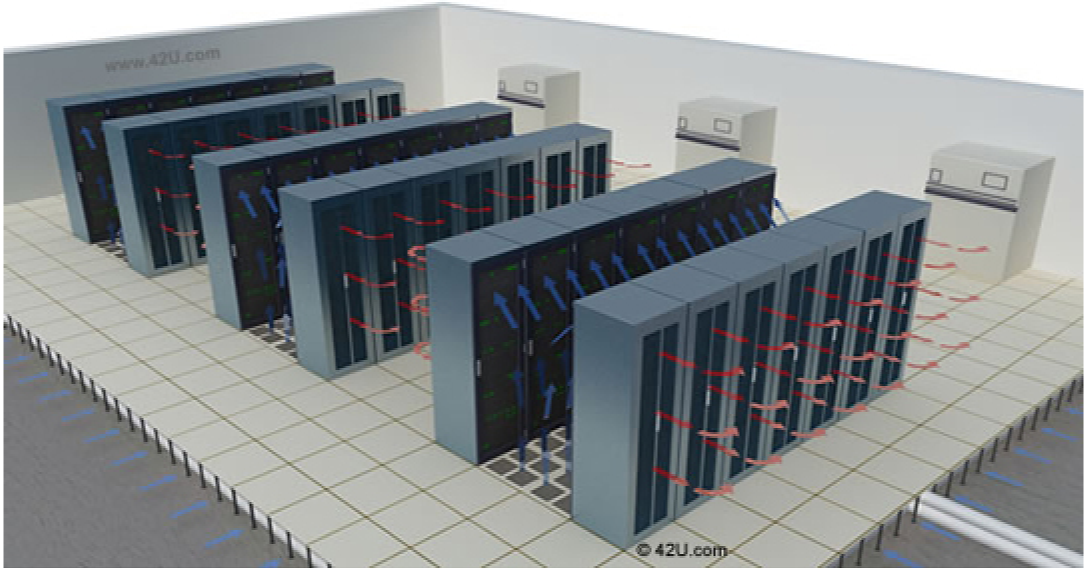


Figure 10 - Proper Rack Configuration, Source: Energy Star

Asset Upgrades:

To fully ensure the facilities are maximizing on energy efficiency measures, managers should check that the equipment in use such as servers, uninterruptible power supplies (UPS), and power distribution units have an energy star rating or meet an energy efficiency standard. If the on-site equipment does not, managers should consider collaborations with vendors to implement more energy efficient equipment.

Through the use of minimal, additional structures or devices, efficiency can also be improved by maximizing on the current setup of the facilities. Implementing additional physical containment structures such as flexible strip curtains can assist in further preventing hot and cold air from mixing, which in return provides more favorable temperatures within the facilities, providing opportunities for free cooling and reducing fan speeds, resulting in energy reductions. Other implementations can include variable-speed fan drives for cooling instead of the traditional computer room air conditioning unit fans which are not efficient or capable of adjusting to varying equipment loads in the facilities and airflow management devices such as diffusers, floor grommets, blank gin panels, etc. to further enhance cooling of equipment, which also minimizes the mixing with hot air and targets locations that may experience or be more prone to hot spots.

Metrics:

Through the use of metrics, managers can also better manage the performance of their equipment. The Power Usage Effectiveness (PUE) is a unit of measure used in the IT industry which indicates the ratio of the total energy usage over the IT energy usage, which can be used to calculate how much energy was needed to meet the cooling load of the equipment. By developing PUE targets and identifying efforts that could help achieve the targets, managers could track their reductions of the cooling load and how much they still need to improve.

Appendix D Data Collection Standards

As mentioned earlier, a standard on energy data collection strategies should be developed to guide facilities of all sizes. The following presents the framework for this potential standard, include recommended metrics, frequency, and granularity.

- Metrics:
    - Total Electricity Usage (kWh) - This allows measurement of the facilities total energy use and subsequent savings.
    - Power Draw (kW) - This can show the impacts of utilizing high efficiency equipment and changing the operating conditions.
    - Nighttime/Daytime Power Draw (kW) - This can show the energy use changes depending on the operating hours of the facility.
    - Maximum Power Draw (kW) - This can indicate the impacts of changing equipment by comparing it to the average power draw.
    - Energy Use Intensity (Btu/square foot) - This can provide a good metric for energy performance based on the area of the building to compare to similar facilities.
    - Greenhouse Gas Emissions (lbs CO2 equivalent) - This can show the environmental impacts of energy savings and can be used to promote an environmentally conscious image.
    - Cost Savings ($/kWh) - This is can showcase the financial benefits of energy conservation measures.
    - PUE - This is can provide a high level rating of the buildings energy efficiency and show the impacts of cooling efficiency improvements.
- Frequency:
    - Interval - The electricity data, specifically the total electricity usage (kWh) and power draw (kW), should be monitored on 15-minute intervals to capture the most granular data and impacts of operational changes. This can typically be captured through a proper utility meter.
    - Monthly - This data can be captured through the utility bills and can indicate impacts from climate and other operational changes.
    - Seasonal - This can showcase the impacts from the climate, which plays a large role in the hub and headends facilities, which typically have more efficient operations in the winter months.
    - Annually - This can capture the typical performance of a facility, which can help for budgeting utility costs.
- Granularity:
    - Sub-Metering - This can be on a system level to monitor large energy users.
    - Facility - This will monitor energy use for the entire building.
    - Regional - This can help regional directors manage the energy use for all of the facilities within their reign of responsibilities.

Appendix E Site Visit Photos

Figure 11 - Site A Server Racks

Figure 12 - Site A IT Equipment

Figure 13 - Site B Server Racks

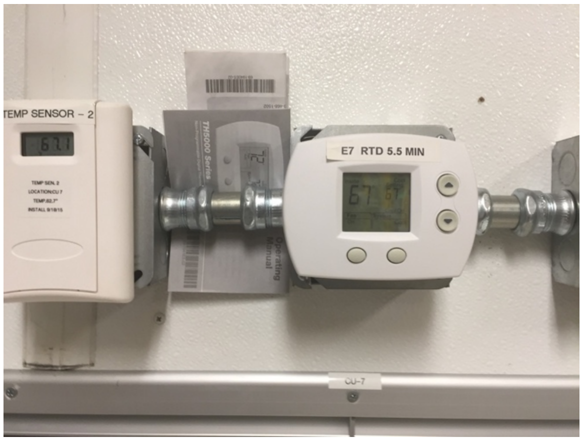
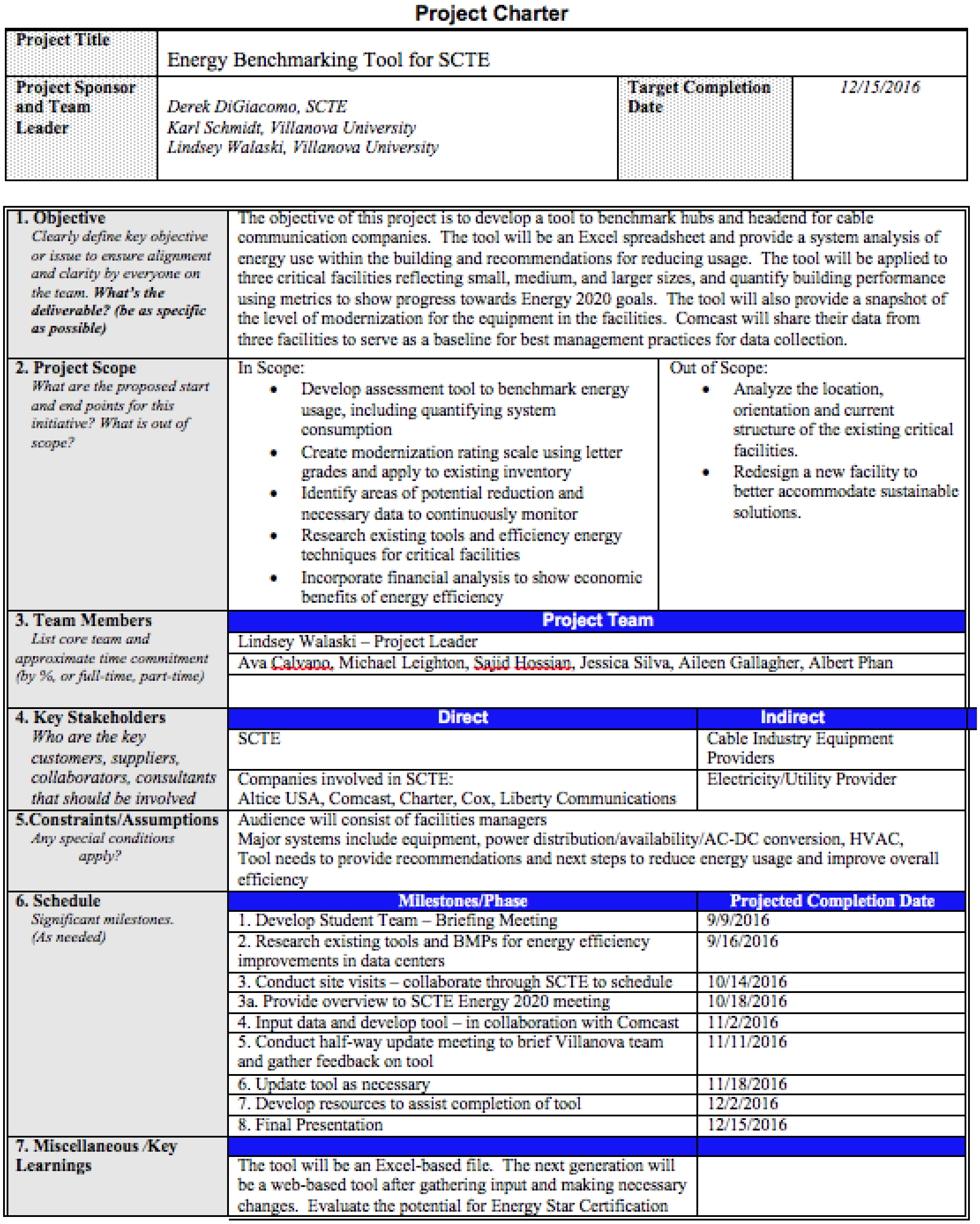


Figure 14 - Site B Programmable Thermostat

Figure 15 - Site C Server Racks

Figure 16 - Site C Exterior

Appendix F Project Charter



Project Charter

Project Title	Energy Benchmarking Tool for SCTE		
Project Sponsor and Team Leader	*Derek DiGiacomo, SCTE* *Karl Schmidt, Villanova University* *Lindsey Walaski, Villanova University*	**Target Completion Date**	*12/15/2016*

1. Objective *Clearly define key objective or issue to ensure alignment and clarity by everyone on the team.* ***What's the deliverable? (be as specific as possible)***	The objective of this project is to develop a tool to benchmark hubs and headend for cable communication companies. The tool will be an Excel spreadsheet and provide a system analysis of energy use within the building and recommendations for reducing usage. The tool will be applied to three critical facilities reflecting small, medium, and larger sizes, and quantify building performance using metrics to show progress towards Energy 2020 goals. The tool will also provide a snapshot of the level of modernization for the equipment in the facilities. Comcast will share their data from three facilities to serve as a baseline for best management practices for data collection.	
2. Project Scope *What are the proposed start and end points for this initiative? What is out of scope?*	In Scope: • Develop assessment tool to benchmark energy usage, including quantifying system consumption • Create modernization rating scale using letter grades and apply to existing inventory • Identify areas of potential reduction and necessary data to continuously monitor • Research existing tools and efficiency energy techniques for critical facilities • Incorporate financial analysis to show economic benefits of energy efficiency	Out of Scope: • Analyze the location, orientation and current structure of the existing critical facilities. • Redesign a new facility to better accommodate sustainable solutions.
3. Team Members *List core team and approximate time commitment (by %, or full-time, part-time)*	**Project Team**	
	Lindsey Walaski – Project Leader	
	Ava Calvano, Michael Leighton, Sajid Hossian, Jessica Silva, Aileen Gallagher, Albert Phan	
4. Key Stakeholders *Who are the key customers, suppliers, collaborators, consultants that should be involved*	**Direct**	**Indirect**
	SCTE	Cable Industry Equipment Providers
	Companies involved in SCTE: Altice USA, Comcast, Charter, Cox, Liberty Communications	Electricity/Utility Provider
5.Constraints/Assumptions *Any special conditions apply?*	Audience will consist of facilities managers Major systems include equipment, power distribution/availability/AC-DC conversion, HVAC, Tool needs to provide recommendations and next steps to reduce energy usage and improve overall efficiency	
6. Schedule *Significant milestones. (As needed)*	**Milestones/Phase**	**Projected Completion Date**
	1. Develop Student Team – Briefing Meeting	9/9/2016
	2. Research existing tools and BMPs for energy efficiency improvements in data centers	9/16/2016
	3. Conduct site visits – collaborate through SCTE to schedule	10/14/2016
	3a. Provide overview to SCTE Energy 2020 meeting	10/18/2016
	4. Input data and develop tool – in collaboration with Comcast	11/2/2016
	5. Conduct half-way update meeting to brief Villanova team and gather feedback on tool	11/11/2016
	6. Update tool as necessary	11/18/2016
	7. Develop resources to assist completion of tool	12/2/2016
	8. Final Presentation	12/15/2016
7. Miscellaneous /Key Learnings		
	The tool will be an Excel-based file. The next generation will be a web-based tool after gathering input and making necessary changes. Evaluate the potential for Energy Star Certification	

Understanding the US DOE Quadrennial Energy Review (QER) Position on Grid Reliability, Security and Resilience

A Technical Paper prepared for SCTE/ISBE by

Derek DiGiacomo, Senior Director Energy Management Systems and Business Continuity,
SCTE | ISBE
140 Philips Rd.
Exton, PA 19341
ddigiacomo@scte.org
610-594-7310

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1. Introduction

The United States electricity system has an enormous responsibility. Over the last one hundred years perhaps no other system in the world has been responsible for the transformation of society and technological advancement in the history of mankind. In the United States, the electricity system in the eyes of the government, holds three primary responsibilities: improvement of the economy, acting responsible for the environment, and improvement of national security. The system is comprised of thousands of generating plants, hundreds of thousands of transmission lines, distribution lines and millions of customers.

The grid is faced with its next generation challenges largely driven by a new distributed energy model fueled largely by solar self-generation and soon to be battery storage systems. As an industry heavily dependent on above ground, somewhat fragile critical infrastructure, it is important to understand how the utility service providers measure their performance especially as it comes to availability.

In over 450 pages and 8 chapters, the QER analyzes trends and issues confronting the Nation’s electricity sector out to 2040, examining the entire electricity system from generation to end use, and within the context of three overarching national goals: (1) enhance economic competitiveness; (2) promote environmental responsibility; and (3) provide for the Nation’s security. In addition to chapter four, Appendix A can serve as a good reference to how the grid operates.

2. What Makes Up the Grid

Let’s get an understanding of the four major components associated with the United States (US) electric grid. Figure one outlines the concept quite nicely. However, in general, generation represents the production of power from the various sources depicted below. Transmission is the network of power lines, transformers and market operators. Distribution is largely the step down transformers and lines commonly seen on the telephone poles and neighborhoods. Finally, the end user and all of the various uses including the self-generation technologies are one of the fastest changing components across the entire grid.

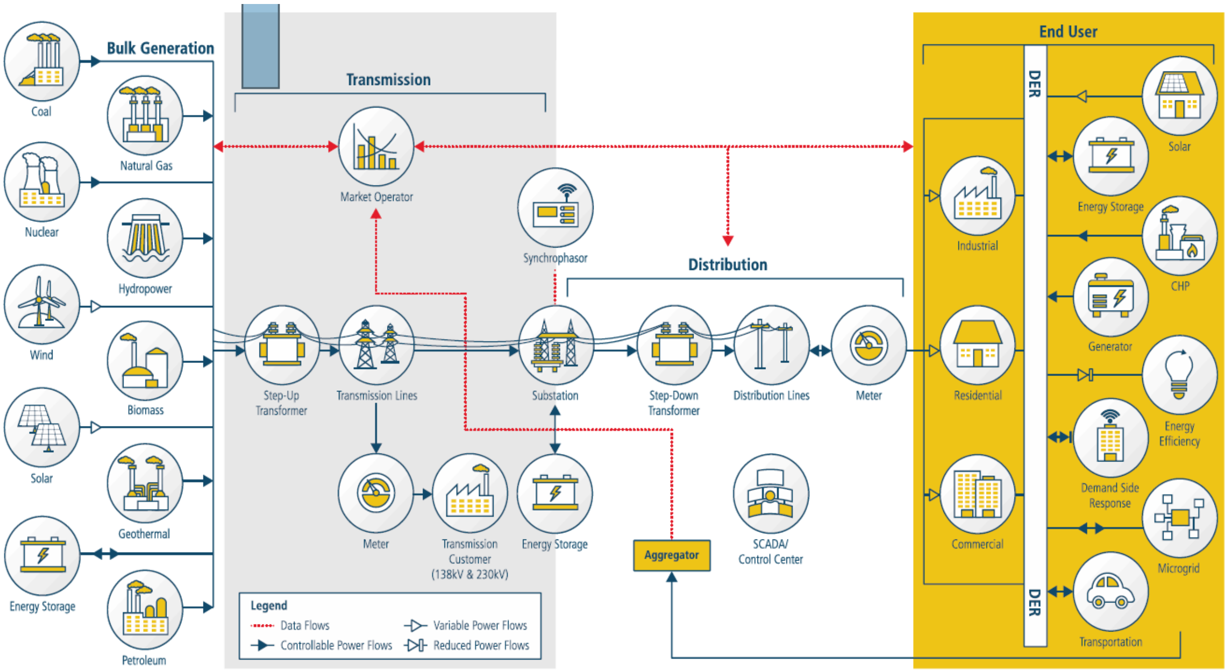


Figure 1 - US Power System Components

3. Key Definitions

We have arrived at a critical time in our electricity grid’s history where we will see proliferation of distributed energy resources and bi-directional communications across the entire ecosystem. The one hundred year plus model is changing. This section will capture the key provisions that are concerning the DOE regarding the reliability, security, and resilience of the grid.

QER defines some key terms:

- Reliability: the ability of the system or its components to withstand instability, uncontrolled events, cascading failures, or unanticipated loss of system components.
- Resilience: is the ability of a system or its components to adapt to changing conditions and withstand and rapidly recover from disruptions.
- Security: refers specifically to the ability of a system or its components to withstand attacks (including physical and cyber incidents) on its integrity and operations.

The DOE, the Federal Energy Regulatory Commission (FERC), the North American Electric Reliability Corporation (NERC), regional planning authorities, utilities, power system operators, states, and other organizations work together to ensure the reliability of the U.S. power system through the implementation of reliability standards, timely planning and investment, and effective system operations and coordination. All of the named parties have an enormous responsibility of ensuring the high standards of the grid are being met especially in the face of a more “connected” system.

4. Standard Measure of Reliability

From the utility industry perspective, reliability is formally defined through metrics describing power availability or outage duration, outage frequency, and outage extent. Reliability within the utility industry is charged to ensure the system operates within limits and avoids instabilities or the growth of disturbances. These practices are not static, and utilities continue to improve their reliability practices and implementation methods to reflect increased consumer expectations. Typical approaches to reliability include hardening, investment, and redundancy to prevent disruptions from reasonably expected hazards.

Data collected in 2015 outlines what the landscape looked like from a per state point of view. The System Average Interruption Duration Index (SAIDI) measures the total duration of an interruption for the average customer given a defined time period and is typically calculated on a monthly or yearly basis. Another metric, the Customer Average Interruption Duration Index (CAIDI), measures how long it takes to restore the system once an outage occurs. Finally, the System Average Interruption Frequency Index (SAIFI) measures the average number of times that a customer experiences an outage during the year. SAIFI is calculated by dividing SAIDI by CAIDI. These metrics tend to apply more to the distribution level vs. generation levels as outages tend to fall more on the distribution infrastructure.

Based on 2016 Energy Information Administration (EIA) data, the average customer experiences 198 minutes of electric power unavailability per year. The following figure taken from the QER outlines the 2015 SAIDI map of the United States:

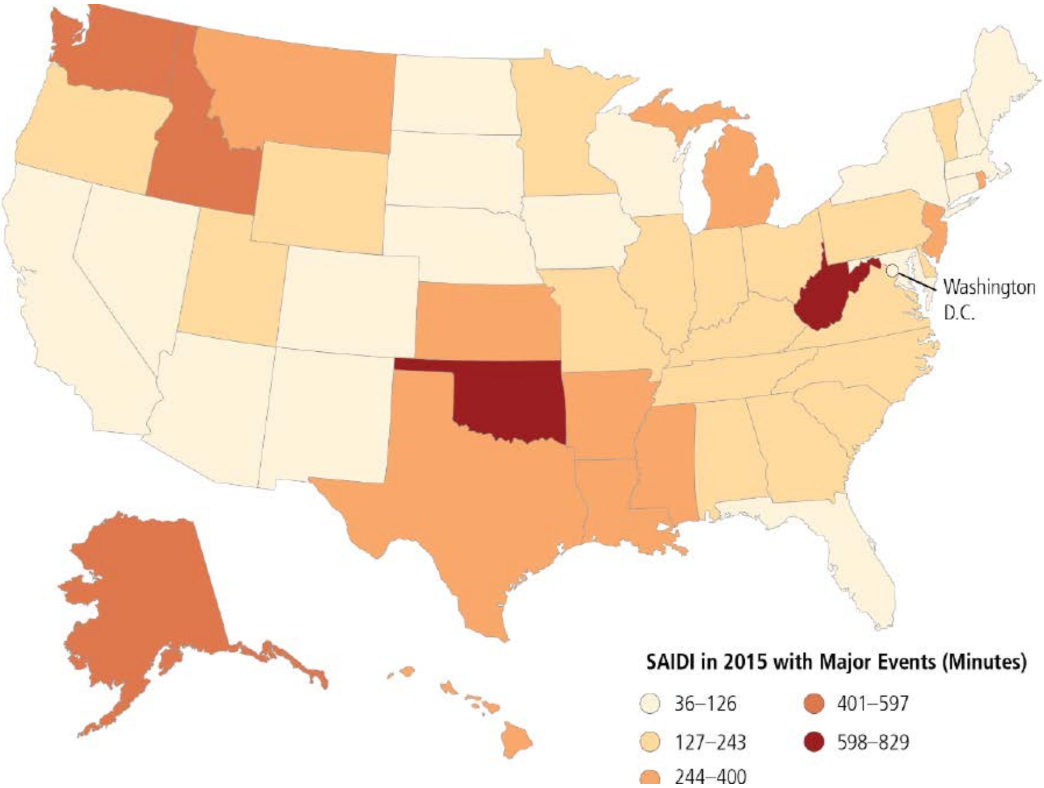


Figure 2 - 2015 SAIDI Map of the United States

There are a number of factors that impact the data reported such as including regional differences, varying regulatory standards, costs, system configuration, customer density, and hazard exposure. Another challenge is the need to further define what is classified as a "major event." Remarkably, energy data collection is fairly new. The Institute of Electrical and Electronics Engineers (IEEE) Standard 1366 formally defined industry reliability metrics in 1998 and the Energy Information Administration (EIA) began collecting distribution-level reliability data, including SAIDI and SAIFI information, in 2013.

5. Time On the Grid

Reliability of the grid is becoming more complex. More controllable loads, new energy storage systems, and more variable generation is becoming a focus for the evolving grid and its measurement standards. New business markets have evolved due to the rapid speed of utility generation and sensitivity of supply. For example, day ahead scheduling and capacity markets represent new utility grid intelligence that can be leveraged to help manage the grid and also create revenue opportunity for customers.

Supply variability is an important part of system operations, where independent system operators ISOs and regional transmission organizations (RTOs) must ensure that risks of unexpected loss or variability of supplies are hedged by having some power plants immediately available (spinning reserves) and other plants able to supply power with short-term notifications of need (non-spinning reserves). The timescale of the grid ranges from milliseconds to decades. Along the time scale varying impact of change can be seen; from protective relay at the millisecond level all the way to planning for long term carbon goals. The sweet spot for customer perception/impact is demand response (minutes), service restoration (hours) and day ahead scheduling (day). As the grid migrates to more non-controlled sources of generation such as utility scale solar and wind; grid operators must plan for the increased time variability technology introduces. Hydro and coal plants were easier to adjust generation based on demand.

With these variable generation assets, this creates an increased need for a "grid traffic cop." Grid dispatch has a powerful role to play to ensure the stability of the system matches demand while at the same time not calling for overproduction resulting in loss of revenue due to over excess generation. Tools at the grid dispatch include: process-flow techniques involving ramping up and throttling down generation plants; via transmission system blending with flexible resources such as hydro; and through demand response (DR), which all can be used to align demand with supply variations for grid services, including frequency regulation. Wind generation tends to handle the bulk of renewable reserves as operators have the greatest control over how many turbines are spinning at any given time.

What happens when the grid is challenged with new end point technologies like that found in the Internet of Things (IoT) functioning at the microsecond scale? These millions of forecasted devices coming online and fluctuating in power demand will require grid operators to react in real time. Autonomous relays and integrating machine learning are two solutions to help address this new scenario. However, both approaches also introduce new risk vectors in the name of cyber security exposure. This next section will dive into how grid operators are considering addressing the new wave concerns of the 21st century.

6. Grid Resiliency Toolkit

This section will outline the various options grid operators can use to help address resiliency.

6.1. Energy Storage

Energy storage will continue to become an important asset to grid operators. Having enough power when and where you need it for many businesses can be the difference between success and outright failure. Technology and chemical advancements in storage has and is changing. Efforts at the DOE are promoting futuristic opportunities largely driven by Advanced Research Projects Agency-Energy (ARPA-E). As captured from the QER, the following graph represents a pictorial representation of energy storage technologies.

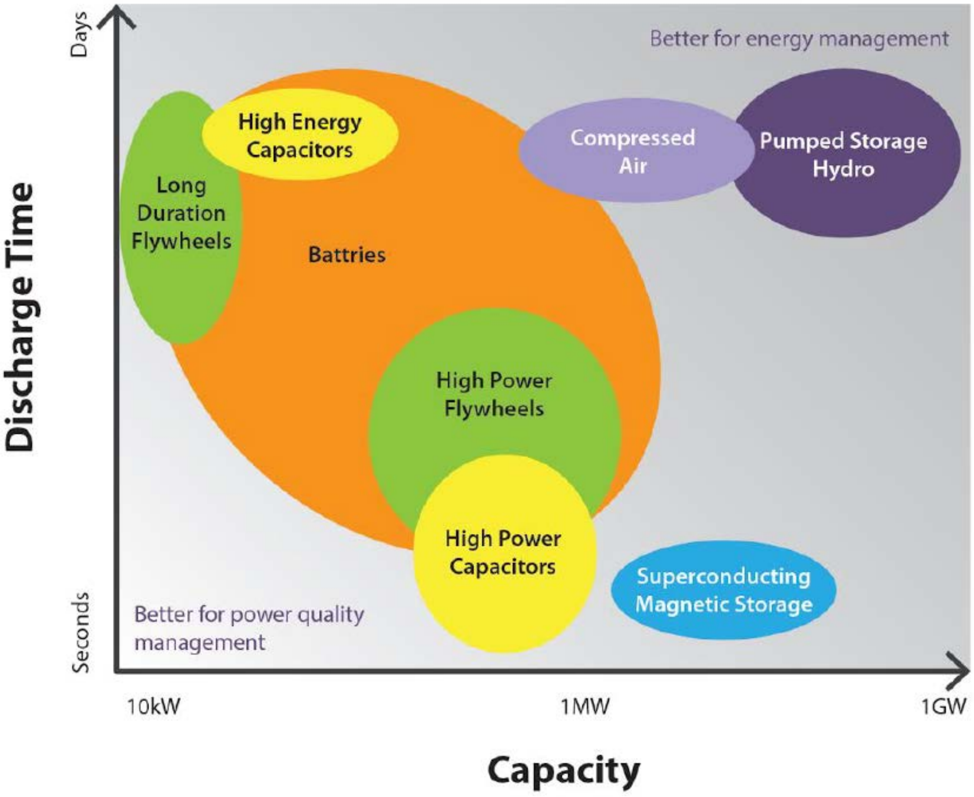


Figure 3 - Energy Storage Technologies

Utility-scale battery storage and distributed battery storage vary by scale and duration, but perform consistently at any scale from a grid management perspective. When distributed storage is aggregated over a planned geographic location, it can offer to local grid operators greater flexibility for managing system reliability and power quality than utility-scale resources. Aggregation can be scaled to fit specific local needs in distribution systems. “Hybridizing” storage solutions with solar and wind power sources may redefine what is meant by “power plant,” and alter how the grid is defined and used.

6.2. Demand Response

The easiest/least expensive watt to provide is the watt that isn’t needed in the first place. That is, rather than spin up reserves, grid operators could call for cooperation of the customer to reduce load for financial incentives to help aid in the forecasted stability of the grid. Driving the demand response is the advent of advanced metering. No longer a single way mode of communication, today’s advanced meters play a pivotal role in automated demand response needs. Based on reports in the QER, as of 2015 there over 65 million smart meters deployed across the US with the bulk appearing in California, Florida, and Texas. Vital to these smart meters is the information and communications technology (ICT) infrastructure connecting the customer back to the data management and controls platforms.

Moving beyond the meter, DOE has developed a new platform: “VOLTTRON™ - (bgintegration.pnnl.gov/volttron.asp) real-time, scalable platform for transactive energy control,” out of the Pacific Northwest National Laboratory that “enables mobile and stationary software agents to perform information gathering, processing, and control actions and independently manage a wide range of applications, such as HVAC [heating, ventilation, and air conditioning] systems, electric vehicles, distributed energy or entire building loads, leading to improved operational efficiency.” This platform provides the capabilities for real-time, scalable distributed control and diagnostics that we need for security and reliability and “…the integration of today's new energy system.”

6.3. Customer Self-Generation

The customer side of the energy equation is in the process of changing as well. Today, self-generation combined with the smart meter mentioned earlier is creating a very dynamic next gen grid. Regulation will help shape the pace of distributed generation and the current state according to the QER is low to moderation adoption (4%) by utility providers. As distributed generation grows, utility providers will need to plan for substation and distribution circuits that support two-way power flows and congestion management.

One question to consider regarding the advancement of self-generation is how to handle excess power being fed back to the grid. Of particular concern is the interconnectivity of the systems. Attack surfaces grow with the proliferation of the self-generating solutions containing imbedded controls and dashboard monitoring. Specific command and controls need to be place to prevent a cascading of malicious activities impacting individuals, regions and perhaps large segments of the grid. Utility providers need to examine use cases from computer/network operators to how to best prevent wide scale spread of damaging activities.

Another concern, solar and wind (which are not synchronously connected to the grid) contribute to a net decrease in system inertia (loss of frequency control). System frequency must be managed tightly around 60 Hertz. It measures how well the supply and demand of electricity are in balance, which has significant implications for how resources are deployed literally minute-to-minute. Conventional generation, such as nuclear facilities or coal-fired power stations, serve as baseload resources as well as spinning reserves. Deviations in frequency are corrected by the spinning mass and governor controls of conventional generators, which automatically adjust electricity output within seconds to correct out-of-balance conditions.

Distribution systems were designed to deliver power to customers rather than receive power from them. When the same grid assets are tasked with handling power delivered to the grid, as well as power delivered to customers, the settings on many field devices (such as capacitors, feeder switches, and relays) need to be adjusted to handle multi-directional power flows. However, upgrades cannot be determined simply by evaluating grid requirements but should be configured to address potential increases in PV deployments. Thus, the concept of “hosting capacity,” much in the same way that Internet services calculate capacity requirements to serve Internet loads, can become key decision criteria for future grid upgrades.

7. The Big Data Challenge for Utility Providers

Flexibility in grid operations requires visibility into connected resources. QER defines visibility as knowledge of "which resources are interconnected, as well as their locations and current capabilities"—is a key attribute for managing the electricity system. Visibility is a necessary condition for managing rapidly changing and complex grid conditions and for providing awareness of incursions, as well as foresight for planning.

Advanced communication and information technologies facilitate visibility. Visualization requires data collection; analysis (e.g., modeling, business cases, etc.); transparency (i.e., sharing data and results); modeling (with both existing and new models). The massive amount of data includes the following items:

- Temporal — real time to planning
- Geographic — seams between balancing areas in the bulk electric system
- Analytical — identification and specification of computer models needed to evaluate the path to the future grid (such as finance tools, transmission planning tools, etc.)
- Price — mechanism for conveying information to customers and suppliers
- Societal impacts – associated risks taken on by the consumer perhaps not accounted for in pricing models
- Business — business models and business-use cases for incumbent service providers and new technology providers
- Technological — characteristics of new technologies and grid elements
- Regulatory — between different layers of jurisdiction and many different types of entities that must be synchronized to make the future grid work
- Vertical industry boundaries — between distribution and bulk system operations.

8. Risk Managment

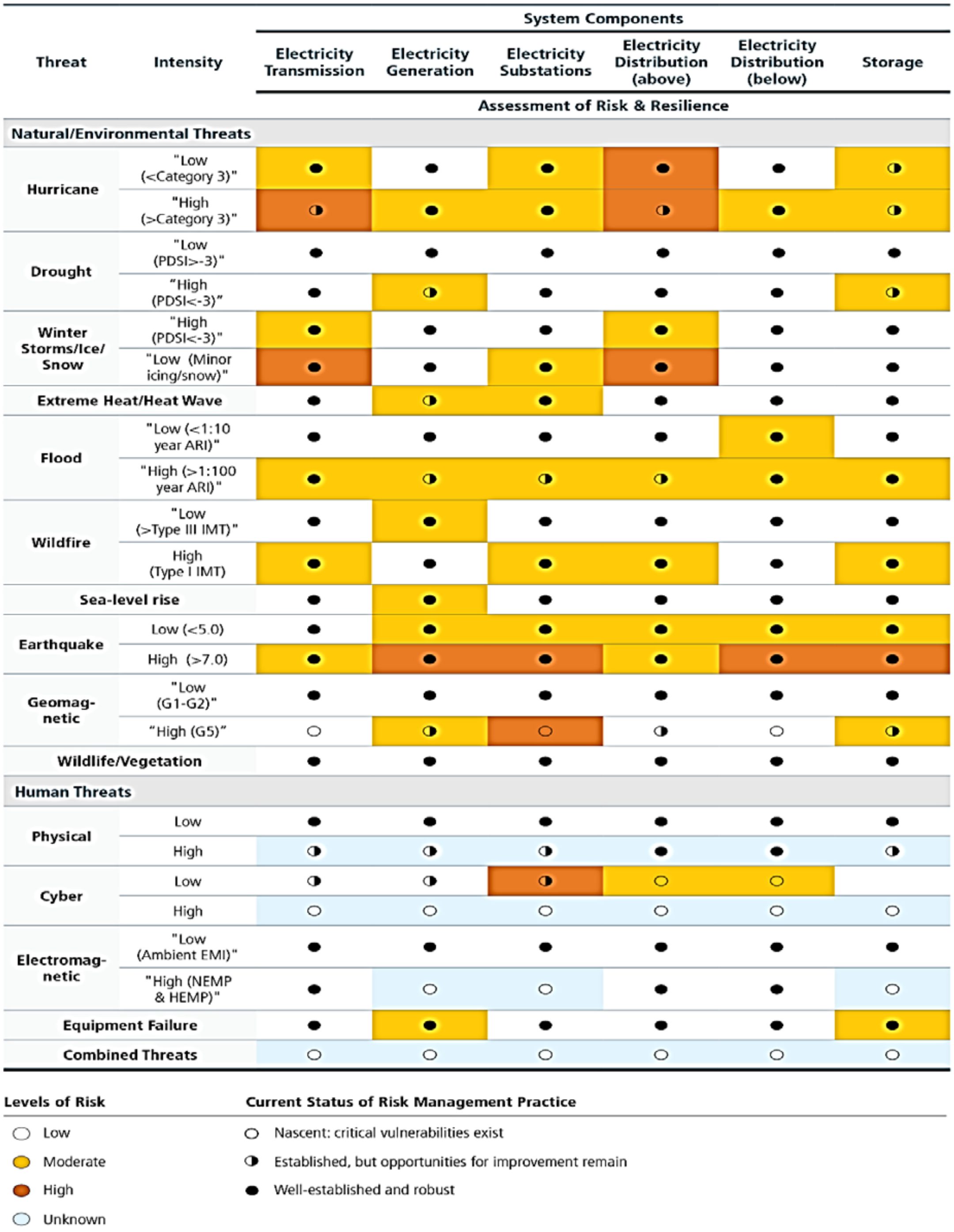
The grid requires management of risks from a wide variety of threats each with different characteristics. Threats and hazards represent anything that can cause disruption and outages, while vulnerabilities are points of weakness within the system that increase susceptibility to such threats. The physical vulnerabilities and specific risks to the electric power system vary among infrastructure components and by geographic location. According to the QER, grid outages cost $5/kWh or for major weather related outages - $20 to $55 billion annually. As illustrated, a lot of financial impacts are riding on the availability of power.

8.1. Risks Defined

Reliability risk is a complex mix of natural and human threats. Risk mitigation includes developing future grid designs that maximize flexibility, as well as making investments in structural, process, and technology solutions, which increase grid resilience to reduce outage events. Some strategies can help reduce risks with respect to a variety of threats, while other strategies are more threat specific. Specific measures include:

- hardening - protection from wind and flooding,
- modernization - investment in sensors, automated controls, databases, and tools,
- general readiness - equipment maintenance, vegetation management, stockpiling of critical equipment, and improved analytics and security upgrades.

QER has provided a table that provides a matrix of integrated assessment of risks to the grid. This matrix illustrates the needs or gaps surrounding the complex, and unfamiliar risks such as cyber-attack, combined threats and geomagnetic disturbances. The other major take-away from the table is that extreme weather is an ever growing risk to above ground distribution resources especially in the southeast regions of the Atlantic coast.



Threat	Intensity	System Components					
		Electricity Transmission	Electricity Generation	Electricity Substations	Electricity Distribution (above)	Electricity Distribution (below)	Storage
		Assessment of Risk & Resilience					
Natural/Environmental Threats							
Hurricane	"Low (<Category 3)"	🟨 ●	⬜ ●	🟨 ●	🟧 ●	⬜ ●	🟨 ◑
	"High (>Category 3)"	🟧 ◑	🟨 ●	🟨 ●	🟧 ◑	🟨 ●	🟨 ◑
Drought	"Low (PDSI>-3)"	⬜ ●	⬜ ●	⬜ ●	⬜ ●	⬜ ●	⬜ ●
	"High (PDSI<-3)"	⬜ ●	🟨 ◑	⬜ ●	⬜ ●	⬜ ●	🟨 ◑
Winter Storms/Ice/ Snow	"High (PDSI<-3)"	🟨 ●	⬜ ●	⬜ ●	🟨 ●	⬜ ●	⬜ ●
	"Low (Minor icing/snow)"	🟧 ●	⬜ ●	🟨 ●	🟧 ●	⬜ ●	⬜ ●
Extreme Heat/Heat Wave		⬜ ●	🟨 ◑	🟨 ●	⬜ ●	⬜ ●	⬜ ●
Flood	"Low (<1:10 year ARI)"	⬜ ●	⬜ ●	⬜ ●	⬜ ●	🟨 ●	⬜ ●
	"High (>1:100 year ARI)"	🟨 ●	🟨 ◑	🟨 ◑	🟨 ◑	🟨 ●	🟨 ●
Wildfire	"Low (>Type III IMT)"	⬜ ●	🟨 ●	⬜ ●	⬜ ●	⬜ ●	⬜ ●
	High (Type I IMT)	🟨 ●	⬜ ●	🟨 ●	🟨 ●	⬜ ●	🟨 ●
Sea-level rise		⬜ ●	🟨 ●	⬜ ●	⬜ ●	⬜ ●	⬜ ●
Earthquake	Low (<5.0)	⬜ ●	🟨 ●	🟨 ●	🟨 ●	🟨 ●	🟨 ●
	High (>7.0)	🟨 ●	🟧 ●	🟧 ●	🟨 ●	🟧 ●	🟧 ●
Geomag-netic	"Low (G1-G2)"	⬜ ●	⬜ ●	⬜ ●	⬜ ●	⬜ ●	⬜ ●
	"High (G5)"	⬜ ○	🟨 ◑	🟧 ○	⬜ ◑	⬜ ○	🟨 ◑
Wildlife/Vegetation		⬜ ●	⬜ ●	⬜ ●	⬜ ●	⬜ ●	⬜ ●
Human Threats							
Physical	Low	⬜ ●	⬜ ●	⬜ ●	⬜ ●	⬜ ●	⬜ ●
	High	🟦 ◑	🟦 ◑	🟦 ◑	🟦 ●	🟦 ●	🟦 ◑
Cyber	Low	⬜ ◑	⬜ ◑	🟧 ◑	🟨 ○	🟨 ○	⬜
	High	🟦 ○	🟦 ○	🟦 ○	🟦 ○	🟦 ○	🟦 ○
Electromag-netic	"Low (Ambient EMI)"	⬜ ●	⬜ ●	⬜ ●	⬜ ●	⬜ ●	⬜ ●
	"High (NEMP & HEMP)"	⬜ ●	🟦 ○	🟦 ○	⬜ ●	⬜ ●	🟦 ○
Equipment Failure		⬜ ●	🟨 ●	⬜ ●	⬜ ●	⬜ ●	🟨 ●
Combined Threats		🟦 ○	🟦 ○	🟦 ○	🟦 ○	🟦 ○	🟦 ○

Levels of Risk	Current Status of Risk Management Practice
⬜ Low	○ Nascent: critical vulnerabilities exist
🟨 Moderate	◑ Established, but opportunities for improvement remain
🟧 High	● Well-established and robust
🟦 Unknown	

Figure 4 - Risk Assessment Matrix

8.2. Climate

This paper is not a report on climate change and the sciences behind global weather patterns, however it is hard not to acknowledge the dependency on what the ambient temperature is with demands on the grid.

As temperatures rise above 65 degrees Fahrenheit, the amount of air conditioners coming online tend to increase. During this higher demand in cooling, one other factor comes into play increase potential for utility equipment failure due to hotter days resulting rise of internal grid equipment operating temperatures. Coastal flooding can be of considerable concern as well during extreme weather events.

8.3. Cyber

Bi-directional communication on the grid opens the service up to a plethora of new risks. Unlike computer networks, the utility grid network and its controls often do not have redundancy that would support taking the system offline for preventative maintenance or incorporation of new security fixes. Interoperability standards, in particular, have the potential to enhance cybersecurity. Improved tools, analytic methodologies, and demonstrations would serve to clarify the circumstances where improved interoperability can improve grid cybersecurity by standardizing security solutions such that utilities can select ‘plug-and-play’ options to mitigate cybersecurity issues.

The United States have been fortunate to date. However, Ukraine was not so fortunate in 2015. In December, the incident compromised six organizations, including three electric distribution companies; disconnected seven 110 kilovolts and 23 35-kilovolt substations (which would straddle Federal and state jurisdiction in the United States); rendered equipment inoperable; overwhelmed the call center with a denial-of-service event to prevent people from reporting outages; and left 225,000 without power for 1 to 6 hours. In the United States this would be a significant incident having cross sector impacts.

8.4. Smart Grid

Smart meters track detailed power usage and allow for two-way communication between the utilities and end users via smart grid technology, which can include remote customer connection and disconnection. Hackers targeting this technology could cause erroneous signals and blocked information to cut-off communication, cause physical damage, or more, and disconnect large numbers of customers to disrupt the grid. Currently the volume of attacks, as mentioned in the QER, industrial control systems as compared to the general Internet (ICS) are still low risk targets. However, as more and more devices get incorporated into the evolving grid, the risk surface area increases. Finally, as more and more of the controls go digital, it can be noted, that as a fall back, mechanical controls can be left in place to act as “valves” to prevent further wide-spread outage.

8.5. Resiliance

Resilience enhancement initiatives are generally focused on achieving at least one of three primary goals:

1. preventing or minimizing damage to help avoid or reduce adverse events;
2. expanding alternatives and enabling systems to continue operating despite damage; and/or
3. promoting a rapid return to normal operations when a disruption occurs (i.e., speed the rate of recovery).

Resilience relates both to system improvements that prevent or reduce the impact of risks on reliability and to the ability of the system to recover more quickly. Unlike reliability, the QER doesn’t refer to metrics for resilience; and threats to system resilience are typically associated with disasters or high-intensity and low-frequency events. An additional complication is that the responsibility for maintaining and improving grid resilience lies with multiple entities and jurisdictions, including federal and state agencies and regulatory bodies, as well as multiple utilities. For investments in electricity sector resilience, approval is generally up to the discretion of state public utilities commissions or equivalent bodies, which are balancing competing often more near-term interests. Furthermore, from the societal perspective, building resilience of critical infrastructure to future disasters involves decision making that also considers social, cultural, and environmental issues, which have both qualitative and quantitative value, from a risk assessment standpoint. There is no established method for quantifying the benefits of investments, which depend on the occurrence of some events with low probabilities.

Maintaining situational awareness is an important aspect of overall resilience management in service to maintaining high grid reliability. Utilities rely on field personnel to assess and report grid system conditions through site inspections. During emergency situations, utilities’ abilities to assess and communicate system status after a large disruption tend to be significantly degraded. Where there is a widespread disruption beyond electricity infrastructure damage, personnel may be responding to a specific emergency situation, which limits work scope. Transportation challenges, such as road blockages and traffic, may also prevent the movement of utility personnel and equipment to assess electricity infrastructure throughout the affected area. Wide communication system outages will also limit utilities’ ability to assess system conditions. When distribution-level SCADA pairs with a distribution management system, operations can be conducted remotely, increasing the speed at which a utility can identify and locate faults on the distribution system and restore service, as well as manage voltage and reactive power to reduce energy losses and integrate distributed generation and storage technologies.

8.6. Dynamic Line Rating Systems for Transmission Systems

Current transmission system operations rely on fixed ratings of transmission line capacity that are established to maintain reliability during worst-case conditions (e.g., hot weather). Line ratings may also be reduced if ambient conditions are abnormally hot and still. There are times when the conditions associated with establishing line ratings are not constraining, and transmission lines could be operated at higher usage levels. According to the QER, dynamic line rating systems help operators identify available real-time capacity and increase line transmission capacity by 10 to15 percent. Dynamic line rating systems can help facilitate the integration of wind generation into the transmission system. This real-time information about overhead conductors can help further enhance situational awareness, while simultaneously providing economic benefits. Incremental investments that increase the capacity of the existing transmission system can provide a low-cost hedge, as well as enhanced real-time awareness. However, economic, financial, regulatory, and institutional barriers limit incentives for regulated entities to deploy these low-capital cost technologies that could increase transmission capacity utilization. NERC has an important role to play in setting relevant standards, which would drive increased operational focus on dynamic line ratings as part of overall response and recovery planning and execution.

8.7. Spare Transformers and Backup Power

Microgrids offer islanding solutions for large facilities and campuses by their integration of DG, storage, and demand side management solutions. Utilities have robust supply chains and inventory management systems that help ensure that spare transformers, including the stocking of interchangeable spare transformers, the ordering of conventional spares in advance, and the early retirement of conventional transformers for use as spares. Conventional spares are typically used for planned replacements or individual unit failures; but these transformer spares can also be used as emergency spares. Under this approach, the spares are identical to those transformers that are to be replaced and often stored at the substation next to existing transformers—which allows for quick energization without the transformer being moved. Obviously, if the geo location is subject to a natural disaster such as earthquake or flood, then the storage of the backup in close proximity will not help. Risk to reward analysis should be done.

The close proximity of such spares to the existing transformers can lead to potential high-intensity and low-frequency physical attacks or weather events. Some utilities retain retired transformers to repurpose them as emergency spares. These are transformers that have retired but not failed, which would allow their use as temporary spares until a new transformer is manufactured and transported. Utilities also use mobile transformers and substations to temporarily replace damaged assets, much in the way that mobile power is used for resilience and repowering efforts.

Replacement of multiple, failed large power transformers (LPTs) is a challenge, due to the cost, complexity and lengthy process involving the procurement, design, manufacturing, and transportation of this equipment. These processes can take months, depending on the size and specifications of the needed LPTs, even under an accelerated schedule and normal transportation conditions. Utilities mitigate the risk of losing LPTs through several strategies, including adopting measures to prevent or minimize damage to equipment, purchasing and maintaining spare transformers (conventional spares), identifying a less critical transformer on their system that could be used as a temporary replacement (provisional replacement transformer), and/or setting up contracts to procure a transformer through a mutual assistance agreement or participation in an industry sharing program.

As reported in the QER, there are currently three key industry-led, transformer-sharing programs in the United States—NERC’s Spare Equipment Database program, Edison Electric Institute’s Spare Transformer Equipment Program, and SpareConnect. Addition research is being conducted as directed by DOE at Oak Ridge National Laboratory regarding further development of transformer resiliency options.

9. Grid Resiliency and SCTE | ISBE APSIS™

As part of the readiness in the face of adverse conditions either natural or man-made, grid management has a roadmap for improving and increasing resiliency. Four steps over the course of the next fifteen years will help ensure that the power grid continues to be a highly reliable strategic advantage in the United States.

These four steps are:

1. 2015: Improvement of analytics and visual display of data resulting in better point of use mapping, dashboards and summaries of activities.
2. 2020: Fault detection and correction as a result of forensic benchmarking, time-based performance analysis and improved alerting in real time.
3. 2025: Adaptive intelligence and preemptive operations and maintenance mainly as a result of optimized human to machine integration, continuous performance monitoring and grid self-management thanks to artificial intelligence.
4. 2030: A fully automated integrated point of production and use system that will begin the next phase of grid lifecycle including cross-source use management with core infrastructure systems such as water, communications and waste management.

Note, number four, hints at activities currently (as of 2017) under development at SCTE ISBE within the standards body. The Adaptive Power Systems Interface Specification (APSIS™) standard has been published in 2015 and is accessible at (scte.org/SCTEDocs/Standards/ANSI_SCTE%20216%202015.pdf). This standard spells out the framework for an end to end adaptive power system that will operate over a cable operator’s (or any network) network. Ideally, APSIS™ will have interfaces not only to the production network, but ideally with building management systems and utility power providers. This extension of control across domains is positioned to provide the deepest benefit to energy and cost savings. At the time of this publication, communication network APSIS™ use cases were being developed.

Smart meters come into play in helping with restoration. Utility providers now have the opportunity to collect data not only on usage but also on availably/outage thanks to deployment of over 60 million customers according to the QER. Provides have a tsunami of data that they must deal with, however this data can and is translating to better restore times due to intelligence gathered from the smart meters. For example, as also pointed out in the QER, during Superstorm Sandy, smart meters reduced PECO Energy's restoration time by 2–3 days.

Another growing risks to availability and reliability at the time of publication include lack of long term planning surrounding extreme weather events and cyber-attacks. There is an increasing impact to the cyber threat level with the continued roll-out of smart meters. Budget for dealing with this growing threat should be allocated however when looking at the budget process and prioritization for the grid, cyber security is a fairly new topic unlike profit, rate structures and natural age based repair needs.

10. Where is the Grid Heading in Terms of Availability?

As highlighted in the previous section the state of advanced grid operations has some lead time. As far as resiliency and tools to ensure availability are concerned, a new planning tool is being considered. Grid operators and researchers are trying to define and develop a probabilistic risk assessment (PRA) tool that offers such an advanced framework to address underlying uncertainties and risks in a very complex revenue enabling system.

Key provisions of the developing PRA include:

- variations in renewable generation levels,
- variations in load level due to weather and DER output,
- generation and transmission equipment performance,
- variations in hydro-generation, and
- and physical threats like weather.

However, the development of the PRA has many obstacles to overcome and viable functioning model probably not available for several years.

11. Conclusion

Never before has the customer had more impact on the overall health of the grid. The organic evolution of the United States power grid needs to ramp up its adoption process of new models of rate structures, preventative maintenance and security measures. Distributed energy generation at the customers site, thanks in large part to accessible solar photovoltaic systems and soon energy storage/electric vehicles bi-directional feed of power can keep the grid operators up at night.

This paper attempted to extract the key provisions surrounding grid availability and reliability in the face of technical advancement as captured in the January 2017 QER publication.

12. Abbreviations

APSIS™	Adaptive Power Systems Interface Specification
CAIDI	customer average interruption duration

DOE	United States Department of Energy
DR	demand response
EIA	Energy Information Administration
FERC	Federal Energy Regulatory Commission
HVAC	heating, ventilation, and air conditioning]
ICS	industrial control systems
ICT	information and communications technology
IEEE	Institute of Electrical and Electronics Engineers
IoT	Internet of Things
ISBE	International Society of Broadband Experts
ISOs	independent system operators
kWh	killowatt hour
LPTs	large power transformers
NERC	North American Electric Reliability Corporation
PECO	Philadelphia Electric Company
PRA	probabilistic risk assessment
QER	Quadrennial Energy Review
RTOs	regional transmission organizations
SAIDI	system average interruption duration
SAIFI	system average interruption frequency index
SCTE	Society of Cable Telecommunications Engineers

12.1. Definitions

Reliability	the ability of the system or its components to withstand instability, uncontrolled events, cascading failures, or unanticipated loss of system components
Resilience	the ability of a system or its components to adapt to changing conditions and withstand and rapidly recover from disruptions
Security	the ability of a system or its components to withstand attacks (including physical and cyber incidents) on its integrity and operations
Visibility	knowledge of which resources are interconnected, as well as their locations and current capabilities

13. Bibliography and References

US DOE’s Quadrennial Energy Review Transforming the Nation’s Electricity System. 2017 (https://energy.gov/epsa/quadrennial-energy-review-second-installment)

ANSI/SCTE 216 2015: Adaptive Power Systems Interface Specification (APSIS™) (http://scte.org/SCTEDocs/Standards/ANSI_SCTE%20216%202015.pdf)

Improving the Efficiency of Cooling in the Headend

A Technical Paper prepared for SCTE/ISBE by

Jim Farmer, Co-Author, Consultant to the Cable TV Industry, SCTE/ISBE Member
2406 Stoney Point Road
Cumming, GA 30041
jofarmer@mindspring.com
(678) 640-0860

David Kozischek, Co-Author, Corning Optical Communications
800 17th Street NW
Hickory, NC 28603
David.Kozischek@corning.com
(828) 901-5902

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1. Introduction

Headends and hubs are getting more sophisticated, with more video options, much more data handling, and telephone soft switches. With this increased sophistication comes more power consumption, which can cause problems to arise. Some electronic equipment is rated for long-term operation at a maximum temperature as low as about 100 degrees Fahrenheit. As switches, servers, and other equipment have evolved, the pressures on cooling have gotten much more severe. A one-rack-unit (1RU) edge QAM chassis, for example, may be rated to consume about 200 watts. Imagine two 100 watt incandescent light bulbs in this 1RU (1.75 inch) rack – that's a lot of heat! Stand behind a "big iron" (high port count) cable modem termination system (CMTS) loaded to maximum capacity and feel the air exhaust temperature.

Cooling of a headend is not unlike cooling of a data center except there is a plethora of different types of equipment with different cooling strategies. Also, while many data centers have raised floors through which they can channel cooled air to each rack, most headends tend to use overhead cabling (a trend in data centers, too), with less capability for handling airflow. While data centers also experience expansion with time, many headends and hubs were built in a different era when power density was not nearly so high, and cooling was easier. Air conditioning was deployed that matched the amount of power being consumed and the cooling problem was averted. Today every cooling dollar needs to work as hard as every other dollar spent on infrastructure.

Let's see if lessons can be learned from data centers, and see how we might apply them to headends and hubs (we'll just say headend, but obviously we are including hubs that have similar cooling requirements). According to International Data Corporation (IDC), up to 60 percent of downtime can be directly attributed to electronic failures due to excessive heat, so addressing heat loads has very beneficial effects. In this paper, we will zero in on a few key issues.

2. Organizing to Save Energy

Energy savings opportunities are in a number of places; however the greatest energy savings happens with the involvement and support of top management. Many successful programs (SCTE 234 or ISO 50001 for example) have been implemented by energy teams who report directly to the board of directors or a high-ranking officer of the company. Management needs to put a priority on efficient cooling, including guidance to the energy team as to what type of payback period is expected. A reasonable criterion might be a 3-year payback for an investment in energy savings. When considering the payback period, don't forget the cost of heat removal (air conditioning) as well as heat generation. Depending on local power costs and the air conditioning efficiency, removing the heat may cost more than generating it in the first place. As a general rule, the EPA says that for every unit of electronics power, an equal unit is required for cooling. Some references state even more power is required for cooling.

3. The Top 12

According to the EPA Energy Star Program, the top 12 opportunities to save energy and hence money in a data center are [1]:

1. Server virtualization *(This is big: virtualization results in higher server utilization, more process power, and fewer servers.)*
2. Decommissioning of unused servers
3. Consolidation of lightly utilized servers
4. Better management of data storage

5. Purchasing more energy-efficient servers, UPSs, and PDUs
6. Hot aisle/cold aisle layout
7. Containment/enclosures
8. Variable-speed fan drives *(general airflow issues)*
9. Properly deployed airflow management devices
10. Server inlet temperature and humidity adjustments
11. Air-side economizer
12. Water-side economizer

In this paper, we will concentrate on opportunities 5-8. The website referenced [1] has many resources to get you thinking about how to save energy and hence money. Some of these opportunities will possibly not apply to your headend, but others will. A lot can be learned from studying the experiences in data centers. The applicability of certain measures may also depend on location: the issues are different in a dry desert climate than in a humid seaside resort, but saving energy/money is a universal goal.

4. Technologies that Save You Energy (Opportunity 5)

Example: You have a few servers and switches in your headend, maybe not as many as in a large data center, but some. Ask, how old they are, and how do they stack up in terms of energy efficiency with newer products? Is there a way you can let some go to sleep during off hours, when your subscribers are demanding fewer server-based services? Some operating systems allow for running the processors at a slower speed when the demand on them is not great, resulting in lower power dissipation. Some can consolidate functions on a fraction of the processor cores available, putting the unused cores to sleep when they are not needed.

There are choices, in many cases, of interconnecting equipment with either fiber or copper cabling. We'll have more to say later about the merits of each, but right now let's talk about the relative merits of the transmitters and receivers in the routers, servers, and CMTSs. Figure 1 indicates an estimate of the power draw of each technology based on a single 10 Gb/s link. Fiber transceivers are lower in power consumption, which not only saves money in operating the equipment, but saves a similar amount in cooling costs.

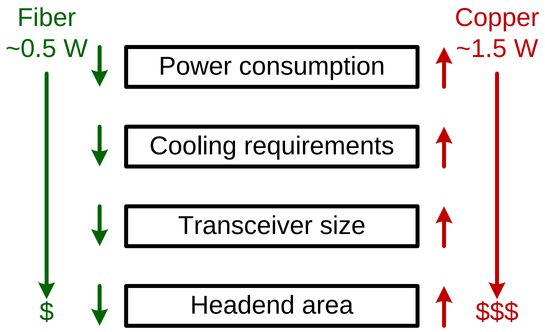

Figure 1 - 10 Gb/s Operating Cost, Fiber vs Copper

Opportunity: There are certainly potential savings in UPSs and power distribution units (PDUs). It is common to use battery-based uninterruptible power supplies to bridge the time between a power failure and when the generator can start then carry the load. Have you looked recently to see if there are more efficient units on the market? If you are in the market for UPSs, are you comparing the total operating cost (which includes efficiency) of the candidate UPSs? You have probably added a lot more equipment to your headend in the years since you purchased your last UPS. Is it capable of handling the load you would present to it today? Same for your generator: if you need it, will it be capable of handling today's load?

Opportunity: Some PDUs step down voltage for distribution to rack-based power distribution units. How efficient are the transformers? How efficient are the rectifiers where AC is converted to DC? How efficient are the voltage regulators? When you get to 48 vdc distribution, you are dealing with a LOT of current. Is your wiring sufficiently sized to handle the current without creating power-robbing voltage drop? These issues can develop over years, as more equipment is added. You have probably experienced the same thing at home: you are using more power than you did maybe 20 years ago, even though equipment has gotten more efficient. This is simply because you have more equipment. And much of that equipment consumes so-called "phantom power," using power even when turned off. To an extent, the same goes for your headend. In particular, UPSs use some power when not in use, to keep the battery float charged and to monitor power, to be ready to start when needed.

5. The Cost of Removing Heat

Several anecdotal reports place the cost of removing heat from a data center or headend, at nearly the same as the cost of operating the equipment. This is a sufficient cost to persuade companies to explore unconventional heat removal techniques. For example, Institute of Electrical and Electronics Engineers (IEEE) recently reported that Microsoft has built an experimental underwater data center, which drives the heat removal cost down from maybe 90 percent of the server powering cost to about 3 percent [2].

6. Some Numerical Examples

Table 1 - Example Annual Costs of Power, Not Including Heat Removal

# connections:	**100 10 Gb/s links**		**200 10 Gb/s links**		**300 10 Gb/s links**	
Power cost per kWH	**Copper**	**Fiber**	**Copper**	**Fiber**	**Copper**	**Fiber**
$0.070	$184	$61	$368	$123	$552	$184
$0.075	$197	$66	$394	$131	$592	$197
$0.080	$210	$70	$421	$140	$631	$210
$0.085	$224	$75	$447	$149	$671	$224
$0.090	$237	$79	$473	$158	$710	$237
$0.095	$250	$83	$500	$167	$749	$250
$0.100	$263	$88	$526	$175	$789	$263
$0.105	$276	$92	$552	$184	$828	$276
$0.110	$289	$96	$579	$193	$868	$289
$0.115	$302	$101	$605	$202	$907	$302
$0.120	$316	$105	$631	$210	$947	$316
$0.125	$329	$110	$657	$219	$986	$329
$0.130	$342	$114	$684	$228	$1,026	$342

We can estimate the cost of transferring data on copper or fiber cables by looking at some scenarios involving the number of links you have and the cost of power in your area. Table 1 illustrates the cost of simply operating either *fiber* (utilizing lightwaves) or *copper* (utilizing electron flow) interfaces, without regard for the cost of power supply inefficiency, the cost of heat removal, or the cost of additional blockage of moving air due to cable blockage. Table 2 assumes a rule-of-thumb air conditioning cost of 100 percent of the power consumed by the equipment. Heat generated by fiber interfaces are lower than the heat generated by copper interfaces. As of December 2016, the average commercial power cost in the US was about 10.5 cents per kWH [3]. The cost ranged from about 0.5 to 12 cents per kWH, depending on location [4][3].

Table 2 - Example Annual Costs of Power, Including Heat Removal

# connections:	**100 10 Gb/s links**		**200 10 Gb/s links**		**300 10 Gb/s links**	
Power cost per kWH	**Copper**	**Fiber**	**Copper**	**Fiber**	**Copper**	**Fiber**
$0.070	$368	$123	$736	$245	$1,105	$368
$0.075	$394	$131	$789	$263	$1,183	$394
$0.080	$421	$140	$842	$281	$1,262	$421
$0.085	$447	$149	$894	$298	$1,341	$447
$0.090	$473	$158	$947	$316	$1,420	$473
$0.095	$500	$167	$999	$333	$1,499	$500
$0.100	$526	$175	$1,052	$351	$1,578	$526
$0.105	$552	$184	$1,105	$368	$1,657	$552
$0.110	$579	$193	$1,157	$386	$1,736	$579
$0.115	$605	$202	$1,210	$403	$1,815	$605
$0.120	$631	$210	$1,262	$421	$1,893	$631
$0.125	$657	$219	$1,315	$438	$1,972	$657
$0.130	$684	$228	$1,367	$456	$2,051	$684

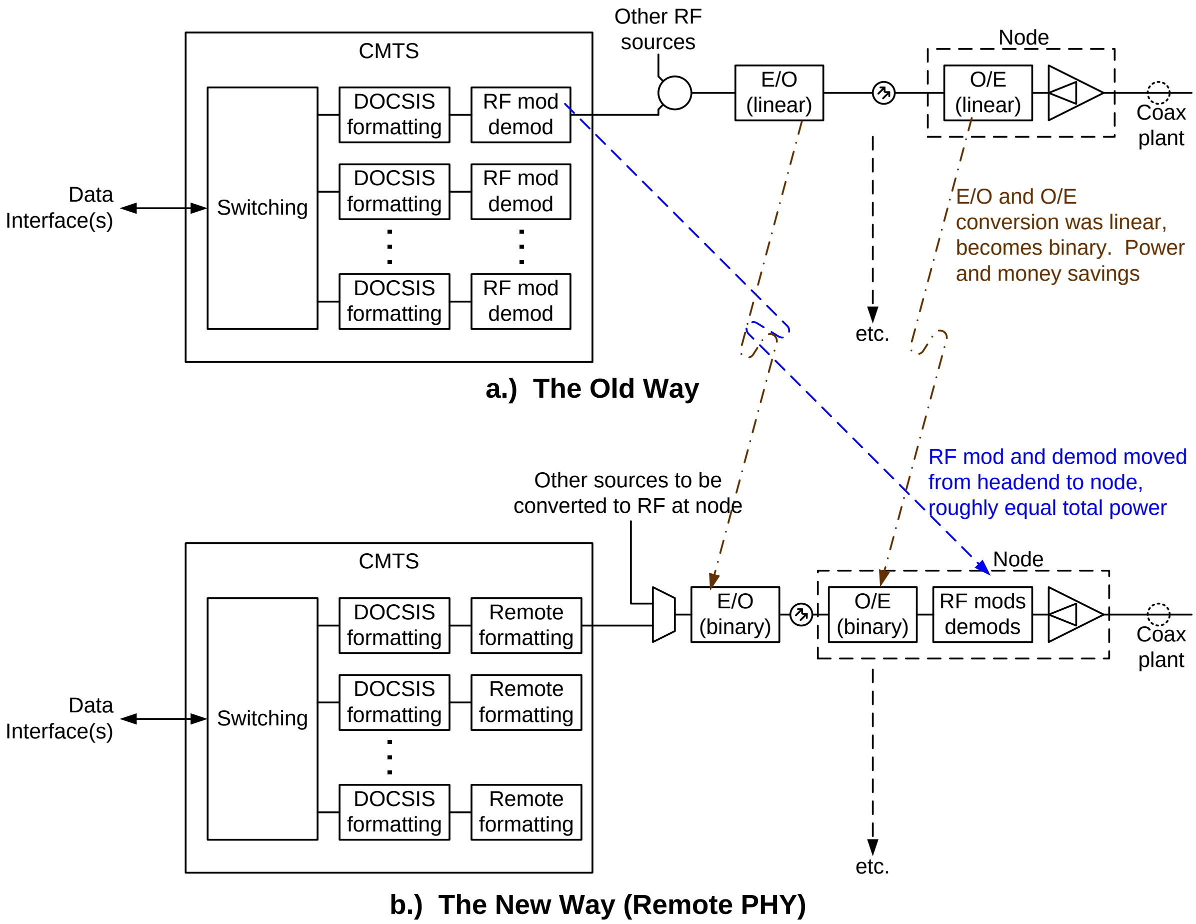

Figure 2 - Moving RF Modulators and Demodulators to the Node (only modulation shown for simplicity)

7. Moving Heat to the Node

There has been a lot of interest in moving the quadrature amplitude modulation (QAM) modulators to the node, particularly but not totally applied to modem systems. This *Remote PHY* (*remote physical layer*) has advantages in terms of cost and some overall power savings, as well as removing some power-hungry equipment from the headend and making some incremental improvement in the quality of signals delivered to the coax plant. However, to an extent you are moving heat from a headend, where you have active heat removal equipment, to a node, where you have only passive heat removal and a more hostile temperature environment.

The top image in Figure 2 illustrates the old way, with radio frequency (RF) modulation and demodulation in the CMTS (and in other equipment). What is desired is to move the modulators to the node. While not primarily seen as a power saving feature (the overall savings are minimal), it does reduce power demand somewhat in the headend by moving out the relatively power-hungry modulation and demodulation processes, and exchanging the linear electrical-to-optical and optical-to-electrical conversion processes to lower power and cheaper binary processes. The downside is more heat moves to the node, which has traditionally been a problem to keep cool, and the timing issues involved in separating the RF from other CMTS functions has created a number of headaches for equipment designers.

Proposals are available that move even more heat-producing circuitry out of the headend, but as far as we know, they are not under active development at time of publication.

8. Hot Aisle/Cold Aisle Layout (Opportunity 6)

Most equipment needing active cooling takes air in from one side and expels it to the other side of the equipment. It is common for equipment to take in air from the front side and expel it to the rear. This leads to the concept of hot aisle/cold aisle, as illustrated in Figure 3. A cold aisle is formed between rows of equipment racks by forcing cold air from the air conditioning system (computer room air conditioning or CRAC) between the rows. Equipment is installed such that it always draws air in from the cold aisle(s) and expels it to the hot aisle(s) on the other side, where it is returned to the CRAC. This improves the efficiency of the air conditioning by making sure that the cold air goes where it does the most good. In some cases containment (of either hot or cold air) is employed to prevent the cold and hot air from mixing, reducing the efficiency of the process.

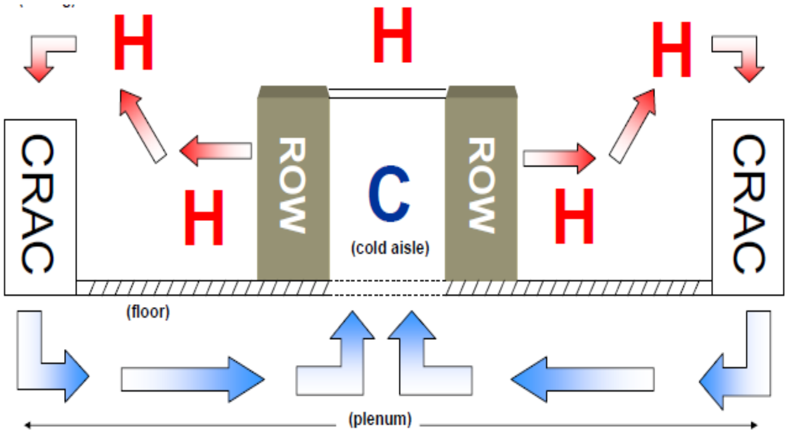

Figure 3 - Hot Aisle/Cold Aisle Concept

The figure assumes a raised floor, which can act as a duct for the cold air. We call such an arrangement a *plenum*. If you don’t have a raised floor, there are other ways to get cold air to the cold aisle. You can use conventional overhead ducting to get the cold air to the cold aisle. There are also CRAC units that fit in a row of racks as just another rack, taking air in from the hot side and expelling the cooled air to the cold aisle.

If equipment, such as many “big iron” CMTSs, takes in air in front and expels it to the rear, then the front side will face the cold aisle. If you have a piece of gear that pulls in air from the rear and expels it to the front, then of course the opposite mounting is employed. We have seen equipment that takes air in on one side and expels it on the other. In this case, baffles will need to be used to direct the air properly.

Some older and less power-dense equipment may use passive cooling rather than active (fan) cooling. Such equipment may locate most heat-producing components near the rear, but it may not. Since such equipment does not produce as much heat for its size, it is probably less important to orient it correctly for cooling purposes.

9. Containment/Enclosures (Opportunity 7)

In order to prevent the cold and hot air from mixing, it is obviously important to enclose the racks so that air cannot get around the equipment in the rack. This runs counter to an old philosophy that says remove back and side panels from a rack to let air circulate more freely. This might have been a good philosophy when equipment was passively cooled, but with the density of modern gear, and the use of fans to move air, putting side panels on racks is a good approach. You may want to go even further to prevent cold and hot air from mixing, sealing leaks in the racks.

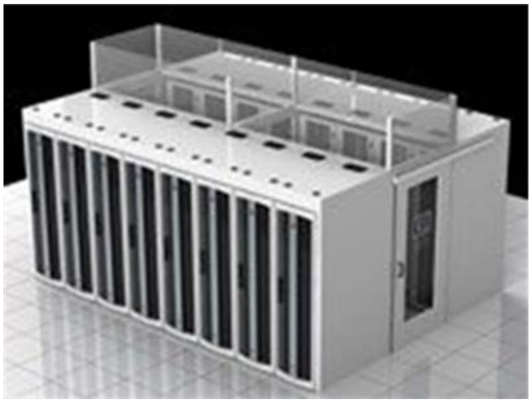

Figure 4 - Hot Air Containment System (Chatsworth)

In some cases, it will be beneficial to add walls or baffles to keep the hot and cold air apart. Figure 4 illustrates a hot air containment system, which can return the hot air to the intake of the CRAC. We want the cold air to do as much work for us as possible, and it will not do that if it is warmed by the hot air – it should be warmed by passing through the equipment needing to be cooled.

Sometimes the ends of the aisle will be closed off by doors in order to prevent cold and hot air from mixing. Doing so can increase your power density (watts dissipated per cubic foot of space) by up to four times, and can increase your cooing efficiency up to three times [5]. This increase in power density is due to more efficient direction of the cold air. The increase in cooling efficiency is due to the greater temperature difference between the hot and cold air. (Note that the efficiency of cooling the *air* increases with a greater difference in hot and cold temperatures, but air that is too hot will not cool *equipment* efficiently.) Depending on power densities, enclosing either hot or cold air aisles may or may not be deemed necessary. Your CRAC vendor will be able to advise you on the best approach in your situation.

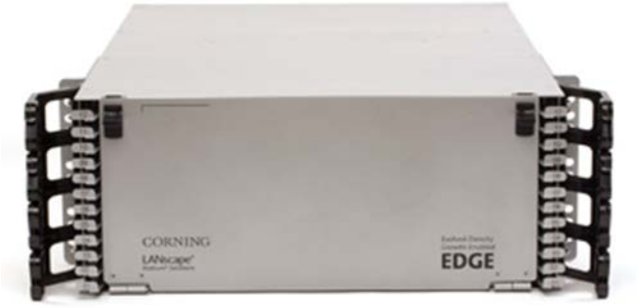

Figure 5 - Enclosed non-heat-producing equipment helps prevent air leakage

There will be some non-heat-producing equipment, such as fiber management, in your headend, as in Figure 5. It should be covered such that it does not let cold air leak into the hot aisle. Some operators go as far as sealing small leaks between the hot and cold aisles in order to prevent air mixing.

10. Variable Speed Fan Drives (general airflow issues) (Opportunity 8)

In this section, general airflow issues are reviewed, though the referenced listing [1] refers to variable speed fan drives. Even many home heating and air conditioning units use variable speed air handling, because it does improve the efficiency of heating and cooling. When less cooling is needed, fan speeds are reduced. This improves the efficacy and efficiency of cooling because it keeps the air moving at all times, improving the consistency of air temperature and reducing the losses associated with air blockages (more on this later).

11. Effect of Reducing Cooling Air Speed

We can illustrate the effect of reducing cooling air speed by referring to an analogy with electrical systems. The volume of air passing a certain point is analogous to current in an electrical circuit. The moving air encounters resistance from turns it must make and from obstructions it encounters, such as grating and cables it must flow around. Finally, the pressure differential between air at the output of a blower and at the input is analogous to voltage. Thus, we have an equivalent of Ohm's law that says pressure=(air flow)*(resistance). The power required to move the air is (power)=(air flow)^2*(resistance). This is the power required to move the air in a circuit consisting of the blower, the cooling apparatus, and the air path in the headend. You can see that the power required moving the air is proportional to the square of the air speed. (There are some non-linear effects in air flow that can cause the resistance to be a function of air speed, thereby exacerbating the effect described here.) Thus, the slower the airflow, the less it costs to pump it through the headend. On the other hand, the slower the air is moved, the less effective it is at removing heat. Hence the advantage of variable speed fan drives, which can slow down airflow when heat removal needs are lower and speed it up when required.

12. Reducing the Resistance to Airflow

Besides slowing the airflow when it is not required to be faster, we can reduce the resistance to airflow by eliminating or reducing as many impediments to airflow as possible. The fewer times the air must change directions as it goes through your headend, the better. Where it enters or exits from grates, the more open the grate the less resistance the air will encounter. Often the air handling is combined with cable raceways, as in the air plenum of Figure 3 above, where it is common to put the cable raceways in the plenum. This may happen in overhead environments too.

Figure 6 - Size comparison of fiber and reduced-size CAT6A bundles

Let’s consider options in certain wiring, to use fiber or copper cabling. If the air handling is shared with cabling, it will be more efficient to use fiber, as illustrated in Figure 6, where 48 CAT6A cables are required to serve the same number of ports as is a single 0.58-inch cable bundle of fibers. The benefit of the smaller size of the fiber cabling is shown in Figure 6, but the savings can also be illustrated using a simulation of airflow around the fiber and copper cabling.

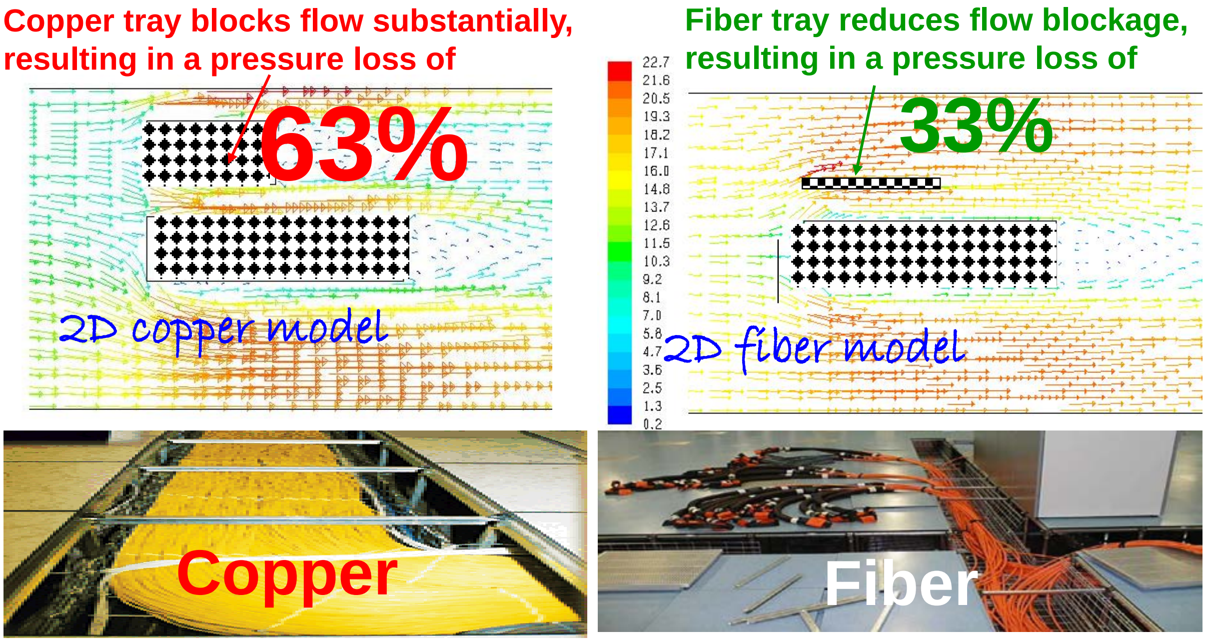

Figure 7 - Simulation of airflow around copper and fiber cabling

Figure 7 illustrates two dimensional simulations of air flow around copper and fiber interconnections. The pressure loss is another way of expressing the resistance the air is encountering. The simulation shows a pressure loss of 63 percent for the copper model and only 33 percent for the fiber model, making the point that the smaller the size of the cabling the less energy it is going to take to move air passed it.

13. Advantages of Fiber in the Headend

Fiber offers a number of advantages over copper (CAT 5/6) cabling in the headend, some of which have been alluded to above. The size of the fiber bundle needed to move a given amount of data is smaller than the size of the bundle of copper wiring needed to move the same amount of data. This smaller fiber bundle obviously impedes airflow less, as illustrated above in Figure 7. It can also make cabling the headend easier, as both the size and weight of cabling is reduced.

In many cases, multimode fiber can be used in the headend. It is not intended to transport signals long distances, but it may work in the headend. Multimode fiber can be preferable over single-mode fiber for several reasons. First, connector attachment with multimode fiber is faster than connector attachment for either single-mode fiber or for CAT 5/6 cable, with less chance for error. Another reason is that the light is visible, making signal tracing easier and drastically reducing the potential of eye damage from inadvertently looking into an active fiber.

As illustrated in Figure 1, fiber transceivers dissipate about one-third the power dissipated by copper transceivers operating at the same data rate. Finally, those who have worked around CATV RF components will really appreciate this last advantage, held in common with fiber optic cable in the plant: there is no possibility of RF pick-up or radiation from fiber optic interconnects, and no possibility of it introducing ground loops.

14. Conclusions

As we strive to get more performance from inside plant, with fewer dollars allocated to get that performance, ultimately our attention falls on the efficacy and efficiency of the cooling in headends and hubs. The better job done in cooling, the better (and cheaper) our plant will perform. For a major renovation or new build, it is likely advantageous to bring in a cooling expert who can define the optimum ways to cool, given your equipment mix and climate.

Appendix: The Difference Between Headends and Hubs [6]

Those from a telephone background call the point where signals are assembled to go to subscribers, a *central office*, or *CO*. Those from a cable TV background call it a *headend*. Either way, it is the point at which communications of all types are assembled for transmission to the customer.

Telco people might call a field-mounted terminal which converts signal formats and sends them the last distance to a home a *digital subscriber line access multiplexer*, or *DSLAM*. Cable telecommunications people call it a *hub* (maybe a *node* would also fit that description, we shall define both below).

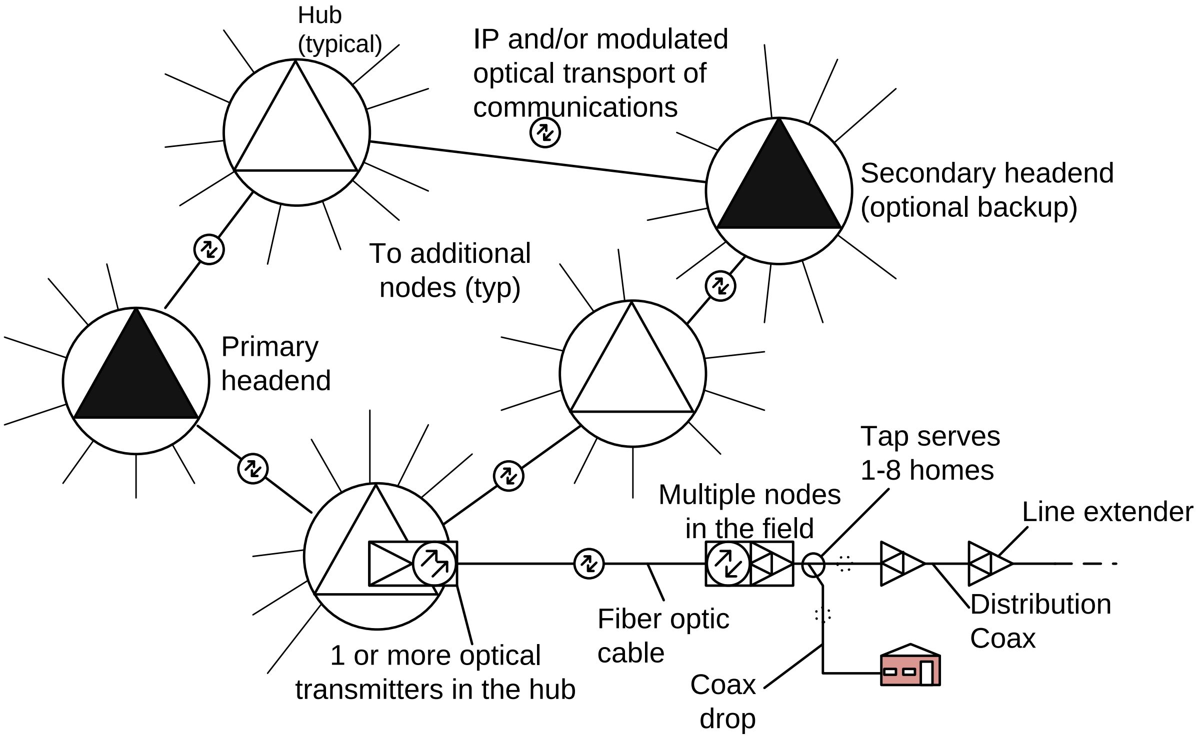

Figure 8 - Headends and Hubs in Cable TV Plant

Figure 8 illustrates a high-level HFC system as it might be applied in a large metropolitan area. A primary headend gathers most or all TV content, and may be the interface point for data and voice services. An optional secondary headend, which mirrors the functions of the primary headend, may be placed in a geographically different part of the metropolitan area, so that if a disaster, such as a fire, occurs at the primary headend, the secondary headend can take over. The headend(s) are linked using fiber optic cables, to hubs, which may serve 10,000 to 20,000 customers. The hub may include certain data and maybe voice equipment and will typically convert signals to the RF modulated format needed on the coaxial cable. The RF signals are in turn modulated onto optical carriers in optical transmitters. The output of these transmitters differs from that which you may have experience with for transmitting data. Rather than transmitting a digital signal, represented by light ON for a binary 1 and OFF for a binary 0 (or vice versa), the optical transmitter of Figure 8 is a linear (analog) transmitter capable of transmitting a wide spectrum of RF signals (typically from 54 MHz to 1,002 MHz or more in North America), each RF signal carrying one of several types of content: one 6 MHz (8 MHz in many parts of the world) channel may carry one analog video signal (declining in use), or multiple digital TV signals, or time-division-multiplexed data including voice. These signals are assigned a frequency band, and many such signals can coexist at one time on one fiber optic transmitter.

The optical transmitter puts signals described above onto a fiber optic cable, which traverses most of the distance to a neighborhood to be served. At the neighborhood, a *node* demodulates the optical signal, turning it back into the RF modulated carriers which went into the optical transmitter. From here, the signals are transported to homes through coaxial cable. RF amplifiers are usually needed to overcome signal loss, which loss may be attributed to two mechanisms. Each time a tap is used remove some signal power to serve one or more homes, conservation of energy dictates that less power is available to go further downstream to other homes. The second mechanism is loss in the coaxial cable itself, which can be significant. If the signal level gets too low, then analog channels get noisy (“snow” in the picture). If digital signals get too low in amplitude, the picture or data disappears, with just a small signal level range where the picture breaks up.

Upstream signals are all RF-modulated carriers, returned over the coax by using lower frequencies on the coax (typically 5 to 42 MHz in North America). At the node they are modulated onto an optical carrier by an upstream transmitter, and then transmitted to the hub, usually on a dedicated fiber. Sometimes the same fiber used for downstream transmission will also be used for upstream transmission, using a different wavelength.

Many areas of the world use other transmission standards. In many locations, RF channels are 8 MHz wide rather than the 6 MHz used in North America, and carry upstream signal at frequencies up to about 65 MHz, with downstream signals being carried from about 85 MHz up. For many years there has been talk in North America about changing our split between upstream and downstream frequencies, but momentum and the market are hard things to overcome.

15. Abbreviations and Definitions

15.1. Abbreviations

CMTS	cable modem termination system
CO	central office
CRAC	computer room air conditioning
DSLAM	digital subscriber line access multiplexer
EPA	Energy Star Program
IDC	International Data Corporation
IEEE	Institute of Electrical and Electronics Engineers
MHz	megahertz
QAM	quadrature amplitude modulation
Remote PHY	remote physical layer
RF	radio frequency

15.2. Definitions

plenum	An enclosed chamber where a treated substance collects for distribution, as heated or conditioned air through a ventilation system.

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[2] Ben Cutler, Spencer Fowers, Jeffrey Kramer and Eric Peterson, *Want an Energy-Efficient Data Center? Build It Underwater*, IEEE Spectrum Special Report, Feb. 21, 2017, http://spectrum.ieee.org/computing/hardware/want-an-energyefficient-data-center-build-it-underwater

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Society of Cable Telecommunications Engineers, Inc.
International Society of Broadband Experts™
140 Philips Road, Exton, PA 19341 - 1318
T: 800-542-5040 F: 610-884-7237

www.scte.org | www.isbe.org