OPTIONS for INTELLIGENT and SUSTAINABLE HFC NETWORK POWERING

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Introduction

Economic constraints, reduced operating budgets and environmental incentives for “green” operations; all of these factors will influence system operators to adopt more intelligent and sustainable operations in the near future.   Recent carbon footprint audits conducted on two major European network operators identified that 80% of their carbon emissions originated from two sources: utility power consumption and fleet vehicle operations (see chart (a))[1]. Improving efficiency in these two areas will provide significant cost reductions for operators.

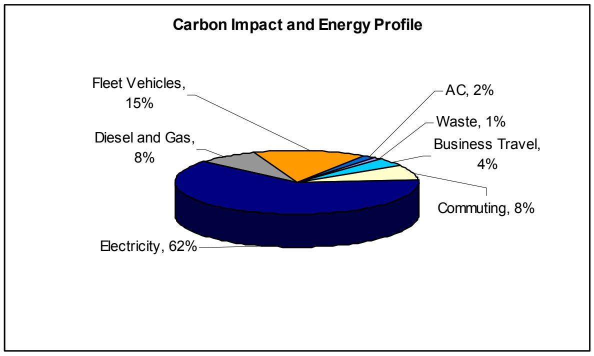


CHART (a)

To realize tangible improvements, operators must demand, and manufacturers must deliver products and tools offering improved energy efficiency and intelligent network power management.

Operators must also be willing to adjust operational practices to take advantage of efficiencies offered through these improved tools. The distributed hybrid fiber-coax (HFC) network powering architecture must be considered holistically to achieve optimal improvements in efficiency and operating costs. In this article, three aspects of HFC network operations will be considered for areas of potential savings in operational expenses: Efficiency of the HFC network powering equipment, management of lead acid battery assets and workflow management through intelligent operational monitoring systems.

HFC Network Powering Equipment Efficiency

Uninterrupted power is essential for today’s network communications equipment. Many long time professionals in the cable television industry will recall a time when broadcast video was the only provided service. The expansion of services was slow with rudimentary two-way services introduced in the 1980s. Ultimately proprietary data cable modems in the 1990’s paved the way for DOCSIS® standards and products, and led to the broadband cable network capabilities of today. With such explosive growth in the last 10 years, no one involved in the early cable television industry could have anticipated the evolution of technology and associated services available in 2010. As residential and commercial customers have grown to depend on these services, the need for network reliability, including uninterruptible power, has become more important. Financial operating losses associated with network power failures are metrics any operator can wield on a moment's notice. Less understood are the ongoing costs of operating network equipment and how improvements to equipment efficiency could provide measurable savings to operating expenses by reducing utility power consumption, while maintaining the same high level of network reliability.

From the carbon footprint audits mentioned earlier, a breakdown of MSO electricity usage shows that 72% of the total corporate electrical utility consumption is attributed to powering the outside plant (OSP) network and associated headend infrastructure (see chart (b))[1]. The other 28% of utility power consumption went to powering offices, warehouse buildings and other administrative functions.

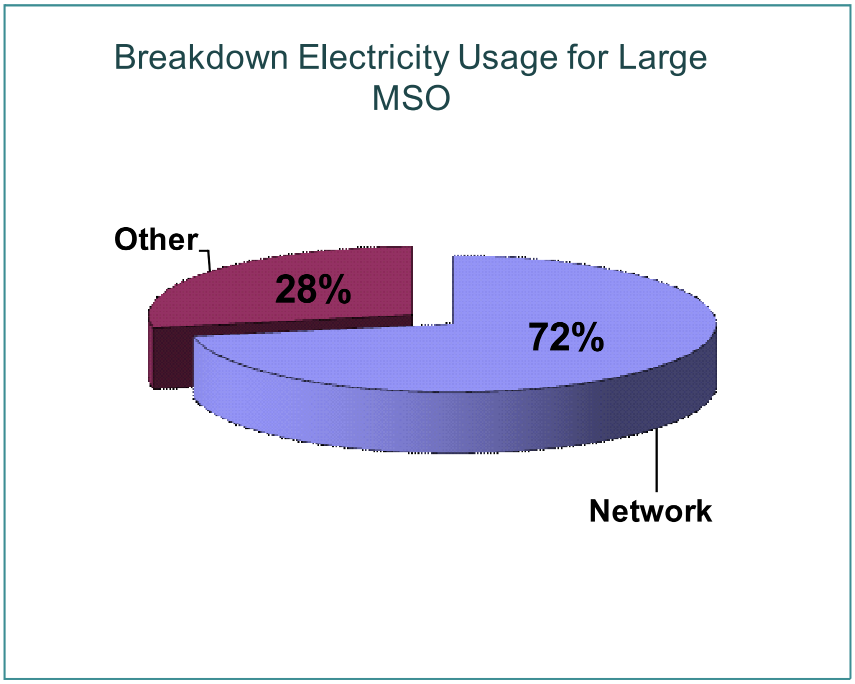


CHART (b)

Since OSP operations represent such a large percentage of the MSO's total utility power consumption, a study of the OSP network powering components used to provide primary and backup power for the active network components is necessary to identify areas for improvement. The OSP is typically a hybrid fiber-coax (HFC) architecture containing active components for optical to copper transition (optical nodes) and copper signal transmission amplification (line amplifiers, line extenders). The HFC uninterruptible power supply (UPS) is a network component providing primary and backup power to all active components in the HFC network. A typical HFC UPS is located in an outdoor-rated enclosure and is either pole- or ground-mounted. The enclosure contains inter-connects to utility power and provides storage for batteries used for backup power during a utility outage. Installations can be equipped with natural gas or propane generator systems providing extended backup power during prolonged utility outages.

[1] Carbon Impact Study prepared by Coppervale, an international energy efficiency and conservation consultancy

The ferroresonant transformer (FT) is a primary component of traditional HFC UPS devices. The FT isolates utility grid power from HFC network power and provides appropriate step-down voltages for the UPS to operate. By design, the FT operates in magnetic saturation providing the active components in the HFC network a high degree of electrical isolation from undesirable energy transients on the public utility grid. Although extremely robust, FT-based power equipment has inherent inefficiencies from induction losses. Also, FT-based power equipment must operate near rated capacity or efficiencies will drop drastically.

Two aspects of FT-based power equipment should be exploited to improve operational efficiency and thereby reduce associated utility power consumption. First, since FT-based equipment efficiencies are optimal when the equipment is operated at or near its rated capacity, network power requirements should be analyzed and FT UPS equipment should be sized and deployed to operate near rated capacity for specific applications. This becomes increasingly relevant as deep fiber applications dictate lower power loads in discrete locations. Chart (c) illustrates how efficiency changes with varying output current on five different FT-based UPS products rated at 15A output capacity.

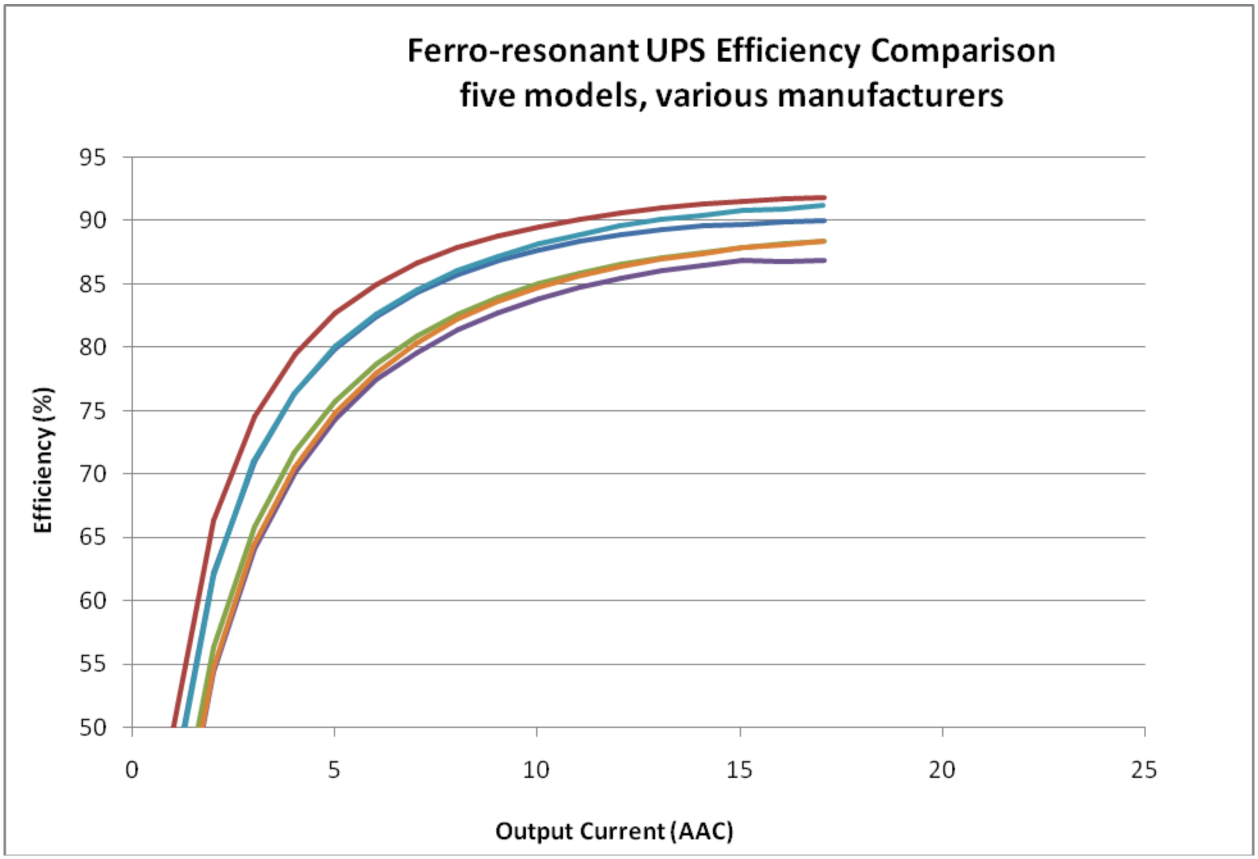


CHART (c)

In this example, five FT-based UPS models were tested. Each model was rated for 15A output current capacity. In all cases, as utilized power decreased below 60%-70% of rated power, the UPS' electrical efficiency reduced dramatically.

The result of operating at lower efficiencies is electrical energy lost in the form of heat. From this chart, a typical UPS rated at 15A with an output load of only 5A of current could be operating at 75% efficiency. This equates to 25% of the consumed utility power being lost. No electrical circuit is 100% efficient so some loss will always be present. As this chart illustrates, approximately 92-93% efficiency is optimal for these FT-based UPS products. The difference between optimal efficiency and decreased efficiencies as observed with lower output current is energy lost in the form of dissipated heat from the FT. A simple example illustrates converting this lost energy to actual cost as follows:

Assumptions:

1. UPS output voltage is 90VAC
2. Utility rate is 10 cents per kWh.

Calculations:

a. UPS Output Power: = 90VAC x 5A = 450W
b. Utility Power Usage: = 450W / 75% = 600W
c. Total Power Loss: = 600W – 450W = 150W
d. Cost of Lost Power: = 0.150kW x $0.10/kWh x 8,760 hours/year
= **$131.40 per year per power supply**

Using this simplified example, an operator with several thousand power supplies operating at similar efficiencies could realize substantial savings in annual utility power cost by auditing power site usage and re-allocating UPS' with lower power ratings to network locations with lower power requirements.

The second method of improving operating efficiency in FT-based powering equipment is through design improvements to the FT core. Manufacturers should be challenged to optimize FT designs to increase efficiencies in existing applications. Optimizing the FT magnetic shunt design and transformer core materials could result in 2-4% efficiency improvements. The resultant FT design would have additional cost due to the use of higher grades of steel and more precise lamination assemblies. Operators should be provided the option to choose these more efficient FT designs and determine if any additional cost is offset by increased efficiencies. In practice, an efficiency improvement of approximately 3% on a 15A UPS translates into an annual utility savings of $25-$45 when operating near rated capacity[2].

[2] Assumes a metered utility rate of 10 cents per KWh

Another method for reducing utility power consumption throughout an organization is through the integration of renewable energy resources like solar and wind. A renewable energy resource can be used to either supplement utility power or provide an additional benefit through an off-grid electrical circuit.

In the Southwest United States, one major MSO implemented a solar grid-tied generation system on their facility's parking structures to produce electricity and help offset utility dependency. This same MSO is currently evaluating off-grid solar augmented HFC power systems to cool equipment and batteries during daytime hours when utility power rates and usage are at peak levels.

Battery Management

Batteries used for uninterrupted service during utility outages represent one of the single highest cost components in an HFC network. Ideally, management tools would provide advanced warning of battery degradation as usage, age and environment diminish battery capacity. This advanced notification would enable operators to schedule proactive site visits to replace weak batteries prior to network outages. In addition, preventive maintenance (PM) visits to individual OSP power supply installations could be completed based on need rather than being arbitrarily scheduled, dramatically reducing fleet activity.

There is no known exact science for predicting capacity or state of health of lead acid batteries. Many estimation methods exist but none alone are reliable predictors. Environmental extremes typically experienced by outside plant network components render these estimations even more unpredictable. Estimation tools must use a combination of methods to provide the best possible prediction of battery capacity, and power equipment must support appropriate battery testing and data logging for predictive calculations to be useful. Finally, power supply transponders and monitoring software must provide accurate and timely reporting of battery health to allow operators to respond appropriately. Table 1 lists some of the inputs used for battery state of health predictions.

Battery Health Indicators

Measured Parameter	Application
Battery Voltage	Individual absolute battery voltage measurements can quickly identify some faulty batteries. Battery manufacturers specify absolute minimum discharge voltages that must be observed to avoid permanent damage to individual batteries within a string. Maximum charge voltage

	specifications must also be observed when recharging batteries to avoid damage.
Battery Temperature	Low battery temperatures diminish runtime during individual discharge cycles but do not normally cause permanent damage. If battery temperatures exceed manufactured limits permanent capacity reduction may result. High temperature capacity degradation is cumulative. Lifecycle temperature history over the installed life of individual batteries is an indicator of future performance.
Battery to Ambient Delta Temperature	Battery temperature should measure within a few degrees of the ambient temperature of the enclosure housing those batteries. A battery temperature > 10°C above its local environment indicates an undesirable condition, such as a shorted internal cell, and significantly impacts battery health.
Battery Conductance	Conductance, measured in mhos, indicates the internal AC resistance of a battery. Trending changes in conductance over a battery's lifecycle provides additional insight into battery health. Changes over time in conductance readings are typically more insightful than any one absolute measurement, however even a single conductance reading below specific thresholds can indicate battery failure has occurred or is eminent.
Deep Discharge Test Results	One absolute method to determine a battery's state of health is to execute a complete discharge test to measure actual runtime. Such tests are typically considered unacceptable in OSP networks due to vulnerability of an actual outage occurring during the recharge period causing service interruptions. Partial discharge tests can provide useful indications of battery health, but the test must discharge enough capacity to identify early voltage anomalies on individual batteries in the UPS' battery string.
Battery dv/dt Delta	Individual batteries in a battery string should exhibit similar discharge voltage (dv) curves over the same time period (dt). As batteries age, internal chemical differences typically cause individual batteries in a common string to discharge at different rates. Significant dv/dt differences between any two batteries in a string will cause premature failure of the entire string.
Discharge History	The number of battery discharge events and the depth of discharge for each event over the lifecycle of a battery string will contribute to determining the state of health of each battery. Recharge time following utility outages is also a good indicator of battery health.
Battery Model and Manufactured Date	Battery design life is specified by each manufacturer. Specific battery model parameters and manufactured date are essential in estimating the maximum usable life of any battery.

Table 1

Historically, OSP management tools available to operators have been deficient of the useful and concise information required to proactively schedule PM services. At best, some of the information listed in table 1 is presented in raw form or loosely interpreted by management systems leaving operators with the option to either ignore the data or attempt to read the tea leaves of battery health indicators.

To realize measurable benefits in this area, operators must demand specific functionality from manufacturers that provide a meaningful indication of battery health. Due to the complexity of predicting battery state of health, operators and manufacturers must agree on a set of metrics that are both meaningful to the operator and achievable by the manufacturer. The scope of implementing these metrics can neither be cost prohibitive to implement nor time prohibitive to develop. Although no single data indicator represents the panacea of battery health, several of the indicators from Table 1 can be combined to produce meaningful information in most cases.

Ideally, a standard definition for battery state of health would be provided to assist operators with advanced PM scheduling, and give equipment manufacturers and software vendors a set of requirements to meet. A simple battery state of health definition would at minimum include three reported states:

Battery State of Health Operator Definition

State	Definition
Batteries OK	Batteries are OK. Regularly scheduled PM visits to this site may be deferred.
PM Recommended	Batteries show evidence of sub-standard performance. A PM visit should be scheduled to evaluate the physical state of the batteries and replace one or multiple cells in the string.
Replace Batteries	Specific measured battery indicators or calculated values definitively show the batteries will not sustain the UPS load during the next utility outage. PM and battery replacement should be prioritized.

Table 2

By implementing a standard definition such as the one shown in Table 2 the onus for determining battery state of health rests squarely on the shoulders of equipment manufacturers and software vendors rather than being left to operator interpretation. This should require each manufacturer to clearly demonstrate their methods and measurement criteria are sufficient to produce acceptable results. Operator requests, including formalized RFP’s that contain battery state of health requirements, would obligate manufacturers to define, develop and ultimately provide these features.

Improved Workflow Management

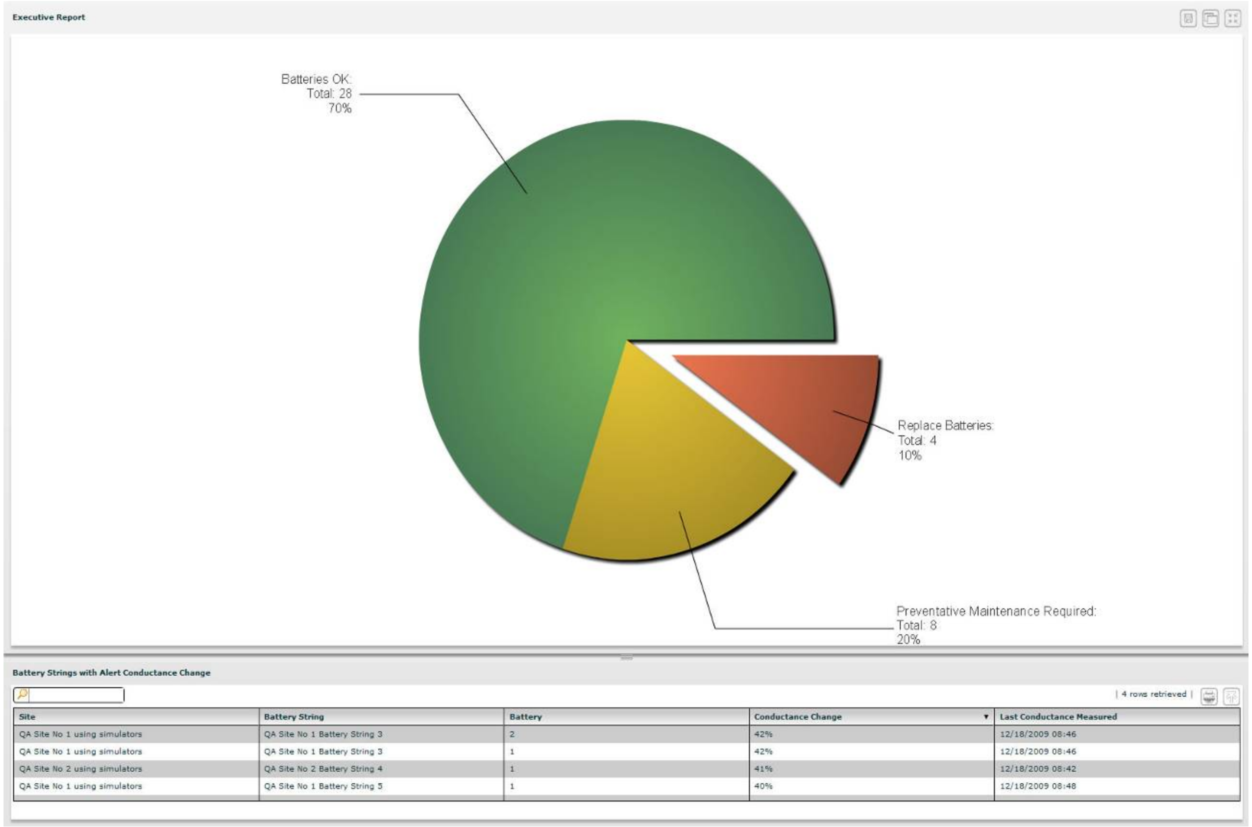
Intelligent Management Systems should translate network element data into useable information. In practice, these systems often report too much data, causing operators to disable alarms and disregard reports that could be useful if effectively managed. Management systems should analyze data and provide recommended actions such as prioritizing visits to sites with a higher probability of diminished battery runtime during future outages. Smart workflow management routing of this type will reduce total fleet truck rolls by reducing scheduled preventive maintenance visits to sites where batteries do not require service and eliminating some emergency response visits during future utility outages. Preventive maintenance for sites with optimal battery runtime can be scheduled less frequently, subsequently eliminating many truck rolls relating to power outages.

Manually tracking battery data for more than a small number of locations is error prone, expensive and unmanageable. Intelligent Management Systems with smart workflow capabilities should provide a means for operators to accurately track and analyze any number of batteries in the field. In addition to reduced truck rolls and therefore reduced carbon footprint, these improved battery management capabilities will allow a more efficient utilization of battery resources. To achieve the benefits allowed by an Intelligent Management System, smart workflow features must automate the tracking, analysis and reporting of battery health.

An Intelligent Management System should support proactive battery maintenance by assessing the current state of each battery and of each battery string. This assessment can be achieved by collecting and analyzing various data parameters including discharge voltage trends from automated standby tests and historical data from actual utility power outages. The ongoing analysis of battery information should result in a prioritized list of OSP power supply locations that require battery replacement during the next scheduled maintenance visit. These batteries can be highlighted with a "replace battery" status in reports generated from the Intelligent Management System.

The Intelligent Management System should also provide an assessment of longer-term battery health. This assessment can be achieved through the analysis of additional battery health indicators (refer to Table 1) such as runtime history, battery conductance, and battery charging characteristics following power outages. Changes in battery conductance should be trended over an extended period of time (e.g. months or years), since individual measurements can vary depending on external parameters such as temperature. Utility outages present the opportunity to analyze battery charging characteristics, a fairly reliable measurement of battery health. These approaches can be used to determine battery health as part of an automated workflow process, allowing the system to provide a prioritized list of outside plant power locations requiring attention based on the overall health of the associated batteries (see Figure 1).

Reports should identify batteries that are nearing their end of useful life, allowing PM visits to be scheduled appropriately.



Site	Battery String	Battery	Conductance Change	Last Conductance Measured
QA Site No 1 using simulators	QA Site No 1 Battery String 3	2	42%	12/18/2009 08:46
QA Site No 1 using simulators	QA Site No 1 Battery String 3	1	42%	12/18/2009 08:46
QA Site No 2 using simulators	QA Site No 2 Battery String 4	1	41%	12/18/2009 08:42
QA Site No 1 using simulators	QA Site No 1 Battery String 5	1	40%	12/18/2009 08:48

Figure 1: Battery Health Prioritization based on Conductance

Ideally the operator could view prioritized battery status reports corresponding to their maintenance structure, which may include reports by region, headend, node, etc. This subdivision allows for both centralized and local management of the operator's batteries. In addition to prioritizing OSP power locations by battery health, locations should be prioritized by a combination of status and geographic location via the Global Positioning System (GPS) coordinates of each site. The system would allow for parameters such as travel time to each site and average site visit duration (e.g., 30 minutes) to estimate the lowest cost routes to each site.

By providing operational reports that include locations prioritized by battery health status and GPS location, the Intelligent Management System should directly support:

- increased network availability through effective UPS battery management

- reduced operational costs through more efficient use of battery resources and reduced scheduled and unscheduled truck rolls
- reduced carbon footprint through a reduction in truck rolls

From an environmental standpoint, the carbon footprint reduction can be significant. For example, each three-mile truck roll generates approximately 4.9 pounds of carbon, based on US Environmental Protection Agency (EPA) estimates.

An Intelligent Management System can automate the tracking and prioritization of battery maintenance based on projected battery health and subsequently the remaining battery life. Maintenance schedules can be planned based on the battery status and geographic location of the batteries relative to other locations requiring service. Effective management of the large volumes of battery data available from OSP networks by an Intelligent Management System allows the operator to realize savings that would otherwise not be achievable.

Summary

Three aspects of HFC network operations were presented as areas of potential savings in operational expenses: Efficiency of the HFC-network powering equipment, management of lead acid battery assets and workflow management through intelligent operational monitoring systems. Improved efficiencies in the ferroresonant transformer were identified as an important way to reduce energy costs along with renewable energy sources such as wind and solar energy.

Since batteries used for uninterrupted service during utility outages represent one of the single highest cost components in an HFC network, efficient battery management is paramount to reducing operations cost and the associated carbon footprint. Key battery health indicators need to be applied to Intelligent Management systems that can automate the collection and analysis of large amounts of battery data in order to convert this data into valuable information required to effectively manage the operator’s battery resources.