BROADBAND NETWORKS

Keeping The Lights On

Protecting Your Remote Active Fiber Elements
Against Unplanned Outages

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INTRODUCTION

Cable operators worldwide are deploying passive optical networks (PON), realizing high-capacity, low latency performance with low maintenance costs. Although PONs are essentially passive, current architectures make use of outside plant (OSP) active optical components. Strand or pedestal mounted Remote Optical Line Terminals (R-OLT) can replace rack mounted OLTs of a few years ago. When fiber runs extend beyond optical transceivers effective range, midspan Erbium Doped Fiber Amplifiers (EDFA) boost optical levels and extend fiber reach. Evolving PON architectures are designed to support higher speeds and extended service areas. Next-generation PON implementations will likely include high speed coherent optic links from headends to new OSP aggregation nodes, enabling even faster services to extend deeper into the network. Each active optical component in our PON architecture requires reliable, uninterrupted power to keep the network running.

This paper reviews aspects of powering the OSP active components of modern PON networks, including: power levels, utility grid isolation, utility backup duration and power system status monitoring. Unique requirements for powering expanded rural fiber networks are discussed as well as considerations for addressing an aging utility grid and the impact of extended outages. Roles and methods for power monitoring and remote management are discussed as well as the need for predictive and restorative maintenance.

PON IS GROWING BRIGHTER

Today's consumer broadband networks need high-speed symmetrical bandwidth and low latency to deliver superior customer experiences for applications like augmented reality/virtual reality, over-the-top streaming video, cloud gaming, videoconferencing, 5G backhaul and other peer-to-peer networking services.

All roads lead to fiber. Fiberoptic cable as a data transport media has no equal with respect to performance and total cost of ownership (TCO). However, DOCSIS over coax cable has outpaced consumer broadband demands exceptionally well. Most experts believe DOCSIS still has many years of life before running short on performance. So, there's no immediate or urgent need to replace the majority of installed coax with fiber. The low TCO and almost unlimited bandwidth of fiber are well understood by operators. As a result, operators have started migrating greenfield and network extensions to all fiber based. In 2021, global research firm Omdia polled broadband operators, asking which type of network upgrades does your company plan to carry out by fall 2026. The poll results in Figure 1 clearly indicate Fiber to the Home (FTTH) deployments as the highest priority.
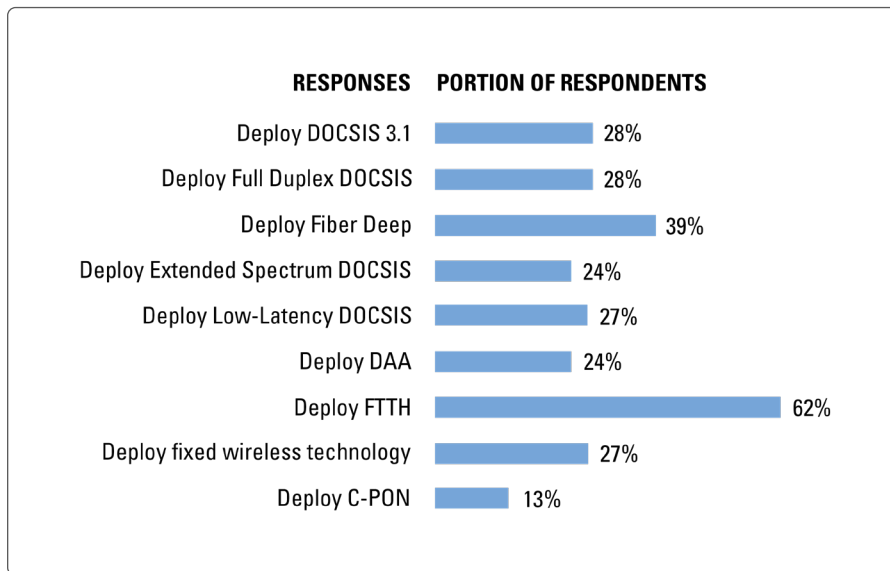
RESPONSES   **PORTION OF RESPONDENTS**

Responses	Portion of Respondents
Deploy DOCSIS 3.1	28%
Deploy Full Duplex DOCSIS	28%
Deploy Fiber Deep	39%
Deploy Extended Spectrum DOCSIS	24%
Deploy Low-Latency DOCSIS	27%
Deploy DAA	24%
Deploy FTTH	62%
Deploy fixed wireless technology	27%
Deploy C-PON	13%

Figure 1 – Broadband Operators Poll (Omedia, 2021)

In a separate poll, broadband equipment providers were asked about access equipment revenue forecasts for North America. The Figure 2 results from this poll clearly identify PON equipment sales leading the ranks and increasing dramatically through 2026.
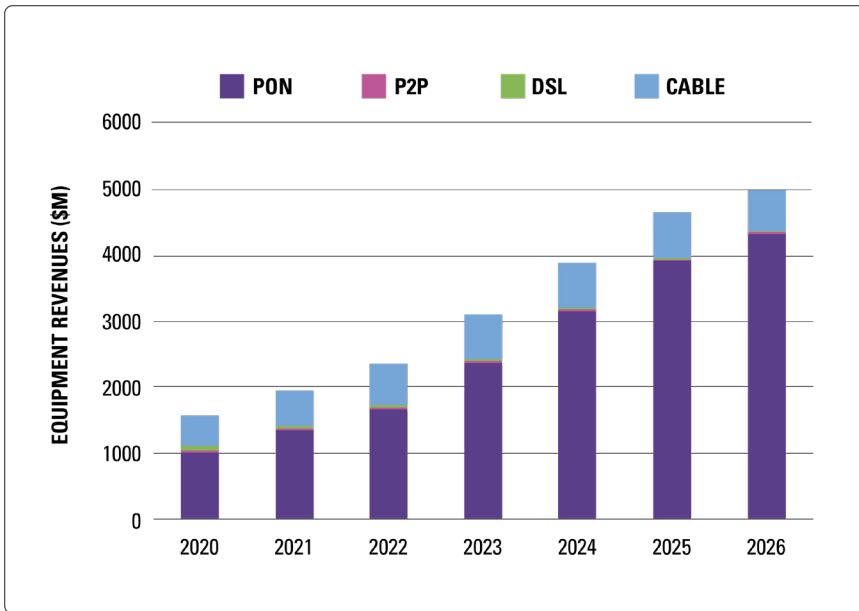

Figure 2 – Broadband Equipment Providers Poll (Omedia, 2021)

There's no doubt that investment in cable broadband access solutions will continue for many years. The strategy for most cable operators is not replacing coax cable with FTTH. The strategy for most operators involves when and where to add FTTH. Another indicator of the trend towards FTTH from the Fiber Broadband Association reports that at the end of 2021, 43% of US households and 60% of Canadian households had access to fiber services.[1]

STRAND-MOUNT R-OLT

Silicon advancements in recent years have enabled R-OLT modules to fit within strand-mount optical node enclosures or housings. Distributed Access Architecture (DAA) node housings can be used for this application. The modules and node housing are

designed such that a R-OLT or R-PHY module could be installed. Some equipment providers advertise the ability for their housing to support both R-OLT and R-PHY modules simultaneously, servicing PON and QAM customers from the same node. This application has been nicknamed DAA-OLT. An example of a strand mount R-OLT module and housing is shown here.
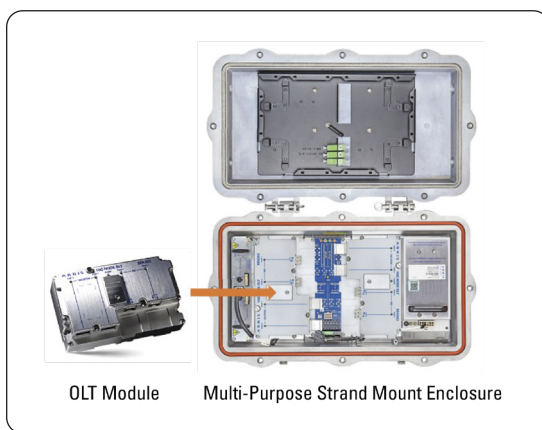

OLT Module   Multi-Purpose Strand Mount Enclosure

Figure 3 – Example Strand-Mount R-OLT

Two large NA operators reported in June 2022 that strand-mount R-OLT equipment will be a primary FTTX upgrade tool for the next few years. One R-OLT equipment vendor has reported that revenues for DAA-PON modules for NA increased from about $300,000 in 2020 to over $10 million in 2021. It looks like PON is here to stay.[2]

ABOUT RDOF

A major contributing factor to accelerated broadband fiber builds in the US is the Rural Digital Opportunity Fund (RDOF). RDOF will provide $20.4 billion in funding over a ten-year period to support broadband networks in rural communities across the US. Among the top RDOF awards, Charter qualified to receive $1.2 billion in federal government support for deployment plans spanning some 1.1 million locations. Tom Rutledge, Charter's chairman and CEO, said that the company has RDOF work underway in all 24 states where it won bids in phase I of the RDOF auction. All told, Charter plans to build fiber and gigabit

services to more than 1 million rural, unserved locations. Through RDOF, the company will add more than 100,000 miles of new network infrastructure to its existing 800,000 miles of infrastructure in the coming years.[3]

The RDOF program does not dictate specific technologies for new broadband services. However, the FCC has proposed creating performance tiers for RDOF funding. High bandwidth, low latency fiber solutions will be most favored.

ANATOMY OF A PON

During a recent CableLabs conference, Stephanie Mitchko-Beale, Charter CTO stated "the speed of change keeps me up at night"[4]. This sentiment is likely shared by anyone responsible for the accelerated FTTH deployments in recent years. FTTH and PON are simple in principle but the popular cliché "the devil is in the details" was never truer than with PON deployments. For more details let's review the simple broadband network block diagram in Figure 4.
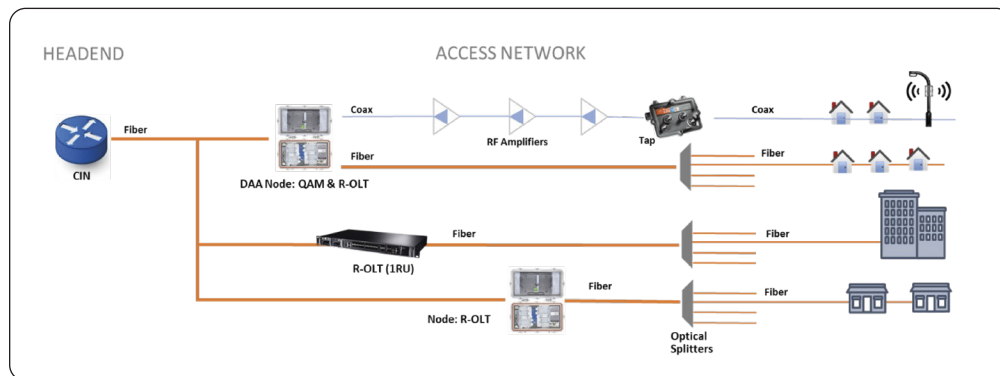

Figure 4 – Sample Broadband Network Diagram

Network architectures vary with operators, geography and many other factors. This block diagram does not represent a specific installation but only a few of the more common network building blocks. Moving from the headend on the left throught the access network on the right, the network elements shown in this diagram include:

- A headend based Converged Interconnect Network (CIN) delivers transport and aggregation functions for diverse networking elements such as DOCSIS, PON OLT, DAA, 4G/5G, and so on. The CIN is the glue enabling various disparate elements to interact and interoperate.

- Fiber distribution is physically routed from the headend to nodes and OLTs. Some operators refer to this fiber segment as optical trunk fiber. Today, this fiber would likely carry 10Gb Ethernet which is fast replacing the CWDM and DWDM analog fiber transmissions of the past.

- DAA node service groups can support QAM video and data using DOCSIS. R-OLT modules can be co-installed in node housings with DAA modules or installed nearby to support PON.

- In densely populated areas, multiple shelf mounted R-OLTs may be housed in curbside equipment enclosures along with fiber distribution, powering equipment and batteries.

- Remote OLT modules installed in strand mounted node enclosures are an alternative to cabinet (rack or shelf) mounted OLTs.

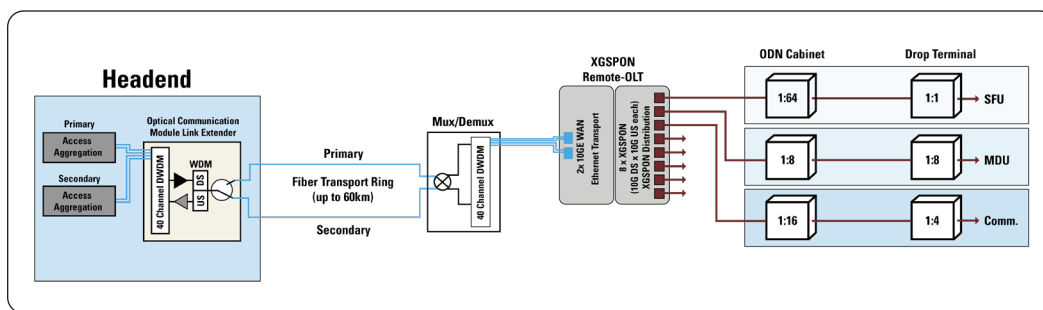Let's review a specific FTTX example presented at the 2021 Cable-Tec Expo by Cox Communications[5].

Figure 5 – Cox Communications FTTX Architecture

A few noteworthy details from this FTTX architecture include:

- The R-OLT is the only active element in the access network. When practical, the OLT is located near the HFC plant to utilize coax for both power and telemetry.

- In greenfield installations where there is no nearby coax to power the OLT, a curbside enclosure may be used to house multiple OLTs, fiber distribution equipment and a backup power system for the OLTs.

- Headend based EDFAs facilitated a fiber transport ring of up to 60km to the R-OLT (either strand-mount or cabinet based). With a 1:64 split, the reach from the R-OLT to the premise is up to 20km. From ODN cabinet to premise is 8km maximum reach.

- The Cox network utilized XGS-PON optical signaling.

PON AND 10G

The CableLabs 10G initiative promotes 10Gb symmetrical services using any number of technologies. Two predominant PON protocols are in use today: XGS-PON and 10G-EPON. Both can directly support the full intent of 10G. XGS-PON is an ITU standard with roots in the telecommunications industry while 10G-EPON is an IEEE standard more common in data centers. Both protocols offer approximately 10Gb symmetrical service. When it comes to powering PON network elements, it doesn't matter which optical communications standard is used.

With change being inevitable, PON architectures beyond 10Gb are anticipated and in some cases, already here. Powering new and upcoming PON devices should be considered to assure that today's powering approach will support future upgrades. CableLabs has presented a next generation PON architecture utilizing a new OSP active component: an optical aggregation node. This next generation PON is shown in Figure 6.
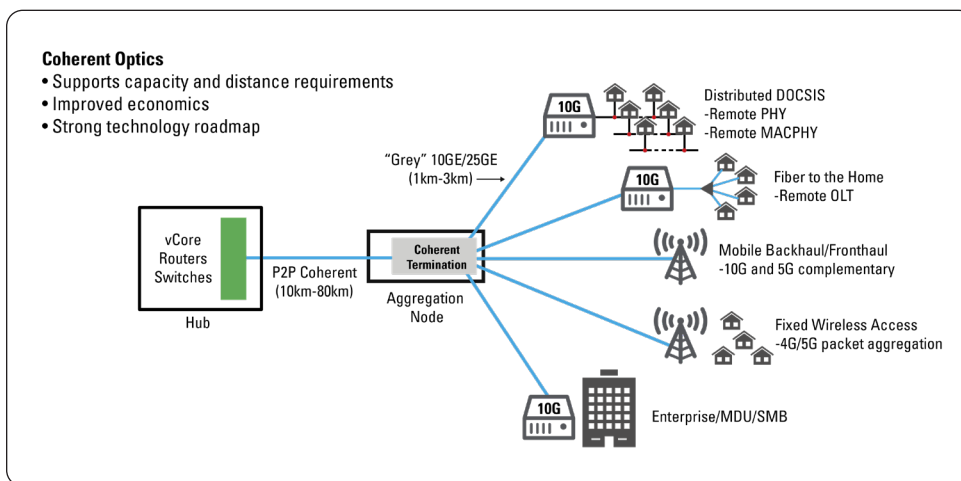
Figure 6 – PON Beyond 10G, CableLabs

This near-future PON enhancement contains a new active component, an Aggregation Node (AN). In this architecture, new high speed fiber communications are pushed deeper into the network by use of high-speed coherent optics between the hub and the new AN. This link could be 50Gb, 100Gb or faster.[6] The AN will act as an optical Ethernet switch providing lower speed (10Gb for example) optical links to downline elements such as DAA nodes and OLTs. The result is higher capacity services deeper into the network and closer to subscribers. From our PON powering vantage point, we've simply added another active element to the mix. Once AN elements begin to be deployed, power requirements will need to be analyzed. Given the state of coherent pluggable combined with known high speed switching elements, we anticipate that an AN may require approximately 200W in a fully configured state. This estimate remains highly speculative until actual architectures using AN prototypes are deployed.

In general, backup power is fiber protocol agnostic. Fiber wavelength, communication protocols (10G-EPON vs. XGS-PON), distribution methods and so on, don't affect power. We need to understand the location and power needs of the few but critical active components. Powering these active elements will be discussed in the next section.

POWERING PON

Powering broadband PON is similar, and often simpler, than powering traditional HFC networks. Optical actives can be powered from the coax network when an HFC plant segment is nearby. More often, PON equipment needs a dedicated UPS and batteries for uninterrupted power. A side-by-side review of HFC and PON powering should illuminate noteworthy differences.

Table 1 – HFC & PON Powering Differences

Powering Consideration	HFC	PON
Powered equipment	Optical nodes, amplifiers, line extenders	OLTs, EDFAs and ANs (future)
UPS to equipment ratio	One-to-many	One-to-one (typically)
Equipment voltage	90VAC	90VAC (strand-mount R-OLTs) 48VDC (shelf mount R-OLTs)
Distance from UPS to equipment	From co-located to 1,000's of feet via powered coax.	Co-located (1)
Total power required	HFC network designs often utilize full UPS capacity. Typical broadband UPS are rated from 1350W to 1620W	Powering a single OLT may require ~140W.
Utility grid protection	Required	Required
Backup power duration	4 to 72 hours (2)	6 to 72 hours
UPS status monitoring	DOCSIS	Fiber

OLTs may be coax powered in situations where HFC coax is nearby.

The CPUC 72-hour telecommunication backup requirement is an extreme case. Operator backup time policies typically vary from 2 to 8 hours.

Let's review some of the important differences between powering HFC and PON.

POWERING HFC VS. PON

Traditional HFC networks include optical nodes, amplifiers, and line extenders. These active components are powered from a UPS through the coax. The number of actives that can be powered from a single UPS depends on a combination of the equipment's total static load and the combined coax span lengths between powered devices. Longer coax spans have higher line resistance, creating greater Joule losses (I.E., power loss due to resistance in coax cable, electrical energy is converted to heat). Cable resistance and current flow through the coax results in a voltage drop across each coax span and a lower end of line voltages. In most cases, cable plants will run short of power or end of line voltage before they run out of devices to be powered. Also, operators' internal design policies guide network designs to limit UPS loads to a percentage of the UPS' rated capacity, often in the 80% range.[7]

Powering PON equipment takes a slightly different approach than powering HFC. The broadband network in Figure 7 shows three different PON segments, each with unique powering schemes. A review of these PON segments and powering options will prove illuminating.
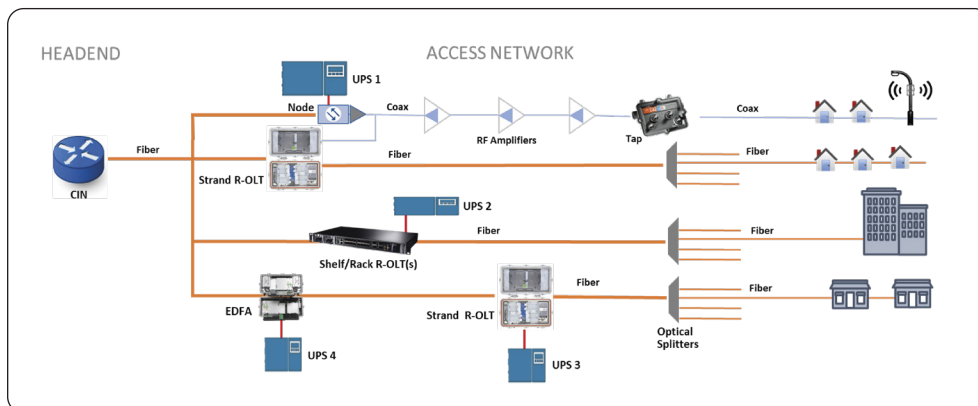

Figure 7 – PON Powering Examples

PON EXAMPLE 1

The network diagram shows UPS 1 powering an optical node, downline amplifiers and a R-OLT. In this scenario the PON R-OLT is installed in the vicinity of a powered coax segment and can be powered from that coax. One operator's rule-of-thumb for coax powered R-OLTs is that if powered coax is available within one-half mile of the R-OLT location, they will extend coax to power the R-OLT. Beyond that distance, it's more cost effective to add a dedicated UPS to power the PON equipment. A typical R-OLT of this style (see Figure 3) would require up to 140W to power and could be configured to support up to 512 FTTX customers through downline optical splitters. A typical broadband UPS used to power nodes, amplifiers and our R-OLT is shown in Figure 8. These UPS system may be pole or ground mounted and typically consist of an enclosure, the UPS and one or more strings of three, 12-volt batteries. If UPS 1 has sufficient power and battery capacity to accommodate the added R-OLT load, no additional powering considerations are needed.

Figure 8 – Typical Broadband UPS

PON EXAMPLE 2

In service areas with a higher population density, PON architectures may dictate supporting many customers from a single fiber distribution point. One option is to utilize outdoor, curbside enclosures housing multiple R-OLTs. UPS 2 in our network diagram represents this scenario. An example of this type of enclosure is shown in Figure 9.
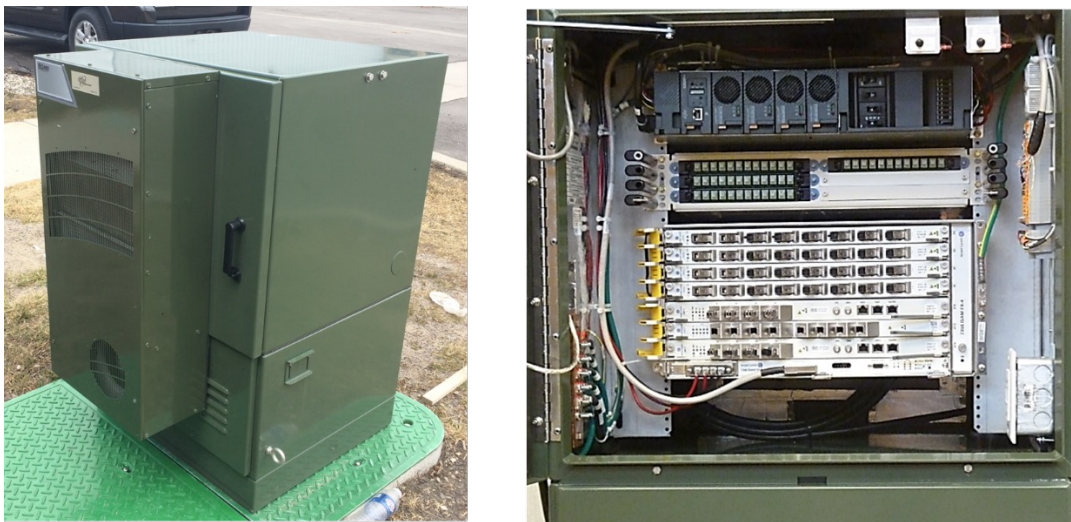

Figure 9 – High Capacity PON Enclosure

The multiple shelf or rack mount R-OLTs in this example will service far more subscribers than our earlier strand mount example. These cabinets would include fiber distribution as well as backup power for the R-OLTs. Shelf mounted OLTs are typically powered from 48VDC. The cabinet would contain a 48VDC rectifier system, likely in an N+1 redundant configuration, and batteries. The cabinet is connected directly to utility power.

Cabinet based OLT systems can be scaled to specific applications. One North American operator has standardized on a curbside cabinet capable of servicing up to eight thousand homes. This cabinet contains multiple OLTs, fiber distribution panels and a 48VDC rectifier system with batteries to provide 6 hours of backup power during utility outages.

PON EXAMPLE 3

The third PON example from Figure 7 represents a strand-mount R-OLT powered from UPS 3. This differs from the UPS 1 example in that there is no nearby coax for R-OLT power. For this application a UPS is dedicated to a single R-OLT or potentially multiple co-located R-OLTs. Figure 10 shows a typical broadband UPS sized appropriately for this application.

Figure 10 – Small Broadband UPS for Dedicated R-OLT Powering

This broadband UPS is similar to the UPS from example 1 with a few exceptions that will be reviewed after a note about RDOF PON.

RDOF PON: ACCOMODATING RURAL FIBER DEPLOYMENTS

As previously discussed, RDOF is bringing broadband, specifically fiber broadband, to many un-served and under-served rural locations in the United States. Does rural fiber deployment differ from its urban or suburban counterparts? The answer is yes. There are two differences to consider. First, rural areas have lower population density than urban or suburban, that goes without saying. Rural areas will likely never need the service group density available from dedicated enclosures housing multiple high-capacity R-OLTs. Also,

rural areas will most often be considered greenfield with no incumbent fiber or coax to leverage. This means that PON example 3 from Figure 7 will likely account for most of our rural fiber installations.

The second consideration with rural fiber deployments deal with fiber span distances. One operator mentioned that their rural deployments are seeing fiber lengths up to 160km from headend end users. To facilitate these distances the optical signal must be amplified. For this operator, the solution is to install optical amplifiers or EDFAs mid-span in the fiber run. An EDFA is shown in Figure 7 under PON example 3. Figure 11 is a typical EDFA used for this type of application.
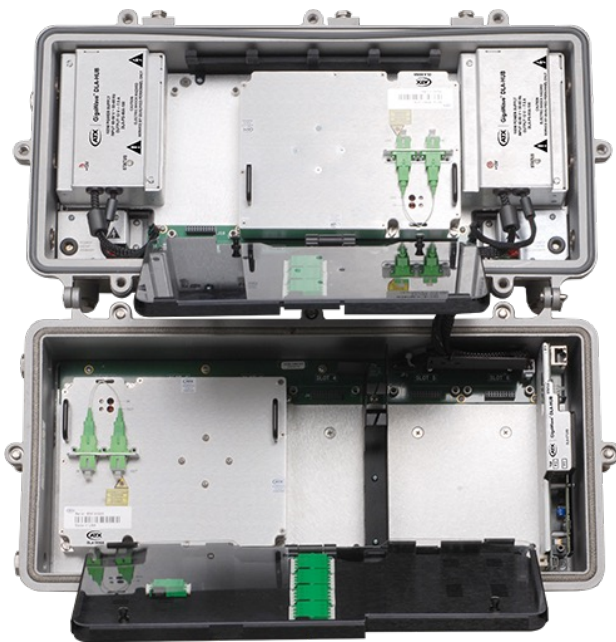

Figure 11 – Sample EDFA (Optical Amplifier)

Like our R-OLT, this EDFA is housed in an outdoor hardened aluminum housing and can be strand, pedestal or underground vault mounted. This EDFA requires about the same amount of power as our R-OLT and would be powered by a similarly sized UPS system. The following sections discuss UPS details that specifically apply to R-OLT and EDFA powering.

SIZING THE UPS FOR SMALL LOADS

Using coax to transport both power and RF has been a CATV practice for over 40 years. This fundamental approach has not changed much over the years. A single stage UPS using a ferrresonant transformer is extremely robust and provides exceptional protection for active network elements from outdoor utility grid hazards. In a later section we'll review more about ferroresonant technology.

One important characteristic of the ferroresonant UPS is that it operates most efficiently when loaded to its maximum rating. Most traditional broadband UPS systems are rated for use between 1350W to 1620W. That ends up being 15A to 18A at 90V. Using a simple Ohms Law calculation: Current = Power/Voltage (we'll ignore power factor for now to keep things simple). In our PON example 3 from Figure 7, the R-OLT required about 140W or about 1.5A at 90V. The efficiency for several similar 15A ferrresonant UPS models is shown in Figure 12.
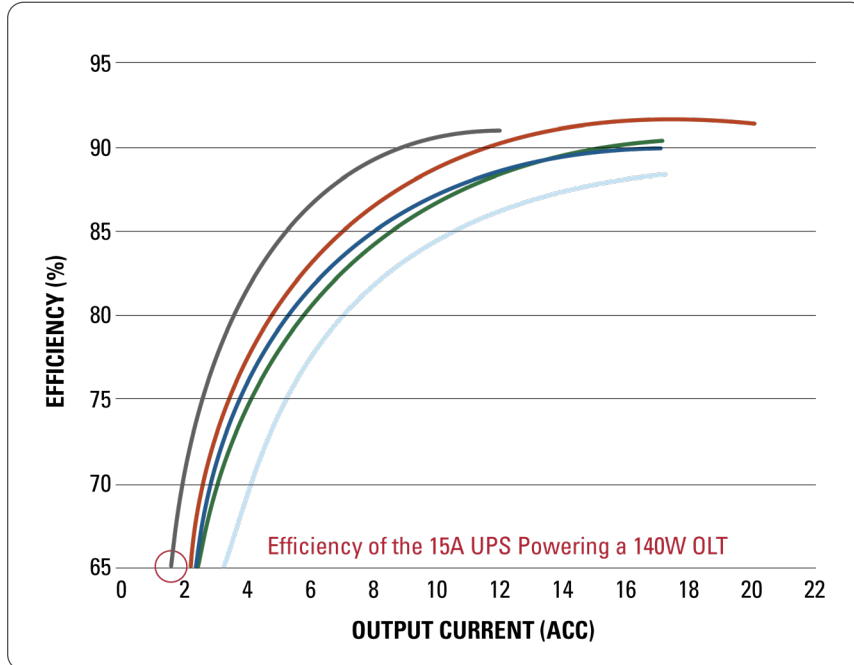

Figure 12 – Ferroresonant 15 Amp UPS Efficiency Graph

If this 15A UPS were dedicated to powering a single R-OLT drawing 1.5A, the UPS efficiency would be under 65% as shown. The lost efficiency would be energy converted to heat in the ferroresonant transformer. This energy loss would occur both under utility power (lost energy means higher utility cost from consumed kW/h) and during battery backup (resulting in waisted battery energy and less available backup time).

The obvious solution is to use a smaller UPS system for smaller loads, like our R-OLT. Ferroresonant UPS systems come in many sized down to 5A or less. Additional benefits of using a smaller, dedicated UPS include:

- Smaller broadband UPS systems use a single 12V battery instead of a 36V string of three, 12V batteries.
- The UPS is smaller, lighter and can be mounted in a smaller enclosure designed for the UPS and a single battery.
- The system cost will be lower due to the size and battery configuration.

The available backup runtime during utility outages varies greatly with the type and condition of the battery used in the UPS system. For example, if our R-OLT UPS system uses a single case size 31, high quality TPPL (Thin Plate Pure Lead) battery designed for outdoor broadband applications, the UPS system would provide over 6 hours of backup runtime for our R-OLT during a utility power outage.

UPS STATUS MONITORING FOR R-OLT POWERING APPLICATIONS

Monitoring broadband UPS systems provides several benefits. The most common benefit is that operators receive real-time status. During extended utility outages it's critical that operators have advanced warning with sufficient time to take action prior to battery depletion, resulting in dropped loads and customers losing service. UPS monitoring also notifies operators of equipment concerns. Notifications may indicate that immediate attention is required or of issues that should be addressed during an upcoming scheduled maintenance visit.

Traditional broadband UPS systems incorporate a purpose-built DOCSIS modem, called a transponder, for status communications between the UPS and the monitoring software.

UPS monitoring over DOCSIS has been used for over 20 years. Operators have well defined process in place for installing, provisioning and operating DOCSIS modems for OSP UPS monitoring.

For PON networks where DOCSIS is not available, an alternative UPS monitoring approach is needed. To address this need, modern broadband UPS systems include a SFP interface (small form-factor pluggable). SFP is a standard interface compatible with pluggable, optical transceiver modules from multiple vendors. A typical pluggable SFP module is shown in Figure 13.

Figure 13 – Example Pluggable Optical SFP Compatible Module

For status monitoring of a UPS system that is powering a R-OLT, a specialized SFP module would be installed in the UPS' SFP socket. This SFP would function as an Optical Network Unit (ONU) or an Optical Network Terminal (ONT), supporting the specific optical protocol used by the R-OLT. An ONT and an ONU are the same things. ONT and ONU both refer to the consumer end equipment in an optical fiber (FTTX) communication link. ONT is an ITU-T term, whereas ONU is an IEEE term. The term ONT would be used if the R-OLT is configured for ITU-T protocols including GPON and XGS-PON. The term ONU would be used when the R-OLT is configured to IEEE protocols including EPON and 10G-EPON. For simplicity, we will use the term ONU going forward to mean either ONU or ONT.

The pluggable SFP ONU would be provisioned and managed by the R-OLT in the same way a home-based ONU operates. This configuration is represented in Figure 14.
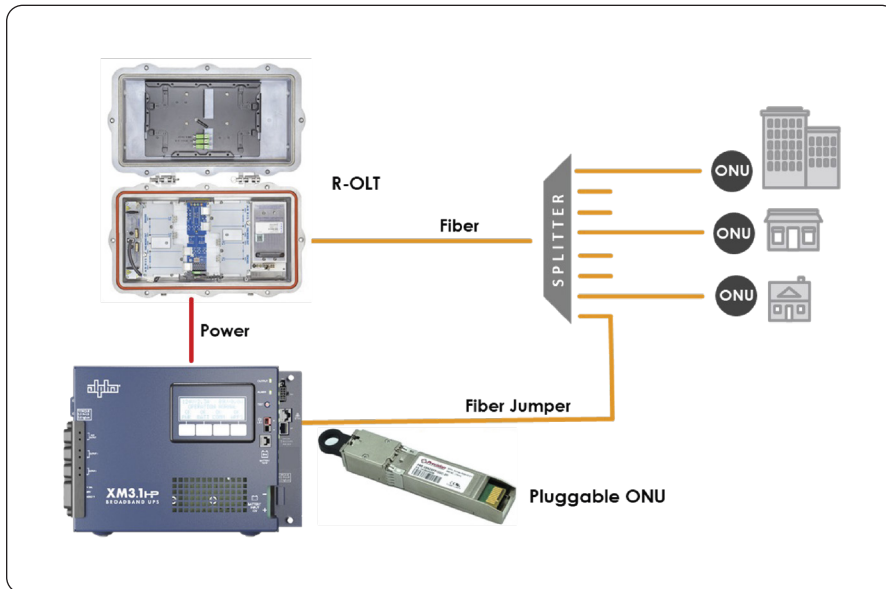
Figure 14 – Example of Pluggable ONU for UPS Monitoring

In this example the R-OLT provisions and manages all ONUs in this PON segment, including the ONU installed in the UPS.

This UPS monitoring approach seems straightforward. However, there is more to this story. UPS status monitoring must be routed to the operator's OSP power supply monitoring software. The operator would likely associate the power supply MAC and assigned IP to the monitoring software in a router or layer 3 switch in their back office. Also, the UPS needs to be configured with the IP address of the monitoring software to enable the UPS to send SNMP traps or alerts. The UPS would often be configured with a list of IP addresses of destinations where SNMP notifications are to be sent. Other UPS parameters may need to be configured as well. In a traditional HFC network where UPS systems use DOCSIS modems for status communications, the DOCSIS configuration files are customized to configure UPS systems, including trap destination addresses. Unfortunately, PON networks have no equivalent to a DOCSIS configuration file, at least not one that can be used for UPS coonfigurationconfiguration.

At first glance, a CableLabs standard called DOCSIS Provisioning of EPON (DPoE) sounds like a promising option for UPS configuration. However, any hope in DPoE provisioning our UPS is short lived. DPoE enables DOCSIS configurations and service tiers to be passed on to the PON network. For example, a PON customer could subscribe to a 100Mb downstream and 10Mb upstream service tier. DPoE can use existing DOCSIS services to configure the PON network to support this service tier for this subscriber. The R-OLT and ONU supporting DPoE work together to implement this type of DOCSIS service. DPoE has no mechanism for configuring equipment behind the ONU on the subscriber side of the network. Within our UPS ONU configuration, the power supply resides behind the ONU in the network, much like a subscriber's computer resides behind a home-based ONU.

To-date, two methods have been used to configure the UPS for monitoring and alarm reporting in a PON network. First, some UPS systems support the use of a configuration file containing TLV (type-length-value) style information, similar to DOCSIS configuration file TLVs. When the UPS is provisioned and receives an IP address from the network DHCP server, the provisioning process typically provides the IP addresses for a TOD (Time-of-Day) server and a TFTP (Trivial File Transfer Protocol) server. The UPS will search the root directory of the TFTP server for a specific configuration file to be used for UPS configuration. This approach is similar to how a DOCSIS configuration file is used to configure cable modems.

The second method available for configuring UPS parameters is by using vendor-specific DHCP options. A DHCP offer contains a variety of information fields beyond just an IP address. The standards for DHCP define various options that can be part of the DHCP offer, which the DHCP server can provide for all or selected requesting devices. For DHCP on IPv4, this information is provided using DHCP option 125. For DHCP on IPv6, this information is provided using DHCPv6 option 17. Options can specifically be used to configure SNMP general settings, access settings, and SNMP notification settings (issuing traps to specific destinations).

There are currently no industry standards defining either of these provisioning schemes. They are proprietary per individual vendors. Operators should proceed accordingly to assure the selected configuration approach is well defined and meets their specific requirements.

UPS STATUS MONITORING FOR EDFA POWERING APPLICATIONS

In a prior section we discussed that powering EDFAs and powering R-OLTs are very similar. Status monitoring the UPS that is powering the EDFA is less straightforward than monitoring the R-OLT UPS system. Our monitoring solution using a pluggable ONU doesn't work without the corresponding R-OLT. If we're powering an EDFA somewhere midspan in a fiber-run, there's likely no nearby R-OLT or coax to for implementing familiar status monitoring methods.
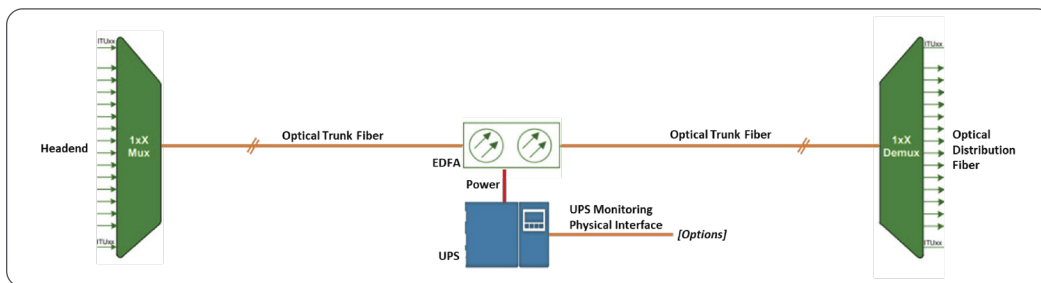

Figure 15 – EDFA UPS Monitoring

Operators have tried multiple approaches to solve this quandary. Unfortunately, there is no one size fits all solution. A few options that have been explored so far are described here.

Dedicate DWDM or CWDM wavelengths. DWDM or CWDM (depending on the fiber traffic) transmit and receive wavelengths could be set aside for UPS traffic. A DWDM/CWDM SFP would be installed in the UPS and the appropriate demux, filter and splicing mechanism would be installed near the EDFA and UPS to facilitate the fiber jumper physical connection.

Dedicated Dark Fiber. A dedicated fiber or fiber pair could be assigned for UPS traffic. A splice tray, patch panel or other appropriate mechanism to patch into the fiber would be installed near the EDFA and UPS. A SFP would be installed in the UPS using the desired optical format.

Cellular data modem. A cellular modem could be installed in the UPS system to implement an out-of-band (OOB) communication interface. A copper Ethernet SFP installed in the UPS would connect to the cellular modem via an RJ-45 (copper) Ethernet

cable. A cellular antenna would be mounted on the outside of the UPS enclosure using weather tight techniques. The modem would be powered from a power converter connected to the UPS output, providing the modem's required voltage.

EDFA proprietary management port. Some EDFA manufacturers support a proprietary interface for configuring and managing each EDFA in the operator's network. Data from each EDFA is routed through the fiber and back to the headend where it is available at a central management console. If the EDFA supports a physical maintenance port to access this management interface then it's feasible for a fiber jumper from the UPS to connect to the port, providing a communications pathway from the UPS to the headend. This would enable UPS traffic to be routed to the UPS management system. A proprietary UPS monitoring system of this type was developed between a remote hub vendor and a UPS vendor and initially deployed in 2015.

Don't monitor the UPS. If none of the current options for EDFA UPS monitoring are desirable, operators may elect to leave UPS systems unmonitored. This could be a conscious choice or may be the result of a deferred decision due to lack of an ideal monitoring option. Either way, the results will be the same. Operators will have no advanced warning of utility outages that are at risk of exceeding the backup runtime of the UPS system. This risk can be mitigated by installing additional batteries to extend runtime, combined with regular maintenance visits to maximize the probability that the UPS system will perform as anticipated in upcoming utility outages. Another tool operators should make use of, especially for unmonitored UPS systems, is the utility event history typically stored in nonvolatile memory in the UPS. Figure 16 shows the history log from a typical broadband UPS.
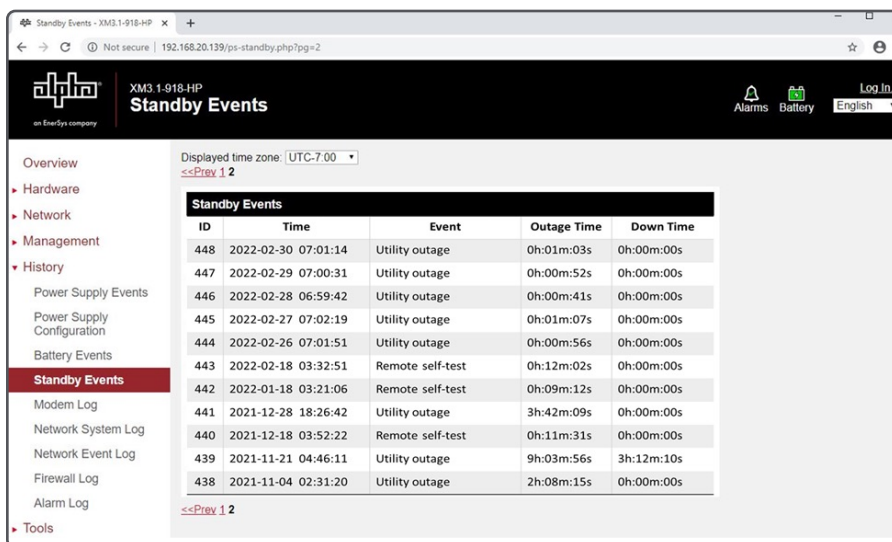
Figure 16 – UPS Event Log

This type of utility power history is typically available through the UPS monitoring system. However, for unmonitored UPS systems, a log of this type is only available on-site and may be the only indicator of the utility power activity at the UPS location. Operators should schedule regular site visits to retrieve and analyze these utility events. As an example of the value of this type of data, the entries from the log in Figure 16 are reviewed in Table 2.

Table 2 – UPS Event Log Review

ID	Event	Description & Implication
444-448	Utility outage	Short duration utility outages occurring at approximately the same time each day. This may indicate an external event effecting the utility grid.
443, 442, 440	Remote self-test	UPS test cycles appear to be initiated by the UPS monitoring system each month at approximately the same time of day.
441	Utility outage	A utility outage lasting 3h:42m. The UPS has sufficient battery capacity to support the network throughput this event.
439	Utility outage	A utility outage lasted 9h:03m. The UPS powered the network for approximately six hours before depleted batteries forced dropping the load.
438	Utility outage	A utility outage lasting 2h:08m. The UPS has sufficient battery capacity to support the network throughput this event.

If this UPS were remotely monitored, a network outage and service interruption could have been avoided (event no. 438) through advanced notification of the extended outage. Also, repeated, short direction outages (event no. 444-448) would be identified for investigation. During one example of these types of short duration, regular outages, an investigation identified a nearby factory's daily start-up processes were the cause of utility transients that triggered the UPS to switch into standby operation.

Our list of EDFA UPS monitoring options did not mention that UPS data must be received in the headend, converted to IP traffic over Ethernet, and routed to the operator's UPS monitoring software. This step must occur irrespective of the data transport method.

The viability of implementing any of these options must be evaluated by operators. In one recent example, an operator determined that the only viable options for their network was using dedicated DWDM wavelengths. They further determined that the negative impact from dropped customers outweighed the cost of implementing dedicated wavelength style monitoring. In another example the operator chose to leave the UPS unmonitored, mitigating risk by stepping up scheduled maintenance to unmonitored locations.

OUTDOOR POWERING HAZARDS

Network operators understand the harsh environmental condition that outdoor equipment must endure. Temperature extremes, wind driven rain, snow and ice can wreak havoc on equipment not designed to endure these conditions. The electrical utility grid presents a laundry list of hazards poised to dismember the best engineered gear. Broadband UPS systems are powered directly from the outdoor utility grid. These UPS systems must be engineered to endure a litany of power grid anomalies including:

Interruption, the complete loss of voltage for thirty (30) cycles or longer.

Transients, a temporary, rapid fluctuation in the measured quantity of total power.

Surges, voltage greater than 110% above normal

Spikes, sudden voltage peaks that can reach thousands of volts

Sags, under-voltage conditions where fluctuation exceeds allowable thresholds for at least a cycle.

Brownouts, intentional or unintentional voltage drop for an extended period.

For over four decades, broadband UPS systems have provided reliable network power through every condition imaginable. Like any technology, these UPS systems have evolved over the years. However, there is one component in the broadband UPS that has remained mostly unchanged throughout the years, the ferroresonant transformer.

FERRORESONANT OVERVIEW

Broadband networks have used ferroresonant (ferro) based UPS systems since the early days of CATV. Figure 17 shows a diagram of a ferro transformer.
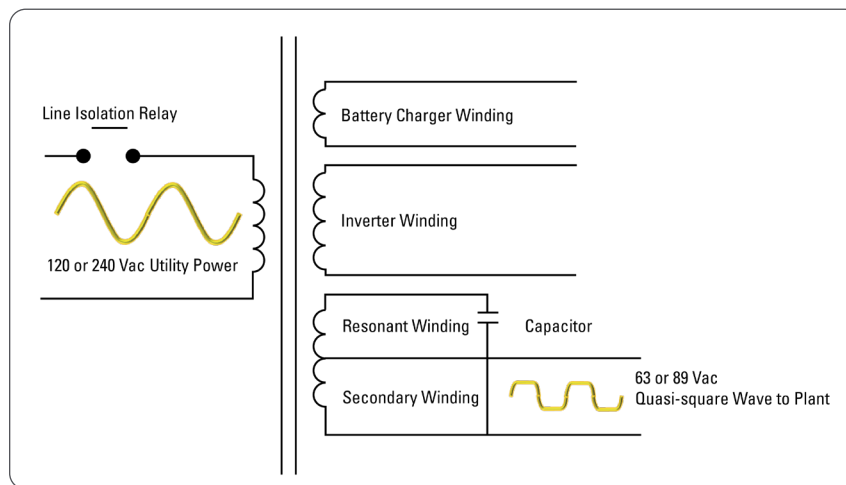

Figure 17 – Ferroresonant UPS Transformer

What makes the ferro transformer ideal for outdoor powering and how has it remained mostly unchanged throughout years of technology advancements? Let's review some transformer basics to answer these questions.

Transformers, both ferro and the more common linear variety, consist of two primary components: windings and cores. Windings are (usually) copper wire, wound onto a

core material such as steel. Energy is transferred by magnetic induction from one set of windings to another by means of varying magnetic flux. In the more common linear transformer, the output voltage is determined by a combination of the input voltage and the ratio of primary windings to secondary windings. In contrast, the ferro transformer uses nonlinear magnetic properties and a resonant circuit to provide a stable output voltage over a wide range of input voltage. During each AC cycle, energy is stored in the resonant circuit (an inductive-capacitive "tank circuit") and then consumed by loads connected to other windings. The tank circuit operates in magnetic saturation, resulting in the output waveform being square or trapezoidal, often referred to as a quasi-square wave (QSW), instead of the more familiar sinusoidal waveform produced at the output of a linear transformer. The ferro's QSW results in more available energy than the sinusoidal counterpart. The QSW vs. sinusoidal energy relationship is illustrated in Figure 18.
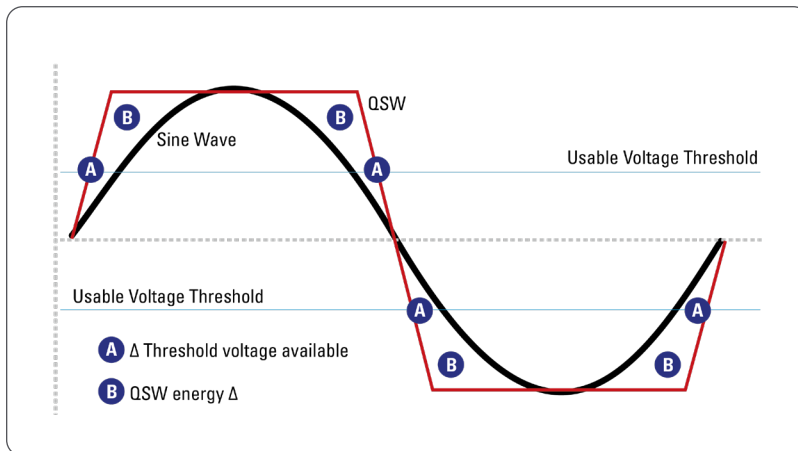

Figure 18 – Sine Wave vs. Quasi-Square Wave Energy

The QSW per cycle voltage rise time is greater than the equivalent linear sinusoidal risetime (dV/dt has a higher slope value). Practically, this means that within every 60Hz AC cycle, the QSW output has more energy available for a higher percentage of each 60Hz cycle than the sine wave, assuming equivalent power factors. Also, the QSW rise time results in more time per cycle above the usable threshold voltage. The threshold voltage is the minimum voltage required for powered equipment to operate. As an example, consider an RF amplifier powered from the ferro UPS. During each AC cycle there is a

period around the voltage zero-cross threshold where the UPS output voltage is too low for the amplifier's power supply to operate. Since the ferro's QSW output voltage rises faster than a linear UPS sine wave output, the amplifier can draw energy from the ferro UPS for a larger percentage of time within each AC cycle.

Greater output energy is one benefit of a ferro UPS. Other important benefit is output short circuit protection. The Ferro can operate for extended periods of time at 150% of its rated capacity. When this level is exceeded, the tank circuit can no longer keep up with the amount of energy being pulled from the output. The ferro will then "fold back" or drop its output voltage to zero. A ferro fold back is shown here.
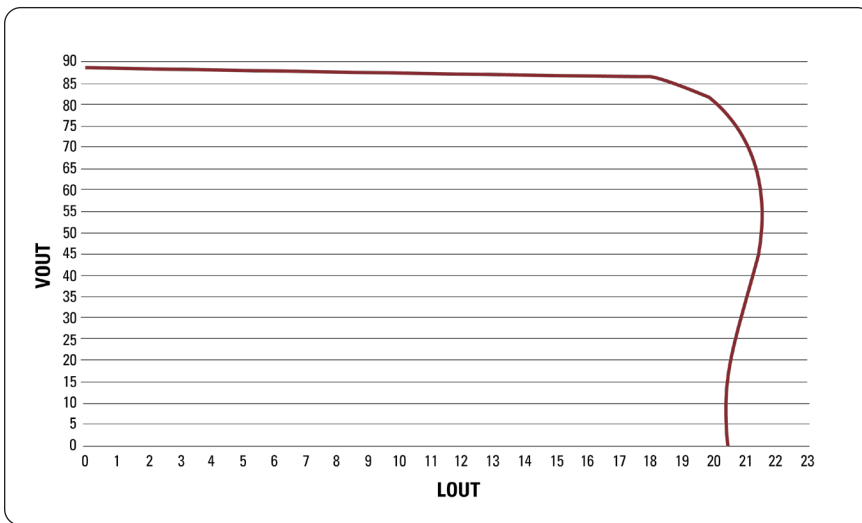

Figure 19 – Ferro Output Fold-Back Overcurrent Protection

HFC networks consist of active equipment separated by spans of fiber optic and coax cable. Damage and wear to equipment, power carrying coax, termination components and technician mishaps can result in electrical short circuits or "faults" in network power. A fault causing the UPS output load to exceed 150% of its rated capacity will result in a UPS output fold back condition, dropping the output voltage. When the fault is remedied, the ferro output is restored and normal network powering resumes. Neither the UPS nor the powered equipment are damaged because of the fold back condition.

Another characteristic of ferro based UPS systems is extremely high transient and noise filtering. The ferro is one of the best-known mechanisms for filtering utility line noise and transients from reaching the output and affecting or damaging network equipment. The ferro boasts an impressive 1000:1 isolation ratio. The nature of the ferro design makes it extremely immune to electrical surges. This means that a 1000-volt surge on the input winding would produce only a 1-volt difference on the output winding. This isolation offers very robust surge protection for powered network equipment.

Ferro based UPS also implement a single stage conversion design. Voltage from the input winding is transferred to the output winding and directly to the network without any additional power conversion steps. When operating on battery backup, the input utility winding is disconnected using a relay and a separate inverter winding is energized by an inverter circuit utilizing battery current to produce energy. The UPS backup function is only required to operate when utility power is lost. In most systems the inverter operates less than 1% of the life of the UPS. This means that for over 99% of the time, the UPS is providing output power by using only the ferro transformer. Since no electronic components are in the critical powering path, the reliability of the ferro based UPS is exceptional.

Since the ferro is constructed of copper & steel. It will typically only fail from physical damage or from catastrophic electrical events such as a direct lightning strike.

CONCLUSION

OSP active PON network elements are subject to extreme outdoor conditions, including utility grid anomalies. The ferroresonant based UPS has been used for many years, effectively isolating network equipment from electrical utility grid hazards. An HFC network segment, including nodes and amplifiers, is typically powered from a single UPS with the coax transporting both power and payload. OSP PON equipment, specifically R-OLTs and EDFAs, are most often powered with dedicated UPS systems. PON UPS systems must be sized for the smaller load of a single active component for the UPS to operate efficiently. PON UPS systems can be housed in physically smaller enclosures with fewer batteries and smaller components than their HFC counterparts. Operators may also decide to house R-OLTs and EDFAs with the UPS system in a single enclosure.

Status monitoring UPS systems powering R-OLTs has recently become straightforward with the use of a pluggable ONU installed in the UPS. Monitoring UPS systems powering EDFAs is not yet as cut and dry. Several monitoring options are possible. Operators need to weigh the pros and cons of each option and determine the method that works for them.

UPS status monitoring provides multiple benefits. First, operators receive advanced warning of utility outages that may extend beyond usable battery runtimes. This advanced warning enabled timely action to keep extended utility outages from becoming service effecting events. Unmonitored UPS systems provide no advanced warning, leaving operators to glean outage data from other sources or to just hope for the best. Another benefit from status monitoring includes notifications of imminent and potential service effecting conditions. This could include advanced indicators that batteries have reduced capacity or that UPS service is needed. Preventative maintenance should be scheduled to correct these items. Unmonitored UPS systems cannot report these conditions, leaving operators to identify them during scheduled maintenance visits, hopefully before a utility outage becomes service effecting.

ABBREVIATIONS

10G-EPON	10 Gbit/s Ethernet passive optical network
AN	Aggregation Node
CATV	Community antenna television
CIN	Converged Interconnect Network
CWDM	Course wave division multiplexing
DAA	Distributed access architecture
DOCSIS	Data over cable service interface specification
DPoE	DOCSIS provisioning of EPON
DWDM	Dense wave division multiplexing
EDFA	Erbium-doped fiber amplifier
EPON	Ethernet passive optical network
Ferro	Ferroresonant transformer
FTTX	Fiber to the (home, curb, premise, etc.)
GPON	Gigabit passive optical network
NA	North America
OLT	Optical line terminal
ONT	Optical network terminal
ONU	Optical network unit
OOB	Out-of-band
OSP	Outside plant
PON	Passive optical network
QSW	Quasi-square wave
RDOF	Rural Digital Opportunity Fund
R-OLT	Remote optical line terminal
SCTE	Society of Cable Telecommunications Engineers
TCO	Total cost of ownership
TFTP	Trivial file transfer protocol
TLV	Type-length-value
TOD	Time of day
XGS-PON	10 Gbit/s passive optical network

LIST OF FIGURES

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ENDNOTES

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