White Paper

Powering the Last Mile: An Alternative to Powering FITL

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POWERING THE LAST MILE: AN ALTERNATIVE TO POWERING FITL

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ABSTRACT

Over the past several years, as reported in earlier NFOEC Proceedings, each Regional Bell Operating Company (RBOC) has experimented or deployed Fiber Distribution cable in one fashion or another. This quest to drive fiber deeper into the outside plant network is dictated by both technological advances and, possibly to a greater extent, competitive pressures. Whether placing an Optical Network Unit (ONU) within 3,000 feet of each subscriber or on the side of the house, each RBOC is demanding the most economical deployment architecture to serve their subscriber base with the greatest bandwidth possible.

Since the 1980's, each RBOC, to varying degrees, has deployed Remote Terminal (RT) sites in each and every feeder route in their network. Many of these sites already are fed by fiber. These fiber-fed RTs in the outside plant marked the RBOC's first major encounter with having to provide remote power and associated battery backup in the outside plant. Usually, the powering architecture for these RTs has consisted of a –48-Vdc rectifier system connected to a –48-Vdc battery bus, all housed in a metal cabinet or concrete hut/CEV. As the quantity of RT sites undergoes rapid growth, and as the powering requirements for the ONUs hosted by these RTs also increase, other powering architectures, including network, or centralized powering, offer potential advantages. This paper discusses a powering architecture where a power node is located together on the same easement and pad as the RT. Compared to conventional powering, this co-located power node and RT allow a dramatic increase in the quantities of ONUs which may be hosted by an RT as well as many other advantages.

1. Introduction

Three different configurations of RTs and ONUs are used as the basis for comparisons between traditional powering and a new powering alternative presented here. In addition to enabling greater numbers of ONUs to be hosted from a single easement, this powering alternative offers reduced operating and maintenance costs. Furthermore, if an RBOC is also providing CATV service via a Hybrid-Fiber Coax (HFC) network, creating a demand for 60/75/90Vac powering, this powering alternative offers the flexibility to power an HFC network as well as the traditional dc, from the same power node. As services grow, such as video, data, and broadband, the co-located power node can grow in capacity as well, keeping pace with revenue streams. Traditional powering provides the requisite eight-hour power reserve with an eight-hour battery plant while the powering alternative provides an infinite power reserve using an engine-generator power source integrated as a system component with a smaller, one-hour or two-hour battery reserve. Comparisons of these two methods for providing the requisite eight-hour backup are contained in Section 2. Any power conversion process is accompanied by losses; Section 3 discusses the financial impact of these losses. In Section 4, several RTs and ONUs are identified for use in comparisons of traditional powering and powering with the co-located power node. Finally, the capabilities for growth with a co-located power node and a summary of the advantages of a co-located power node are offered in Sections 5 and 6.

2. Eight-Hour Outside-Plant Backup: Combinations of Batteries and Generators

Eight hours of backup time are dictated by Bellcore standards for remote terminals, copper distribution, and fiber-in-the-loop (FITL) powering. Options for providing this eight-hour backup time include an eight-hour, battery-only solution, or a combination of an engine generator and batteries. Here, comparisons are made for the size, weight, and initial costs for three different powering alternatives: (1) eight-hour, battery only; (2) Power Node with two-hour battery with an engine generator; and (3) Power Node with a two-hour battery and an engine generator.

2.1 Generator Information

Two output power levels will be considered here: 2kW and 6kW. In support of these power levels, two –48-Vdc engine generator and control systems are considered. Each of these is controlled with a standard generator-control system. This standardized generator-control system is compatible with a wide range of generators, including output powers from 3kW to 7.5kW, and output voltages of both –48Vdc and 96Vdc. For the 2-kW output power level, the smallest available generator, 3kW, is used, while for the 6-kW output power level a 7.5-kW generator is used. A summary of these two generators is contained in Table 1. These generators are integrated into the power node enclosure. In addition to the engine and generator, a 75-ampere-hour battery is needed for cranking power during generator starting. Smaller generators, such as at the 3-kW power rating, have the rectification built in to the alternator, while the larger generators require a rack-mount rectifier and filter system to convert the ac output from the alternator to a dc output. These generators are powered either with natural gas or propane. Most metropolitan and suburban

Generator Power Rating	**3kW**	**7.5kW**
Dimensions	19”x21”x21”	34”x21”x27”
Volume	4.8 ft^3	11.2 ft^3
Weight	130 lbs.	310 lbs.
Ignition Battery	12V, 75AH	12V, 75AH
Control Unit	standard	standard

Table 1. Details of the 3kW and 7.5kW engine-generator systems.

areas have a natural gas distribution system to which these generators may be connected, eliminating the need for refueling.

The standardized generator control system autonomously initiates an auto-test cycle at a programmable interval, typically bi-weekly. Over a year, this bi-weekly, 15-minute maintenance cycle accrues a generator run time of 6.5 hours. The generator control system initiates a generator start based on either a low dc bus voltage or after the ac line is disqualified for a user-programmable period, typically ten minutes. To calculate a generator expected lifetime, based on the 2,000-hour operating warranty, the predicted annual generator run time is needed. Annual run time results from two sources: maintenance cycle; and operation during power outages in excess of ten minutes. If the ac utility availability is 95 percent, and if 90 percent of the outages lasts less than ten minutes, the generator will operate about 44 hours per year in addition to maintenance cycles. Thus, the total anticipated annual generator run time is approximately 50 hours per year. With a 2,000-hour operating warranty, and following the recommended preventative maintenance schedule, the generators have a theoretical anticipated lifetime of forty years.

2.2 Costs

For power nodes based on batteries and battery-generator systems, two types of costs must be considered: initial costs and operating costs. Initial costs are considered first. Using pricing for telecom-grade batteries, and generator costs from published manufacturer's pricing, Fig. 1 illustrates the very significant savings in initial costs when a generator is combined with either a 1-hour battery plant or a 2-hour battery plant. In the 2-kW case, a combination of a 2-hour battery plant and a generator is approximately 70 percent of the initial cost of an 8-hour battery-only energy storage. Even greater savings are realized in the 6-kW example, where a two-hour battery plant in combination with a

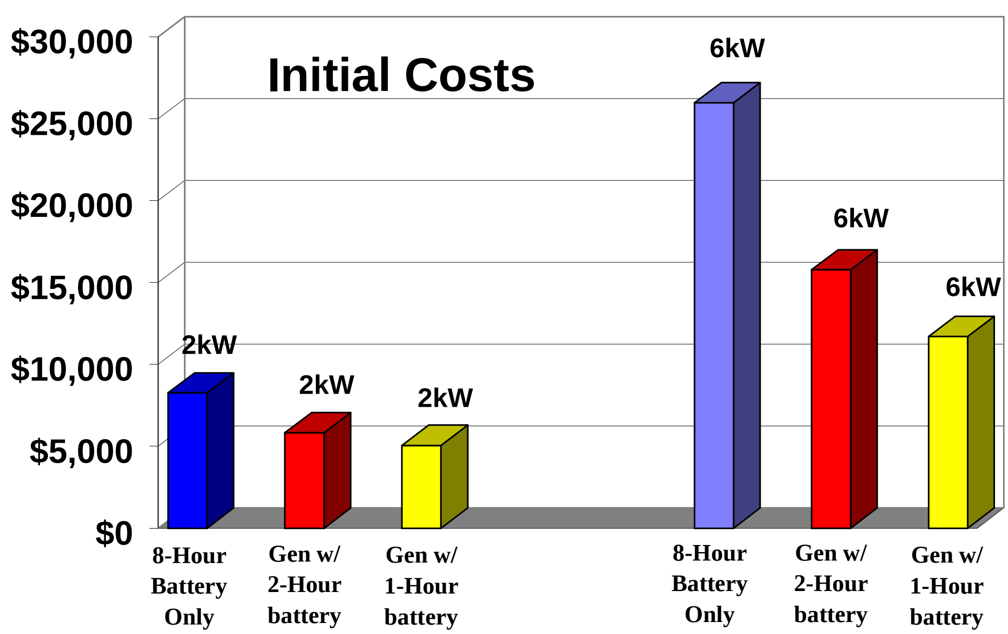

Figure 1. Comparisons of initial cost for two power levels, 2kW and 6kW. Comparisons are made among an eight-hour, battery only solution, and combination of generator and a one-hour and two-hour battery backups.

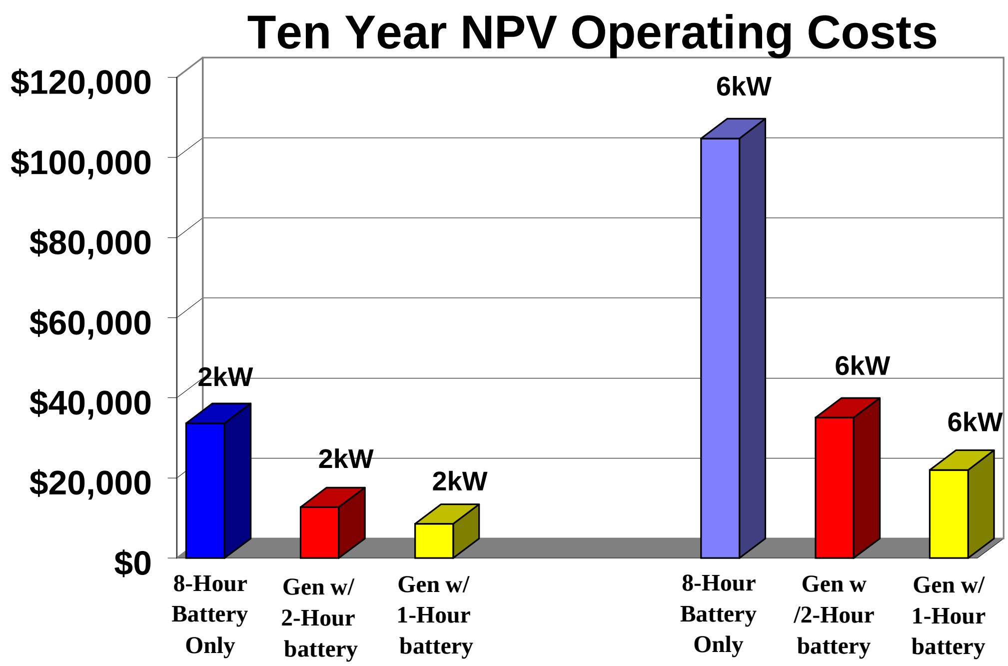

Figure 2. Illustration of ten-year operating costs based on a two-year battery life.

generator is approximately 60 percent of the initial costs of a battery-only 8-hour backup. At these 6-kW power levels, costs are high, so a 60-percent savings is significant.

The greatest unknown when comparing operating expenses for a power node with a generator-battery system and a power node using a battery-only system, is the useful lifetime of the batteries in the outside plant. Our experiences with batteries in over 400,000 installations in outside plant, worldwide, is that life expectancies range from between two years to five years; these expectancies are based on a temperature-compensated charging algorithm.

Battery expenses are even greater when the replacement costs for these two-year-life-expectancy batteries is considered. Over a ten-year period, five sets of batteries can easily be required, for example in the initial product, and in years two, four, six, and eight. To illustrate the expense of battery replacements, cast in terms of present value, consider the cost of a set of batteries as X. A present-value calculation for the initial batteries, and the replacement batteries in years two, four, six, and eight, is 4.2X. Thus a ten-year cost of ownership, in terms of present value, with a $26,000 price for a set of eight hours of battery reserve at a 6-kW power level, is $109,200. With the cost of two hours of battery reserve at $6,500 (one quarter of the eight-hour reserve cost), the present value for a ten-year ownership with a two-year battery replacement cycle, is $27,300. An engine-generator cost of $8,500, for example, creates an energy-storage system with infinite reserve time at a $35,800 present-value cost for a ten-year ownership. Compare this with the $105,000 present-value cost for an eight-hour, battery-only reserve power node. These comparisons are made graphically in Figure. 2.

If initial costs are considered alone, a power node with an engine generator is less costly than a traditional battery-only power node for power levels in excess of about 2kW. When ten-year cost of ownership is considered, the battery replacement costs are so great that a power node with an engine generator is less costly than a traditional power node for virtually any (>1kW) power level.

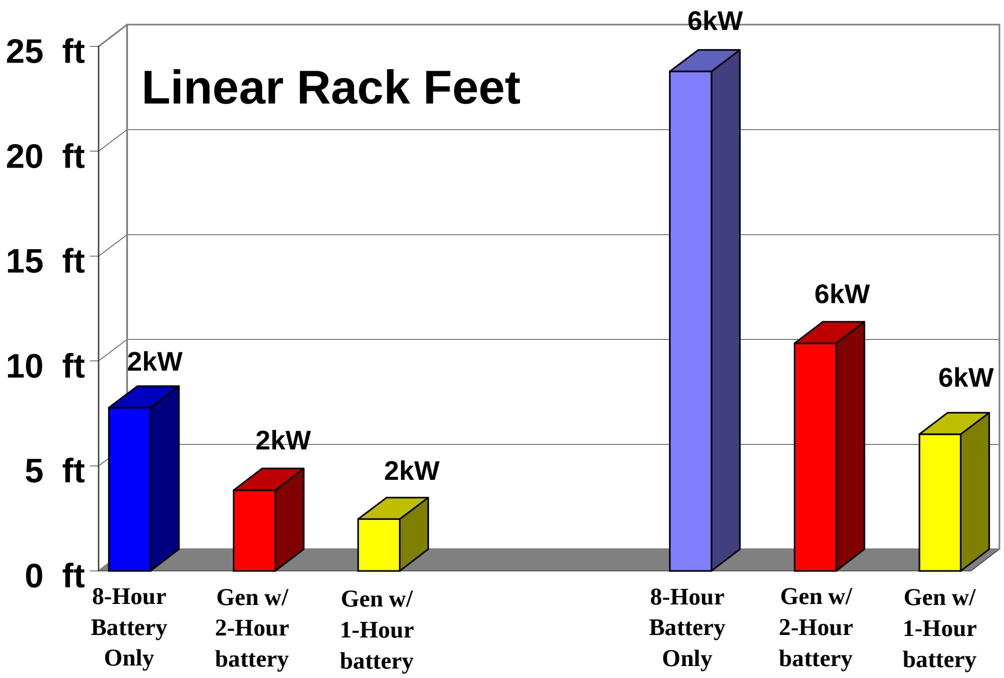

Figure 3. Comparison of physical size occupied by different dc energy-storage systems: eight-hour of battery only, a two-hour battery plant with an engine generator, and a one-hour battery plant with an engine generator.

2.3 Physical Size Considerations

Within a power node, the purpose of any battery plant, or combination of battery-plant and engine generator, is to provide sufficient dc energy storage to support eight hours or more of operation. Before comparisons can be made among a battery-only power node, and a power node with a generator and either a one-hour or two-hour battery plant, the physical size of the batteries must be estimated. In addition to the dimensions of each battery, physical space is needed surrounding each battery for installation and servicing of the batteries, as well as for battery wiring. To accommodate space for installation and servicing, battery dimensions are increased: width by 1 inch, depth by 2 inches, and height by 3 inches. Also, to provide space for wiring, shelving, and temperature monitoring, the overall battery volume is increased by 20 percent above the amount computed from the enlarged battery dimensions identified earlier. As confirmation that this algorithm produces reasonable estimates, a comparison between the predicted volume and measured volume for a standard battery enclosures showed an agreement within ten percent between the computational results from the algorithms described here and the actual product dimensions.

A power node with a 2-hour battery plant and generator combination offers a tremendous reduction in size compared to the 8-hour battery plant. Figure 3 illustrates these size reductions graphically. At 2kW, the equivalent of about eight feet of rack space would be occupied by eight hours of battery reserve, while only four feet are consumed by a power node with an engine generator and a two-hour battery reserve. At 8kW, even further savings in physical space are realized.

2.4 Weight

In consideration of applications where weight may be an issue, and to further illustrate the savings that an engine-generator with a one-hour or two-hour battery plant offers, the weights of these different solutions are examined and seen in Fig. 4. For a 2-kW power output, the weight of the two-hour battery plant and engine-generator is only 28 percent of the weight of the eight-hour battery plant. At 6kW, the engine-generator with two-hour battery plant is only 17 percent of the weight of the battery-only eight-hour plant.

2.5 Generator Control and Engine Controls and Safety Shutdowns

The engine-generator is intended to function in automatic, unattended operation with all the necessary safeguards to provide self-protection in the event a problem should arise. Several internal safety features above and beyond applicable regulations of the NFPA and ANSI are integrated into the engine-generator and control system. Among the sensors and sensor interfaces are the following:

-Gas Hazard: A device that sense Butane, Propane, and Methane in a calibrated amount to detect and alarm before the level exceeds a safe level. The end result is a gas hazard alarm which disables the engine-generator run function.

-Water Intrusion: A device that senses a rising water level internal to the enclosure. The device is located below all engine-generator air intakes.

-Pad Shear: A magnetic sensor which detects enclosure displacement such as caused by seismic, vehicular impact, or other force that could compromise the gas piping integrity and safety. The result is an alarm which disables the engine-generator run function.

-Fuel Pressure: A device that senses pressure of either LP or Natural (Methane) vapor gas pressure, either by contact enclosure or switch and provides this information to the status monitoring system to notify the central office, head end, or network manager of the

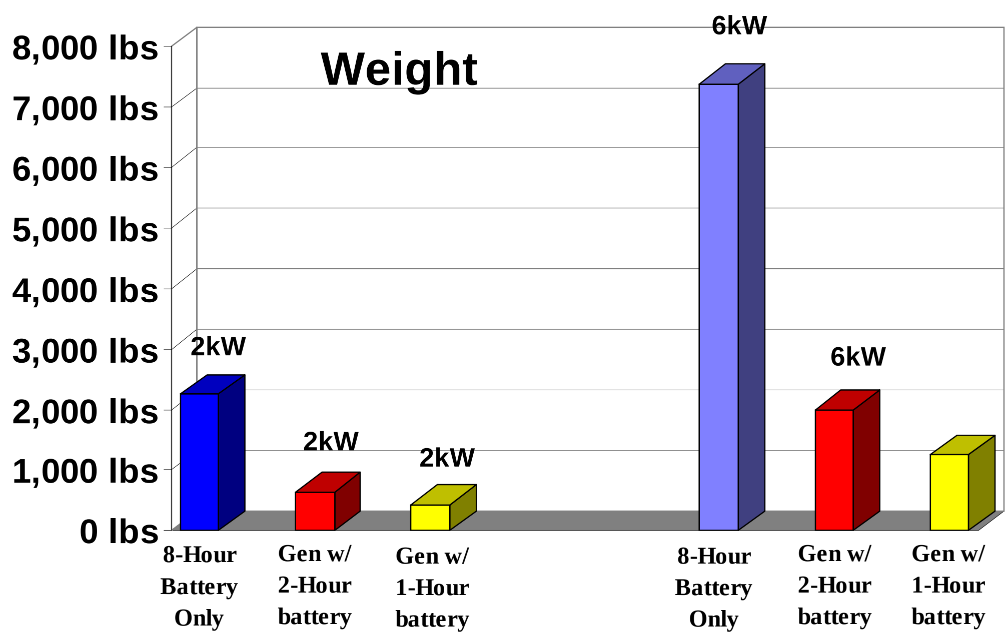

Figure 4. Comparison of weight by different energy-storage systems.

low fuel condition.

With over 1,500 installations of engine-generators in outside plant telecommunication applications, we have a great deal of practical experience and knowledge regarding the design and operation these engine-generators.

3. Cost of Power-Conversion Losses

Power conversion and control is always intended to function with the highest possible efficiency. In reality, all power conversion comes at the cost of some energy loss. From a financial viewpoint, what are acceptable conversion efficiencies? Given the $0.10/kilowatt-hour cost of utility energy, over a ten-year period, a power-conversion efficiency of 85 percent, and a 1-kW output power, the ten-year present-value of electric power is about $7,600. If the conversion efficiency is increased one percent, to 86 percent, a $88 present-value savings results. Thus, for example, in a comparison between a 85-percent efficient and 88-percent efficient 6-kW power nodes, the present value of the 10-year energy costs is $1,584 more with the less efficient power node. The efficiencies discussed in this paragraph are the conversion efficiency between the ac utility input and the various dc outputs. Often, this conversion path contains two conversions, one with the input rectifiers, converting the ac utility to the –48-Vdc bus, and the second, the conversion of the –48-Vdc bus to the –130Vdc for ONU powering.

A similar comparison may be made for the other form of input energy to the power node: the battery plant. Here, the conversion efficiency under consideration is the efficiency of the conversion between power from the dc battery bus and the output power. As this conversion efficiency increases, less battery ampere hours are needed to provide the eight-hour reserve. For a kilowatt of output power, an eight-hour battery plant occupies about 15 ft^3. If the conversion efficiency is increased by ten percent, the battery volume decreases by 1.5 ft^3. Differences between conversion efficiencies are seldom as great as ten percent, and more typically might be two percent. For a 6-kW output power, a two percent difference in conversion efficiency produces a 1.8 ft^3 savings in space. Any reduction in the ampere-hour requirements produces savings in initial costs as well as savings in maintenance costs. Unfortunately, batteries are only available in discrete sizes of ampere-hour ratings such that realistically these small percentage reductions in ampere-hour requirements cannot produce any reduction in battery plant size or costs.

4. RT and ONU Overview

A number of constraints limit the quantity of ONUs, and hence the number of living units, which may be hosted by an RT. For a given RT enclosure, these constraints include: limited amount of equipment rack space; maximum operating temperature of the modules and components located; and the finite volume of battery space available to provide the requisite eight-hour battery backup. The powering alternative presented here mitigates each of these limitations.

Name	RT physical size
Large RT	104”w x 50”d x 70”h
Small RT	66”w x 21”d x 66”h

Table 2. Physical dimensions of the two RTs under consideration here.

Many different combinations and architectures are possible with a FITL system, including physical size of the RT enclosures and size of ONUs. To focus and organize the discussion presented here, two different RT enclosures are considered: a large RT enclosure and a small RT enclosure. Physical dimensions of these two enclosures are given in Table 2.

Data transmission functions of a typical RT site, whether in a large or small RT enclosure, are accomplished with an integrated or OEM OC-3 multiplexor, common control assembly, and fiber bank(s). In support of these data transmission functions of the RT, two distinct powering functions exist: (1) a –48-Vdc rectifier and 8-hour backup system for powering the internal RT electronics; and (2) a –130-Vdc power system, also with an 8-hour backup, for powering hosted ONUs. Power for the internal RT functions is almost universally at a –48-Vdc voltage which is created with a –48-Vdc battery bus, with an eight-hour reserve capacity, receiving input power from redundant utility-powered rectifiers. The –130Vdc is created from the –48-Vdc battery bus with –48Vdc/–130Vdc dc-to-dc converters.

In conjunction with the two different RT enclosures discussed here, three different ONUs are examined. As seen in Table 3, the first configuration is an ONU-48 which is fully configured with 48 RPOTs lines. Second is an ONU-24, configured for only eight RPOTs lines out of a potential of 24 RPOTs lines. The configuration of ONU-24 is representative of installations in lower-density residential areas, especially where future upgrades of services are expected. Finally, the most cost-effective deployment, is a larger ONU, an ONU-96, which has a 96-RPOTs line capacity, and is fully utilized to its 96-RPOTs line capacity.

4.1 RT Power Dissipation and Processing

As greater numbers of ONUs are hosted from an RT, increased power dissipation, hence increased heat generation, arise from two distinct power conditioning functions: (1) conditioning of power for the internal RT functions; and (2) conditioning of power for the external ONU powering. Theoretically, if the power conversion processes were lossless, and thus 100-percent efficient, the first component of heat generation within the RT

Configuration	ONU Physical Size	ONU Services	ONU Utilization
ONU-48	pedestal	48 RPOTs lines	100%
ONU-24	pedestal	8 RPOTs lines	33.3%
ONU-96	pole-mount or ground-mount cabinet	96 RPOTs lines	100%

Table 3. Examples of ONUs considered here.

would still exist. Power-conversion efficiency has absolutely no effect on the heat generated by the power dissipated in internal RT functions. As the quantity of hosted ONUs increase, power required to operated the RT hosting this increasing pool of ONUs also increases. As each additional common control assembly or channel bank is added, additional power is dissipated. The second source of heat generation in the RT is the result of the inefficiencies of the power-conversion processes. These are added to the existing thermal load of the fiber bank and common control assembly.

As stated earlier, power dissipation within the RT arises from two separate functions: (1) power dissipation by the RT equipment such as the fiber banks and the common control assembly; and (2) power-processing losses in the conversion from the utility input to the –48-Vdc bus voltage and the conversion of the –48-Vdc bus to the –130Vdc needed to power the remote ONUs. Figures 5 through 7 illustrate these losses for the three different ONU configurations discussed earlier. As the number of ONUs served out of an RT grows, at some point a maximum number of ONUs which may be served by a single common control is reached and additional common control units are necessary, all of which place additional power dissipation within the RT enclosure. This can be seen in Figure 5, where the internal dissipation exhibits a nonlinearity as a second common control is needed for ONU quantities greater than 144.

In the case of the full-capacity, smaller ONU-48, the dissipation in the RT is dominated by the conversion losses. In general, for all the cases presented, the conversion losses generate more heat than the internal RT dissipation, though for small quantities of the under-utilized, smaller ONU-24s, internal heat dissipation exceeds conversion losses. Of the total hear which must be dissipated in the RT enclosure, the power-processing and conversion losses represent a significant portion, as large as 90 percent, of the total cabinet losses. As the quantity of hosted ONUs increase, the conversion losses are dominant.

If the conversion losses could be removed from the RT cabinet, the thermal stress within the RT enclosure is dramatically reduced. The powering alternative presented here places the power-processing and conversion functions in a separate enclosure dedicated to these functions. This dramatic reduction in thermal loading of the RT enclosure is one of the advantages of a co-located power node.

4.2 RT Battery Capacity and Rack Space

RT is the amount of volume available for the battery energy-storage system. For the two RTs under consideration here, the finite, fixed size of the battery drawer limits the ampere-hour capacity of the battery plant. As summarized in Section 6, removing the battery plant from the RT and placing it on a co-located power node, allows a greater number of ONUs to be hosted out of the RT by adding additional high density fiber banks and eliminating the thermal load of the power-processing components themselves.

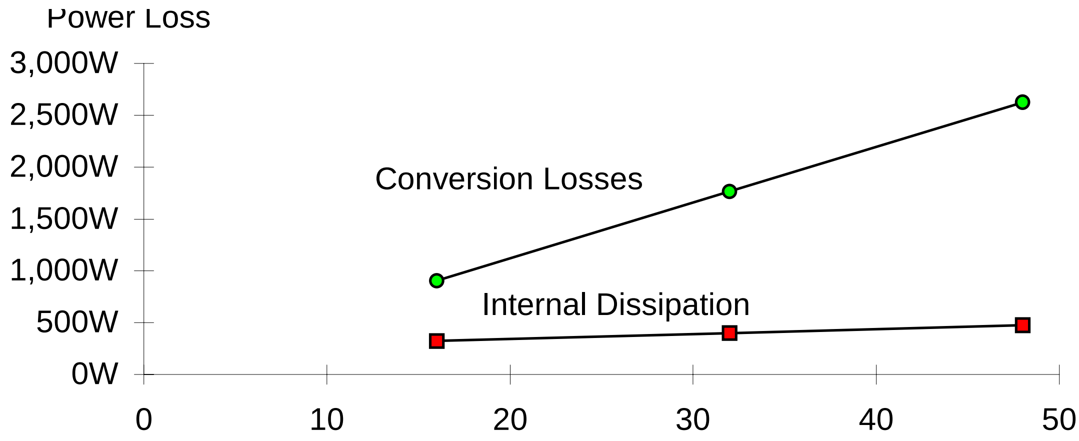

Figure 5. Power losses in an RT versus quantity of ONU-48s hosted.

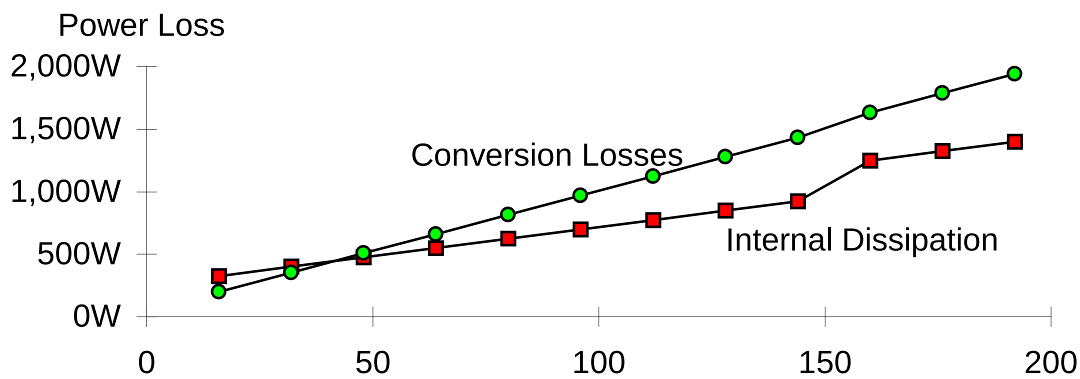

Figure 6. Power losses in an RT versus quantity of ONU-24s hosted.

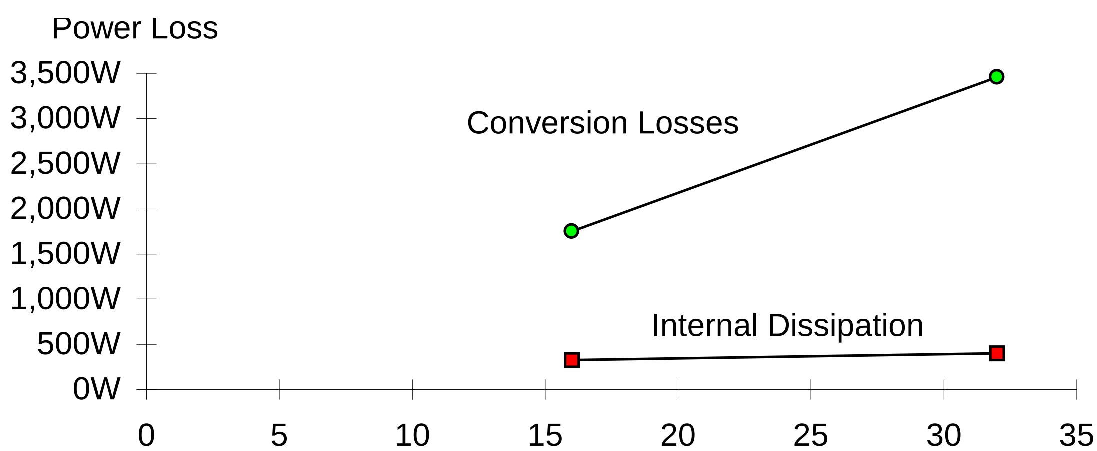

Figure 7. Power losses in an RT versus quantity of ONU-96s hosted.

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Another limiting factor for the RT is the amount of rack space available for the common control assemblies and channel banks. With the transfer of the power-processing equipment to a co-located power node, and using this co-located power node for the battery plant too, a great deal of rack space within the RT becomes available for additional common control assemblies and channel banks to support additional hosted ONUs.

5. Growth Potential

Many differing plans are underway for revenue growth among stiffening competition. Migration paths must be available to support POTS, data, ADSL, and video services as these are added. With growth and increasing acceptance of these services even more power is demanded at the RT. For instance, with a video upgrade, increased powering is needed on the order of 25W for every eight video feeds. Similarly, for ADSL, though the eight-hour battery backup is unnecessary, requires a normal operating power of approximately 7W per line, with a need for a fifteen-minute backup time.

6. Summary of Benefits of a Co-Located RT and Power Node

By co-locating a power node with the RT, many of the restrictions discussed here are removed. Consider the comparisons made in Table 4. In some cases, the addition of the co-located power node increased the potential number of hosted ONUs by a factor of seven. Co-locating such a universal power platform on the same easement and pad as the RT further reduces initial installation cost of the site. Co-location also allows the power node to grow in capacity along with the services; as additional power, or even HFC powering is needed, the universal power platform allows such growth.

This approach of co-locating a power node with the RT allows the RT to be utilized to its fullest capacity and thus servicing greater numbers of livings units. Without the co-located power node and RT, multiple RTs or significantly larger enclosures or concrete huts would be required. This greater utilization of the RT, unencumbered by the limitations of the batteries and power, also means less easements are needed and thus offers

RT Size	ONU Type	Standalone RT Capacity	Capacity of Co-located RT and Power Node
smaller RT	ONU-48	**7** ONU-48s	**52** ONU-48s
smaller RT	ONU-24	**32** ONU-24s	**80** ONU-24s
smaller RT	ONU-96	**3** ONU-96s	**23** ONU-96s
larger RT	ONU-48	**32** ONU-48s	**52** ONU-48s
larger RT	ONU-24	**96** ONU-24s	**192** ONU-24s
larger RT	ONU-96	**16** ONU-96s	**24** ONU-96s

Table 4. Comparison of RT capacities for different RTs and ONUs. The two columns at the right illustrate the gains with a co-located power node. For example, with a smaller RT, and an ONU-48, the standalone RT can serve 7 ONU-48s, while a co-located RT and power node can serve more than seven times are many, or 52 ONU-48s.

lower installation and acquisition costs. In fact, distance becomes the only practical limiting factor. It is conceivable that the amount of savings in the utilization of smaller RT enclosures and resulting easement elimination can easily pay for the power node itself. The virtual unlimited hold up provided by the generator and the modular configurability of the power node ensure that ample hold-up time and power reserve necessary to accommodate the increased demand of full broadband and future services as yet undefined, without the need to add additional cabinets or expand existing easements.