POWERING THE LAST MILE:
AN ALTERNATIVE TO POWERING FITL

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Abstract. Over the past several years, many telephone Local Exchange Carries (LECs) and cable Multiple System Operators (MSOs) have 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, these LECs and MSOs are demanding the most economical deployment architecture to serve their subscriber base with the greatest bandwidth possible.

Since the 1980's, principally the LECs have 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 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. This co-located power node may also be configured to provide 60/75/90Vac power for HFC networks, out of the same power node.

1. Introduction

Three different configurations of RTs and ONUs are used as the basis for comparisons between traditional powering, where there is no co-located power node, 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 MSO or LEC 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.

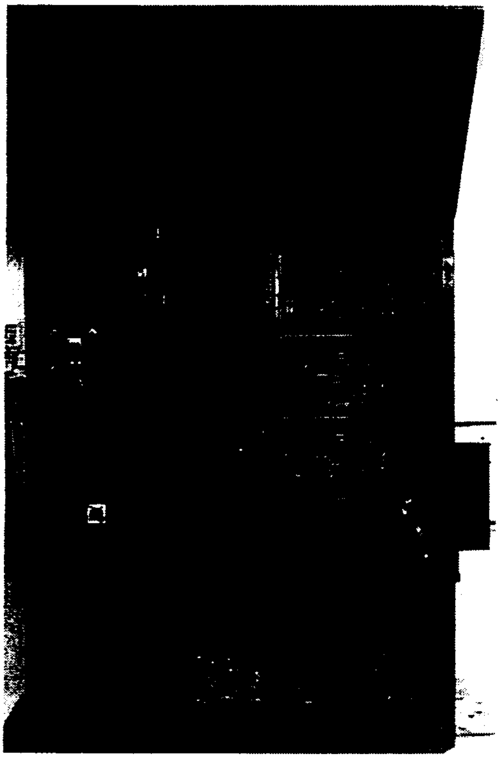

Figure 1. Photograph of Power Node with 7.5-kW internal engine-generator. The engine-generator is located at the bottom of the Power Node, while the standard controller is the 1.75-inch high, 19-inch wide module just above the engine generator.

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. An example of this generator and standard controller is seen in the Powever Node in Fig. 1. This standard 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. As seen in Fig. 1, the generator is integrated into the power node enclosure. In addition to the engine generator, a 75-ampere-hour battery is needed for cranking power during generator starting. Smaller generators, such as the 3-kW model, have rectification built in to the alternator, while high-power generators require a rack-mount rectifier and filter system for converting ac output from the alternator to a useable dc output. All of these generators are either powered from natural gas or propane. In most metropolitan and suburban areas these generators are connected to the natural gas distribution system, eliminating the need for refueling and thus creating a virtually unlimited reserve time.

	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
Auxiliary Electronics	none	rectifier/filter

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

The 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. A start sequence for this engine generator is initiated by either a low dc bus voltage or after the ac line is disqualified for a user-programmable period, typically ten minutes. Expected generator liftimes are based on the run time of the generator, both run time from the autonomous test function and the run time due to power outages in excess of ten minutes. These engine-generators are waranteed for 2,000-hours of operation. 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. Adding the 6.5 hours of annual run time from the autonomous test function, 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

In comparisons of battery-only power nodes and power nodes with battery-generator systems, operating expenses arise from two different sources: 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. 2 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. At the 2-kW power level, the intial cost of a combination of a 2-hour battery plant and generator is approximately 70 percent 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 generator is approximately 60 percent of the initial cost of a battery-only 8-hour backup. At these 6-kW power levels, costs are high, so a 60-percent savings is significant.

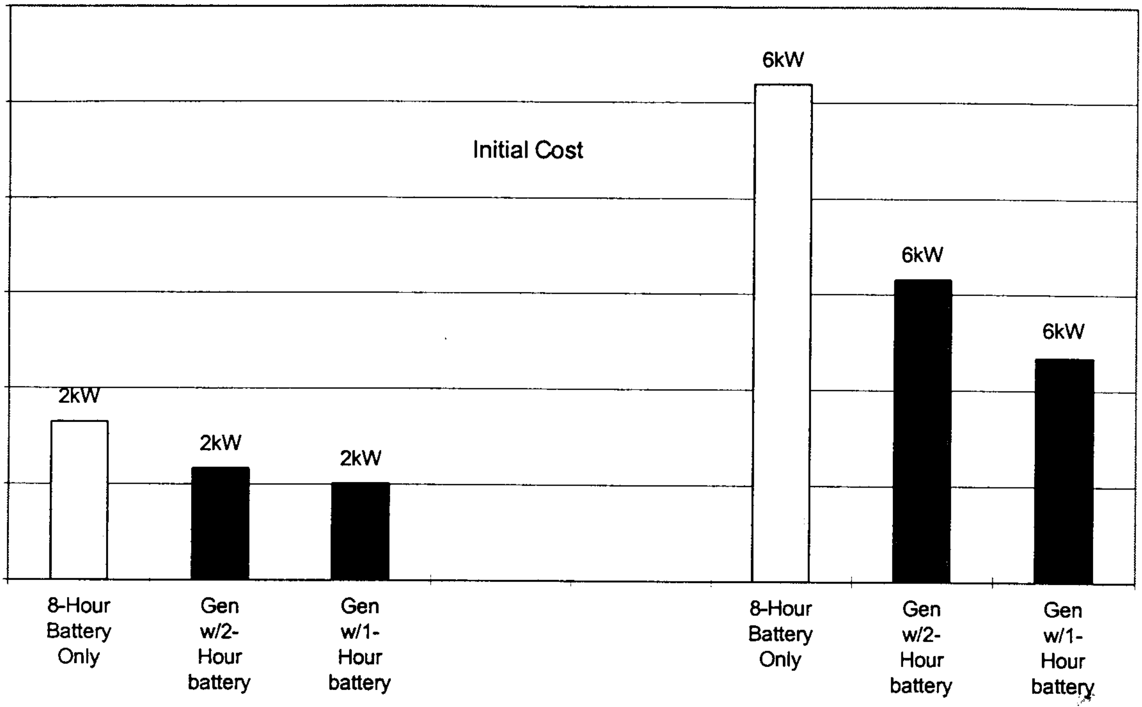

Figure 2. Comparisons of initial cost for two power levels, 2kW and 6kW. Comparisons are made among an eight-hour, battery only solution, and combination of generator and a one-hour and two-hour battery backups.

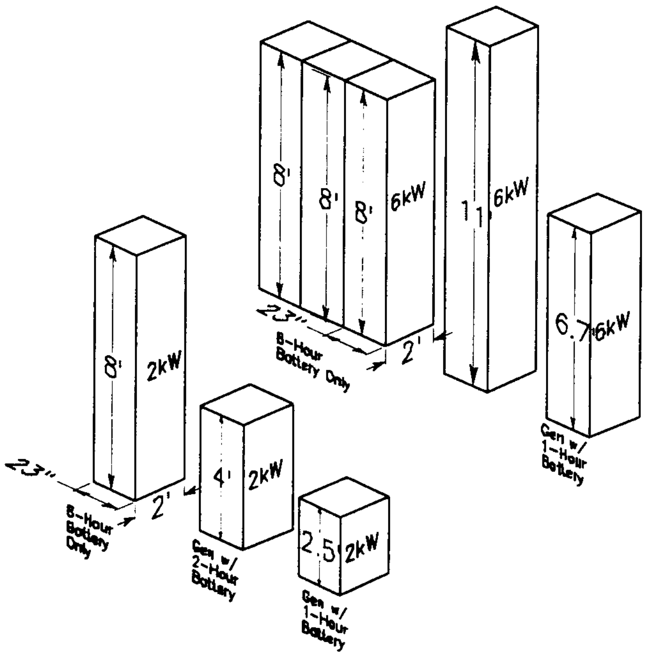

Figure 3. Comparison of physical size occupied by different dc energy-storage systems: eight-hour battery only, a two-hour battery plant with engine generator, and a one-hour battery plant with engine generator. The three rectangles in the foreground represent the physical size for a 2-kW load, while the three in the background are for 6-kW.

The greatest unknown when comparing operating expenses for a power node with a generator-battery system and a power node with a battery-only system, is the anticipated lifetime of batteries in outside plant. Our experiences with batteries in over 500,000 outside-plant installations, worldwide, is that battery life expectancies range between two years to five years; these expectancies are based on a temperature-compensated charging algorithm.

Battery expenses are even greater when replacement costs for these two-year-life-expectancy batteries are considered. Over a ten-year period, five sets of batteries are required: initial installation, and replacemetns in years two, four, six, and eight. To illustrate the present-value expense of battery-based reserve over a ten-year ownership interval, consider the cost of a set of batteries as X. A present-value calculation for the initial complement of batteries, with replacement batteries in years two, four, six, and eight, yields a present-value cost of 4.2X. Thus, the present-value expense for a ten-year ownership interval, with a $20,000 price for eight hours of battery reserve at a 6-kW load, is $84,000. With the cost of two hours of battery reserve at $5,000 (one quarter of the eight-hour reserve cost), the present value for two hours of battery reserve, over a ten-year ownership period, with a two-year replacement cycle, is $21,000. Before a cost comparison can be made between a battery-only reserve and a generator-battery combination, the initial $7,000 cost for an engine-generator must be added to the battery costs. An engine-generator and a two-hour battery plant produces a power node with infinite reserve time, and represents a $28,000 present-value cost for a ten-year ownership period. Compare this with the $84,000 present-value cost for an eight-hour, battery-only reserve power node.

If initial costs alone are considered, a power node with an engine generator is less costly than a traditional battery-only power node at powers in excess of about 2kW. When ten-year cost of ownership is considered, 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.

2.3 Physical Size Considerations

Within a power node, the function 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

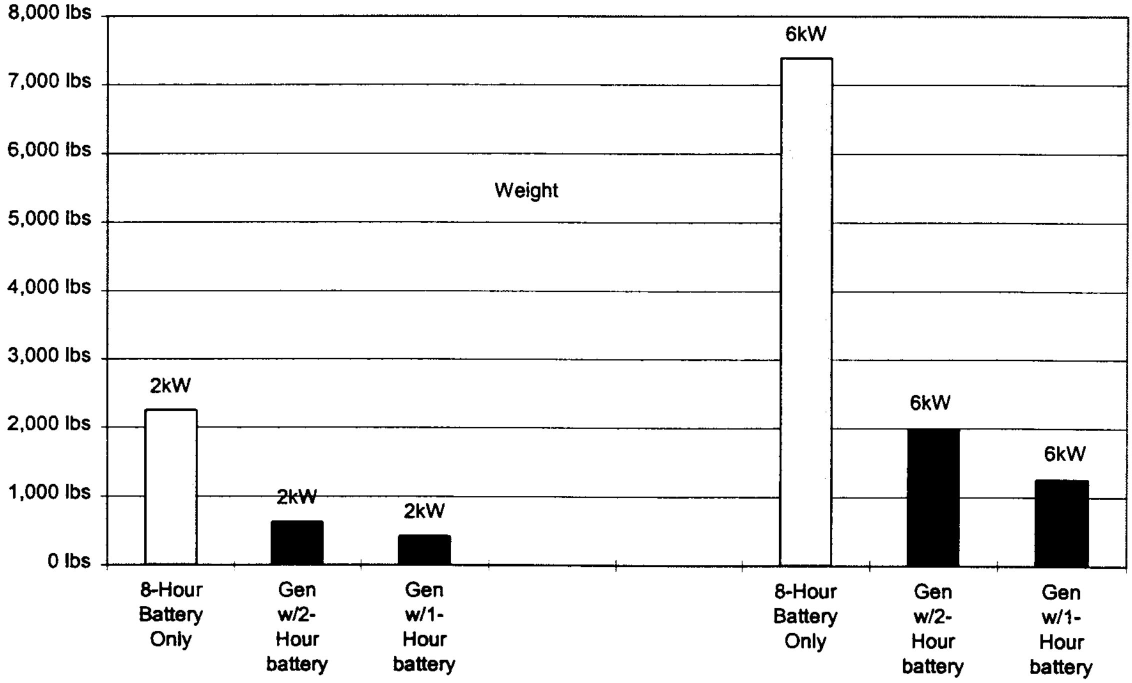

Figure 4. Comparison of weight by different energy-storage systems.

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.

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.

Compared to an 8-hour, battery-only power node, a power node with a 2-hour battery plant and generator combination offers a tremendous reduction in physical size. Figure 3 graphically illustrates these reductions in physical size. For 2kW, the equivalent of about eight feet of 19-inch rack space is occupied by eight hours of battery reserve, while only four feet is 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 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 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 which senses the 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 low fuel condition.

With over 1,500 installations of engine-generators in outside plant telecommunication applications, a great deal of practical experience and knowledge regarding the design and operation these engine-generators has produced a reliable, rugged, safe system.

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 energy loss, however small. From a financial viewpoint, what are acceptable conversion efficiencies? Given a cost of utility energy of $0.10/kilowatt-hour, and a power-conversion efficiency of 85 percent, for a 1-kW output power the ten-year present-value of electric power is about $7,600. An increase in conversion efficiency of one percent, to 86 percent, produces an $88 present-value savings. Thus, for example, in a comparison between power nodes with 85-percent and 88-precent efficiencies, at 6-kW, over a ten-year ownership interval, the less-efficienct node has additional $1,584 present value energy cost. 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 conversion stages: input rectifiers forming the first stage, converting the ac utility to the –48-Vdc bus, while the second stage conversion creates –130Vdc from the –48-Vdc bus for ONU powering.

A similar comparison can be made for the other input energy source: the battery plant. Here, the conversion efficiency of importance is relates the energy-conversion efficiecny between dc-battery input power and power-node output power. More efficient conversion reduces the required battery ampere hours for the eight-hour battery reserve time. 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 within the RT; and the finite physical space available to provide the requisite eight-hour battery backup. The powering alternative presented here mitigates each of these limitations.

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

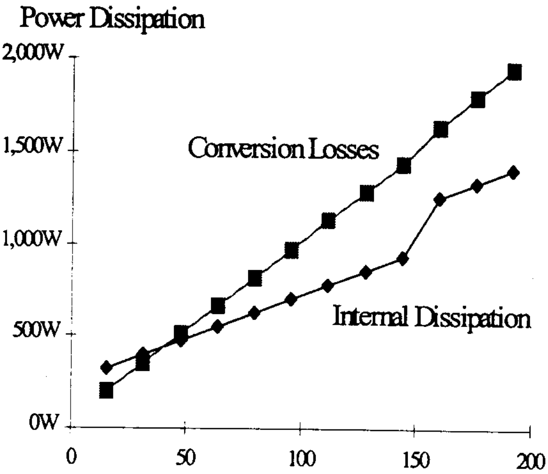

Figure 5. Power losses in an RT versus quantity of ONU-48s hosted.

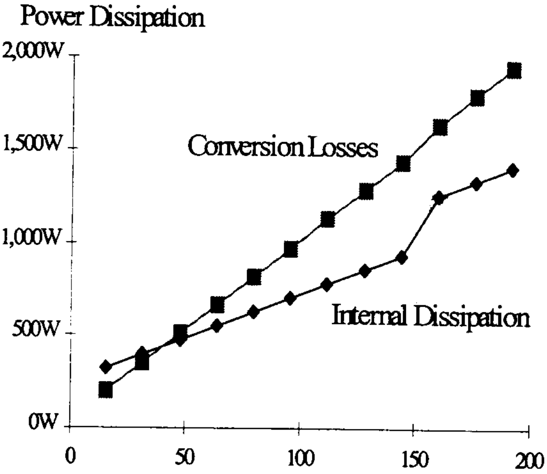

Figure 6. Power losses in an RT versus quantity of ONU-24s hosted.

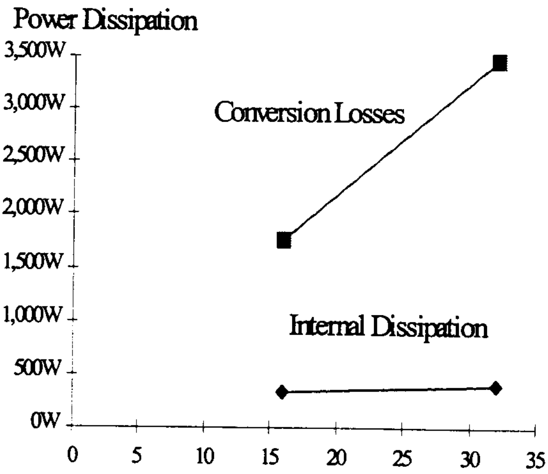

Figure 7. Power losses in an RT versus quantity of ONU-96s hosted.

Configuration	ONU Physical Size	ONU Services	ONU Capacity
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.

conversion processes were lossless, and thus 100-percent efficient, the first component of heat generation within the RT 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 6, 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 heat 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

As stated earlier, another limitation in the quantity of ONUs which may be hosted by an 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.

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.

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 as many, or 52 ONU-48s.

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 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.

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