Planning & Engineering Guidelines for Remote Line Power Networks

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Abstract - Telecom network elements, both wireline and wireless, continue to move closer to the end user to meet bandwidth needs. From Fiber-to-the-Home (FTTH) and Digital Subscriber Line (DSL) in wireline networks to Distributed Antenna Systems (DAS) and small cell wireless networks, the network trend is to move from a centralized to a distributed architecture. Since they serve fewer users, the network elements require less power per location, but the number of sites increases exponentially. The sheer number of sites makes it difficult for the power utility companies to meet the communications service provider's turn-up dates. Moreover, the low power consumption per location provides little incentive for the utility to accelerate construction to meet the communications service provider's deployment plans.

This trend toward distributed networks has led to the increased use of Remote Line Power (RLP) as an alternative means of energizing the remote devices. With RLP, the service provider delivers power to each device over copper cables that originate from a centralized location. Sometimes the copper cables come from excess capacity in existing Outside Plant (OSP) networks. In other cases, such as small cell networks, the service provider lays new copper cables in conjunction with the fiber backhaul cable that connects each site. Either way, the communications service provider controls its destiny.

Deployment of Remote Line Power networks changes some of the practices and processes for planning and engineering. The copper cables that typically supplied -48Vdc power for POTS now deliver ±190Vdc. Both -48Vdc and elevated voltage cable pairs may be included in the same cable and sometimes the same binder group. Reach is affected due to the size of the load and the use of higher voltages. And the presence of the elevated voltage necessitates additional precautions to ensure technician safety.

This paper addresses the new planning and engineering requirements for RLP networks. It provides details on how RLP works, how far it can reach, and how to qualify cable pairs for use in these circuits. The paper concludes with recommendations for best practices for deploying Remote Line Power.

I. INTRODUCTION

The wireline network has been trending toward distributed architectures for decades. Digital loop carriers and Fiber-to-the-Curb were forerunners of the trend, but DSL, Fiber-to-the-Home, and now, G.Fast have continued to move the network closer to the end user. The wireless network is following suit as traditional Macro cells are supplemented by Distributed Antenna Systems, C-RAN networks, and Small Cells. Powering these distributed networks presents new challenges as this new wave of transmission equipment is more scattered and numerous, making power demand less concentrated than predecessors such as Digital Loop Carrier systems and Macro Cells. The sheer quantity of devices increases the number of locations requiring power and, in many cases, battery backup. Conventional local power solutions are more capital-intensive, expensive to maintain (especially with batteries), and difficult to manage. Moreover, the large number of sites, such as the case with small cell networks, creates a logistical problem for obtaining electricity from local power utilities. The result has been a resurgence in the deployment of Remote Line Power.

Remote Line Power is a method of energizing remote devices using power delivered from a central source over copper cable. The centralized power source may be a telco Central Office, or a power cabinet located in the Outside Plant (OSP) network. In either case, the source consists of -48Vdc power equipment and battery backup, which is converted to a higher voltage for distribution over copper cables to deliver power to the remote device. The benefits of RLP include (1) simplified maintenance by eliminating batteries at the far edge of the network; (2) reduced capital expenditures by avoiding the need for power equipment cabinets and individual batteries/chargers at each remote site; and (3) improved deployment logistics by minimizing the dependency on local electrical utilities to supply AC power to each site.

Examples of distributed networks that are often powered by RLP include:

- Fiber-to-the-Home (FTTH) networks, with a single copper pair and down-converter delivering power to

the Optical Network Termination (ONT) units located at the customer's premises
- G.Fast networks, with the copper pairs and a sealed down-converter energizing the Distribution Point Unit (DPU) located within a few hundred meters of the customers served
- Fiber-to-the-Node (FTTN) networks, with 2-3 cable pairs supplying power directly to small 12- and 48-channel VDSL2 DSLAMs that have built-in down-converter circuitry
- Small Cell networks, with 2-4 cable pairs and one or two sealed down-converters supplying power to the small cells deployed much closer to customers than Macro Cells

II. Remote Line Power – How It Works

Before discussing how to plan RLP networks, it's important to have a basic understanding of how the technology works. Remote Line Power is unique because the load is located far from the power source, perhaps as much as 6-7 kilometers away. Because of this distance, the voltage loss in the cable connecting the load can be as important as the power consumption of the load itself. Elevating the voltage above nominal -48Vdc reduces the current and resulting I2R losses in the cable. But, for safety reasons the voltage cannot be increased indiscriminately; likewise, the standards bodies limit the amount of power delivered to ensure the safety of the technicians who install and service the cables and circuits.

Remote Line Power equipment used in outdoor applications includes a special DC-DC converter, called an Up-converter, which converts nominal -48Vdc voltage to ±190Vdc, and another special DC-DC converter known as a Down-converter, which converts the ±190Vdc voltage down to a voltage suitable for powering the load. The load voltage is typically -48Vdc or -12Vdc. Some network equipment, such as Mini/Sealed DSLAMs, incorporate the down-converter functionality into the DSLAM to provide specific operating voltages for the DSLAM. A simple block diagram of a Remote Line Power circuit is shown in Figure 1.

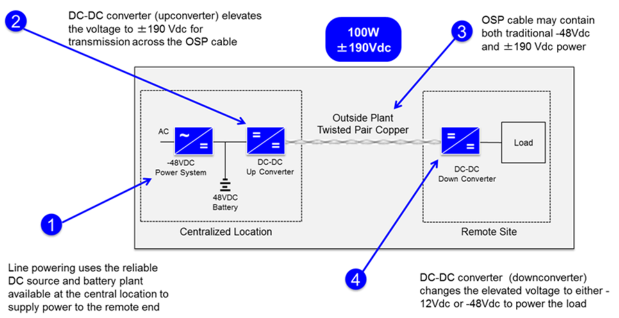

Figure 1 RLP Block Diagram

For safety considerations, there are standards [1] that limit the maximum power delivered over a Remote Line Power circuit to 100 Watts. The maximum Tip-to-Ring voltage is 400Vdc, and the maximum voltage from Tip-to-Ground or Ring-to-Ground is 200Vdc. Most power equipment vendors limit the voltages to 190Vdc from a conductor to ground and ±190Vdc across the Tip and Ring. These reduced voltages allow for tolerances and ensure compliance with the safety standards. Similarly, the actual maximum output power of the up-converter is usually limited to 96W to provide for some headroom with the 100W standard.

III. Planning Considerations

Planning and engineering Remote Line Power networks differs from centralized architectures. RLP is a crossover technology with power added to outside plant (OSP) cables. Combining power and OSP requires additional practices and processes for planning, engineering, and deployment. It involves the Inside Plant (ISP) group, who must ensure that the central site has sufficient power and a means to connect to the cables, and the OSP group, who must provide enough functional copper pairs to deliver the power to the end devices. The two groups must work together to perform testing for commissioning and acceptance.

Once the location of the remote network elements is defined, the planner can determine the location of the centralized power source based on the four main considerations in planning a Remote Line Power network:

1. **Power characteristics of the load** (consumption can range from 10W for an ONT up to 500W for a Small Cell)
2. **Cable pair availability**
3. **Distance between the remote devices and the power source**
4. **Cable make-up** (gauge, whether the cable is aerial or buried, the number of available pairs, etc.)

Load Power Characteristics

A single RLP circuit is limited to 100W, so load power consumption is a key piece in the planning and design effort. Network design for low power devices that consume less than 100W (e.g., ONTs, G.Fast DPUs, and some sealed DSLAMs) is rather straightforward since a single circuit can power them. For larger devices such as higher count DSLAMs and Small Cells, two or more circuits may be required to deliver sufficient power. The outputs of the Down-converters must be combined through a diode-or circuit in order to deliver an adequate amount of power at the right voltage level. The Down-converter devices may include this feature. In some cases, devices such as sealed DSLAMs may have integrated down-converter and diode-or functionality, so multiple copper cable pairs can terminate directly on the DSLAM.

Cable Pair Availability

An obvious consideration is whether there are available cable pairs. Often, wireline networks already have the copper cable is in place, having been replaced by the fiber serving the network element. But even the availability of pairs does not guarantee suitability. A rule of thumb is that cable pairs that previously provided voice or DSL service will usually be suitable for RLP voltages. But cable pairs that have been abandoned for some time or those that involve pulp insulated cable in the feeder cables will normally require testing to qualify them for service. This cable qualification process is addressed later in the paper.

In the case of Small Cell networks where no copper exists, service providers and neutral host network builders often deploy new copper alongside the fiber used to provide backhaul from the small cell. The copper may be installed either in a separate sheath or in a composite fiber-copper cable. Distance and economics determine the gauge of the copper cables.

Distance

Distance from the power source to the load is another key attribute in planning a RLP network. Revisiting the water pipe example, a shorter pipe would allow water to move through it more quickly than a longer pipe. Likewise, for copper cables, longer cables mean more resistance. For low power devices, a single circuit on a 24AWG cable pair may reach 20kft or more.

Cable Make-up

There are three main attributes of OSP cable: cross-sectional area (gauge), cable temperature, and cable length. Each attribute is discussed below in terms of how it affects the Line Power calculations.

Cable Cross-sectional Area (Gauge): The cross-sectional area of a cable determines its current-carrying capacity. In the same way a large water pipe will allow more flow than a small pipe, a cable with a larger cross-sectional area will allow more current to pass. In other words, the larger cross-sectional area offers less resistance to the flow of current.

Throughout all North America and many other regions, the cross-sectional area of a cable is defined by a standardized wire gauge system called American Wire Gauge (AWG). As shown in Figure 1, the lower the number of the gauge, the bigger the cable. For example, a 22AWG cable has a larger cross-sectional area than a 26AWG cable, and thus has a lower resistance. From a Line Power perspective, a 22AWG cable has a longer reach than a 26AWG cable. The most common cable gauges for OSP applications are 19, 22, 24 and 26 AWG.

Cable Temperature: Cable resistance also varies with temperature. The higher the temperature, the higher the resistance. Aerial cable will usually operate at a higher temperature (and thus, higher resistance) than buried cable. In other words, a buried cable will have a longer reach in a line-powered circuit than an aerial cable, assuming the cable gauge is the same. The Line Power formulas include factors for temperature variations, though focusing on whether the cable is aerial of buried is usually sufficient. Limiting the choices to buried and aerial simplifies the equations while still providing the data necessary to make informed decisions on Line Power reach and capacity. This same technique is often used in vendor calculators. Table 1 includes the resistance for various OSP cable gauges for both aerial and buried cables.

Table 1 Resistance for OSP Cables

Wire Size (AWG)	Ω / kft / pair	Ω / kft / pair
	Aerial (165°F)	Buried (65°F)
18	15.53	12.74
19	19.56	16.04
20	24.64	20.21
21	31.04	25.46
22	39.10	32.07
23	49.26	40.41
24	62.05	50.90
25	78.16	64.12
26	98.47	80.77

IV. Determining the Power Network Architecture

The planning design falls into two general categories. The more conventional approach is the Home Run architecture, where a building such as a Central Office is the home for the centralized power source. The power train components include the utility AC connection and associated protection devices, the rectifier plant and DC power distribution, and the up-converter equipment. The output of the up-converters is connected to the OSP cables via a traditional Main Distribution Frame (MDF). A CO is an ideal site to source the power since it already includes power conversion, battery and cable connectivity equipment, and is in a controlled environment which is easier to work in.

An alternative design is the Mid-Span architecture, in which the source power equipment, batteries, and cable connection/protection equipment are housed in an equipment enclosure known as a Remote Power Node (RPN). The RPN function is typically an outdoor-rated cabinet, though a building/hut or Controlled Environment Vault (CEV) would work as well. The Mid-Span power source may be a cabinet dedicated to power or combined with a network element (e.g., DSLAM) to power downstream devices. The Mid-Span architecture is typically used in Small Cell networks, serving clusters of small cells from a central RPN.

The two design topologies are shown in Figure 2.

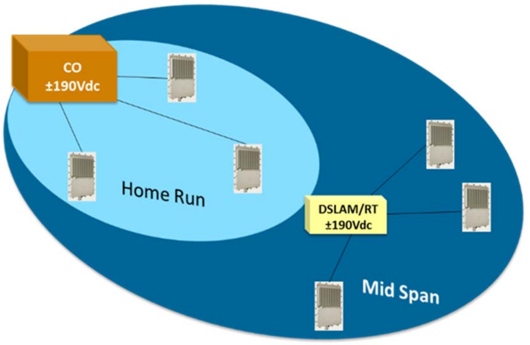

Figure 2 RLP Deployment Architectures

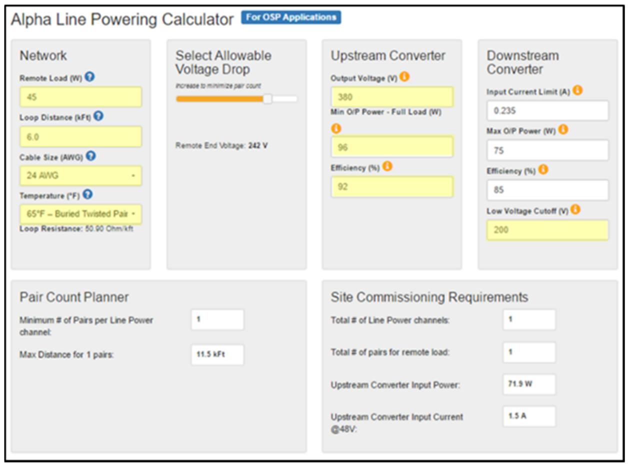

Figure 3 RLP Cable Calculator

Coverage requirements are the deciding factor in placement of network elements. Once these locations are identified, the network planners can determine if the Home Run or Mid-Span architecture is best for providing the Remote Line Power circuits. In wireline applications, the preference is to use the Home Run architecture. The Serving Central Office provides convenient access to the OSP cables via the Main Distribution Frame (MDF), an existing 48Vdc power train, and ample floor space for adding equipment. In wireless applications, on the other hand, the Mid-Span application is the most frequent approach since there is no existing copper cable in the wireless network. A closer look at the Home Run example shows how the planning process works.

<u>Home Run Architecture</u>

The planner must determine the number of available cable pairs that serve the site, the cable pair make-up, a convenient point to access the cables with the up-converter equipment, and the distance to a potential source of power. The first step is to look at the OSP Cable Records to (1) verify that the copper cable pairs appear at both the OSP sites and at the CO; (2) identify the cable make-up along the route; and (3) determine the end-to-end distance of the route. Assuming the cable pairs provide a continuous metallic path from the CO to the network elements, the second step is to identify the power characteristics of the network devices. This information, which includes both power consumption and minimum operating voltage, is often available from the equipment vendor's data sheets.

The third step is to enter the power characteristics and cable information into an on-line calculator typically provided by the Remote Line Power equipment vendor. The calculator will reveal the number of 100W circuits required to power the load. See Figure 3 for a snapshot of a typical calculator.

In some cases, however, the distance will be so great that the voltage at the network element will not meet the unit's minimum voltage requirements. A fourth step is needed to reduce the resistance of the cable. This can be accomplished by bonding two or more pairs together. While the there is no theoretical limit to how many pairs can be bonded together, a practical limit is 3-4 based on available OSP splicing devices. Two pairs in parallel cut the end-to-end resistance in half; three pairs result in a total resistance 1/3 of the original pair. Four pairs result in a total resistance 1/4 of the original pair. The bonding technique for two cable pairs is shown in Figure 4.

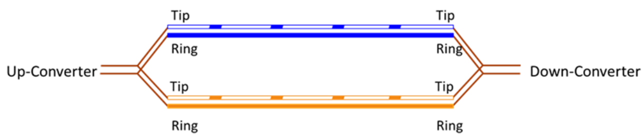

Figure 4 Paralleling Cable Pairs

Though the Home Run architecture is the primary approach in wireline applications, the CO is not always the best location for the up-converter equipment. Possible situations include:

- There is no continuous metallic path between the remote devices and the CO (e.g., when the feeder cable has been replaced by fiber)
- The distance between the remote devices and the CO is too great to power the units (e.g., at the edge of an exchange where a housing development is located on what was previously farming property)
- The cable pairs are not suitable for Remote Line Power (this is discussed in the next section)

When the CO is not the best location, the wireline carrier can use the Mid-Span approach. Likewise, the wireless service provider deploying a Remote Line Powered Small Cell network will use a variation of Mid-Span architecture for delivering the power.

Mid-Span Architecture

In this method, an OSP cabinet is the typical housing for the power equipment. The cabinet may be an existing cabinet, such as a Digital Loop Carrier cabinet that is being re-purposed for power, or it may a new installation. Both approaches require the same basic power components, including:

- A source of AC power from the electrical utility
- A rectifier plant that converts the AC to nominal -48Vdc and distributes it inside the cabinet
- One or more strings of batteries to provide back-up
- An optional port for connecting a generator
- Remote Line Power equipment to convert the nominal -48Vdc to ±190vdc
- Protection and connection devices to connect the output of the Remote Line Power equipment to the OSP cables

The size of the cabinet will be determined by the number of circuits to be powered and the amount of batteries required. One approach to managing the size of the cabinet is to provide just enough battery back-up (e.g., one hour) to enable technicians to reach the site with a portable generator that provides extended run time.

IV. Qualifying the Cable Pairs for RLP Service

The primary requirement for delivering Remote Line Power service is end-to-end continuity in the cable pairs. The continuity can be affected by open circuits, short circuits, ground faults, high resistance faults, etc., along the route. These faults typically occur at splice points, and are frequently the result of water intrusion. Gel-filled (e.g., plastic insulated conductor [PIC] cables) and dry-block cables are more resistant to water intrusion than air core cables, so they are preferred for use with Remote Line Power systems. Remote Line Power circuits should not be deployed on air-core and pulp cables unless the cable pressurization has been verified.

In 2016, the Alliance for Telecommunications Industry Solutions (ATIS) developed a simple 4-step test procedure to verify that cable pairs are suitable for Remote Line Power service [2]. The four test procedures include:

1. Test the pair for AC Voltage
2. Test the pair for DC Voltage
3. Test the pair for Insulation Resistance
4. Test the pair for DC Loop Resistance

The tests require an Ohmmeter or Multifunction Test Set for tests #1, #2, and #4, as well as an Insulation Resistance Test Set capable of supplying 500Vdc tip to ring, and 250Vdc tip or ring to ground for Test #3.

If a cable pair fails any of the tests, the service provider must either resolve the fault in the pair or select a different available cable pair.

V. Equipment Engineering

Once the planners have finalized plans for using Remote Line Power, the next step is to engineer the power equipment, Inside Plant connectivity, and Outside Plant cabling. Since each of these steps follows standard design procedures, this section will focus on the major steps.

Power Equipment

The process for engineering the power equipment is the same for both Home Run and Mid-Span Architectures. There are differences in the detailed engineering, including size and capacity, the amount of existing power capacity, access to the OSP cables, environmental equipment hardening, cooling, etc. For this paper, we are focusing only on the six (6) general steps involved in calculating the power requirements for a Remote Line Power application:

1. Select the Up-converter equipment

   There are a variety of solutions available, including 23-inch and 19-inch rack-mount shelves, 4-module compact housings for cabinet applications, and sealed 4-circuit modules for adding onto an existing OSP cabinet. The selection depends on the location of the source power as well as the planned requirements for service.

2. Determine the input power requirements for the up-converter equipment.

   This information can be obtained from the equipment vendor data sheet or can be calculated based on the specific application requirements. The best practice is to size the 48Vdc power plant and batteries based on full deployment of the line power equipment using a worse-case condition for power consumption.

3. Size the Fuse or Circuit Breaker protecting the 48Vdc Input

   Each connection from the 48Vdc plant to the Line Power equipment should include an overvoltage protection device such as a fuse or circuit breaker. The Line Power system is a DC-DC converter and appears as a load on the 48V rectifier plant. When AC power is unavailable to the 48V plant, the Line Power system will be powered by batteries that will operate until they reach their prescribed cut-off voltage, which is often 42Vdc. To size the input fuse, the Total Input Power must be divided by 42Vdc to determine the input current requirements during an AC outage.

   High capacity up-converter shelves may have dual inputs. The input connections may supply power to a specific group of up-converter modules or to all the modules in a fully redundant mode. This information is important to know when sizing the input protection device as well as the input cabling.

4. Size the Input Cabling for the Up-converter Equipment

The input cabling must be sufficiently sized to carry the current. Cable ampacity should always equal to or exceed the protector size. As noted in step 3, the cabling must match the input power connections of the up-converter shelf.

5. Sizing the Battery Backup

   The up-converter equipment increases the load on the power plant and batteries. In some applications, there is sufficient capacity in the battery strings to provide the required reserve for the up-converter equipment. The battery requirements should be determined based on individual company practices for recharge and backup.

6. Select the Down-converter Equipment

   The down-converter equipment comes in a variety of styles ranging from single-, dual-, and quad-channel units to modular shelves. The selection of the down-converter equipment depends on the load. A single channel, 48V/30W down-converter may be sufficient to power an ONT, whereas two four-channel 48V/300W down-converters may needed to power larger Small Cells.

Inside Plant Cable Engineering

The output of the Up-converter ultimately connects to copper cables. In a Central Office, the connection point is the MDF. The rack-mount up-converter shelves are typically connectorized with Amphenol connectors providing access to the outputs of the line power circuits. A connectorized tie cable is usually run from the line power equipment shelf to the Horizontal side of the MDF, where it terminates on a terminal block. To connect to the OSP cables, jumpers are run from the Horizontal terminal block to the Vertical side of the MDF where the protection devices are located. A block diagram of this connection is shown in Figure 6.

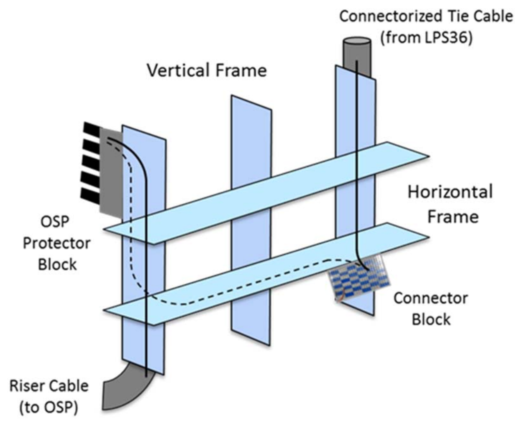

Figure 5 MDF Connections for RLP

Outside Plant Engineering

Due to the growth in FTTH and DSL applications, the OSP cables are often already in place and available for use as Remote Line Power circuits. The power circuits can operate over any cable gauge, with distance contingent on the size of the cable (e.g., 22AWG cables have longer reach than 26AWG cables). The physical connections at splice points are also the same as with other services. The cable pairs can be connected using modular connectors (e.g., 3M's MS2™ connector) or discrete connectors (e.g., 3M's Scotchlok™ connectors). Other than the caution previously noted about pulp and paper insulated cables, there is truly no distinction in OSP engineering for power or transport services.

Because the Remote Line Power circuits are DC only, there is also no electrical reason to separate them other cable pairs carrying traffic (e.g., POTS, DSL, etc.). However, some companies choose to segregate the circuits to ensure the OSP technicians are aware of the elevated voltages in the pairs. The pairs and/or binder groups also are marked so that the technician can readily see that the pair or binder group contains Remote Line Power circuits.

Remote Power Node Engineering

In a Mid-Span application, the RPN is either a cabinet, shelter, or CEV located in the outside plant. This design requires additional engineering steps, though they generally mirror the power and OSP engineering steps in the Home Run architecture. A source of AC from the local utility is require. The enclosure must be equipped with -48Vdc power system, batteries, and the up-converter equipment to produce reliable ±190vdc power. There must also be protection and connection equipment to provide proper connection to the OSP cables.

New installations usually involve fully equipped cabinets for the line power equipment vendors. Existing cabinets, such as those used for DLC or DSLAM equipment, can be retrofitted in the field and converted to an RPN. In some applications, typically involving DSLAMs, the transmission equipment vendor will include a compact shelf of line power equipment to power downstream devices.

VI. BEST PRACTICES

This paper has covered how Remote Line Power works, how to plan and engineer an installation, and how to qualify cable pairs for ±190Vdc service. Experience with deployment in a variety of applications has resulted in the development of several best practices that help facilitate deployment. This section covers the best practices for planning, engineering, and installation.

Cable Pair Selection

- Once the site is identified, chose routes with the largest gauge of cable or cable mix available to enhance reach.
- Perform the Cable Qualification Procedure prior to deployment to verify the availability of quality cable pairs.
- If there are ample pairs available in the cable, designate a binder group to dedicate to power to help raise awareness for technicians.

- To determine distance, use a vendor Line Power Calculator to determine proper number of circuits and cable pairs.

Inside Plant Engineering

- Design the 48Vdc power plant and batteries to serve the maximum capacity of the Line Power equipment, even if the system is not fully loaded.
- In applications where the OSP cable terminates in a MDF, dedicate a block on the horizontal side of the frame that segregates the Remote Line Power circuits to help prevent accidental contact with the elevated voltage.
- On the vertical side of the MDF, use high voltage (300Vdc) protectors that are a different color (e.g., red) than the conventional black protectors to distinguish the Line Power circuits from other 48Vdc circuits.
- If two or more cable pairs need to be connected in parallel (i.e., bonded), do the jumper work on the vertical side of the MDF. In other words, jumper individual positions on the vertical side together, then run a single jumper to the horizontal side. This will make it easier to troubleshoot the pairs by minimizing the number of jumper wires that cross from the horizontal to vertical side of the MDF.

Design for Redundancy

- Whenever there are available cable pairs, it is prudent to design the circuit in an N+1 manner. In other words, if two circuits delivered over two cable pairs can adequately power the load, a 3rd circuit over a separate cable pair provides assurance in the event of a fault in one of the primary pairs.
- Most up-converter modules include multiple channels (i.e., ±190Vdc circuits). When multiple circuits are required to power the load, it is a best practice to assign the circuits to different modules to provide redundancy in the Line Power shelf and makes it easy to perform maintenance without taking the powered equipment out of service.

Inside Plant Installation

- At the MDF or cross-connect, protect the cable pair with Priority circuit caps or insulators.
- At the MDF, use a unique colored jumper wire for the connection between the horizontal and vertical sides so that technicians can recognize the presence of the line power voltage.

Outside Plant Installation

- Remove load coils and bridged taps from the pairs selected for Line Power service.

Safety

- Identify and tag or mark all power pairs where accessible to technicians (prints / records / MDF / pedestals).
- When cable pair bonding is required, both ends of the cable pair must be bonded. At the MDF, join the Tips and join the Rings on the Vertical side by running jumpers between the conductors. In the OSP, join the pairs at the pedestal or splice case nearest to load.

VII. CONCLUSION

The planning and engineering of RLP networks does require additional steps when compared to traditional local power solutions. But the process is relatively simple and understandable, and follows a straightforward process. One of the most important considerations is to get the Outside Plant and Inside Plants working together up front to minimize issues once the construction and installation process begins.

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