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A cost-effective method of controlling lightning effects and improving safety in wayside bungalows that incorporate PTC electronics

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Abstract

The rail industry of today is a growing, reliable, and fuel-efficient form of ground freight and passenger transportation. The rail industry is part of our nation's critical infrastructure and is composed of approximately 250,000 miles of track (Figure 1).

The Positive Train Control (PTC) Mandate will soon be fulfilled by 41 railroads around the US. The ongoing implementation of PTC has uncovered the need for a higher level of functioning of lightning arresters and surge protective devices (SPDs), which will provide a safer environment for the newly installed PTC components at the trackside. The increased level of safety stems from the better protection of downstream PTC components that modern, electronic SPDs offer. PTC components are protected from the effects of lightning by SPDs installed at the signal cable entrance to signal bungalows. These primary surge protectors offer additional benefits that include cost-effective solutions to mitigate the effects of lightning within the wayside bungalow.

INSIDE:

** Mr. Schroeder passed away in 2016.*

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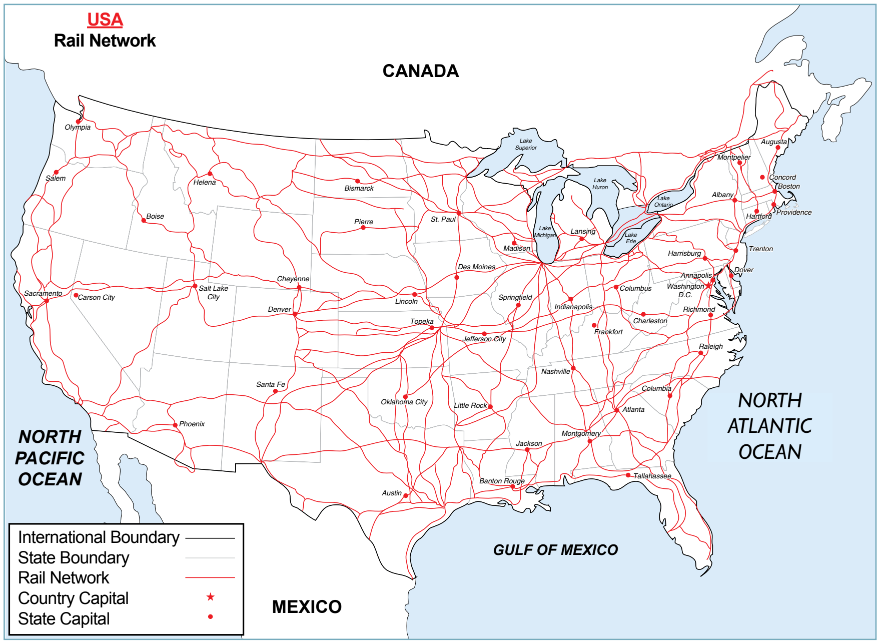

Figure 1: USA Class 1 rail network – Short Line RRs not shown

This paper will:

- Review the role of PTC in acting as an industry driver for improved communications and electronic systems, including lightning surge protection.
- Compare and contrast the construction and operation of the BE-AR SPD and the legacy Association of American Railroads (AAR) devices when these devices are used inside wayside railroad bungalows.

Introduction

PTC has been implemented on many miles of track primarily to address safety concerns:

1. To prevent train-to-train collisions
2. To prevent over-speeds
3. To prevent incursions into work zones
4. To prevent the movement of a train through a switch in the wrong position

PTC has added new electronic and communication system functions and capabilities to existing infrastructure. It has also added these same functions to switch locations that were not previously monitored by any signal system (also known as “dark territory”).

Approximately 56,000 miles of track have been equipped with PTC. The economic impact of implementing PTC technology in the railroad system has cost about $14 billion. Figure 2 shows an illustration of a functioning PTC system.

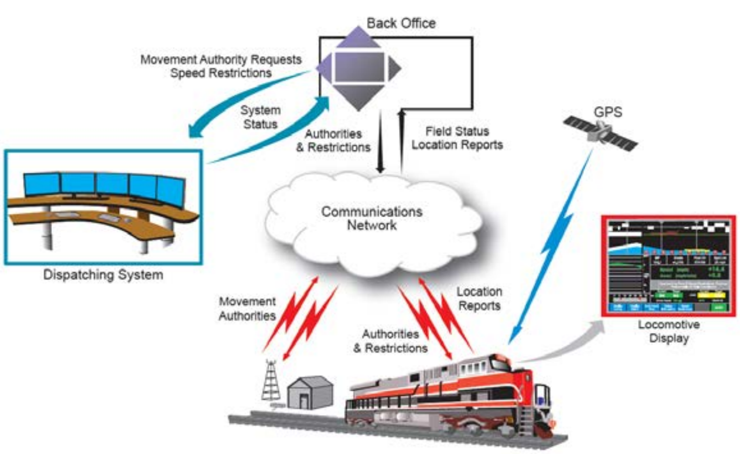

Figure 2: Positive train control (PTC) system

Legacy surge devices

Legacy (AAR) surge arresters have been in use since the late 1940s. The patent shown below represents the earliest variations of the technology employed by the railroads during the electromechanical era.

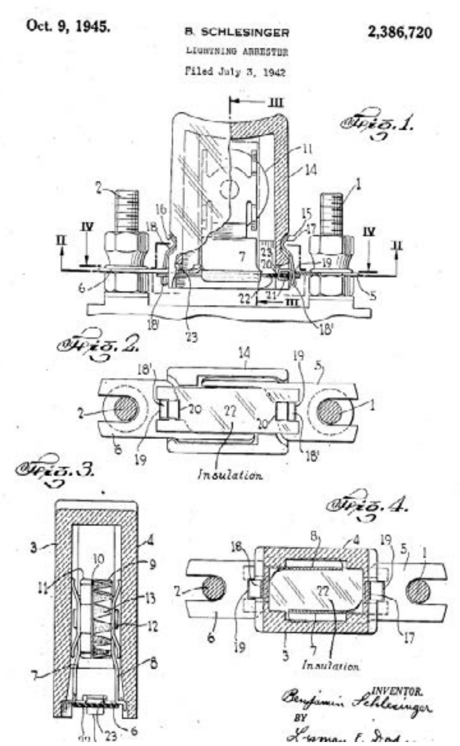

Figure 3: Patent #2,386,720 – Lightning arrester

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The implementation of PTC has accelerated the use of microprocessor-based electronic circuitry for controls located in the wayside signal bungalows.

Microprocessor-based control circuitry is significantly more susceptible to the effects of lightning strikes than legacy electromechanical control circuitry. For example, the older electromechanical relays built from copper and brass could withstand higher let-through voltage events. This fact has been a driver for the use of pre-existing, alternative forms of wayside lightning protection devices that increase the reliability of wayside equipment operation during and after lightning strikes. This new approach to lightning protection in wayside bungalows can increase the reliability and safety of PTC systems. This paper will focus on the significant differences between the electrical/mechanical functioning, the cost of operation, safety advantages, and system efficiencies between the legacy and next-generation devices.

To provide a baseline for this discussion, we will first review the construction and equipment practices of legacy lightning protection devices predominantly in use in signal bungalows. Figure 4 is an example of a present-day AAR surge arrester using a design very similar to the original design patent. Features of the current state of the AAR arrester technologies are listed below.

Figure 4: Electromechanical lightning arrester

Features of the current state-of-the-art air-gap arrester technologies are:

- Surge protective device technology: Spark-gap-based
- Operating voltage: 0 to 50 V DC and others
- Breakdown voltage: 700 to 1000 Volts
- Discharge current: 50 kA $_{max}$
- Let-through voltage = 2500 $_{Vnom}$

Mechanical characteristics:

- The surge arrester is used in conjunction with a terminal mounting block.
- The terminal mounting block consists of three, four, or five binding post configurations (14-24 thread), depending on position and usage.
- Wire-bending techniques, ring-tongue terminals, loose washers, and nuts are used to connect wires to the binding posts.
- The SPD is mechanically connected between two of the binding posts.
- The design includes a hardware-based "Golden Nut" isolation disconnect.

Figure 5 shows the mechanical construction of the AAR surge arrester.

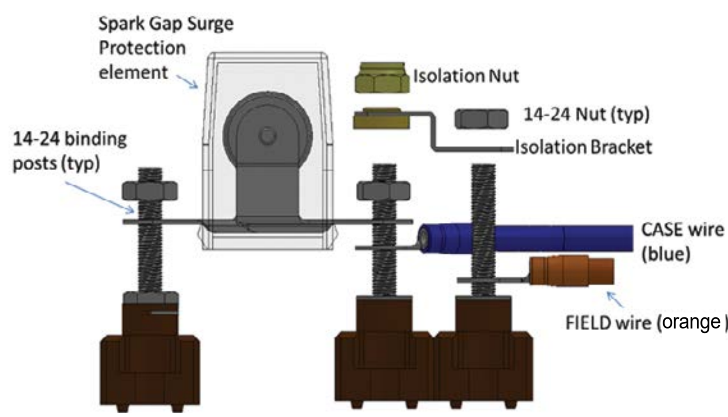

Figure 5: AAR surge protective construction

AAR device performance testing procedures

Equipment practices have been developed for the use and application of AAR devices within the bungalow environment. These equipment practices include:

- Installation practices
- Insulation resistance testing of field wire
- Surge arrester field replacement
- Surge arrester replacement methodology

The implementation of these practices will be illustrated for the AAR devices and then compared to the implementation of the same practices using a newer technology – base element American railroad (BE-AR) surge protective devices.

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Installation practices

Depending on the size of the bungalow, more than 100 arresters may be used in the wayside bungalow for the protection of signal and communication circuitry. An example of a typical bungalow-style installation of arresters is shown in Figure 6.

Figure 6: Typical bungalow-style AAR arrester installation

The construction of the individual AAR-style arrester has been previously reviewed and is shown in Figure 5. Note the placement of the arrester element between the two terminal mounting blocks and the positioning of the various nuts, wires, and washers within the assembly. The combination of a standard AAR surge protection device and a bungalow-protection circuit configuration is shown in Figure 7.

Figure 7: Standard surge arrester circuit configuration

Subsequent to the mounting of the arresters in the bungalow, the technician must make wire terminations to the field and case wire. This is accomplished by stripping back the field and case wires, trimming the wire insulation, forming a ring tongue out of bare wire, or crimping a ring terminal onto the bare wire, and then connecting the wire to a post with a nut.

Insulation resistance testing of field wire

To ensure continuing functionality of the protective circuitry within the bungalow, the AAR devices are periodically tested on-site for a minimum insulation resistance (IR) value between the field wire and the appropriate ground reference point.

The test sequence described below references the lead placements shown in Figures 8 and 9.

1. The “field” wire (orange) is tested periodically for its insulation resistance value. This test is performed with a megohmmeter. The megohmmeter measures high-resistance values associated with insulation resistance.
2. To do this test, the “case” wire (blue) and the SPD element “ice cube” must be disconnected from the circuit.
3. This is accomplished by removing the gold nut, to release tension – and thus conductance – on the spring link.
4. Then the megohmmeter is connected between the field wire post and the ground reference, and the insulation resistance between the field wire and ground reference is measured.
5. Lastly, the gold nut is retightened to attach the case wire and the SPD to the field wire.

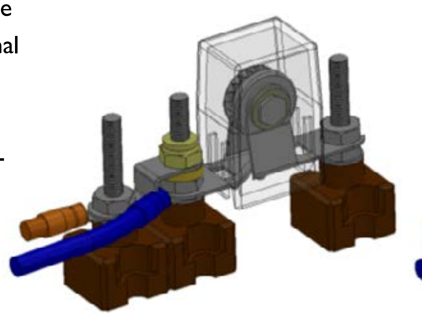

Figure 8: Normal lead placement

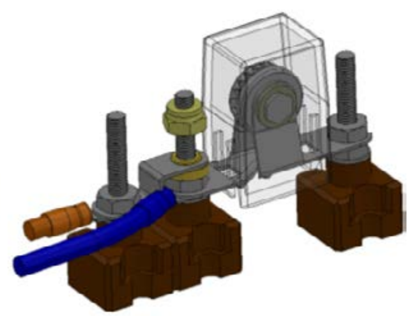

Figure 9: Configuration during megohmmeter test

Surge arrester field replacement

Another requirement of the individual air-gap surge arrester in the bungalow environment is that it must be field-replaceable in case of device failure due to voltage surge or lightning strike. The criterion for failure of the arrester is 30 percent carbon coverage of the inside plastic cover of the arresters, based on a subjective visual inspection of the arrester, as viewed through the clear plastic enclosure surrounding the air-gap surge arrestor. Inspection after a lightning strike, as well as periodic inspections of all arresters within a bungalow, is required to ensure compliance with this criterion. Replacement of a failed individual arrester requires turning off power to the entire bungalow protective circuit to ensure maintainer safety during replacement of the failed arrester. The following section describes replacement of a failed arrester.

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AAR arrester replacement

After securing track time and powering down the bungalow protective circuitry, the replacement of the failed arrester involves removing all of its mounting hardware from the ground, field, and case wires, and the failed arrester from the inline circuit. A new arrester is mounted onto the correct terminal block posts, and any associated wiring and mounting hardware are reassembled onto the terminal block posts. The assembly is then put back into the inline circuit and the bungalow protective circuit is reenergized. In Figures 10 and 11, you can see typical bungalow protective circuit configurations and space limitations. No disarrangement of wires is allowed in this process.

Figure 10: Bungalow protective circuitry configuration

Figure 11: Bungalow protective circuitry configuration

BE-AR terminal blocks

The BE-AR terminal block has been developed as an alternative to current practices to meet the more demanding electronic and mechanical performance criteria associated with the PTC IC-based equipment to improve safety by protecting critical PTC components, and to reduce the time and labor required for installation. The electronic circuits associated with PTC systems have increased sensitivity to lightning strikes and voltage surges, so they require faster response time and lower let-through voltage at the SPD level. Associated mechanical improvements are also needed to shorten the time required for equipment practices to meet more vigorous cost targets as a result of PTC implementation. This section of the paper will review the electrical and mechanical performance characteristics of the BE-AR terminal block.

To begin, Figures 12a and 12b show a comparison of the BE-AR and the AAR terminal blocks assembled in a typical wayside terminal configuration.

Figure 12a: AAR terminal blocks

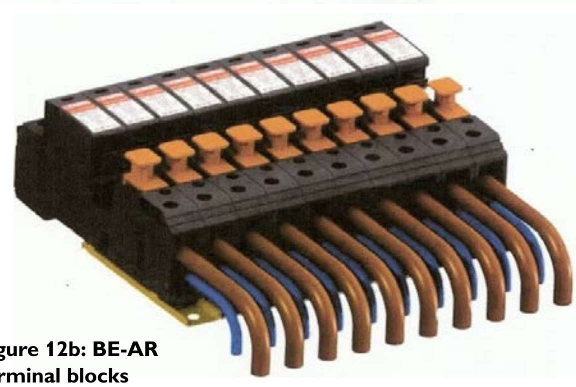

Figure 12b: BE-AR terminal blocks

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Several differences are apparent:

- Fewer parts are associated with the BE-AR terminal block
- The BE-AR terminal block has a more organized wire assembly
- The BE-AR terminal block provides faster DIN rail-mount and mechanical hold-down assembly

Upon closer examination, you can see the BE-AR terminal block is composed of two components: a product base and a product plug. In the sections to follow, we will review the mechanical and electrical characteristics of the BE-AR terminal block.

BE-AR base

Figure 13 shows a side view of the BE-AR base.

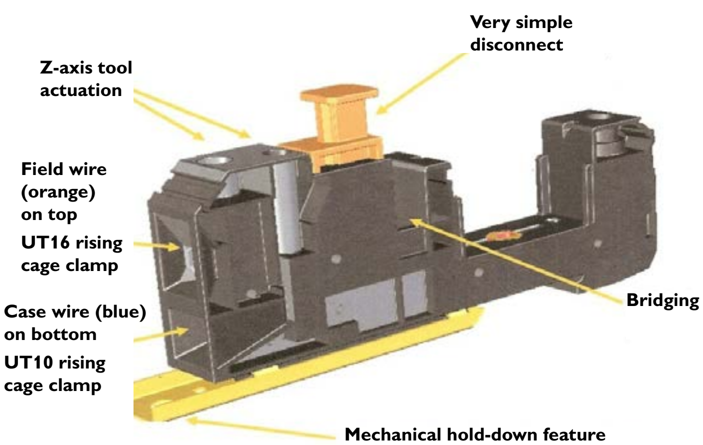

Figure 13: BE-AR base element

The base element incorporates several innovative design features that minimize the installation time and the time required for maintenance of the unit, without compromising the robustness of the connection systems. The base design features include:

- A cavity on the upper left side of the unit for the attachment of the field wire, using a rising cage screw clamp (#16-#4 AWG).
- A cavity on the lower left side of the unit for the attachment of the house wire, using a rising cage screw clamp (#20-#6 AWG).
- Z-axis access on top of the left side of the base for tightening cage screw clamps and securing field and house wires.
- A pull-disconnect/push-connect post feature located on the top left side of the base that facilitates efficient high-pot testing of the field wire. The disconnect post is alligator-clip-accessible during the high-pot testing.
- DIN rail-mount slot at the center of the base for securing the assembly to the DIN rail.
- A cavity on the upper right side of the unit for the attachment of the ground wire, using a rising-cage screw clamp (#20-#2 AWG). A tool actuation slot is provided on the top of the right side of the base to tighten the rising-cage screw and secure the ground wire and optional ground busbar.
- A three-position connector on the lower right side of the base provides connection to an available remote monitoring feature of the unit. The remote monitoring feature provides real-time data feedback during operation of the unit.

BE-AR plug

Plugs of different voltage ratings can be used in conjunction with the base element, depending on the specific application for the unit. Protection plugs are available for aspect circuits, track circuits, track equalizer circuits, relay circuits, and digital circuits. The following discussion will focus on the use of a surge protection plug designed for digital circuit applications, the VAL-MS 75 VF ST (Figure 14).

Figure 14: The VAL-MS 75 VF ST BE-AR surge protective plug

The VF circuit design is specifically designed for applications that cannot afford leakage current at any level. Low-level track circuits can be reduced to unusable levels if a current leak in the form of carbon trail or resistive breakdown occurs in an arrester. The VF circuit utilizes a varistor which is current limiting, and a spark gap, which is a switching device. The varistor is non-linear and reduces the current flow in proportion to the voltage. The spark gap requires a small amount of voltage and current to remain in conduction. The two in series effectively stop unintended conduction unless there is a damaging voltage present.

The electrical characteristics of the VAL-Ms 75 VF ST plug are shown below:

Electrical characteristics

- Surge protective device technology: Hybrid MOV and gas-tube technology
- UL nominal discharge surge current, In = 10 kA
- VPR (3 kA/6 kV, IEEE Combo Wave) = 370 V
- Protection Level, 20 surges (10+, 10-, 8/20 µs), Up = 1003 V @ 25 kA
- Protection Level, 2 surges (1+, 1-, 8/20 µs), Up = 1815 V @ 48 kA
- Lightning Protection Level, 20 surges (10+, 10-, 10/350 µs), UIMP = 584 V @ 5 kA
- Lightning Protection Level, 2 surges (1+, 1-, 10/350 µs), UIMP = 788 V @ 15 kA

In addition to the above electrical characteristics, all surge protection plugs incorporate advanced design features that enhance safety and the operation of the assembly and reduce the maintenance costs associated with the product. These features include:

- A thermal disconnect, to prevent a thermal runaway condition in case of a product fault condition
- A visual fault indication, to facilitate the removal of a failed plug-in case of a product fault condition
- Lower let-through voltage
- Fail open

Now that we have reviewed the mechanical and electrical attributes of the BE-AR terminal block, let's compare the time required to complete various equipment practices using the standard AAR device versus BE-AR terminal block.

Equipment practice comparisons

- Installation time analysis
- Field-test time analysis
- Visual inspection for carbon
- SPD field replacement

Installation time analysis

The following analysis represents the time required using current wiring practices for the initial installation of an existing AAR SPD on the shop floor, and then the time required for trackside bungalow installation. We then compare that total installation time to the time required to install an equivalent BE-AR product base.

Table 1: Installation time comparison

One-circuit device installation time comparison			
Existing AAR SPD equipment practice		***BE-AR SPD***	
Install three AAR terminal blk assembly	120 secs.*	Install DIN rail	20 secs.*
Strip field wire	10 secs.**	Attach BLKFT module	2 secs.*
Fit and form ring tongue to field wire	20 secs.**	Secure screw	5 secs.*
Install ring tongue onto posts	10 secs.**	Strip field wire	10 secs.**
Strip case wire	10 secs.*	Install field wire	10 secs.**
Fit and form ring tongue to case wire	20 secs.*	Strip case wire	10 secs.*
Install ring tongue onto posts	10 secs.*	Install case wire	5 secs.*
Install ice cube	30 secs.*	Install SPD plug	2 secs.*
Install L-bracket	5 secs.*		
Install and torque five retaining nuts	45 secs.*		
Installation time per circuit	**155 secs.**	**Installation time per circuit**	**39 secs.**

**shop floor installation   **bungalow installation*

As the data show, the per-circuit time difference between the two installation processes is 116 seconds. Extending the per-circuit time difference to a 20-circuit module would result in a time difference of (116 * 20). That is 2,320 seconds, or 38.6 minutes per 20-circuit module, a significant reduction in assembly costs in favor of the BE-AR module.

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Field test time analysis

As previously mentioned, to ensure continuing functionality of the protective circuitry within the bungalow, the AAR device is periodically tested on-site for a minimum insulation resistance (Ir) value between the field wire and a ground reference. Following is a one-circuit analysis of the time required to execute this test for both the AAR device and the BE-AR module.

The 13-second time differential on a one-circuit basis would expand to a 260-second, or 4.3-minute advantage, if 20 circuits were tested within the bungalow during a typical field test.

Table 2: Field test time comparison

Existing AAR equipment practice		*BE-AR SPD*	
Remove brass float nut	10 secs.	Lift disconnect post	1 sec.
Replace brass nut and torque	5 secs.	Lower disconnect post	1 sec.
Time to execute ohmmeter test	**15 secs.**	**Time to execute ohmmeter test**	**2 secs.**

Visual inspection for carbon

The criteria for failure of an individual legacy device is the presence of 30 percent carbon residue on the inside plastic of the ice cube housing. This is determined by a visual inspection of the individual module and assumes no disassembly of the module for the inspection. Current practice is to guess at the amount of carbon buildup and replace any modules that may (or may not) need replacement.

In contrast, the BE-AR assembly has a red indicator on the top of the plug module that displays if the module has failed. Time differences between the visual inspection of the ice cube case and the observation of the BE-AR's red indicator display is estimated at about 2 to 3 seconds per module. Aggregation of this figure for a 20-circuit module would result in a time difference of 50 seconds per module. These time differences do not take into account the possibility of dropped and lost hardware.

In addition, the BE-AR module has remote monitoring capability. It can send a signal to a set of local contacts, notifying the operator that an individual module is bad. There is no need for the inspector to walk to the bungalows post-event, to look at the individual circuits.

SPD field replacement

The need to replace a failed AAR module involves establishing track clearance time, de-energizing the affected cable, and removing and replacing the failed module. Not considering the time required to establish track clearance and de-energizing cables, the time estimate for the removal and replacement of the module is estimated to be 180 seconds, using the installation figures shown above.

In contrast, the BE-AR module is hot-swappable, meaning that the plug portion of the module can be replaced while the base portion of the assembly remains active. This means that no track clearance or de-energizing of the track circuit is required to change the BE-AR plug module. The time required to change the plug module is the time required to unlatch and relatch the plug module – an estimated 4 seconds.

Per the above analysis, the per-module time difference in replacing the SPD is about 2.9 minutes per module, or 58 minutes per 20-circuit module, in favor of the BE-AR module.

Remote indication

The remote contacts in the BE-AR base indicate if an SPD plug has been removed or has removed itself from the circuit. This happens when the SPD conducts enough sustained current to indicate a catastrophic failure event, in which case it will open a thermal disconnect.

Remote monitoring has been used for many years in locations where regular inspections are impractical or unnecessary. Routine maintenance can detect such failures, but remote monitoring can also detect them between maintenance cycles. Failure of arresters that are not monitored will only become evident when there is either loss of a signal performance or consequent destruction of equipment.

In the BE-AR plugs, the remote monitoring will disconnect the SPD when it fails in a way to interfere with signaling operations and alert the system to the resulting surge exposure. This allows for preventative measures before equipment is damaged or operations are lost.

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Conclusion

The BE-AR assembly has been designed to address PTC-era electrical and mechanical requirements of lightning surge protection in wayside bungalow equipment while improving safety in the system. Lower electrical let-through voltage associated with MOV-based SPDs will enable the proper functioning of microprocessor-based PTC electronics, such as the wayside interface unit, wayside management servers, radios, etc. Hot-swapping, remote-sensing features designed into the BE-AR assembly will enable cost-effective field operation.

The comparison of the implementation of equipment practices between legacy AAR devices and the BE-AR assembly shows a distinct advantage in favor of the BE-AR assembly. Quantitative analysis of the equipment practices used show a 102-minute labor cost edge for BE-AR, based on assembly, testing, and field replacement of 20 module assemblies.

Implementing the BE-AR device design into the wayside lightning protection network will ensure a properly functioning, cost-efficient network in the PTC environment.

Based on a paper originally published in 2013.

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