IEEE Standard for Transient Overvoltage Protection of DC Electrification Systems by Application of DC Surge Arresters

IEEE Vehicular Technology Society

Developed by the
Rail Vehicle Transportation Standards Committee

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Abstract: The design and application of dc surge arresters to protect dc electrification system from transient overvoltage caused by lightning and switching surges is the purpose of this standard. Lightning surges can cause high energy transient overvoltages by direct or indirect coupling with a dc electrification system. Transient overvoltage protection from lightning and switching surges of various dc transit electrification systems can be achieved by the application of metal-oxide varistor (MOV) gapless-surge arresters. The application of surge arresters to running rails in areas where lightning activity is severe requires special study of protection coordination with rail-ground shorting devices [also called voltage-limiting devices (VLDs)] and review of track circuits applied at the transit system. Such study and criteria of selecting VLDs is not included in this standard. However, a surge arrester applied to running rails in higher keraunic areas has been included and requires coordination with both the VLD devices and track circuits applied in the transit system. Many modern light- and heavy-rail transit projects use VLDs, although their application can be avoided by implementing other design measures, such as insulated platforms, or by simply coating the vehicle surface with some special insulation. The purpose of installing VLDs at dc transit projects is to enhance the safety of personnel from the touch potential (rail-ground voltage) on the train vehicle surface. No industry standard on VLDs exists today in North America. Only IEC EN 50526-2 covers VLD.

Keywords: IEEE 1627™, keraunic level, lightning arrester, lightning surges, maximum continuous operating voltage, metal-oxide varistor, MOV, OCS, overhead contact system, residual discharge voltage, SPD, surge arrester, surge-protective devices, switching surges, temporary overvoltage, transient overvoltage, voltage margin of protection, VSA

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Introduction

This introduction is not part of IEEE Std 1627-2019, IEEE Standard for Transient Overvoltage Protection of DC Electrification Systems by Application of DC Surge Arresters.

This standard applies to dc electrified transit systems that use different configurations to supply dc traction power from the dc traction power substations (TPSSs) to the vehicles. The probability of lightning surges striking a dc electrified transit system depends on its geometry; its height above the ground surface; the track lengths; the tracks' relative location with respect to the presence of tall buildings, trees, towers etc.; and the lightning flash-to-ground intensity of the general area of the rail transit system. If the expected frequency of direct lightning (ND) exceeds its tolerable frequency of lightning (NC) (established by National Electrical Code® (NEC®) (NFPA 70®) and IEC 62305) after the lightning probability risk assessment analysis, then the lightning-protection system (LPS) should be applied (refer to NFPA 780 and the IEC 62305 series to understand how to perform LPS risk analysis and apply it to protect systems from lightning surges).[1] LPSs shall be designed and installed to dc transit electrification systems based on the surge environment and the LPS analysis.

A LPS is not necessary if expected ND is below the expected NC and the dc transit electrification system is considered self-protected from lightning. However, surge arresters should still be applied to protect equipment insulation damage from inherent switching surges and surges induced by nearby lightning.

Arbitrary installation of direct-stroke diverters; such as lightning rods and ground wires above the transit system, such as overhead contact system (OCS) poles; change the geometry and may increase chances of more lightning exposure. Based on such reasoning, it appears that even in the area of higher lightning strokes, the application of ground wires and ground rods above the OCS should not be used as LPSs. The approach of this standard is to develop a transient overvoltage protection scheme that focuses on the basic approach of selection and application of dc surge arresters, their grounding configuration, and grounding of transit system support structures. To achieve such a protection scheme, a review of the following is necessary:

a) Selection of appropriately rated dc surge arresters.
b) Grounding of surge arresters by use of an insulated individual grounding conductor (as short as practical) connected to their individual ground electrodes.
c) For a transit system consisting of an OCS, the grounding of surge arresters shall not be bonded to metallic OCS poles to keep lightning surge hazards away from the poles that can cause insulation breakdown of the insulators and that can cause damage to pole foundation. In addition, poles may become electrical shock hazards, and leakage current of the arrester may cause damage to pole rebar over time.

The selection of basic lightning impulse insulation levels (BILs) for dc electrification equipment is the scope of work for a future IEEE/APTA subcommittee standard, thus no further discussion is included in this standard. A discussion on BILs level of dc switchgear is included in Table 6. BIL values of dc switchgear are also included in IEC 61992-1:2006.

DC transit electrification system components and associated structures cannot simply be compared to electric utility transmission lines as the physical configuration and location of conductive conductors supported on insulated structures of the two systems are quite different: An OCS structure is very close to ground and running rails where lightning spark to ground and OCS structure can occur simultaneously. Therefore, the concept of lightning protection by use of ground/shield wire does not apply to dc electrification systems. However, in the case of single-phase ac electrification OCSs (not included in this standard), an overhead ground wire that carries return traction ac current as well as shield wire above the ground wire are applied.

[1]Information on references can be found in Clause 2.

Prior to and during the development of this standard, there were reports of surge-arrester failures on several transit systems resulting in service interruption and equipment failures. Questions were raised regarding the grounding of OCS support poles and the pros and cons of using surge arresters in the OCS. Most importantly, there was no clear understanding of the proper selection and application location of dc surge arresters to OCSs and, in general, to dc electrification systems. This standard now provides technical understanding of surge-arrester application to dc transit projects.

To establish a lightning-protection design scheme for dc electrification systems, the derivation of lightning intensity and lightning stroke surge energy using lightning parameters is required. For such a derivation of lightning intensity, surge arrester selection is established based upon the typical available lightning data.

When considering lightning protection for dc transit electrification system components, especially for the OCS, numerous questions arise, such as:

a) Will a dc surge arrester handle surge energy if a lightning flash (strike) directly hits the OCS wire near the arrester location?

b) If a lightning flash directly hits the OCS wire between two TPSSs, what will be the energy discharged through the surge arresters at respective feeder poles?

c) In higher keraunic areas, is there a need to apply dc surge arresters at the midpoint of two adjacent substations to enhance the lightning protection of the OCS?

d) Do we need to apply surge arresters at the connection points of underground dc supplementary feeder cable to OCS contact wire located approximately every 122 m to 152.4 m (400 ft to 500 ft), where overhead messenger wire design is not possible in areas due to aesthetics and other restrictions of height of the messenger wires?

e) Should there be a shield/ground wire above the messenger to enhance lightning protection?

f) Should we apply surge arresters at dc disconnect sectionalizing switches?

g) Should surge arresters be considered at the running rails, especially at elevated structures and bridges?

Responses to the above questions are discussed in this standard.

Origin and development IEEE Std 1627-2019

The Overhead Contact Systems Subcommittee was formed in 2001 with the purpose of developing standards governing the design, construction, and maintenance of the OCS and current collection system.

IEEE Std 1627-2019, IEEE Standard for Transient Overvoltage Protection of DC Electrification Systems by Application of DC Surge Arresters, was developed by Working Group 17 of the Overhead Contact Systems Subcommittee of the Rail Transit Vehicle Interface Standards Committee of the IEEE Vehicular Technology Society.

Working Group 17 was established to develop standards governing the transient overvoltage protection of dc transit systems. The primary concern of the working group was a lack of uniform practices and a lack of understanding of the proper application of dc surge arresters, and grounding configurations. Precise information of the transient environment, expected magnitude, duration, and frequency of transient surges is very unpredictable, and there has been no recorded data available to guide application engineers in the selection and application of appropriate dc surge arresters. However, it is clear that the unpredictable threat of transient overvoltage caused by power-system switching surges and lightning surges exists that can occur without warning, causing damage to the dc transit system equipment without proper application of surge-protective devices(SPDs).

It appears that the lack of knowledge of the transient environment and understanding the parameters and rating of dc surge arresters led to guesswork in the selection and application of such protective devices, causing failures at some installations. At some transit properties, failures of dc surge arresters and associated transit equipment damage have been reported. A lack of understanding of characteristics of transient overvoltage; dc surge arrester ratings; their proper selection, installation, and grounding configurations; and a lack of their clear test and application data from the manufacturers has been a major concern in the industry, which led to the development of this standard. Proper application of dc SPDs to practically divert surge energy away from the surge location at the dc transit system relates directly to their effect on equipment protection and personnel safety from surge hazards.

The previous PAR for IEEE P1627 expired in December 2015, just before the committee was finalizing the ballot review comments. Thus, a new PAR was submitted and approved by the IEEE Standards Association in June 2016. This standard is based on the new PAR.

Contents

IEEE Standard for Transient Overvoltage Protection of DC Electrification Systems by Application of DC Surge Arresters

1. Overview

1.1 Scope

This standard covers the application of dc surge arresters for transient overvoltage protection of dc transit electrification systems. These dc transit electrification systems include light rail, heavy rail, streetcar, and trolley bus systems. This standard covers the selection and application of metal-oxide varistor (MOV) gapless-surge arresters to divert surge energy away from the transit system components. It does not cover low-voltage SPDs that are required within dc traction power system equipment, such as rectifier units, vehicle propulsion systems, or other sensitive components of the dc transit system.

1.2 Purpose

It is the purpose of this standard to provide uniform practices for lightning and switching transient overvoltage protection of dc transit electrification by proper selection of dc surge arresters based on the surge environment and site conditions of the transit system. This standard allows the use of SPDs in dc transit systems to avoid insulation failure due to transient overvoltage. Transient overvoltage protection is just as important as short-circuit protection. This standard will minimize equipment damage caused by transient overvoltages, increasing system reliability that will result in reduced maintenance.

1.3 Contents

First, the basic characteristics of transient surges, their origin, and energy and propagation behavior are described in Clause 4 and Clause 7. This is followed by a brief description of the surge environment expected at dc electrification system in Clause 5 and Clause 7. Clause 5 also includes dc SPD requirements for comparison of transient overvoltage protection, dc surge arrester tested parameters by manufacturers, surge arrester application analysis calculation, and energy absorbing (handling) capability. Clause 6 and Clause 7 cover analysis of lightning strikes to the dc transit electrification system components. Clause 8 covers surge arrester grounding and grounding of OCS poles. Clause 9 includes dc surge arrester application locations and discussion of application parameters including various voltages assigned to a dc surge arrester to help in the selection of dc surge arresters. In addition, Clause 9 includes insulation and BIL levels of dc switchgear. Clause 10 covers dc surge arrester service requirements. Clause 11 covers dc surge arrester assembly and testing and design and field tests, including an application example of dc surge arresters to OCSs.