SLOVENSKI STANDARD
SIST-TP CLC/TR 50646:2018

01-oktober-2018

Železniške naprave - Stacionarne naprave - Specifikacija za reverzibilne d.c. podpostaje

Railway Application - Fixed Installations - Specification for reversible d.c. substations

Bahnanwendungen - Ortsfeste Anlagen – Spezifikation rückspeisefähiger Unterwerke für Gleichstrombahnen

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Ta slovenski standard je istoveten z: **CLC/TR 50646:2015**

ICS:

29.280	Električna vlečna oprema	Electric traction equipment

SIST-TP CLC/TR 50646:2018 **en**

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TECHNICAL REPORT

RAPPORT TECHNIQUE

TECHNISCHER BERICHT

CLC/TR 50646

December 2015

ICS 29.280

English Version

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This Technical Report was approved by CENELEC on 2015-10-26.

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European Committee for Electrotechnical Standardization
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European foreword

This document (CLC/TR 50646:2015) has been prepared by CLC/SC 9XC "Electric supply and earthing systems for public transport equipment and ancillary apparatus (Fixed installations)".

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Introduction

This document originates from the Technical Specification issued by UIC/UNIFE on the same topic, and was offered as a CENELEC Technical Report. The purpose of this Technical Report is to provide recommendations for reversible DC substations.

Reversible substations are capable of feeding the train regenerative braking energy (up to 100 %) back to the AC high voltage distribution network, while maintaining the capability of exchanging energy between trains on the DC line. A substantial amount of energy can be saved for DC systems which operate electric trains fitted with regenerative braking, on commuter services or operating on steep gradient lines. The system receptivity can be improved by feeding the excess regenerative braking energy to the upstream AC network (e.g. AC railway network or national grid) at a higher voltage level.

This document provides recommendations if DC Reversible Traction Substations are installed to improve line receptivity of DC power supply networks. This document is suitable for newly manufactured traction substations as well as for upgrading and renewal of existing lines. This technical recommendation aims at improving the energy efficiency of the DC transport system, reducing energy consumption, and contributing to a greener environment.

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1 Scope

This Technical Report provides recommendations for DC reversible substations. These recommendations apply to systems and components that facilitate the flow of energy to and from the upstream AC grid including their related interfaces.

These recommendations provide the necessary functions for the recovery of braking energy. It is intended to be used in fixed electrical installations with nominal voltage not exceeding 3 000 V DC which supply electrical power to vehicles used in public guided transport systems, i.e. railway vehicles, tramway vehicles, underground vehicles and trolley-buses

It is intended to provide an overview of state-of-the-art applications, define the minimum recommendations that are presently available, and provide functional recommendations to be applied to these substations.

This document focuses mainly on the substation converters and the traction transformers. Other devices such as switchgear - if they are the same as in classic substations - are not addressed here. Moreover this specification addresses performance, constraints, validation and acceptance criteria for the implementation of reversible substations.

This document provides the minimum recommendations to be fulfilled. However, due to the different possible solutions and different types of existing technologies, this document does not provide technical specifications of the basic components that facilitate the functionalities described.

2 Normative references

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The following standards, in whole or in part, are normatively referenced in this document and are essential for its application. For dated references, only the cited edition applies. For undated references the latest edition of the referenced document (including any amendment) applies.

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EN 50160, *Voltage characteristics of electricity supplied by public electricity networks*

EN 50163, *Railway applications — Supply voltages of traction systems*

EN 50327, *Railway applications — Fixed installations — Harmonisation of the rated values for converter groups and tests on converter groups*

EN 50328:2003, *Railway applications — Fixed installations — Electronic power converters for substations*

EN 50329, *Railway applications — Fixed installations — Traction transformers*

EN 50388, *Railway Applications — Power supply and rolling stock — Technical criteria for the coordination between power supply (substation) and rolling stock to achieve interoperability*

IEC 60050, *Electropedia: The World's Online Electrotechnical Vocabulary ("IEV Online")*

3 Terms, definitions and abbreviations

3.1 Terms and definitions

For the purpose of this document, the terms and definitions given in IEC 60050 and the following apply.

3.1.1
contact line
conductor system for supplying electric energy to vehicles through current-collecting equipment

[SOURCE: IEC 60050-811-33-01:1991]

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3.1.2
dynamic braking
use of the electrical machine of the traction unit as a generator during the braking phase in order to achieve speed reduction and thus convert the kinetic energy of the traction unit during its braking phase into electrical energy

3.1.3
electronic power converter
operative unit for power conversion comprising one or more sets of semiconductor devices

[SOURCE: IEC 60050-551-12-01:1998, modified – The definition was shortened and the Note and figure contained in the original definition are not reproduced here.]

3.1.4
minimum threshold voltage
U_{thi}
lower limit of the DC output voltage range within which Reversible Substation can work in inverter mode

3.1.5
regenerative braking energy
net energy coming from the dynamic braking and injected into the contact line

Note 1 to entry: It does not include on board losses and auxiliary load.

3.1.6
reversible substation
RSS
traction substation that allows the flow of energy from the contact line to the upstream grid (railway network or national grid)

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3.1.7
semiconductor device
device whose essential characteristics are due to the flow of charge carriers within a semiconductor

[SOURCE: IEC 60050-521:2002, 521-04-01]

3.1.8
vehicle
single item of rolling stock

Note 1 to entry: Examples of a single item of rolling stock include a locomotive, a coach and a wagon.

[SOURCE: IEC 60050-811-02-02:1991]

3.2 Abbreviations

AC: Alternating Current

DC: Direct Current

EMC: Electro-Magnetic Compatibility

EMI: Electro-Magnetic Interference

IGBT: Insulated Gate Bipolar Transistor

RSS: Reversible Substation

TSI ENE: Technical Specification for Interoperability for Energy subsystem

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4 General

4.1 Application of reversible substation

Existing standards provide requirements for the power supply system at the interface between traction units and fixed installations: EN 50163 for feeding voltages and frequency levels and their variations in different situations and EN 50388 for technical criteria for coordination between rolling stock and power supply to achieve interoperability.

These standards consider the aspect of vehicle regenerative braking energy that can be reused as follows:

- on-board for auxiliary devices or heating/ventilation/air-conditioning functions; the on-board demand is usually far too low to absorb all the braking power supplied;
- other trains: energy is used by other trains taking power in the vicinity. This depends on traffic density, headways, and the profile of line voltage.

In classic DC systems, if the energy is not fully recovered by the above means, the energy will be lost and dissipated into brake resistors, generally on-board, or in mechanical braking, contributing to energy waste and thermal losses. Besides being energy inefficient, if used in a confined environment (such as tunnels and underground passenger stations), it can significantly increase the temperature of that environment and affect the air quality caused by brake pad dust.

If the DC railway system is fitted with energy storage systems (on-board or trackside) and/or with reversible substations (RSS), the wasted energy can be reused or in the case of RSS, fed back into the upstream AC railway network, in the same way as that for AC electric traction systems.

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The reversible substation allows the transfer of regenerative braking energy - combination of kinetic and gravity energy for steep gradient lines - to the upstream network. Furthermore, the amount of regenerative energy that is transferred is not limited by the upstream network.

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The TSI ENE requires the use of traction unit regenerative braking capability as a service brake, in AC or in DC systems, to promote energy efficiency. Additionally, the interoperability billing system encourages Railway Undertakings to be charged in the future for the net energy consumption of their trains.

4.2 Energy efficiency analysis

The technical analysis of energy savings shows that the optimum use of dynamic braking on DC lines can achieve the following:

- improving the line receptivity on DC networks to nearly 100 % in normal and degraded mode as it is the case for AC power supply system,
- minimizing system losses,
- giving priority to energy exchange between vehicles,
- suppressing rheostat braking without transferring the additional load onto the mechanical braking which will reduce heat dissipation, mass and volume of on-board equipment.

Additionally, by implementing appropriate technology, balancing the loads of paralleled substations can optimize energy flow, thereby improving energy efficiency. To achieve some or all of these objectives, one of the architectures described in 4.3 should be adopted.

4.3 System architecture

Converters with power semiconductors in bridge circuits are used to convert three-phase AC to DC. They can be classified as line-commutated converters (uncontrolled or controlled type) or self-commutated converters.

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Substations intended for feeding only are commonly designed as uncontrolled line-commutated converters (i.e. diode rectifier).

Beside diode rectifiers, controlled line-commutated converters and self-commutated converters can also be used for rectification purposes. Both technologies are not commonly used in today’s DC substations because cost-efficiency and reliability of diode rectifiers so far exceed the advantages of these converters. However, a main advantage of these technologies is the control of DC feeding voltage which enables these types of converters to be used for load management between substations and to reduce energy losses in the contact line.

Controlled line-commutated converters and self-commutated converters can also be used for inverting purposes. However, while a single bridge self-commutated inverter is able to support energy flow in both directions (rectification and inversion), a line-commutated converter needs two anti-parallel bridges to operate.

Generally, but not exclusively, the following main converter technologies can be realized:

a) reversible substation with uncontrolled rectifier:

   1) uncontrolled rectifier and controlled inverter (diode rectifier and thyristor inverter);

   2) uncontrolled rectifier and self-commutated inverter (diode rectifier and IGBT Inverter);

b) reversible substation with controlled rectifier or self-commutated converter:

   1) controlled rectifier and controlled inverter (thyristor rectifier and thyristor inverter);

   2) controlled rectifier and self-commutated inverter (e.g. thyristor rectifier and IGBT inverter);

   3) self-commutated converter (IGBT single bridge converter).

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For upgrading existing substations, where the transformer-rectifier-set is still in a good condition, options a) 1) and a) 2) above are usually the easiest technologies to deploy.

In case of new construction of substations, any of the options b) 1) to b) 3) can be taken into consideration to avoid restrictions for the inversion function (in relation to the no-load voltage of uncontrolled rectifiers).

The main advantage of b) 1) to b) 3) is to decrease the no-load voltage during inversion. This function enables the inverters to improve the collection of braking energy from different vehicles that are distributed in the system.

Options a) 2) and b) 2) allow operation of the self-commutated inverter when the rectifier is active (in parallel to the rectifier). This can be used for reactive current compensation, active filtering of harmonics or to operate as a booster during load peaks.

From the converter topology point of view, b) 3) represents a simple configuration, because one bridge allows energy flow in both directions. However, in this configuration the high thermal load of the semiconductors should be taken into account.