



IEEE Guide for Energy Feedback System for DC Traction Power Supply System

IEEE Vehicular Technology Society

Developed by the
Rail Transportation Standards Committee

IEEE Std 2657™-2021

STANDARDS

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Rail Transportation Standards Committee
of the
IEEE Vehicular Technology Society

Approved 23 September 2021

IEEE SA Standards Board

Abstract: In the dc electric railways, when a train regenerates power, usually the power has to be consumed within the dc network because the dc traction power systems are often not reversible. Several technologies improve receptivity: energy consumption, energy feedback, and energy storage. Solution selection depends on the application. The energy feedback systems (EFSs) convert energy to ac power system as system dc voltage rises. Engineers are helped by this guide to decide where these EFSs can provide the greatest benefits, determine which design solutions will have the maximum effectiveness, and evaluate the costs and benefits of developing new EFS projects.

Keywords: dc traction, economic consideration, energy saving, energy feedback system, IEEE 2657™, modeling and simulation, voltage stabilization

The Institute of Electrical and Electronics Engineers, Inc.
3 Park Avenue, New York, NY 10016-5997, USA

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PDF: ISBN 978-1-5044-7996-7 STD24965
Print: ISBN 978-1-5044-7997-4 STDPD24965

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Participants

At the time this draft guide was completed, the Energy Feedback System Working Group had the following entity membership:

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Patrycjusz Antoniewicz, Vice Chair
Wei Liu, Secretary

<i>Organization Represented</i>	<i>Name of Representative</i>
ABB.....	Patrycjusz Antoniewicz
CRRC Zhuzhou Institute Co., Ltd.	Zhixue Zhang
Hunan Hengxin Electric Co., Ltd.	Changhui Yan
Southwest Jiaotong University	Wei Liu
State Grid Corporation of China (SGCC).....	Bingtao Cui
Windsun Science & Technology Co., Ltd.	Hanxue Fang

The Working Group gratefully acknowledges the contributions of the following participants. Without their assistance and dedication, this guide would not have been completed.

Xue Chen	Gui Liu	Tianjian Yu
Shunquan Hu	Guifang Mei	Jian Zhang
Wojciech Kolomyjski	Huapeng Niu	Yan Zhang
Xuebin Lang	Qiubo Peng	Yuebin Zheng
Hongbo Li	Wei Wu	Jinhuan Zhou
	Min Yu	

The following members of the entity Standards Association balloting group voted on this guide. Balloters may have voted for approval, disapproval, or abstention.

0xSenses Corporation	Hunan Hengxin Electric Co.,	State Grid Corporation of
Anhubao Corporation	Ltd.	China (SGCC)
Beckhoff Automation	Secheron S.A.	Windsun Science &
CRRC Zhuzhou Institute Co.,	Siemens Corporation	Technology Co., Ltd.
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	University	

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Edward A. Addy
Doug Edwards
Ramy Ahmed Fathy
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Daozhuang Lin
Kevin Lu
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Chenhui Niu
Damir Novosel
Annette Reilly
Dorothy Stanley

Mehmet Ulema
Lei Wang
F. Keith Waters
Karl Weber
Sha Wei
Howard Wolfman
Daidi Zhong

*Member Emeritus

Introduction

This introduction is not part of IEEE Std 2657-2021, IEEE Guide for Energy Feedback System for DC Traction Power Supply System.

This introduction provides background on the rationale used to develop this guide, which may aid in the understanding of the application of energy feedback systems. The need for economic consideration and performance metrics to assist in the development of energy feedback systems is discussed. The importance of safety and environmental concerns and the integration of an energy feedback system into existing operating rail systems and their introduction as part of a new rail system are discussed. Means of simulating operation and integration for the objective of optimization are also discussed. The following topics are covered: normative references, definitions, applications, common topologies, specifying an energy feedback system, economic considerations, modeling and simulation of energy feedback system, performance, safety and environment, installation and integration, and verification and validation.

It should be noted that this document mainly refers to IEEE Std 1887™-2017,¹ and even some contents are basically the same, as noted throughout the guide.

¹Information on references can be found in Clause 2.

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IEEE Guide for Energy Feedback System for DC Traction Power Supply System

1. Overview

1.1 Scope

This guide specifies the requirements and testing methods for a stationary energy feedback system to be used in trackside installations for a dc electrified railway power supply network. This system can harvest electric energy from the dc power supply network and feed the energy back to the ac power supply network.

This guide covers terms and definitions, rating values, performance requirements, and test requirements. Performance requirements include efficiency, temperature, lifetime, control and protection, electromagnetic compatibility (EMC), and mechanical characteristics. Test requirements will cover methods and criteria for type test, routine test, and commissioning test.

However, the systems with the following functions are not included in this guide:

- Resistive consumption of regenerated power
- Energy storage system

1.2 Purpose

The purpose of this guide is to achieve the following objectives:

- Definition of the energy feedback system:
 - Terms and definitions for the energy feedback system
 - Rated value
 - Typical topologies
- Definition of the performance for the energy feedback system:
 - General requirements such as rating, efficiency, temperature and lifetime
 - Control and protection requirements, include inverter/converter/static var generator/active power filter control, short circuit protection, earth-fault protection, overload protection
 - Electromagnetic compatibility (EMC)

- Mechanical characteristics
- Standardization of the test for the energy feedback system:
 - The kinds of tests (type test, routine test, and commissioning test)
 - The methods and standards of the tests

1.3 Word usage

The word *shall* indicates mandatory requirements strictly to be followed in order to conform to the standard and from which no deviation is permitted (shall equals is required to).^{2,3}

The word *should* indicates that among several possibilities one is recommended as particularly suitable, without mentioning or excluding others; or that a certain course of action is preferred but not necessarily required (should equals is recommended that).

The word *may* is used to indicate a course of action permissible within the limits of the standard (may equals is permitted to).

The word *can* is used for statements of possibility and capability, whether material, physical, or causal (can equals is able to).

2. Normative references

The following referenced documents are indispensable for the application of this document (i.e., they must be understood and used, so each referenced document is cited in text and its relationship to this document is explained). For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments or corrigenda) applies.

ANSI/IEC 60529-2004 Degrees of protection provided by enclosures (IP Code)(identical national adoption).^{4,5}

IEC 60850, Railway Applications—Supply Voltages of Traction Systems.

IEC 62236-5, Railway Applications—Electromagnetic Compatibility.

IEC 62497-1, Railway Applications—Insulation Coordination—Part 1 Basic requirements—Clearances and creepage distances for all electrical and electric equipment.

IEC 62590 Railway applications—Fixed installations—Electronic power converters for substations.

IEC 62749, Assessment of power quality-characteristics of electricity supplied by public networks.

IEC 62924, Railway applications—Fixed installations—Stationary energy storage system for dc traction systems.

²The use of the word *must* is deprecated and cannot be used when stating mandatory requirements, *must* is used only to describe unavoidable situations.

³The use of *will* is deprecated and cannot be used when stating mandatory requirements, *will* is only used in statements of fact.

⁴ANSI publications are available from the American National Standards Institute (<https://www.ansi.org/>).

⁵IEC publications are available from the International Electrotechnical Commission (<https://www.iec.ch>) and the American National Standards Institute (<https://www.ansi.org/>).

IEEE Std 519™-2014, IEEE Recommended Practice and Requirements for Harmonic Control in Electric Power Systems.^{6,7}

IEEE Std 1653.3™, IEEE Guide for Rail Transit Traction Power Systems Modeling.

IEEE Std 1662™-2016, IEEE Recommended Practice for the Design and Application of Power Electronics in Electrical Power Systems.

IEEE Std 1887™-2017, IEEE Guide for Wayside Energy Storage Systems for DC Traction Applications.

3. Definitions

For the purposes of this document, the following terms and definitions apply. The *IEEE Standards Dictionary Online* should be consulted for terms not defined in this clause.⁸

energy feedback system (EFS): An inverter system that recovers regenerative braking energy from the dc traction power supply system to the ac distribution system. It includes transformer, auxiliary devices such as transfer switches, alternate source transformers, regulators, isolation devices, and so on.

4. Applications of the energy feedback system

The main objective of the EFS is to recover regenerative braking energy that is not absorbed by other vehicles and to feed it back into the upstream distribution network. The receptivity level that can be reached for a given dc railway system will depend on its own characteristics and design criteria. To comply with the energy regeneration objective, review the following steps:

- The recovery of energy in inverter mode should be possible between a minimum voltage and maximum voltage, and should take into account the limited duration.
- A priority should be given to energy exchange between trains (and their auxiliaries) in order to help capture energy that can be utilized on the dc network.
- Circulation of energy between rectifier and inverter in the substation or between adjacent substations should be controlled.
- For a combination of controlled rectifier and inverter, it is recommended that voltage settings are coordinated to respond to rapid changes in power flow and help any traction and braking gaps.

EFS may provide side functions such as follows:

- Voltage boost mode allows for boosting dc traction voltage; in this mode, the inverter functions as the rectifier but without overload capacity.
- Reactive power compensation mode allows for compensating reactive power upon an overriding control system request.
- Harmonic compensation mode allows for helping harmonics to achieve conformity with the reference regulations and standards.

Only one EFS operating mode may be active at any given time.

⁶The IEEE standards or products referred to in Clause 2 are trademarks owned by The Institute of Electrical and Electronics Engineers, Incorporated.

⁷IEEE publications are available from The Institute of Electrical and Electronics Engineers (<https://standards.ieee.org/>).

⁸*IEEE Standards Dictionary Online* is available at: <http://dictionary.ieee.org>. An IEEE account is required for access to the dictionary, and one can be created at no charge on the dictionary sign-in page.

Transitions between energy feedback mode and other modes should not affect the electric braking performance of the trains.

The supply and operation of this additional mode should be agreed on by manufacturer and user.

5. Common topologies

5.1 Introduction

In general, electrical energy can be fed back into different points of the ac utility leading to different technical solutions. The most common feedback points are the primary side of the rectifier transformer, the secondary side of the rectifier transformer, and the auxiliary power supply system.

Each technical solution has its characteristic strengths and benefits. In many cases, more than one technical solution may be suitable for a particular application. This overview is not intended to indicate the suitability of one technical solution over another for a particular application but to provide an overview of the various solutions currently available.

5.2 Energy feedback system connection to primary side of the rectifier transformer

AC side of EFS can be connected to the primary side of the power rectifier transformer through a dedicated medium voltage (MV) transformer (Figure 1).

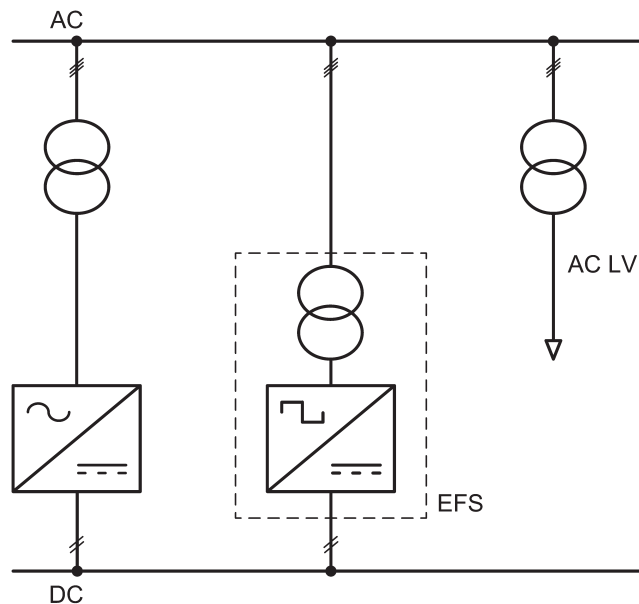


Figure 1—EFS connection to primary side of the rectifier transformer

This solution provides the following advantages:

- Isolation from substation equipment
- Circulating current phenomena does not appear

Nevertheless, a technical solution needs the following:

- Additional equipment with larger footprint
- Additional switching apparatus on ac MV side

5.3 Energy feedback system connection to secondary side of the rectifier transformer

AC side of EFS can be connected to the secondary side of the power rectifier transformer through dedicated transformer or autotransformer (Figure 2 and Figure 3).

These solutions provide the following advantages:

- Additional equipment with smaller footprint
- Shared ac switching apparatus

Nevertheless, a technical solution needs the following:

- Consideration of circulating current phenomena which may appear in the following scenarios:
- High output voltage of the EFS transformer/autotransformer
- High no-load dc voltage of rectifier
- High impedance of rectifier transformer respective to the EFS nominal power

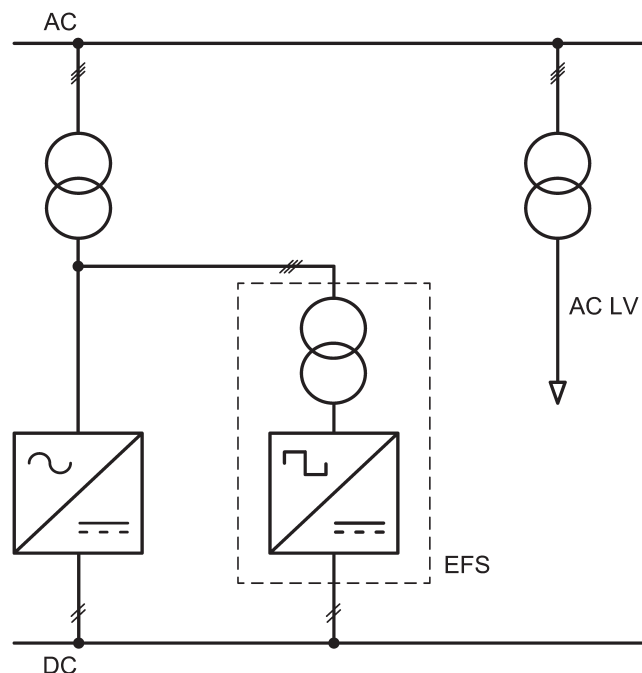


Figure 2—EFS connection to secondary side of the rectifier transformer through dedicated transformer