

IEEE Guide for Wayside Energy Storage Systems for DC Traction Applications

IEEE Vehicular Technology Society

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Rail Transportation Standards Committee

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IEEE Std 1887™-2017

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Rail Transportation Standards Committee
of the
IEEE Vehicular Technology Society

Approved 14 February 2017

IEEE-SA Standards Board

Recognized as an American National Standard

Abstract: Traction power systems experience some of the most extreme variations in local power loads as compared to most other large scale electric power supply networks. These variations create challenges in the construction of reliable electric power delivery systems and in the performance of the rolling stock dependent on power supplied by the system. A solution is offered by energy storage by smoothing out these power variations, absorbing energy as system voltage rises, and delivering energy as voltage drops. Engineers are helped by this guide to identify where these solutions can provide the greatest benefits, design solutions with the greatest impact, and quantify the costs and benefits of deploying new solutions.

Keywords: dc traction, energy recovery, energy storage, fixed guideway transportation, IEEE 1887, railway, traction power, wayside energy storage, wayside energy storage system

The Institute of Electrical and Electronics Engineers, Inc.
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PDF: ISBN 978-1-5044-3719-6 STD22412
Print: ISBN 978-1-5044-3720-2 STDPD22412

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Introduction

This introduction is not part of IEEE Std 1887™-2017, IEEE Guide for Wayside Energy Storage Systems for DC Traction Applications.

This introduction provides background on the rationale used to develop this guide, which may aid in the understanding of the application of wayside energy storage. The need for economic consideration and performance metrics to assist in the development of energy storage systems is discussed. The importance of safety and environmental concerns and the integration of energy storage 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 technologies, common topologies, specifying a wayside energy storage system, economic considerations, modeling and simulation of energy storage, performance, safety and environment, installation and integration, and verification and validation.

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IEEE Guide for Wayside Energy Storage Systems for DC Traction Applications

1. Overview

1.1 Scope

This guide is intended to be a performance-based guide to assist engineers involved in the design, specification, and technical evaluation of traction wayside energy storage systems.

1.2 Purpose

Traction power systems experience some of the most extreme variations in local power loads as compared to most other large scale electric power supply networks. These variations create challenges in the construction of reliable electric power delivery systems and in the performance of the rolling stock dependent on power supplied by the system. Energy storage offers a solution by smoothing out these power variations, absorbing energy as system voltage rises, and delivering energy as voltage drops. This guide will aid engineers in identifying where these solutions can provide the greatest benefits, designing solutions with the greatest impact, and quantifying the costs and benefits of deploying new solutions.

With the rapid evolution of advanced power electronics, control methods and storage technologies available, combined with the wide range of applications, it is not possible, nor desirable, to include specific design requirements which might limit or preclude new ideas and concepts from being developed.

From a systems perspective, the goal of this guide is to provide an overview of the following:

- Common terminology used to describe performance
- Common applications and technologies
- Common equipment topologies
- Specification of energy storage systems
- Economic considerations and cost-benefit analysis
- Modeling and simulation
- Performance and functional considerations
- Interoperability considerations
- Tools and methods to verify safety

- Installation and integration considerations
- Tools and methods to measure and verify system performance

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.

IEC 60850, Railway Applications—Supply Voltages of Traction Systems.¹

IEC 62236, Railway Applications—Electromagnetic Compatibility.

IEC 62497, Railway Applications—Insulation Coordination.

IEEE Std 1584™, IEEE Guide for Performing Arc-Flash Hazard Calculations.^{2,3}

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

IEEE Std C2™, National Electrical Safety Code® (NESC®).⁴

MIL-STD 882, System Safety.⁵

MIL-STD 1629, Procedures for Performing a Failure Mode, Effects, and Criticality Analysis.

NFPA 130, Standard for Fixed Guideway Transit and Passenger Rail Systems.⁶

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.⁷

active control energy storage: A storage system that uses a power converter to control the flow of power in and/or out of the unit.

authority having jurisdiction (AHJ): The organization(s) responsible for enforcing requirements of a code or standard or having authority for approving equipment or installations against a code or standard.

black box model: A model that describes the behavior of a system in terms of its inputs, outputs, and/or transfer characteristics, without requiring any knowledge of its internal workings.

cost-benefit analysis: A tool used to analyze and compare design alternatives to achieve the desired project objectives.

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⁵MIL publications are available from the U.S. Department of Defense (<http://www.defense.gov/>).

⁶NFPA publications are available from the National Fire Protection Association (<http://www.nfpa.org/>).

⁷*IEEE Standards Dictionary Online* is available at: <http://dictionary.ieee.org>.

design cycle: The charge/discharge cycle that generally represents the maximum capability of equipment including maximum power and energy and minimum cycle time. For some applications, the design cycle may be equivalent to the operating cycle.

design efficiency: Efficiency of charge/discharge cycle while operating at the design cycle.

design life: The specified lifetime which the equipment is designed for while operating at the operating cycle.

electrochemical storage: Type of energy storage medium where energy is stored in chemical form using one or more electrochemical cells or batteries.

electrostatic storage: Type of energy storage medium where energy is stored in an electric field using a capacitor.

emergency backup: A mode of operation in which energy storage is used to supply energy to trains in the event of power failure or other degraded operation.

energy recovery: A mode of operation in which energy storage is used to store and release regenerated energy from trains.

failure modes and effects (FMEA): A design tool using a “bottom-up” approach to analyze possible failure modes in a system and to analyze the effects and identify mitigations.

failure modes and effects criticality analysis (FMECA): A design tool using a “bottom-up” approach to analyze possible failure modes in a system and to analyze the criticality to safety and identify mitigations.

frequency regulation: A mode of operation in which energy storage is used to inject energy into, or withdraw energy from, a traction power system in response to a utility power transmission system’s frequency deviations or power imbalances.

hazard analysis (HA): A design tool using a “top-down” approach to analyze potential safety hazards associated with equipment and identify mitigations.

load shifting: A mode of operation in which energy storage is used to store and release bulk amounts of energy for the purposes of shifting load from one period of time to another.

mechanical storage: Type of energy storage medium where energy is stored in a kinetic or mechanical potential form, typically using a flywheel or other device.

net present value (NPV): The present value (PV) of all incoming cash flows minus the present value of all cash outflows.

non-usable energy: Nominal energy not normally available for regular charge/discharge cycles defined by the operating cycle. Energy is usually expressed in kilowatt-hours (kWh).

normal operation: Regular traction power system operation when the configuration is not impaired by an outage to a substation or a feeder segment.

operating and support hazard analysis (O&SHA): Similar to a hazard analysis (HA), but used to analyze safety hazards associated with equipment operation and maintenance.

operating cycle: The charge/discharge cycle that represents the expected, or average, operation for which the equipment design life is specified.

operating efficiency: Efficiency of charge/discharge cycle while operating at the operating cycle.

passive or limited control energy storage: A storage system where the flow of power is not controlled and is determined by traction line voltage and characteristics of the energy storage medium.

peak shaving operation: A mode of operation in which energy storage is used to store and release energy with the intent to reduce short-term fluctuations in power demand.

power purchase agreement (PPA): An agreement between a transit authority or operator and the utility provider outlining cost structure for the sale and purchase of electrical energy.

present value (PV): The current value of a future incoming or outgoing cash flow given a specified rate of return.

standby mode: An operating mode where the energy storage is neither charging nor discharging.

supervisory control and data acquisition (SCADA): A system used to monitor and control—typically from a remote location—power supply and distribution and other equipment.

total energy capacity: Nominal capacity of the energy storage medium and is the sum of the usable energy and non-usable (or static) energy. Energy is usually expressed in kilowatt-hours (kWh).

traction power system: System that supplies and delivers power from wayside to trains.

usable energy: Nominal energy normally available for a single charge/discharge cycle when operating at the operating cycle. Energy is usually expressed in kilowatt-hours (kWh).

voltage regulation: A mode of operation in which energy storage is used to reduce fluctuations in the traction power voltage, typically voltage sags.

wayside energy storage system (WESS): A stationary (fixed) system to store and release electrical energy.

4. Applications

4.1 Introduction

Common applications of energy storage in traction power systems include the following:

- Energy recovery
- Voltage regulation
- Emergency backup
- Peak shaving
- Load shifting
- Frequency regulation

Each of these applications is described as follows.

4.2 Energy recovery

In energy recovery applications, energy storage is used to reduce energy consumption through the capture and release of regenerated energy from rolling stock. Typically, energy produced by the train during braking is consumed by other trains operating in the vicinity.

In the circumstance where there are no other trains available (insufficient electrical load), the excess energy is typically dissipated as heat by an on-board, or wayside, resistor bank.

Energy storage can be used to store energy that would otherwise have been consumed by the resistor bank, and then release it back into the traction power system when there is sufficient electrical load.

4.3 Voltage regulation

In voltage regulation applications, energy storage is used to reduce the level of fluctuation in the traction power system voltage.

Trains are normally designed to operate within a given range of voltage. If voltage fluctuates outside this range, train operation can be adversely affected.

Energy storage can be used to help keep voltage fluctuations within the operating limits of the train.

Undervoltage conditions are caused by momentary overloading of the power system, usually from too many trains operating in close proximity, or simultaneous acceleration of several trains in a single area. Energy storage can be used to supplement the traction power substations to help mitigate excessive voltage sag.

Overvoltage conditions are caused by regenerative braking of trains in locations where there is insufficient electrical load available to absorb the energy produced by the trains. Energy storage can help ensure there is sufficient electrical load available to mitigate such overvoltage conditions. This operation is similar to the energy-recovery application (see 4.2).

4.4 Emergency backup

In emergency backup applications, energy storage is used to provide energy to the traction power system in the event of partial or complete disruption of the traction power supply.

A typical scenario involves using energy storage, during a partial or complete traction power outage, to enable trains to complete their travel to the next passenger station where passengers can safely disembark the train.

Requirements for energy storage such as required power, energy capacity, and duration of operation, depend on the specific emergency operating procedures intended by the transit authority.

4.5 Peak shaving

In peak shaving applications, energy storage is used to store and release energy with the intent to reduce short-term fluctuations in transit system power demand.

The objective of peak shaving is to reduce peak power demands to minimize size of power delivery equipment and/or realize financial benefit through reduction of utility power demand charges.