

INTERNATIONAL STANDARD

NORME INTERNATIONALE

**Railway applications – Fixed installations – Electronic power converters –
Part 3-1: AC traction applications – Electronic power compensators**

**Applications ferroviaires – Installations fixes – Convertisseurs électroniques de
puissance –**

**Partie 3-1: Applications de traction en courant alternatif – Compensateurs
électroniques de puissance**



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IEC Secretariat
3, rue de Varembe
CH-1211 Geneva 20
Switzerland

Tel.: +41 22 919 02 11
info@iec.ch
www.iec.ch

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Partie 3-1: Applications de traction en courant alternatif – Compensateurs
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INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

COMMISSION
ELECTROTECHNIQUE
INTERNATIONALE

ICS 45.060.01

ISBN 978-2-8322-4774-7

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

**RAILWAY APPLICATIONS – FIXED INSTALLATIONS –
ELECTRONIC POWER CONVERTERS –****Part 3-1: AC traction applications –
Electronic power compensators**

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The text of this International Standard is based on the following documents:

Draft	Report on voting
9/2843/FDIS	9/2864/RVD

Full information on the voting for its approval can be found in the report on voting indicated in the above table.

The language used for the development of this International Standard is English.

This document was drafted in accordance with ISO/IEC Directives, Part 2, and developed in accordance with ISO/IEC Directives, Part 1 and ISO/IEC Directives, IEC Supplement, available at www.iec.ch/members_experts/refdocs. The main document types developed by IEC are described in greater detail at www.iec.ch/publications.

A list of all parts in the IEC 62590 series, published under the general title *Railway applications – Fixed installations – Electronic power converters*, can be found on the IEC website.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under webstore.iec.ch in the data related to the specific document. At this date, the document will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
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INTRODUCTION

Single-phase AC traction systems are typically used for railway lines with high power load up to the double-digit MW range. The nature of the loads serving the intended traffic in those railway lines leads to permanent power fluctuations. Due to their inherent structure, single-phase traction systems are prone to having difficulty with power quality indicators such as power factor, voltage fluctuation and/or imbalance within the electric traction system and/or the feeding three-phase power network. In order to improve the power quality, an electronic power compensator can be applied.

Components of electronic power compensators especially electronic power converters must withstand the more rugged electric environment when compared with those for other industrial use, due to the nature of electric traction systems mentioned above. This includes not only high load fluctuation, but also frequent switching operation with inrush current and short circuits caused by faults on the overhead contact line systems. Therefore, specific requirements are needed in addition to the common requirements for converters for other industrial use.

This document defines typical system configurations and basic requirements as well as appropriate test methods for electronic power compensators used for single-phase AC traction systems. This document is intended for the use by railway operators, manufacturers and system integrators.

RAILWAY APPLICATIONS – FIXED INSTALLATIONS – ELECTRONIC POWER CONVERTERS –

Part 3-1: AC traction applications – Electronic power compensators

1 Scope

This document specifies the requirements and test methods for electronic power compensators for 1AC traction systems. This equipment is used to improve electric power quality inside the electric traction system and/or at the interface to the 3AC power network, applying power electronics technology.

This document applies to equipment which is installed to achieve one or more of the following objectives as its function(s):

- to mitigate voltage fluctuation;
- to improve power factor;
- to reduce imbalance at the interface to the 3AC power network.

NOTE In some cases, this type of equipment is used to reduce harmonics from the traction load towards the 3AC power network, and for energy saving.

The equipment designed to conform to each particular installation site and the packaged equipment for generic use both fall within the scope of this document.

This document applies to equipment with all possible configurations to implement different technical solutions for compensation, but equipment consisting of only passive components is excluded.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60050-151:2001, *International Electrotechnical Vocabulary (IEV) – Part 151: Electrical and magnetic devices*

IEC 60050-151:2001/AMD1:2013

IEC 60050-151:2001/AMD2:2014

IEC 60050-151:2001/AMD3:2019

IEC 60050-151:2001/AMD4:2020

IEC 60050-151:2001/AMD5:2021

IEC 60146-1-1:2009, *Semiconductor converters – General requirements and line commutated converters – Part 1-1: Specification of basic requirements*

IEC 60146-2:1999, *Semiconductor converters – Part 2: Self-commutated semiconductor converters including direct d.c. converters*

IEC 60529, *Degrees of protection provided by enclosures (IP Code)*

IEC 60850, *Railway applications – Supply voltages of traction systems*

IEC 61000-4-30:2015, *Electromagnetic compatibility (EMC) – Part 4-30: Testing and measurement techniques – Power quality measurement methods*
IEC 61000-4-30:2015/AMD1:2021

IEC 61936-1, *Power installations exceeding 1 kV AC and 1,5 kV DC – Part 1: AC*

IEC 62236-2, *Railway applications – Electromagnetic compatibility – Part 2: Emission of the whole railway system to the outside world*

IEC 62236-5, *Railway applications – Electromagnetic compatibility – Part 5: Emission and immunity of fixed power supply installations and apparatus*

IEC 62313, *Railway applications – Power supply and rolling stock – Technical criteria for the coordination between power supply (substation) and rolling stock*

IEC 62590:2019, *Railway applications – Fixed installations – Electronic power converters for substations*

IEC 62695:2014, *Railway applications – Fixed installations – Traction transformers*

3 Terms, definitions and abbreviated terms

3.1 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 62590:2019 and the following apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at <http://www.electropedia.org/>
- ISO Online browsing platform: available at <http://www.iso.org/obp>

3.1.1

power quality

characteristics of the electric current, voltage and frequency at a given point in an electric power system, evaluated against a set of reference technical parameters

Note 1 to entry: These parameters might, in some cases, relate to the compatibility between electricity supplied in an electric power system and the loads connected to that electric power system.

[SOURCE: IEC 60050-614:2016, 614-01-01]

3.1.2

power factor

under periodic conditions, ratio of the absolute value of the active power P to the apparent power S :

$$\lambda = \frac{|P|}{S}$$

Note 1 to entry: Under sinusoidal conditions, the power factor is the absolute value of the active factor.

[SOURCE: IEC 60050-131:2002, 131-11-46]

3.1.3**compensate**

<electric power>improve power quality at a certain point of the circuit

3.1.4**electric traction system**

railway electric distribution network used to provide energy for rolling stock

Note 1 to entry: The system includes:

- contact line systems,
- return circuit of electric traction systems,
- electric installations, which are supplied from contact lines either directly or via a transformer,
- electric installations in power plants and substations, which are utilized solely for generation and distribution of power directly to the contact line,
- electric installations of switching stations.

[SOURCE: IEC 60050-811:2017, 811-36-21, modified – third dash in the list of the Note 1 to entry was removed.]

3.1.5**1AC traction system**

single phase traction system

electric traction system operating with single phase AC

Note 1 to entry: The system includes auto-transformer system.

3.1.6**near end**

<of electric traction system> area in electric traction system close to the traction substation

Note 1 to entry: This term is typically used for the single-side-fed electric traction systems.

3.1.7**far end**

<of electric traction system> area in electric traction system most distant from the traction substation, typically near a sectioning post

Note 1 to entry: This term is typically used for the single-side-fed electric traction systems.

3.1.8**feeding section**

electric section of the route fed by individual track feeder circuit-breakers within the area supplied by one or more substations

[SOURCE: IEC 60050-811:2017, 811-36-25]

3.1.9**3AC power network**

three phase power network

three-phase electric circuit or set of electric circuits, interconnected or having intentional capacitive or inductive coupling between them

Note 1 to entry: In this document, this term is used to indicate an upstream power supply network.

3.1.10**traction unit**

locomotive, motor coach or train-unit

[SOURCE: IEC 60050-811, 811-02-04]

3.1.11**voltage drop**

<of electric traction system> change of the voltage at the location of traction unit due to impedance of electric traction system as well as impedance of the 3AC power network, measured when traction current flows from or into traction units

3.1.12**voltage fluctuation**

<of electric traction system> series of supply voltage changes or continuous variation of the RMS or peak value of the voltage

Note 1 to entry: Whether the RMS or peak value is chosen depends upon the application, and which is used should be specified.

[SOURCE: IEC 60050-161:1990, 161-08-05, modified – “series of voltage” was replaced with “series of supply voltage”.]

3.1.13**voltage imbalance**

in a polyphase system, condition in which the RMS values of the phase voltages or the phase angles between consecutive phases are not all equal

[SOURCE: IEC 60050-161:1990, 161-08-09]

3.1.14**negative sequence component**

<of a three-phase system> one of the three symmetrical sequence components which exists only in an unsymmetrical three-phase system of sinusoidal quantities and which is defined by the following complex mathematical expression:

$$X_2 = \frac{1}{3}(X_{L1} + a^2 X_{L2} + a X_{L3})$$

where a is the 120-degree operator, and X_{L1} , X_{L2} and X_{L3} are the complex expressions of the phase quantities concerned, and where X denotes the system current or voltage phasors

[SOURCE: IEC 60050-448:1995, 448-11-28]

3.1.15**electronic power converter**

operative unit for electronic power conversion, comprising one or more electronic valve devices, transformers and filters if necessary and auxiliaries if any

[SOURCE: IEC 60050-551:1998, 551-12-01, modified – Note and Figure 1 were removed.]

3.1.16**self-commutation**

commutation where the commutating voltage is supplied by components within the converter or the electronic switch

[SOURCE: IEC 60050-551:1998, 551-16-15]

3.1.17**line-commutation**

external commutation where the commutating voltage is supplied by the line

[SOURCE: IEC 60050-551:1998, 551-16-12]

3.1.18
electronic power compensator
EPC

equipment to improve power quality of the circuit to which it is connected, controlling current and/or voltage by use of electronic power converters

3.1.19
static var compensator
SVC

electronic power compensator adjusting reactive power

Note 1 to entry: The whole arrangement consists of fixed elements and adjustable elements. Line-commutated or self-commutated converters are examples of adjustable elements.

3.1.20
balancer

<of traction substation> electronic power compensator to reduce imbalance

Note 1 to entry: A positive side effect of a balancer is reducing voltage fluctuation and/or improving power factor in the 1AC traction system as well as the 3AC power network.

3.1.21
railway static power conditioner
RPC

set of converters which exchanges active power between different sections in the electric traction system as well as injects reactive power

Note 1 to entry: Currently, the only configuration that has been used in the already commissioned RPC is that which consists of a pair of self-commutated single-phase inverters connected back-to-back to each other through a common DC link.

Note 2 to entry: It is used to connect two feeding sections supplied by two traction substations, as well as two feeding sections supplied by two single-phase voltage sources of different phases from the same traction substation.

3.1.22
STATCOM
SVG

static var compensator using set of self-commutated converters

Note 1 to entry: "STATCOM" is used in Europe and "SVG" is used in Japan.

3.1.23
Steinmetz principle

principle for balancing voltage and/or current of an unbalanced 3AC circuit by applying reactive load between two or more pairs of phases

3.1.24
Scott connection

method of interconnecting the windings of two single-phase transformers for the transformation of three-phase voltages to two-phase voltages or vice versa

Note 1 to entry: The voltage and current of 3AC side will balance when the two loads of two 1AC side circuits are equal.

[SOURCE: IEC 60050-421:1990, 421-10-06, modified – Note 1 to entry was added.]

3.1.25
V-connection

two single phase loads between 2 different pairs of phases of a 3AC power network

Note 1 to entry: This leads statistically to a better-balanced load than one combined single-phase load.

3.1.26**rated capacity**

<of electronic power compensator> capacity of electronic power compensator to fulfil its main purpose, where calculation method and condition of equipment for measurement are defined depending on the purpose and configuration of the equipment

Note 1 to entry: Typical rated capacity is expressed in active power, reactive power, apparent power or current.

3.1.27**rated voltage**

<of electronic power compensator> voltage of electronic power compensator to operate, where part and condition of equipment for measurement are defined depending on the purpose and configuration of the equipment

3.1.28**rated current**

<of electronic power compensator> current of electronic power compensator to operate, where part and condition of equipment for measurement are defined depending on the purpose and configuration of the equipment

3.1.29**rated frequency**

<of electronic power compensator> frequency of electronic power compensator to operate, where part and condition of equipment for measurement are defined depending on the purpose and configuration of the equipment

Note 1 to entry: Intended operational frequency of the electronic power converter is taken from IEC 60850.

3.1.30**conventional efficiency**

η

power efficiency determined from calculation and/or measurement using the specified method

Note 1 to entry: Especially for large equipment as explained in 7.1.4, it is sometimes difficult to measure the power efficiency directly by testing equipment with rated load due to various restrictions.

3.1.31**control function**

function intended to regulate the behaviour of equipment or systems

[SOURCE: IEC 61892-2:2019, 3.9]

3.1.32**protective function**

<of electric traction system> function that operates to prevent harm to persons and/or damage to equipment

3.1.33**immunity level**

<for compensator> specified value of an electrical disturbance below which the equipment is designed to meet the required performances or continue operation or avoid damage

[SOURCE: IEC 62590:2019, 3.11.2, modified – converter was replaced with equipment.]

3.1.34**type test**

conformity test made on one or more items representative of the production

Note 1 to entry: In the context of this document, the word “type” expresses a group of products that has completely same design. The products with similar design but different ratings are considered as different type.

[SOURCE: IEC 60050-151:2001, 151-16-16, modified – Note 1 to entry was added.]

3.1.35**routine test**

conformity test made on each individual item during or after manufacture

[SOURCE: IEC 60050-151:2001, 151-16-17]

3.2 Abbreviated terms

EPC	electronic power compensator
RPC	railway static power conditioner
STATCOM	static synchronous compensator
SVC	static var compensator
SVG	static var generator
TCR	thyristor controlled reactor

4 Types of electronic power compensators**4.1 General**

The type of electronic power compensators is categorized as follows:

- a) type of compensation:
 - 1) single-phase compensation by injection of reactive power into 1AC traction system;
 - 2) multi-phase compensation by coordination of active and/or reactive power at the 1AC traction system side of a traction transformer;
 - by exchange of active power between phases and/or circuits;
 - by coordination of reactive power in phases.
 - 3) multi-phase compensation by coordination of active and/or reactive power at the 3AC power network side of a traction transformer.
- b) electrical position of installation in the electric traction system:
 - 1) the far end, intermediate or the near end of a 1AC traction system;
 - 2) 1AC traction system side of a traction transformer;
 - 3) 3AC power network side of a traction transformer, and possibly the receiving point of a traction substation or transmitting point of a 3AC substation for power transmission dedicated to traction.
- c) one or more purpose and function:
 - 1) reduction of voltage drop and/or voltage fluctuation inside 1AC traction system;
 - 2) peak load reduction
 - 3) improvement of power factor on 3AC power network side;
 - 4) mitigation of voltage fluctuation on 3AC power network side;
 - 5) mitigation of imbalance on 3AC power network side;
 - 6) mitigation of harmonics from traction load towards 3AC power network.

d) type of commutation:

- 1) self-commutation;
- 2) line-commutation.

NOTE 1 Line-commutation type equipment is no longer the state of the art, but is still used around the world. It is noted that a lot of harmonic issues often rise with this type of installation.

NOTE 2 An equivalent variable reactance element can be realized by using a fixed element in combination with a controlled element. The most common example is a fixed capacitance in combination with a TCR. Combination of fixed elements with converters using self-commuting principle is also possible.

NOTE 3 There may be other compensation methods besides the ones described in Clause 4.

Figure 1 shows an example of the possible electrical installation position of electronic power compensators. The power quality may be improved by one piece of equipment or a combination of different EPC.

The following subclauses from 4.2 to 4.4 describe typical technical solutions for compensation and configuration of equipment to implement their application around the world, as summarised in Table 1. However, this description is not exhaustive, and does not intend to prevent any other types, including future ones, from being selected.

NOTE 4 For simplification, active power losses in the EPCs are neglected in all figures in subclauses 4.2 through 4.4.

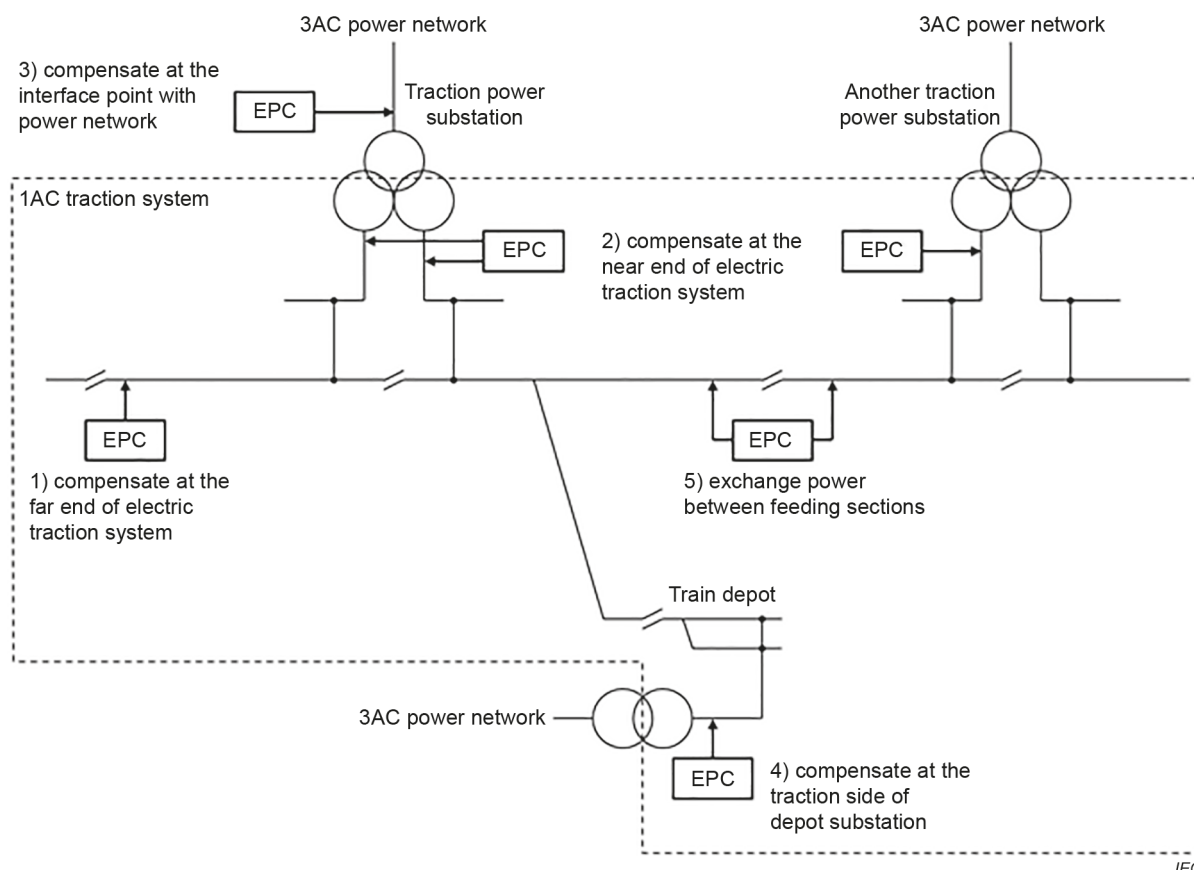


Figure 1 – Example of the possible electrical position of electronic power compensators

Table 1 – Types of typical electronic power compensators

Type of compensation	Electrical position	Purpose and function	Control strategy	Type of rated capacity	Example of equipment	Sub-clause
Single-phase compensation by injection of reactive power into a 1AC traction system	• far end or middle of 1AC traction system	• voltage drop compensation	• AC voltage control	• reactive power, in MVar	SVC	4.2.2
	• near end of 1AC traction system	• power factor compensation	• reactive power control	• reactive power, in MVar	SVC	4.2.3
Multi-phase compensation by coordination of active and/or reactive power at the 1AC traction side of a traction transformer	• near end of 1AC traction system	• three-phase imbalance compensation • three-phase voltage drop compensation • power factor compensation	• active power control • reactive power control • AC voltage control	• apparent power, in MVA	RPC	4.3.2
	• far end of 1AC traction system	• energy saving • voltage drop compensation • peak load reduction • voltage stabilization	• active power control	• apparent power, in MVA	RPC	4.3.2.4
	• near end of 1AC traction system	• three-phase imbalance compensation • three-phase voltage drop compensation • power factor compensation	• negative sequence component control • reactive power control • AC voltage control	• reactive power, in MVar ^a	STATCOM SVG	4.3.3 4.3.4
application on 3AC power network (Multi-phase compensation by coordination of active and/or reactive power at the 3AC power network side of a traction transformer)	• 3AC power network side of a traction transformer	• three-phase imbalance compensation • three-phase voltage drop compensation • power factor compensation	• negative sequence component control • reactive power control • AC voltage control • active power control	• apparent power, in MVA	STATCOM SVG	4.4

^a It is indicated by apparent power in MVA in some countries.

NOTE All the types of compensators listed above can be used for harmonic compensation and energy saving as well.

4.2 Single-phase equipment which injects reactive power into a 1AC traction system

4.2.1 General

There are two different purposes resulting in different locations for the use of single-phase equipment injecting reactive power into an 1AC traction system as shown in 4.2.2 and 4.2.3.

There is a wide variety of possible configurations for this kind of equipment. Present state-of-the-art is self-commutated converters, but older systems are still in use. These systems may use power electronics in combination with passive components, such as in the TCR.

4.2.2 Equipment installed on the far end or middle of a 1AC traction system

4.2.2.1 Purpose and function

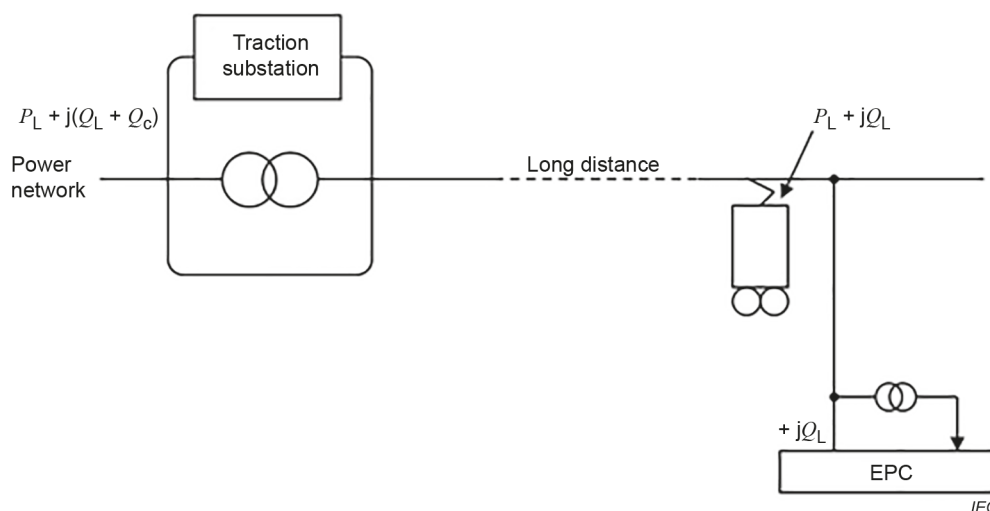
The purpose of this type of equipment is to stabilise voltage at locations far away from the substation. More stable supply voltage improves operation performance of traction units powered by the 1AC traction system. SVC is an example of this type. See Figure 2.

4.2.2.2 Configuration and interface

This equipment consists of components for adjusting reactive power and are typically connected with a traction system at the end of a feeding section.

4.2.2.3 Control strategy

The equipment acts as a lagging or leading load depending on whether the voltage measured at that point is higher or lower than the criteria.



Key

P_L active power of a feeding section

Q_L reactive power of a feeding section

Q_C reactive power consumed by EPC ("Load convention" is used. Typically $Q_C < 0$ in this application)

NOTE For simplification, active power loss and reactive power caused by the electric traction system are neglected.

Figure 2 – Single-phase equipment installed on the far end or middle of a 1AC traction system

NOTE The symbol "j" in all figures in this document is an imaginary unit.

4.2.3 Equipment installed on the near end of a 1AC traction system

4.2.3.1 Purpose and function

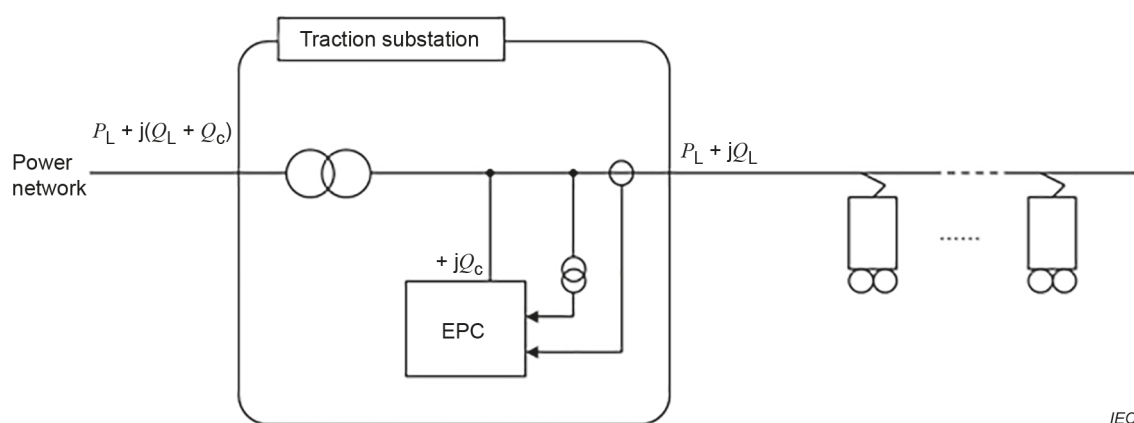
The purpose of this type of equipment is to improve the power factor seen from the power network. SVC is an example of this type. See Figure 3.

4.2.3.2 Configuration and interfaces

This equipment consists of components for adjusting reactive power and are typically connected with a traction system in the substation.

4.2.3.3 Control strategy

The value of the reactance element is controlled by the converter as a lagging or leading load to cancel all or part of the reactive power Q_L yielded in the 1AC traction system.



Key

P_L active power of a feeding section

Q_L reactive power of a feeding section

Q_c reactive power consumed by EPC ("Load convention" is used. Typically $Q_c < 0$ in this application)

Figure 3 – Single-phase equipment installed on the near end of a 1AC traction system

4.3 Multi-phase equipment connected to the 1AC traction side

4.3.1 General

Equipment installed into more than one phase of the 1AC traction system is categorized into several types as shown in 4.3.2 and 4.3.3.

4.3.2 Equipment exchanging active power between a pair of different 1AC circuits and/or injecting reactive power into 1AC circuits

4.3.2.1 Purpose and function

The purpose of this type of equipment is to improve balance and/or mitigation of voltage fluctuation in the 3AC power network with active and reactive power control. This type of equipment is called RPC.

4.3.2.2 Configuration and interfaces

An RPC consists of a set of converters which are parallelly connected to different 1AC circuits respectively. These 1AC circuits may be:

- one of the sections of the 1AC traction system;
- one of the phases of the traction side of the traction transformer (See NOTE in 4.3.2.3).

The entirety of the equipment can be installed at the near end of the section, generally in the substation, as well as at the far end, such as in the sectioning post.

4.3.2.3 Control strategy of an RPC located at a traction power substation

The substation RPC exchanges active power between different 1AC circuits to which converters of the RPC are connected. It also injects reactive power into one or more of these 1AC circuits.

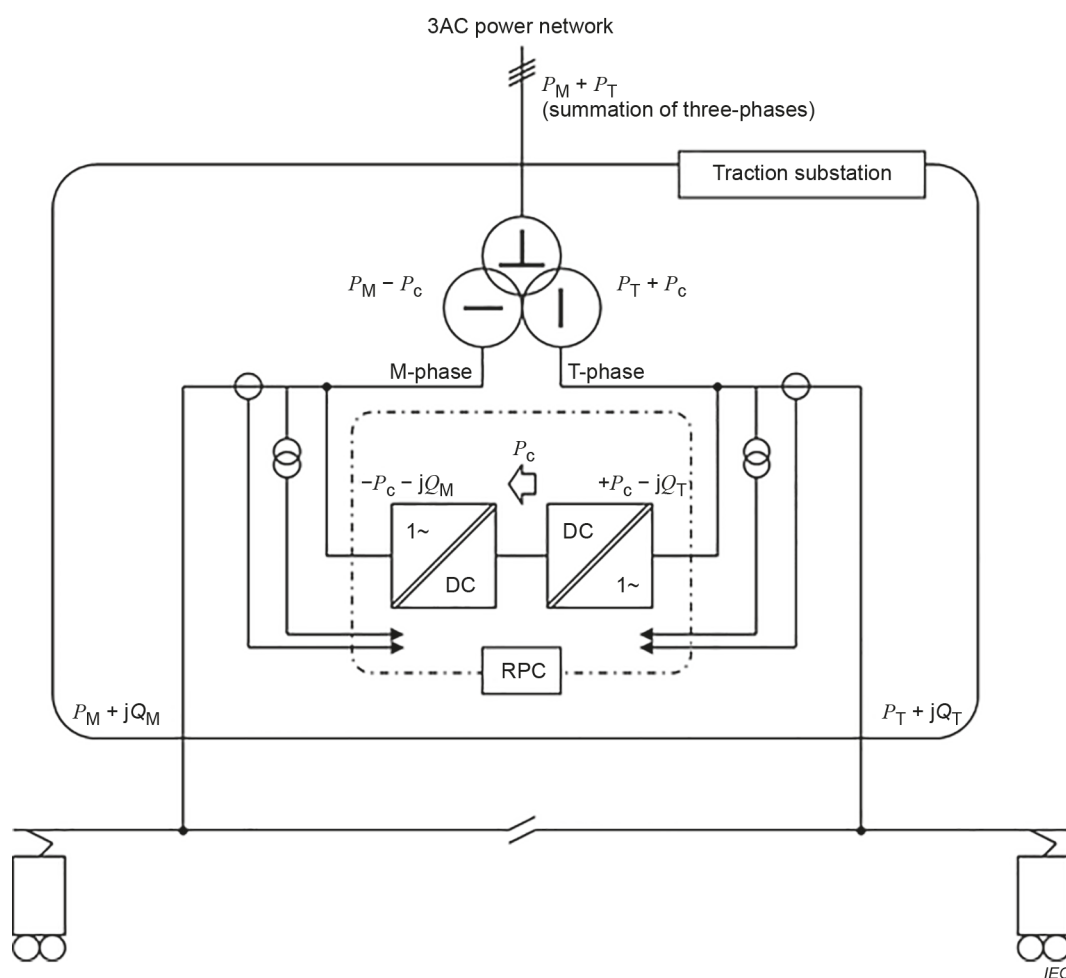
If a three-phase to two-phase conversion with orthogonal 1AC circuits is used an RPC is applicable. Transformers for this purpose are defined in Clause 10 of IEC 62695:2014, Scott transformer for example. The 3AC load can be symmetrized if both 1AC loads are equal. For this purpose, half of the difference of the active power P_c of the 1AC circuits is exchanged. See Figure 4.

Depending on the capacity of the equipment, the improvement of balance and/or mitigation of voltage fluctuation in the 3AC power network side can be achieved by compensating reactive power of each phase Q_M , Q_T through the same method as described in 4.2.

NOTE 1 According to the operating condition of the 1AC traction system, some RPCs are operated for the purpose of voltage reduction at the end or intermediate of the 1AC traction system, by injection of reactive power just the same as SVCs.

NOTE 2 When the load of a substation is only one feeding section, for example, a substation dedicated to a rolling stock depot, one of two orthogonal 1AC circuits may be used. In this case, the 3AC side will be balanced by exchanging active power between phases through an RPC connected to each phase of the traction side (See 4) of Figure 1).

An RPC may also exchange active power between two phases whose difference of phase angle are 60° or 120° . The balance in the 3AC side is improved in this case, but complete balancing is reached only if an additional measure is taken for active power transmission from the remaining one phase to the other two phases.



Key

- P_M, P_T total active power of a feeding section on M-phase and T-phase respectively
- Q_M, Q_T total reactive power of a feeding section on M-phase and T-phase respectively
- P_c active power transferred from T-phase to M-phase to decrease negative sequence component of three-phase side

NOTE DC link in RPC is an example to transfer active power between two phases. Other solutions are possibly used as well.

Figure 4 – Equipment exchanging active power between a pair of orthogonal 1AC circuits and/or injecting reactive power into 1AC circuits

NOTE For simplification, it is assumed that each electronic power compensator has enough compensation capacity to entirely compensate the reactive power and/or eliminate the voltage/current imbalance on 3AC side with the ideal condition in the figures in 4.2 to 4.4. In realistic cases, compensation is usually carried out with best effort, because the capacity of the electronic power compensator is limited.

4.3.2.4 Control strategy of an RPC located at the far ends of two different feeding sections

Regenerative energy from braking traction units is consumed by other powering traction units in the same section of the 1AC traction system. When the energy demanded by those other traction units is less than the regenerated energy, the superfluous energy returns to the 3AC power network through the traction transformer, but sometimes without being metered and charged.

An RPC connects in terms of power flow two 1AC circuits with different power sources. It means the equipment can exchange active power between two sections of the 1AC traction system supplied by adjacent substations at their far end. This enables the superfluous regenerative energy in one section to be transmitted to and consumed in the other section. This also enables better voltage stability and lower distribution losses.

The equipment is installed at the far end of the 1AC traction system typically in the sectioning post. The converter connects two feeding sections of the 1AC traction system supplied by different traction substations possibly with phase difference. Typically, each of the two converters of the RPC is connected to each section of the 1AC traction system supplied by different traction substations possibly with phase difference. See 5) of Figure 1.

The control strategy of this type of RPC is different from that described in 4.3.2.3. The RPC operates collaborating with two traction substations on both sides. Information exchange between the RPC and these substations may be needed to control the equipment properly.

4.3.3 Application of Steinmetz principle

4.3.3.1 Purpose and function

The purpose of this type of equipment is to improve balance and/or mitigation of voltage fluctuation in the 3AC power network with reactive power control. STATCOM is an example of this type. See Figure 5.

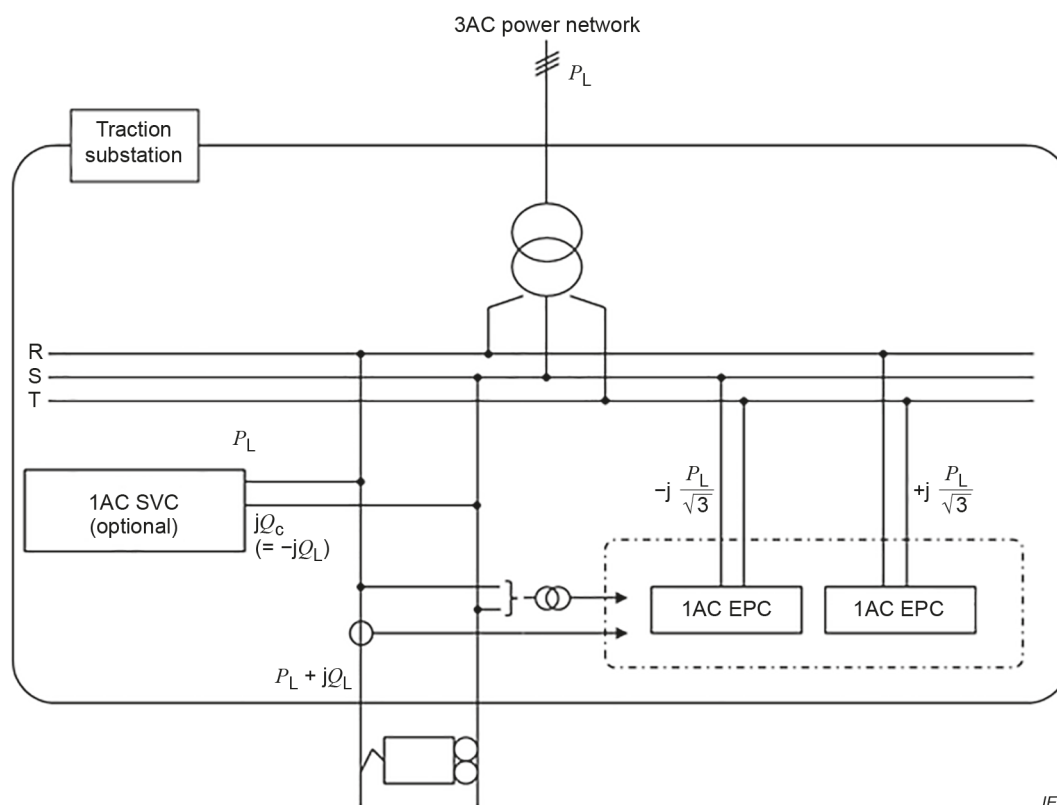
4.3.3.2 Configuration and interfaces

Two sets of single-phase SVCs described in 4.2.1 are inserted into each pair of phases other than the one connected to the 1AC traction system.

A single-phase SVC, be it line-commutated or self-commutated, may be combined at one or more phases with train running load, to improve the power factor at the power receiving point by compensating the reactive power from traction units with low power factor driving systems.

4.3.3.3 Control strategy

Two sets of single-phase SVCs are asymmetrically controlled totally as one group in such a way that the 3AC power network side is loaded with balanced current.



Key

P_L total active power of a feeding section

Q_L total reactive power of a feeding section

Q_c reactive power consumed by single-phase SVC ("Load convention" is used. Typically $Q_c < 0$ in this application)

NOTE 1 "1AC EPC" stands for SVC, STATCOM or SVG.

NOTE 2 One of EPCs acts as capacitive, and the other acts as inductive.

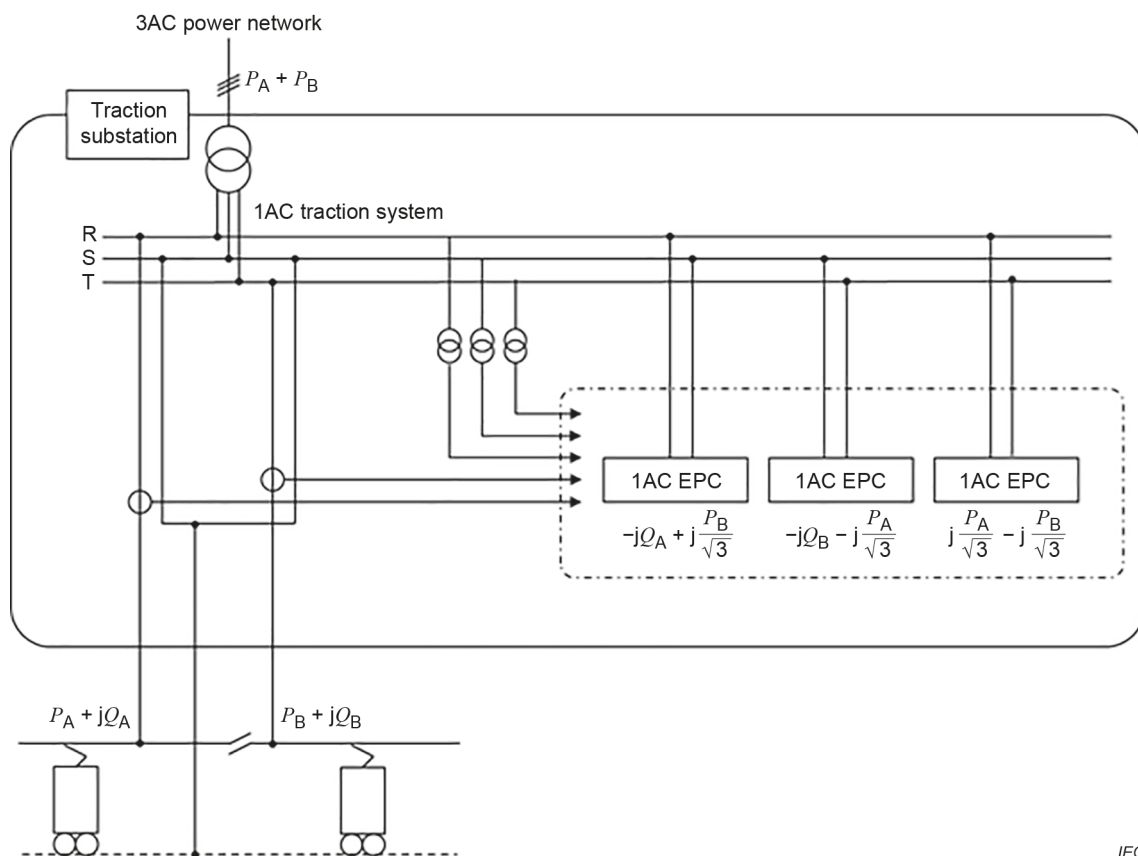
Figure 5 – Application of Steinmetz principle

4.3.4 Equipment connected to the traction side of the V-connection transformer

A conventional method to reduce imbalance is the V-connection. Two sections of a 1AC traction system are connected between different pairs of phases of the feeding 3AC power network. This can be realized by a special V-transformer, a three-phase transformer, or two single phase transformers.

The remaining imbalance can be further reduced by using the Steinmetz principle. Three independently controlled single-phase SVCs apply reactive power to the 3AC power network. See Figure 6

The description of 4.3.3 may be used with the principle of superposition for two loads and their needed compensation. The superposition leads to a partial extinction of the needed compensation power. The three single-phase SVCs can be combined in one unit, but need independent control.



IEC

Key

P_A, P_B active power of a feeding section A and B

Q_A, Q_B reactive power of a feeding section A and B ("Load convention" is used.)

Figure 6 – Equipment connected to traction side of the V-connection traction transformer

4.4 Application on 3AC power network

4.4.1 General

The three-phase imbalance can also be reduced with equipment installed at the 3AC power network side of a traction transformer as shown in 4.4.2. The equipment used for this purpose may be similar to that of 4.3.3, but the electrical position of installation is different. See Figure 7.

4.4.2 Equipment connected to the 3AC power network side of a traction transformer

4.4.2.1 Purpose and function

The three-phase imbalance is expressed as the negative sequence component. The purpose of this type of equipment is to reduce the three-phase imbalance of the load as seen from the 3AC side of the traction substation by using a balancer at the 3AC power network side of a traction transformer (group). This solution may be applied to any type of 1AC traction system including a Scott-connection system as well as a V-connection system.

4.4.2.2 Configuration and interfaces

The configuration of the target 1AC traction system may be any of various types

The equipment is installed in the 3AC power network side of the traction transformer. There is multiple possible equipment configuration and ways of connecting to the phases. For example:

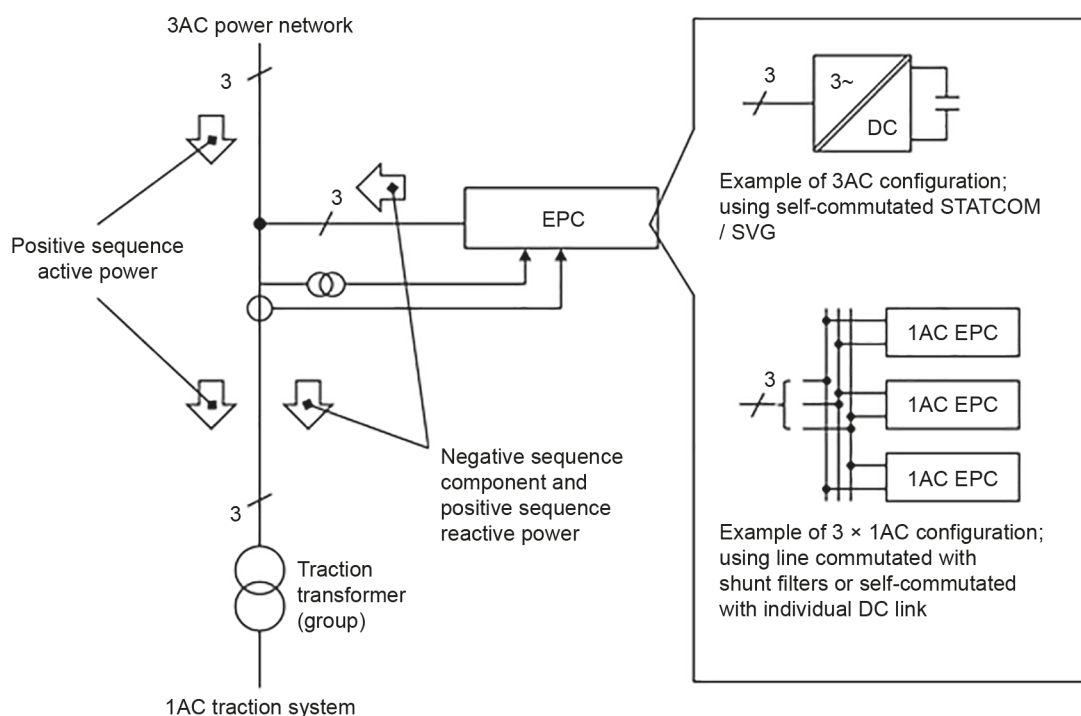
- three-phase STATCOM or three-phase SVG;
- three sets of single-phase SVC between each pair of phases.

4.4.2.3 Control strategy

This kind of equipment symmetrises the load as seen from 3AC power network side of the traction transformer by asymmetrically injecting reactive power into each pair of phases, or by exchanging active power between phases. The equipment also compensates reactive power when it has enough capacity.

This equipment can balance the load current. Different algorithms are needed for each of the tasks.

The equipment applied for this purpose is asymmetrically controlled unlike those generally used for 3AC power network despite equipment itself is similar.



IEC

NOTE "1AC EPC" stands for SVC, STATCOM or SVG.

Figure 7 – Equipment which reduces imbalance at the 3AC power network side of a traction transformer

4.4.2.4 Equipment which reduces imbalance generated in multiple traction substations as a whole

In some 1AC traction systems, a bulk receiving substation receives power from the 3AC power network and distributes to a group of traction substations through railway dedicated transmission lines.

In these cases, expanding on the concept described in other parts of 4.4, imbalance generated in multiple traction substations can be reduced as a whole at the bulk receiving substation. The equipment of this purpose asymmetrically compensates reactive power and exchanges active power between phases of the transmission line. See Figure 8.

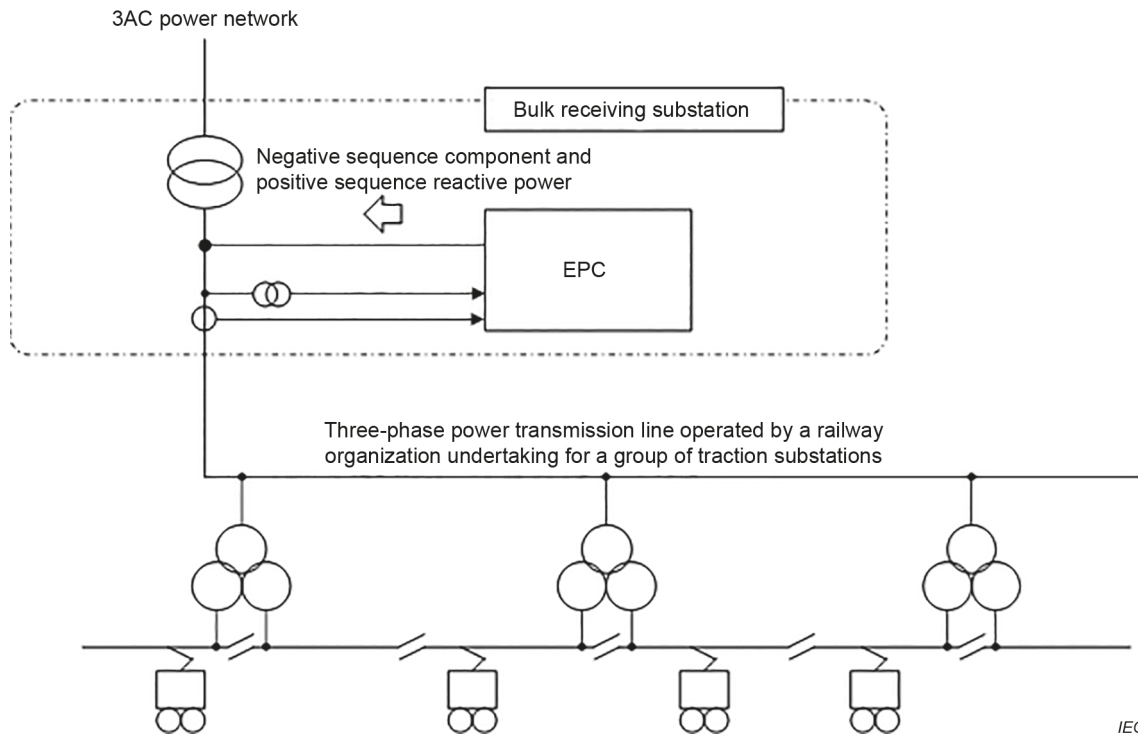


Figure 8 – Equipment which reduces imbalance generated in multiple traction substations as a whole

5 Design and integration

5.1 General

The design of an electronic power compensator is typically performed applying the following steps:

- survey of the power quality criteria;
- survey of the condition of the 3AC power network;
- traction load requirements;
- estimation of the power quality without any countermeasures;
- choice of the countermeasures;
- evaluation of the electronic power compensator;
- specification of the electronic power compensator.

This design process which is needed to achieve the effect of installation is described from a purely technical point of view. The entity who has responsibilities for the total system integration of the electric traction system with an electric power compensator may be different depending on the projects. Therefore, the actual attribution of roles among the stakeholders in the process described in Clause 5 is out of the scope of this document. The possible stakeholders are:

- railway operators;
- railway infrastructure managers;

- j) system integrators;
- k) manufacturers;
- l) 3AC power network operators.

5.2 Survey of power quality criteria

The criteria for power quality in AC traction systems shall conform to the specifications of IEC 60850 and IEC 62313. Special national conditions shall precede others, if any.

When an infrastructure manager receives 3AC or 1AC power from a power supply company, special national conditions and/or requirements specified by power supply companies shall have precedence, if any.

The examples of criteria for power quality are shown in Annex C.

5.3 Survey of the condition of the 3AC power network

The condition which is inherent to the 3AC power network to be connected by the traction substation for the target feeding section, and may affect the quality of power, shall be specified. Short-circuit capacity and harmonic impedance of the power network are two of the important parameters to be considered.

The condition for estimation of the value to be chosen as the short-circuit capacity shall be determined considering the criteria which was specified to be satisfied through the survey in 5.2.

Generally, the minimum value is needed for estimation of the power quality, and the maximum value is needed for specification of short-circuit withstanding requirements of the equipment. The following values of the 3AC power network shall be determined:

- minimum short-circuit capacity;
- maximum short-circuit capacity;
- harmonic impedance for relevant network configurations.

5.4 Traction load requirements

The maximum value and/or range of variation of active and reactive power expected in the section of AC traction system where the equipment will be installed shall be defined. More detailed study may be performed upon agreement between the user and the manufacturer.

In the case where the equipment will be installed into an existing line, the results of measurements in the target AC traction system may be used as a part or all the load estimation.

5.5 Estimation of the power quality without any countermeasures

5.5.1 General

The extent of deterioration of power quality in the target AC traction system and/or the 3AC power network shall be estimated according to the load and the condition of the power source estimated in 5.3 and 5.4.

In the case the equipment will be installed into an existing line, the results of measurements in the target AC traction system and/or 3AC power network may be used as a part or all of the load estimation.

5.5.2 Calculation of voltage drop in a 1AC traction system

The voltage drop in a 1AC traction system may be calculated by the method shown in Annex A.

5.5.3 Calculation of three-phase imbalance at the interface to 3AC power network

The three-phase imbalance at the interface to a 3AC power network may be calculated by the method shown in Annex B. The description of Clause 10 of IEC 62695:2014 may be referenced. Special national conditions shall have precedence, if any.

5.5.4 Calculation of power factor at the interface to 3AC power network

The power factor is calculated as the ratio of the absolute value of the active power to the apparent power estimated at the interface to a 3AC power network.

In case where large three-phase voltage imbalance is expected due to for example large upstream impedance, the power factor on 3AC side should be calculated with the exact formulae considering detail effect of three phase imbalance. See Table B.1. For a fluctuating load, the power factor should be calculated using the integral of the active power as well as the apparent power for the specified duration, considering instantaneous power flow. The calculation of the power factor at the point of common coupling should comply with the electric power purchase agreement between railway infrastructure manager and corresponding power supply company. Definition of this duration may be part of the step described in 5.2.

The user and the manufacturer shall agree on the more detailed definition of the power factor and its measurement method for the purpose of 5.5. IEC 61000-4-30 can be used as guidance for this purpose.

5.6 Choice of the countermeasures

In case the extent of deterioration of power quality estimated in 5.5 exceeds the permissible range determined in 5.2, a solution shall be chosen. The following measures shall be considered:

- a) solution by installing an electronic power compensator;
- b) solution by strengthening the power source infrastructures such as generation plants or transmission lines;
- c) solution by coordinating the transportation capacity of the railway line concerned.

If more than one solution is possible, an economical comparison should be made.

5.7 Evaluation of the electronic power compensator

When the solution by installing an electronic compensator is chosen in 5.6, requirements for keeping the power quality within the permissible range shall be defined. The most appropriate method of compensation shall be selected referencing Clause 4. The required compensation power shall be determined for the selected method of compensation. The policy of compensation shall be decided in advance as follows:

- a) full compensation of the power quality;
- b) minimum compensation needed to keep the power quality within the permissible range;
- c) partial compensation.

The policy concerning the required compensation power for the case when the equipment is needed to stop partially for maintenance shall be agreed upon between the user and the manufacturer, if necessary.

Full compensation is not always needed but may have contractual impacts for the user and their 3AC power network operator.

5.8 Specification of the electronic power compensator

5.8.1 General

An electronic power compensator shall be designed according to the method and required compensation power determined in 5.7. Coordination with other systems shall be considered in design.

5.8.2 Coordination with other systems

Harmonics, produced by the equipment of an electronic power compensator shall not affect the performance of other systems, especially signalling and/or communication systems.

The effects of harmonics shall be evaluated by a method such as simulation or calculation which is agreed upon between the user and the manufacturer.

The user shall indicate the frequency ranges which could affect signalling and/or communications systems

The user shall provide relevant harmonic impedance curves to allow the calculation of harmonic currents and proper design of filters, if needed. If it is necessary either to measure the harmonic impedance curves on the existing traction system or to calculate the curves for the new traction system to be built, the user and the manufacturer shall agree on the method to perform it.

Effect of harmonics propagating from outside of the electronic power compensator, such as predistortion in the 3AC power network or harmonic source in the 1AC traction system shall also be considered, to make the equipment resistant to these harmonics.

6 Performance requirements

6.1 General

6.1.1 Rating

6.1.1.1 General

The rated values of the electronic power compensator are the values determined in the system design described in Clause 5 such that the equipment can deliver an output without exceeding any specified limit values, including those of the parts used, and without causing any damage, when the equipment is operated under specified operating conditions.

There is a set of rated values needed for the intended operation. The boundary conditions for every value shall be agreed upon between the user and the manufacturer.

6.1.1.2 Load requirements

Load requirements shall conform to 6.4.3 of IEC 60146-1-1:2009.

In the case where other values are chosen, the duty class (see 151-16-02 of IEC 60050-151:2001) required for operation shall be specified upon agreement between the user and the manufacturer.

6.1.1.3 Rated capacity

The rated capacity shall be the maximum value of the capacity of the compensator under the normal operating conditions and shall be agreed upon between the user and the manufacturer. Examples are shown in Table 1.

EXAMPLE For an RPC which is used in combination with a three-phase to two-phase conversion transformer, as described in 4.3.2, the maximum value of the apparent power (not active power) which can be exchanged on every connection between the converter and the 1AC traction system can be defined as the rated capacity.

6.1.1.4 Rated voltage

The rated voltage shall be the nominal voltage of the system under the specified operating conditions and shall be agreed upon between the user and the manufacturer.

NOTE There is the case where the normal operating voltage is different from the nominal voltage. For example, the normal operating voltage is sometimes set above the nominal voltage intending to reduce transmission losses in the line.

EXAMPLE For an RPC, U_n which is specified in IEC 60850, of the electric traction system to which the equipment is connected can be defined as the rated voltage.

6.1.1.5 Rated current

The rated current shall be the maximum value of the current of the system under the normal operating conditions and shall be agreed upon between the user and the manufacturer.

The maximum current which can continuously flow under the rated voltage of the electric traction system or the specified traction power supply voltage can be defined as the rated current.

6.1.1.6 Rated frequency

The rated frequency shall be the nominal frequency of the system under the normal operating conditions and shall be agreed upon between the user and the manufacturer.

EXAMPLE For an RPC, the frequency, which is specified in IEC 60850, of the electric traction system to which the equipment is connected can be defined as the rated frequency.

6.1.2 Number of connected phases

The number of phases which are connected to the electronic power compensator shall be specified.

6.1.3 Temperature rise

The temperature of each semiconductor device used in the electronic power converter shall not exceed the allowable maximum temperature specified by the manufacturer of the semiconductor device. The allowable upper limit temperature of any accessory or auxiliary equipment of the electronic power converter shall comply with the standards for the equipment.

From the temperature rise and the expected load cycles, the expected lifetime may be calculated particularly for semiconductor valve device assemblies.

6.1.4 Losses and efficiency

6.1.4.1 General

The figures for the losses shall be given for the whole range of operation power in adequate steps.

The power efficiency of equipment is defined as the conventional efficiency which is derived from the total loss measured or calculated, unless otherwise specified. Measured efficiency may be used if the measurement can be performed without difficulty.

For equipment which has no actual flow of active power, such as SVCs, total loss should be used as the indicator of energy performance, instead of power efficiency.

The conventional efficiency shall be calculated using the following formula. The total loss is the sum of the losses of converters, transformers and other components determined respectively:

$$\eta = \frac{P}{P + P_L} \times 100 (\%)$$

where

η is the conventional efficiency,

P is the rated capacity of the equipment,

P_L is the conventional total loss.

6.1.4.2 Included losses

The following losses shall be included when determining the efficiency:

- a) internal losses in the converter assembly such as valve devices, fuses, potential dividers, current balancing means, snubber circuits and voltage surge absorbers;
- b) losses in converter transformers, transducers, interphase transformers, current limiting and balancing reactors between transformer and converter assemblies;
- c) losses due to main connections between converter transformers and converters for cases when they are built together and delivered as a unit;
- d) power consumed by auxiliaries such as permanently connected fans or pumps and relays unless otherwise specified;
- e) losses in passive filters, only when installed as an integral part of the compensator;
- f) power consumed by the control equipment.

NOTE Power consumed by permanently connected cooling fans which operate only when the temperature of the equipment is higher than the specified threshold and revert to a stand-by state when the temperature falls lower than the threshold value, is included.

6.1.4.3 Not included losses

The following losses shall not be included when determining the efficiency, but shall be stated separately if requested by the user:

- a) losses due to main connections between converter transformers and converters for the case when they are delivered as separate units;
- b) losses due to main connections to circuit breakers, disconnectors, switchgears and to the load;
- c) losses in circuit breakers, disconnectors, switchgears, and control gears other than those mentioned in 6.1.4.2;
- d) losses due to heating, ventilation of the building and supply of the coolant from outside;
- e) losses due to auxiliary apparatus which operate only intermittently.

NOTE Operation of cooling pumps for the purpose of preventing the cooling medium from freezing when the ambient temperature is extremely low is regarded as intermittent operation.

6.2 Control and protective function

6.2.1 Start and stop sequence

The operation sequences of the electronic power compensator, for system start-up, system stop and for system failure shall be defined and be implemented.

Other operation sequences, such as the sequence for switching the operation mode of the equipment for substations for example, shall be upon agreement between the user and the manufacturer.