SIEMENS

System Manual

SINAMICS

S120/S150

Requirements placed on third-party motors

Edition 09/2020

www.siemens.com/drives

SIEMENS

SINAMICS

S120
Requirements placed on third-party motors

System Manual

09/2020
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Legal information

Warning notice system

This manual contains notices you have to observe in order to ensure your personal safety, as well as to prevent damage to property. The notices referring to your personal safety are highlighted in the manual by a safety alert symbol, notices referring only to property damage have no safety alert symbol. These notices shown below are graded according to the degree of danger.

⚠ DANGER
indicates that death or severe personal injury **will** result if proper precautions are not taken.

⚠ WARNING
indicates that death or severe personal injury **may** result if proper precautions are not taken.

⚠ CAUTION
indicates that minor personal injury can result if proper precautions are not taken.

NOTICE
indicates that property damage can result if proper precautions are not taken.

If more than one degree of danger is present, the warning notice representing the highest degree of danger will be used. A notice warning of injury to persons with a safety alert symbol may also include a warning relating to property damage.

Qualified Personnel

The product/system described in this documentation may be operated only by **personnel qualified** for the specific task in accordance with the relevant documentation, in particular its warning notices and safety instructions. Qualified personnel are those who, based on their training and experience, are capable of identifying risks and avoiding potential hazards when working with these products/systems.

Proper use of Siemens products

Note the following:

⚠ WARNING
Siemens products may only be used for the applications described in the catalog and in the relevant technical documentation. If products and components from other manufacturers are used, these must be recommended or approved by Siemens. Proper transport, storage, installation, assembly, commissioning, operation and maintenance are required to ensure that the products operate safely and without any problems. The permissible ambient conditions must be complied with. The information in the relevant documentation must be observed.

Trademarks

All names identified by ® are registered trademarks of Siemens AG. The remaining trademarks in this publication may be trademarks whose use by third parties for their own purposes could violate the rights of the owner.

Disclaimer of Liability

We have reviewed the contents of this publication to ensure consistency with the hardware and software described. Since variance cannot be precluded entirely, we cannot guarantee full consistency. However, the information in this publication is reviewed regularly and any necessary corrections are included in subsequent editions.

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Introduction

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1.1 The SINAMICS converter family

With the SINAMICS converter family, you can solve any individual drive task in the low-voltage, medium-voltage and DC voltage range. From converters to motors and controllers, all Siemens drive components are perfectly matched to each other and can be easily integrated into your existing automation system. With SINAMICS you are prepared for digitization. You benefit from highly efficient engineering with a variety of tools for the entire product development and production process. And you also save space in the control cabinet – thanks to the integrated safety technology.

You can find additional information about SINAMICS at the following address (http://www.siemens.com/sinamics).

1.2 General information about SINAMICS documentation

SINAMICS documentation

The SINAMICS documentation is organized in the following categories:

- General documentation/catalogs
- User documentation
- Manufacturer/service documentation

Extensions or changes made by the machine manufacturer must be documented by the machine manufacturer.

For reasons of clarity, this documentation does not contain all of the detailed information on all of the product types, and cannot take into consideration every conceivable type of installation, operation and service/maintenance.

Siemens MySupport/Documentation

You can find information on how to create your own individual documentation based on Siemens content and adapt it for your own machine documentation at the following address (mailto:docu.motioncontrol@siemens.com).

Additional information

You can find information on the topics below at the following address (https://support.industry.siemens.com/cs/de/en/view/108993276):

- Ordering documentation/overview of documentation
- Additional links to download documents
- Using documentation online (find and search in manuals/information)

Questions relating to the technical documentation

Please send any questions about the technical documentation (e.g. suggestions for improvement, corrections) to the following email address (https://support.industry.siemens.com/My/ww/en/documentation).

FAQs

You can find Frequently Asked Questions about SINAMICS under Product Support (https://support.industry.siemens.com/cs/de/en/ps/faq).

Siemens Support while on the move

With the "Siemens Industry Online Support" app, you can access more than 300,000 documents for Siemens Industry products – any time and from anywhere. The app supports you in the following areas, for example:

- Resolving problems when executing a project
- Troubleshooting when faults develop
- Expanding a system or planning a new system

Furthermore, you have access to the Technical Forum and other articles that our experts have drawn up:

- FAQs
- Application examples
- Manuals
- Certificates
- Product announcements and much more

The "Siemens Industry Online Support" app is available for Apple iOS and Android.

Data matrix code on the rating plate

The data matrix code on the rating plate contains the specific device data. This code can be read-in with any smartphone and technical information for the appropriate device can be displayed via the "Industry Online Support" mobile app.

Websites of third-party companies

This document includes hyperlinks to websites of third-party companies. Siemens is not responsible for and shall not be liable for these websites or their content, as Siemens has not checked the information contained in the websites and is not responsible for the content or information they provide. The use of such websites is at the user's own risk.

1.3 Usage phases and their documents/tools

Usage phase	Document/tool
Orientation	SINAMICS S Sales Documentation
Planning/configuration	• SIZER Engineering Tool • Configuration Manuals, Motors
Deciding/ordering	SINAMICS S120 catalogs • SINAMICS S120 and SIMOTICS (Catalog D 21.4) • SINAMICS Converters for Single-Axis Drives and SIMOTICS Motors (Catalog D 31) • SINAMICS Converters for Single-Axis Drives – Built-In Units (D 31.1) • SINAMICS Converters for Single-Axis Drives – Distributed Converters (D 31.2) • SINAMICS S210 Servo Drive System (D 32) • SINUMERIK 840 Equipment for Machine Tools (Catalog NC 62)
Installation/assembly	• SINAMICS S120 Equipment Manual for Control Units and Supplementary System Components • SINAMICS S120 Equipment Manual for Booksize Power Units • SINAMICS S120 Equipment Manual for Chassis Power Units • SINAMICS S120 Equipment Manual for Chassis Power Units, Liquid-cooled • SINAMICS S120 Equipment Manual water-cooled chassis power units for common cooling circuits • SINAMICS S120 Equipment Manual for Chassis Power Units, Air-cooled • SINAMICS S120 Equipment Manual for AC Drives • SINAMICS S120 Equipment Manual Combi • SINAMICS S120M Equipment Manual Distributed Drive Technology • SINAMICS HLA System Manual Hydraulic Drives
Commissioning	• Startdrive Commissioning Tool • SINAMICS S120 Getting Started with Startdrive • SINAMICS S120 Commissioning Manual with Startdrive • SINAMICS S120 Function Manual Drive Functions • SINAMICS S120 Safety Integrated Function Manual • SINAMICS S120 Function Manual Communication • SINAMICS S120/S150 List Manual • SINAMICS HLA System Manual Hydraulic Drives
Usage/operation	• SINAMICS S120 Commissioning Manual with Startdrive • SINAMICS S120/S150 List Manual • SINAMICS HLA System Manual Hydraulic Drives
Maintenance/servicing	• SINAMICS S120 Commissioning Manual with Startdrive • SINAMICS S120/S150 List Manual
References	• SINAMICS S120/S150 List Manual

1.4 Training and support

Training

You can find information on SITRAIN at the following address (http://www.siemens.com/sitrain). SITRAIN offers training courses for products, systems and solutions in drive and automation technology from Siemens.

Technical Support

To ask a technical question or create a support request, click on "Support Request" at the following address (https://support.industry.siemens.com/cs/ww/en/sc) and select "Create Request".

1.5 Directives, standards, certificates

Relevant directives and standards

You can obtain an up-to-date list of currently certified components on request from your local Siemens office. If you have any questions relating to certifications that have not yet been completed, please ask your Siemens contact person.

Certificates for download

The certificates can be downloaded from the Internet:

Certificates (https://support.industry.siemens.com/cs/ww/de/ps/13206/cert)

EC Declaration of Conformity

You can find the EC Declaration of Conformity for the relevant directives as well as the relevant certificates, prototype test certificates, manufacturers declarations and test certificates for functions relating to functional safety ("Safety Integrated") on the Internet at the following address (https://support.industry.siemens.com/cs/ww/en/ps/13231/cert).

The following directives and standards are relevant for SINAMICS S devices:

- **European Low Voltage Directive**
  SINAMICS S devices fulfil the requirements stipulated in the Low-Voltage Directive 2014/35/EU, insofar as they are covered by the application area of this directive.
- **European Machinery Directive**
  SINAMICS S devices fulfil the requirements stipulated in the Low-Voltage Directive 2006/42/EU, insofar as they are covered by the application area of this directive.
  However, the use of the SINAMICS S devices in a typical machine application has been fully assessed for compliance with the main regulations in this directive concerning health and safety.

- **Directive 2011/65/EU**
  SINAMICS S devices comply with the requirements of Directive 2011/65/EU on the restriction of the use of certain hazardous substances in electrical and electronic devices (RoHS II).
- **European EMC Directive**
  SINAMICS S devices comply with the EMC Directive 2014/30/EU.
- **EMC requirements for South Korea**
  SINAMICS S devices with the KC marking on the type plate satisfy the EMC requirements for South Korea.
- **Eurasian conformity**
  SINAMICS S comply with the requirements of the Russia/Belarus/Kazakhstan customs union (EAC).
- **North American market**
  SINAMICS S devices provided with one of the test symbols displayed fulfill the requirements stipulated for the North American market as a component of drive applications.
  You can find the relevant certificates on the Internet pages of the certifier (https://iq.ulprospector.com).
- **Specification for semiconductor process equipment voltage drop immunity**
  SINAMICS S devices meet the requirements of standard SEMI F47-0706.
- **Australia and New Zealand (RCM formerly C-Tick)**
  SINAMICS S devices showing the test symbols fulfill the EMC requirements for Australia and New Zealand.
- **Quality systems**
  Siemens AG employs a quality management system that meets the requirements of ISO 9001 and ISO 14001.

Not relevant standards

China Compulsory Certification

SINAMICS S devices do not fall in the area of validity of the China Compulsory Certification (CCC).

EMC limit values in South Korea

이 기기는 업무용(A급) 전자파적합기기로서 판매자 또는 사용자는 이 점을 주의하시기 바라며, 가정외의 지역에서 사용하는 것을 목적으로 합니다.
For sellers or other users, please bear in mind that this device is an A-grade electromagnetic wave device. This device is intended to be used in areas other than at home.

The EMC limit values to be observed for Korea correspond to the limit values of the EMC product standard for variable-speed electric drives EN 61800-3 of category C2 or the limit value class A, Group 1 to KN11. By implementing appropriate additional measures, the limit values according to category C2 or limit value class A, Group 1, are observed. Further, additional measures may be required, such as using an additional radio interference suppression filter (EMC filter).
The measures for EMC-compliant design of the system are described in detail in this manual respectively in the EMC Installation Guideline Configuration Manual.

The final statement regarding compliance with the standard is given by the respective label attached to the individual unit.

1.6 Additional information HW

Ensuring reliable operation

The manual describes a desired state which, if maintained, ensures the required level of operational reliability and compliance with EMC limit values.

Should there be any deviation from the requirements in the manual, appropriate actions (e.g. measurements) must be taken to check/prove that the required level of operational reliability and compliance with EMC limit values are ensured.

Spare parts

Spare parts are available on the Internet at the following address (https://www.automation.siemens.com/sow?sap-language=EN).

Product maintenance

The components are subject to continuous further development within the scope of product maintenance (improvements to robustness, discontinuations of components, etc).

These further developments are "spare parts-compatible" and do not change the article number.

In the scope of such spare parts-compatible further developments, connector/connection positions are sometimes changed slightly. This does not cause any problems with proper use of the components. Please take this fact into consideration in special installation situations (e.g. allow sufficient clearance for the cable length).

Use of third-party products

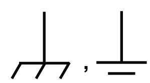
This document contains recommendations relating to third-party products. Siemens accepts the fundamental suitability of these third-party products.

You can use equivalent products from other manufacturers.

Siemens does not accept any warranty for the properties of third-party products.

Ground symbols

Table 1-1 Symbols

Icon	Meaning
	Connection for protective conductor
	Ground (e.g. M 24 V)
	Connection for function potential bonding

1.7 General Data Protection Regulation

Compliance with the General Data Protection Regulation

Siemens respects the principles of data protection, in particular the data minimization rules (privacy by design).

For this product, this means:
The product does not process neither store any person-related data, only technical function data (e.g. time stamps). If the user links these data with other data (e.g. shift plans) or if he stores person-related data on the same data medium (e.g. hard disk), thus personalizing these data, he has to ensure compliance with the applicable data protection stipulations.

Prerequisites for the use of third-party motors 2

Target group

This document addresses two target groups:

- Manufacturers who sell electric motors intended for SINAMCS S120 drives.
  The term "electric motor" here refers to the minimal configuration, consisting of only a stator and rotor without bearing or encoder, all the way to the complete servo motor with shaft, bearing and encoder.
  From the perspective of a spindle manufacturer, the purchased electric motor is the functional unit stator + rotor. From the perspective of the spindle user, the electric motor is the complete system to which the spindle manufacturer has added a bearing, shaft and encoder. With this in mind, it is the spindle manufacturer who actually sells the electric motor.
- Customers who plan on using third-party motors (non-Siemens list motors) on SINAMICS S120 converters.
  The following chapters are mainly intended for machine and plant manufacturers: Qualitative requirements placed on a series inductance (Page 91) and DC-Link Smoothing Filter (Page 171).

Application

In the practical implementation, it is to be expected that motor manufacturers themselves will not make the effort to obtain this document and comply with it. On the other hand, the motor manufacturer is interested in complying with the requirements of his customer. It is therefore very strongly recommended that SINAMICS users who plan on using third-party motors include the technical rules of this document in the specifications that they agree on with their motor supplier.

Benefits

This document is intended to simplify using third-party motors with the SINAMICS drive system. It covers low-voltage converters belonging to the SINAMICS S120/S150 series, in the "servo" and "vector" control modes. SINAMICS medium-voltage converters are not discussed in this document. This document discusses the two most widely established motor types:

- Rotating, permanent-magnet synchronous motors (PEM)
- Rotating induction motors (IM)

This document discusses motors that are supplied from third-party suppliers without having been subject to a Siemens system test. The technical rules documented here form the basis for straightforward commissioning and are the precondition for fulfilling the expectations placed on the motor. Therefore, a description is given

- of the form in which the converter setting parameters should be derived from the physical properties of the motor. This should prevent incorrect parameter assignments and misunderstandings (e.g. confusing the phase voltage with the line-to-line voltage).
- which properties the motor should fulfill regarding its dimensioning, its series dispersion, its stability and the quality of its features so that the motor operates perfectly with the converter.

Further, reference is made to generally applicable requirements, for example

- Voltage strength of the winding
- Requirements regarding the temperature sensor
- Requirements regarding the encoder

As the last points are not linked to specific motor types (permanent-magnet synchronous motors, induction motors etc.), but are applicable for all motor types, then as far as possible, reference is made to existing documents and standards.

Encoderless operation

Encoderless operation, in particular, puts very high requirements on the electrical quality of the motor as well as the accuracy of the supplied converter parameters. For example, you most likely cannot expect to see robust encoderless operation from a motor with high harmonic content in its rotating field. The same is true when the supplied converter parameters only provide an inaccurate description.

Bindingness of the requirements

For third-party motors that have not been subject to a Siemens system test, the system compatibility must be secured so that important and specific minimum requirements are placed on the physical properties and the derived converter setting parameters of the motor. If comparable motors from the Siemens range exist, which in individual aspects do not precisely match the requirements here, than this would not represent a contradiction. The released Siemens list motors have been subject to a system test. As a consequence, their correct system behavior has been verified and a parameter assignment saved which ensures that the expectations placed on the motor in its operating behavior are met.

Conversely, it is also permissible for individual aspects of third-party motors to not fully comply with the requirements specified here if the motors have been tested in the intended SINAMICS drive and accepted by the customer. In particular, deviations are permissible regarding the necessity and dimensioning of series inductances, if the appropriate tests have been performed and the customer has accepted the drive.

Theoretically equivalent star connection

- When engineering and operating SINAMICS drives, all electrical variables are transformed into the equivalent circuit diagram of the star connection to be used as converter parameters. All equivalent circuit diagram variables, such as inductances or resistances, should therefore be specified as line variables that are assigned to the equivalent star circuit diagram.

Note

Theoretically equivalent star connection

For a delta connection, convert into a theoretically equivalent star connection.

- All currents should be specified as phase currents in [A_{rms}] (in relation to an equivalent star connection).
- All voltages should be specified as terminal voltages (terminal - terminal) in [U_{rms}] (in relation to an equivalent star connection).
- If the motor is to be separately cooled (force ventilated, water cooled etc.), then the data – especially those relating to rated operation for precisely this cooling type – apply, including the specified conditions (cooling temperature, cooling pressure, ...).
- All equivalent circuit diagram data such as resistances, inductances, etc., should be specified as single-line equivalent circuit diagram data of an equivalent star connection.

Specification of branch data

It is not permissible to specify branch data between two winding connections (e.g. for windings that can be switched between Y – Δ) instead of the equivalent star connection.

Note

Specification of branch data

When branch data is specified, make it quite clear that the data cannot be used as direct SINAMICS parameters.

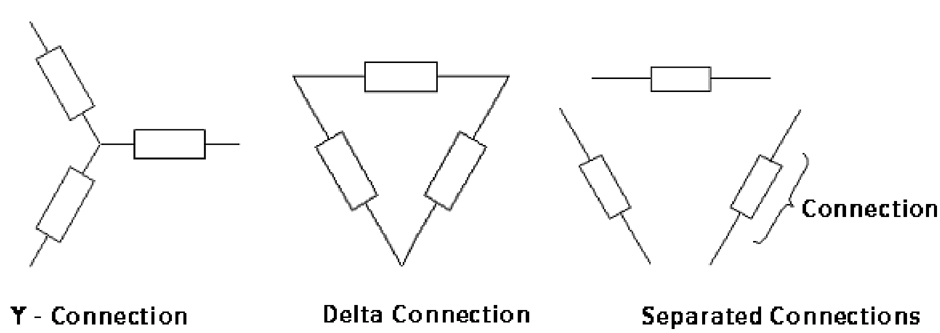


Figure 2-1 Branch circuits

Note

Specification of terminal-terminal values for resistances and inductances

It is not permissible to specify terminal-terminal values for resistances and inductances.

"Single-line equivalent circuit diagram data" always involves the terminal-neutral variables.

Specification of terminal-terminal values for resistances and inductances

It is not permissible to specify terminal-terminal values for resistances and inductances.

Note

Specification of terminal-terminal values for resistances and inductances

"Single-line equivalent circuit diagram data" always involves the terminal-neutral variables.

- The operating parameters, such as torque-generating current, field-generating current, rated frequency, etc. should be generated for the field-orientated operating mode. This means that the rated operating point to generate the equivalent circuit diagram data always refers to the field-orientated operating mode.
  The currents are always sinusoidal, with superimposition of the corresponding current ripple, which is obtained as a result of the pulse width modulation (PWM) of the converter voltage. The frequency of the sinusoidal current corresponds
  - for synchronous motors, the synchronous frequency,
  - for induction motors, the synchronous frequency plus the slip frequency at the rated operating point.

  Constant torque operation should be used as basis. Dynamic current changes, which occur as a result of superimposed speed or torque control, do not have to be taken into account. However, the temperature rise as a result of the pulse width modulated current ripple must be taken into account.
- If not otherwise agreed or if not stated differently in the document, a value of 380 V_{rms} (terminal – terminal) is defined as the maximum operating voltage of the fundamental wave to be used. The modulation depth of a DC link voltage of 600 V is therefore 90% exhausted. The remaining 10% is to be used as reserve for control and as buffer for the sample distribution.
- Contrary to the maximum operating voltage that can be used, to evaluate the voltage stress, the following maximum possible DC link voltage must be used:
  - $U_{DC\ link}$ = 720 V should be used for motors connected to Booksize power units for line voltages up to 480 V and
  - $U_{DC\ link}$ = 1035 V should be used for motors connected to Chassis power units for line voltages up to 690 V.

  The reference value of the DC link voltage to evaluate the voltage stress therefore deviates from the reference value of the DC link voltage for the electric fundamental voltage that can be used. This does not constitute a contradiction.

Rated variables and rated operating conditions

"Rated variables" refers here to those variables that relate to rated operation, i.e. uninterrupted duty (S1 - 100%) at rated speed with rated power.

- Under the specified rated operating conditions, in continuous operation the motor must be able to be operated with thermal and electrical stability. The operating state under rated operating conditions (rated speed and rated torque) is referred to as the "rated operating point" below.
- For data that relates to the rated operating conditions, the basis is a motor in a thermally steady state. This means that the motor (winding, rotor cage, EMF constant of the permanent magnets etc.) is at its typical temperature in rated operation (uninterrupted duty S1 - 100 %).
- If the manufacturer specifies a series inductance, then its inductance for the currents, voltages and temperature rise should be taken into account. The series inductance is then part of the converter - series inductance - motor system. A new data sheet with converter setting parameters must be generated if the series inductance changes.
- Unless explicitly specified otherwise, power, torque and speed are always mechanical variables in relation to the shaft.

Note

Terminology

In the applicable literature, the terms "rated" (e.g. rated power) and "nominal" (e.g. nominal power) are frequently synonymously used.

In the manuals for SINAMICS components, the term "rated" is primarily used.

Fundamental safety instructions 3

3.1 General safety instructions

⚠ WARNING

Danger to life when live parts are touched

Touching live components can result in death or serious injury.

- Only work on electrical devices when you are qualified for this job.
- Always observe the country-specific safety rules.

Generally, six steps apply when establishing safety:

1. Prepare for shutdown and notify team members who will be affected by the procedure.
2. Disconnect the machine from the supply.
   – Switch off the machine.
   – Wait until the discharge time specified on the warning labels has elapsed.
   – Check that it really is in a no-voltage condition, from phase conductor to phase conductor and phase conductor to protective conductor.
   – Check whether the existing auxiliary supply circuits are de-energized.
   – Ensure that the motors cannot move.
3. Identify all other hazardous energy sources, e.g. compressed air, hydraulic systems, water.
4. Isolate or neutralize all hazardous energy sources, e.g. by closing switches, grounding or short-circuiting or closing valves.
5. Secure the energy sources against switching on again.
6. Make sure that the machine is completely locked ... and that you have the right machine.

After you have completed the work, restore the operational readiness in the inverse sequence.

⚠ WARNING

Electric shock due to hazardous voltage when an unsuitable power supply is connected

Death or serious injury can result when live parts are touched in the event of a fault.

- Only use power supplies that provide SELV (Safety Extra Low Voltage) or PELV- (Protective Extra Low Voltage) output voltages for all connections and terminals of the electronics modules.

WARNING

Electric shock when live parts are touched on damaged devices

Improper handling of devices can cause damage.

Hazardous voltages can be present at the housing or exposed components on damaged devices.

- Ensure compliance with the limit values specified in the technical data during transport, storage and operation.
- Do not use any damaged devices.
- The components must be protected against conductive contamination (e.g. by installing them in a cabinet with degree of protection IP54 according to EN 60529). If conductive pollution can be excluded at the installation site, a lower degree of cabinet protection is permissible.

WARNING

Fire hazard for the motor due to overload of the insulation

There is a greater load on the motor insulation through a ground fault in an IT system. A possible result is the failure of the insulation with a risk for personnel through smoke development and fire.

- Use a monitoring device that signals an insulation fault.
- Correct the fault as quickly as possible so the motor insulation is not overloaded.

WARNING

Electric shock if there are no connected cable shields

Hazardous touch voltages can occur through capacitive cross-coupling due to unconnected cable shields.

- Connect cable shields and unused conductors of power cables (e.g. brake conductors) at least on one side to the grounded housing potential.

WARNING

Electric shock if there is no ground connection

For missing or incorrectly implemented protective conductor connection for devices with protection class I, high voltages can be present at open, exposed parts, which when touched, can result in death or severe injury.

- Ground the device in compliance with the applicable regulations.

WARNING

Electric shock when disconnecting plug connections during operation

When opening plug connections in operation, arcs can result in severe injury or death.

- Only open connections when the equipment is in a no-voltage state, unless it has been explicitly stated that they can be opened in operation.

⚠ WARNING

Danger to life when safety functions are inactive

Safety functions that are inactive or that have not been adjusted accordingly can cause operational faults on machines that could lead to serious injury or death.

- Observe the information in the appropriate product documentation before commissioning.
- Carry out a safety inspection for functions relevant to safety on the entire system, including all safety-related components.
- Ensure that the safety functions used in your drives and automation tasks are adjusted and activated through appropriate parameterizing.
- Perform a function test.
- Only put your plant into live operation once you have guaranteed that the functions relevant to safety are operating perfectly.

Note

Important safety notices regarding safety functions

If you use safety functions, you must observe the safety notices in the safety manuals.

3.2 Equipment damage due to electric fields or electrostatic discharge

Electrostatic sensitive devices (ESD) are individual components, integrated circuits, modules or devices that may be damaged by either electric fields or electrostatic discharge.

NOTICE

Equipment damage due to electric fields or electrostatic discharge

Electric fields or electrostatic discharge can cause malfunctions through damaged individual components, integrated circuits, modules or devices.

- Only pack, store, transport and send electronic components, modules or devices in their original packaging or in other suitable materials, e.g conductive foam rubber of aluminum foil.
- Only touch components, modules and devices when you are grounded by one of the following methods:
  - Wearing an ESD wrist strap
  - Wearing ESD shoes or ESD grounding straps in ESD areas with conductive flooring
- Only place electronic components, modules or devices on conductive surfaces (table with ESD surface, conductive ESD foam, ESD packaging, ESD transport container).

3.3 Warranty and liability for application examples

Application examples are not binding and do not claim to be complete regarding configuration, equipment or any eventuality which may arise. Application examples do not represent specific customer solutions, but are only intended to provide support for typical tasks.

As the user you yourself are responsible for ensuring that the products described are operated correctly. Application examples do not relieve you of your responsibility for safe handling when using, installing, operating and maintaining the equipment.

3.4 Security information

Siemens provides products and solutions with industrial security functions that support the secure operation of plants, systems, machines, and networks.

In order to protect plants, systems, machines and networks against cyber threats, it is necessary to implement – and continuously maintain – a holistic, state-of-the-art industrial security concept. Siemens’ products and solutions form one element of such a concept.

Customers are responsible for preventing unauthorized access to their plants, systems, machines and networks. These systems, machines and components should only be connected to the enterprise network or the Internet if and only to the extent necessary and with appropriate security measures (firewalls and/or network segmentation) in place.

You can find more information on protective measures in the area of industrial security by visiting:
https://www.siemens.com/industrialsecurity.

Siemens’ products and solutions undergo continuous development to make them more secure. Siemens strongly recommends performing product updates as soon as they are available and using only the latest product versions. Use of product versions that are no longer supported, and failure to apply latest updates may increase customer’s exposure to cyber threats.

To stay informed about product updates, subscribe to the Siemens Industrial Security RSS Feed under
https://www.siemens.com/industrialsecurity.

3.5 Industrial security

Further information is provided on the Internet:

AUTOHOTSPOT

> ⚠ **WARNING**
>
> **Unsafe operating states resulting from software manipulation**
>
> Software manipulations, e.g. viruses, Trojans, or worms, can cause unsafe operating states in your system that may lead to death, serious injury, and property damage.
>
> - Keep the software up to date.
> - Incorporate the automation and drive components into a holistic, state-of-the-art industrial security concept for the installation or machine.
> - Make sure that you include all installed products into the holistic industrial security concept.
> - Protect files stored on exchangeable storage media from malicious software by with suitable protection measures, e.g. virus scanners.
> - On completion of commissioning, check all security-related settings.

3.6 Residual risks of power drive systems

When assessing the machine- or system-related risk in accordance with the respective local regulations (e.g., EC Machinery Directive), the machine manufacturer or system installer must take into account the following residual risks emanating from the control and drive components of a drive system:

1. Unintentional movements of driven machine or system components during commissioning, operation, maintenance, and repairs caused by, for example,
   - Hardware and/or software errors in the sensors, control system, actuators, and cables and connections
   - Response times of the control system and of the drive
   - Operation and/or environmental conditions outside the specification
   - Condensation/conductive contamination
   - Parameterization, programming, cabling, and installation errors
   - Use of wireless devices/mobile phones in the immediate vicinity of electronic components
   - External influences/damage
   - X-ray, ionizing radiation and cosmic radiation
2. Unusually high temperatures, including open flames, as well as emissions of light, noise, particles, gases, etc., can occur inside and outside the components under fault conditions caused by, for example:
   - Component failure
   - Software errors
   - Operation and/or environmental conditions outside the specification
   - External influences/damage

3. Hazardous shock voltages caused by, for example:
   - Component failure
   - Influence during electrostatic charging
   - Induction of voltages in moving motors
   - Operation and/or environmental conditions outside the specification
   - Condensation/conductive contamination
   - External influences/damage
4. Electrical, magnetic and electromagnetic fields generated in operation that can pose a risk to people with a pacemaker, implants or metal replacement joints, etc., if they are too close
5. Release of environmental pollutants or emissions as a result of improper operation of the system and/or failure to dispose of components safely and correctly
6. Influence of network-connected communication systems, e.g. ripple-control transmitters or data communication via the network

For more information about the residual risks of the drive system components, see the relevant sections in the technical user documentation.

Motor-related converter parameters and the associated requirements placed on the motor quality

4

4.1 Motor-related converter setting parameters

Table 4-1 Motor data that are used as converter setting parameters

Parame-ters	Meaning	Unit	Sync / async	See page
p0304	Rated voltage	V_{rms}	a	→ (Page 38)
p0305	Rated current	A_{rms}	s and a	→ (Page 42)
p0307	Rated power	kW	a	→ (Page 44)
p0308	Rated power factor		a	→ (Page 39)
p0310	Rated frequency	Hz	a	→ (Page 47)
p0311	Rated speed	rpm	s and a	→ (Page 45)
p0312	Rated torque	Nm	a	→ (Page 43)
p0314	Number of pole pairs		s and a	→ (Page 47)
p0316	Torque constant	Nm/A	s	→ (Page 31)
p0317	Voltage constant	V_{rms}/1000 rpm	s	→ (Page 31)
p0318	Stall current	A_{rms}	s	→ (Page 66)
p0319	Static torque	Nm	s	→ (Page 68)
p0320	Rated magnetizing current/short-circuit current	A_{rms}	s and a	→ (Page 53)
p0322	Maximum speed	rpm	s and a	→ (Page 69)
p0323	Maximum current	A_{rms}	s	
p0326	Stall torque correction factor	%	s and a	→ (Page 76)
p0327	Optimum load angle	Degrees	s	→ (Page 73)
p0328	Reluctance torque constant	mH	s	→ (Page 73)
p0329	Motor pole position identification current	A_{rms}	s	
p0335	Motor cooling method		a	→ (Page 87)
p0338	Maximum current	A_{rms}	s and a	
p0341	Moment of inertia	kgm^2	s and a	
p0348	Speed at the start of field weakening Vdc = 600 V	rpm	s and a	→ (Page 55)
p0350	Stator resistance, cold	Ohm	s and a	→ (Page 68)
p0353	Series inductance	mH	s and a	→ (Page 48)
p0354	Rotor resistance, cold	Ohm	a	→ (Page 37)
p0356	Stator leakage inductance	mH	s and a	→ (Page 48)
p0358	Rotor leakage inductance/damping inductance, d axis	mH	a	→ (Page 48)
p0360	Magnetizing inductance	mH	a	→ (Page 33)
p0391	Current controller adaptation, starting point Kp	A_{rms}	s and a	→ (Page 63)
p0392	Current controller adaptation, starting point Kp adapted	A_{rms}	s and a	→ (Page 63)

Parameters	Meaning	Unit	Sync / async	See page
p0393	Current controller adaptation, P gain adaptation	%	s and a	→ (Page 63)
p0604	Motor overtemperature alarm threshold	°C	s and a	→ (Page 87) / → (Page 121)
p0605	Motor overtemperature fault threshold	°C	s and a	→ (Page 88) / → (Page 122)
p0640	Current limit	A_{rms}	s and a	
p1402.2	Current controller adaptation enabled		s and a	→ (Page 63)
p1800	Pulse frequency	kHz	s and a	→ (Page 60)

4.2 Parameters that characterize the motor

Motor data, which are used to characterize the motor, but which are not used in the converter parameter assignment, are listed below. They must be included in the data sheet of the motor manufacturer.

Table 4-2 Parameters that characterize the motor

Name in the document	Function	Unit	Sync / async	See page
Lm_Iμ_small	Magnetizing inductance for a low magnetizing current	mH	a	→ (Page 33)
Iμ_sat_start	Magnetizing current, above which the magnetizing inductance goes into saturation	A_{rms}	a	→ (Page 33)
	Switching threshold for PTC (or bimetallic switch) to monitor the motor temperature	°C		

4.3 Requirements regarding motor quality

Quality requirements regarding the motor, which are not directly linked to converter setting parameters, are subsequently listed. The data listed here does not have to be included in the data sheet of the motor manufacturer; however, the motor must comply with the quality requirements specified here.

Table 4-3 Parameters that characterize the motor

Name in the document	Quality feature	Sync / async	See page
Degrees_Iμ_small	Gradient of the flux curve of the magnetizing current at the rated operating point	a	→ (Page 33)
	Sinusoidal waveform of the EMF	s and a	→ (Page 40)
	Pole and slot cogging under no-load operation	s and a	→ (Page 41)

Name in the document	Quality feature	Sync / async	See page
	Pole and slot cogging at the rated torque	a	→ (Page 41)
	Short-circuit strength also toward the transient short-circuit current if a Voltage Protection Module (VPM) or an internal armature short-circuit is intended as protective measure.	s	→ (Page 72)

4.4 Torque constant and voltage constant

Note

The data in this chapter only apply to synchronous motors

The data provided here for torque and voltage constants only apply to synchronous motors.

p0316 motor torque constant

$$p0316 = \frac{\text{Torque}}{\text{Torque-generating current}}$$

The torque constant for the motor is specified under rated operating conditions:

- The rated torque is generated. The torque at the motor shaft, which has already possibly been reduced as a result of friction, is evaluated.
- The motor, especially the rotor with its permanent magnets, has reached the steady-state operating temperature in S1 duty.
- As current, in the denominator of the torque constant, only the torque-generating current Iq is evaluated. If the rated operating point is located in the field weakening range, then the field-generating component of the current is not included in the torque constant (current in the base speed range as rms phase current in the motor feeder cable).
- As torque in the sense of parameter p0316, only the torque is evaluated that is generated under a commutation angle of 90 (see Chapter "Optimum load angle and reluctance torque constant (Page 73)").

Requirements placed on the motor

The torque constant must be adequately constant over the complete, permitted range of the torque-generating current.

- When compared to the initial value for no-load operation (kt0), the reduction at rated current must not exceed 10%. See the figure below.
- When compared to the initial value for no-load operation, the reduction at maximum torque-generating current must not exceed 20%. See the figure below.

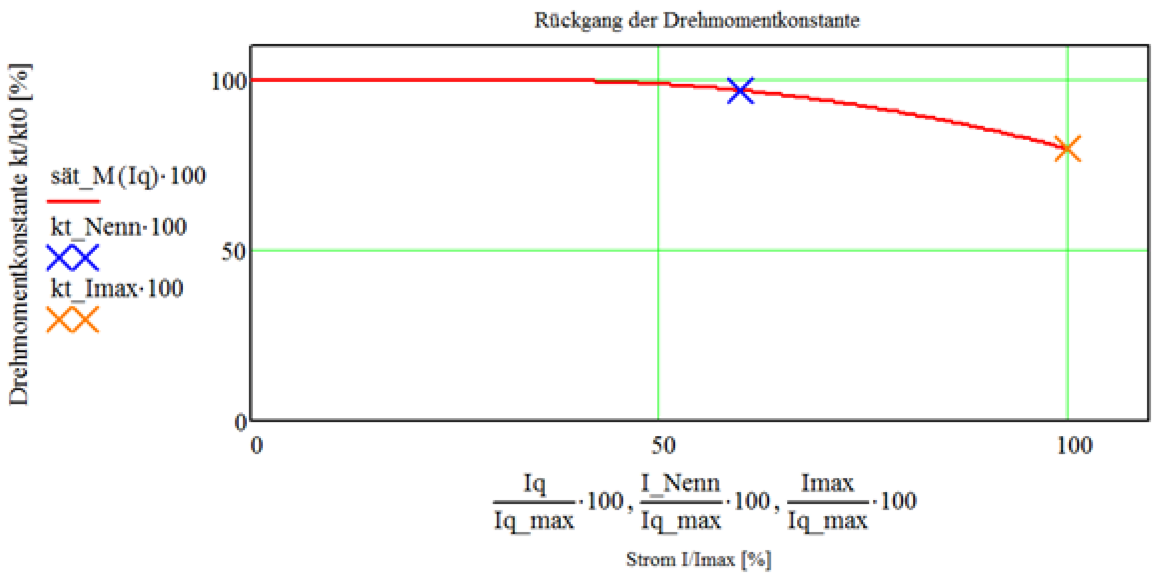


Figure 4-1 Permissible (saturation-related) decrease of the torque constant

The torque constant must be adequately constant with respect to permissible temperature and speed variations.

- When compared to the standstill value, the deviation of the torque constant over the permissible speed range must not exceed ±3%.
- When compared to the 20 °C value, the deviation of the torque constant over the permissible temperature range must not exceed +10%...-5%.

Note

Torque constant for the motor at operating temperature and under rated operating conditions

The torque constant defines the motor in a warm operating state under rated operating conditions. It can therefore be expected that in the case of permanent-magnet synchronous motors, it increases when the rotor is cold.

Note

Increased torque accuracy

If an increased torque accuracy is desired across the entire operating range, p0316 can alternatively be defined as shaft torque without friction and the friction characteristic (p3280-p3849) in the converter can be enabled at the same time. The entry of the friction compensation (r3841) should preferably take place over the supplementary torque p1569.

---

p0317 motor voltage constant

The terminal voltage (rms line-to-line voltage) that is obtained for a cold motor at a speed of 1000 rpm is evaluated as voltage constant. The voltage constant is determined under a no-load operating condition. This corresponds to a separately-driven generator with open terminals. If this operating state is not permissible as a result of the magnitude of the induced voltage at a speed of 1000 rpm, then a linear interpolation is made from the still permissible speed with open terminals up to 1000 rpm.

- Rms value of the terminal voltage (not terminal - neutral point)
- Speed 1000 rpm
- The motor, especially the rotor with its permanent magnets, is "cold" (20 °C).
- Load state no-load (preferably externally driven with open terminals)

As the energy level is maintained, the voltage constant and the "inner[1)]" torque of a permanent-magnet synchronous motor have a fixed relationship with one another. In an operating state for low currents (unsaturated motor) and for a cold rotor, the "inner" torque constant effective there is derived from the voltage constant using a fixed 60.46 factor.

kT for low currents and cold motor = 1/60.46 · p0317 · $[(Nm/A_{rms}) / (V_{rms}/rpm^{-1})]$

If the torque constant specified by the motor manufacturer corresponds to the value shown above, then the motor manufacturer did not incorporate temperature effects of the magnetization, effects of the magnetic saturation nor friction losses in the torque constant.

[1)] The "inner" torque is the air gap torque. The mechanical torque at the shaft is then reduced by the friction components.

Note

Induction motors

For induction motors, the torque constant is not transferred to the converter as direct parameter.

The converter internally calculates using a torque factor. This is so that the torque specified by the speed controller can be correctly implemented. The internally used torque factor comprises, among other things, the parameters entered for the rated speed and rated power.

In order to obtain a correctly scaled speed controller, the data for the induction motor rated power must match the power and/or torque derived from the equivalent circuit diagram with the appropriate accuracy.

4.5 Magnetizing inductance

p0360 motor magnetizing inductance/magnetizing inductance d-axis saturated

The magnetizing inductance (p0360) is transferred as parameter for the rated magnetizing current under no load (p0320). To understand the operating behavior, it is necessary to describe the interdependency between the magnetizing inductance and the magnetizing current. The two parameters p0320 and p0360 serve as coordinates for the basis point to define the magnetizing inductance characteristic. Within the context of transferring the motor data, the characteristic of the magnetizing inductance in relation to the magnetizing current must be defined using an additional interpolation point.
The magnetizing current is reduced when the field weakening starts. Therefore, the magnetic saturation of the magnetizing inductance decreases. With decreasing magnetizing current, the magnetizing inductance increases up to a full-scale value that describes the unsaturated motor. As of that value, the magnetizing inductance remains at its constant maximum value even if the magnetizing current is reduced even further. The course of the magnetizing inductance can be conclusively characterized using this current-independent maximum value as trend

interpolation point. Upon request, this interpolation point is to be specified in the motor data sheet to describe the saturation behavior.

Coordinates of the interpolation point for description of the saturation behavior:

- Maximum value of the magnetizing inductance (= value in the constant range)
- Magnetizing current at the transition from saturation into the constant range

Designating the coordinates of the subsequent diagram:

Basis point:

- Lm_Iμ_rated (= converter parameter p0360)
  Magnetizing inductance at the specified rated magnetizing current
  (= max. magnetizing current in operation)
- Iμ (= converter parameter p0320)
  Field-generating current, for which motor operation was dimensioned. It is valid for the speed range below field weakening.

Note

Magnetizing current

The magnetizing current is occasionally called the no-load current as this is obtained as the terminal current of a motor in a no-load condition in a field-oriented operating mode.

Additional interpolation point:

- Lm_Iμ_small (= not a converter parameter)
  Magnetizing inductance for low currents
- Iμ_sat_start (= not a converter parameter)
  Magnetizing current where saturation starts (= decrease in the magnetizing field inductance)

Note

Field-generating current

The terms "field-generating current", "magnetizing current" and "no-load current" are frequently used synonymously in literature when describing the operating behavior of field-orientated control.

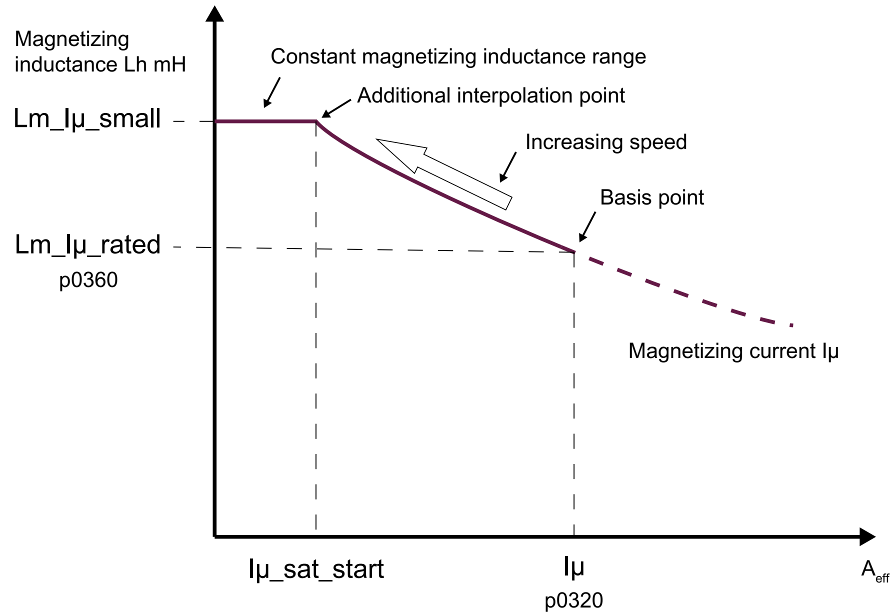


Figure 4-2 Dependency of the magnetizing inductance on the magnetizing current (operating state: no-load operation)

The magnetizing inductance is described using four pieces of information, two of which are converter parameters:

Table 4-4 Magnetizing inductance data that must be included in the manufacturer's data sheet

Parameter name	Meaning	Unit	Secondary condition/function
p0360	Magnetizing inductance	mH	At the specified magnetizing current p0320
p0320	Magnetizing current	A_{rms}	Effective magnetizing current below the speed at the start of field weakening
Lm_Iμ_small	Magnetizing inductance for a low magnetizing current	mH	To evaluate the saturation behavior Load state: No-load operation (additional interpolation point)
Iμ_sat_start	Magnetizing current, above which the magnetizing inductance goes into saturation	A_{rms}	(Additional interpolation point)

These two interpolation points were indirectly specified in earlier Simodrive controls as MD1143 desaturation speed or upper speed Lh characteristic and MD1144 degree of desaturation or gain factor Lh characteristic.

Requirements placed on the motor:

- Gradient of the flux magnetizing current curve (this is relevant for the closed-loop flux control):
  Degree_Iμ_rated
  The currently effective magnetizing current is automatically corrected by the converter flux controller, so that a defined target flux value is obtained. The target value is obtained from the product of the specified magnetizing field inductance, Lm_μ_rated, and the specified rated magnetizing current, Iμ:
  Target flux value (input for the flux controller):
  Ψ_Iμ_rated = Lh_Iμ_rated · Iμ
  The actual flux value is continuously measured in the converter. Above a specific threshold speed (p1752), the flux controller corrects the magnetizing current so that the target flux value is obtained. In order for the flux controller to reliably approach the target value, the gradient of the flux-current curve must not be too low.
  Requirement:
  The gradient of the flux magnetizing current curve at the rated magnetizing current, degree_Iμ_rated, must be at least 20% of the initial value for low currents, degree_Iμ_small. In other words: The saturation of the flux curve must not be so extreme that at the rated magnetizing current, the gradient has dropped to less than 20 % of the initial value.

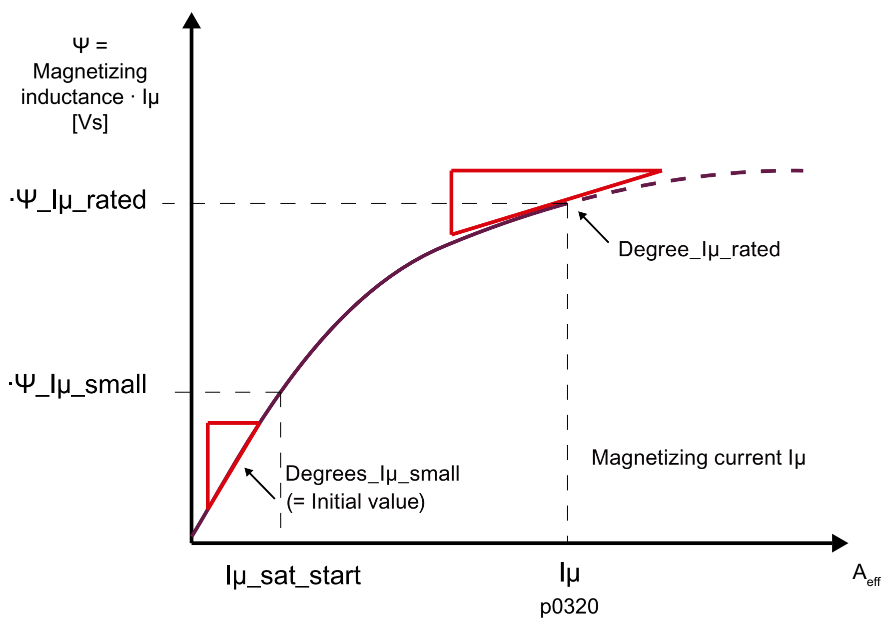


Figure 4-3 Dependency of the flux on the magnetizing current

- Constancy of the magnetizing inductance with respect to the operating state (relevant for quality aspects):
  The magnetizing inductance must be stable with respect to the operating parameters:
  - Slip
  - Torque-generating current
  - Temperature

  In the released operating range, the permissible changes must not exceed +10% and -5%. Especially a change in the magnetizing inductance, which would be caused by the torque-generating current, is undesirable, and it is not permissible that it exceeds the specified limits.
  A dependency of the magnetizing inductance on the magnetizing current is permissible; see also the figures above "Dependency of the magnetizing inductance on the magnetizing current" and "Dependency of the flux on the magnetizing current".

4.6 Motor rotor resistance when cold

Note

Data provided in this chapter

The data regarding the motor rated voltage provided here only apply to induction motors.

p0354 motor rotor resistance, cold

The rotor resistance to be specified must be converted to the number of windings in a "single-line neutral point equivalent circuit diagram, terminal-neutral point" so that it can be handled directly as a stator-related equivalent circuit diagram variable.

The rotor resistance is determined for the rated operating point. At the rated operating point, the rated temperature prevails, and the motor outputs the rated power at the rated speed. By specifying the rotor resistance at the rated operating point, possible current skin effects of the rotor can be included in the resistance value. For the data in the motor data sheet (p0354), the motor manufacturer must convert the rotor resistance to the 20 °C value. The resistance value must be specified in the motor data sheet to at least three valid numbers.

The rotor resistance is a crucial variable for the field-orientated mode of operation of induction motors. The machine data of the rotor resistance must adequately define the actual rotor resistance converted to the stator. As a consequence, the deviation between the value specified in the manufacturer's data sheet and the actually effective value can be a maximum of ±7%.

Note

Calculated motor data

If the motor data are not measured, but calculated, set the "rated magnetization at the rated torque" (slip frequency at the rated operating point, etc.) as load condition.

Requirements placed on the motor

The rotor resistance must be adequately stable with respect to the operating parameters:

- Slip
- Torque-generating current
- Magnetizing current

"Adequately stable" means that the permissible change in the rotor resistance in the released operating range must not exceed +10% and -10%.

The rotor resistance increases with temperature. The SINAMICS closed-loop control takes this into account if an analog temperature sensor is integrated in the motor winding. The cage temperature is indirectly monitored based on the winding temperature.

The rotor resistance saved in the model is adapted to the indirectly monitored temperature. The closed-loop control assumes a temperature coefficient that corresponds to that of copper. Temperature coefficients that significantly deviate from that for copper cannot be parameterized in the closed-loop control.

As a consequence, the temperature coefficient of the cage material must be close to the coefficients for copper or aluminum.

Table 4-5 Temperature coefficients

• For copper	$\Delta R_{copper} / \Delta T$	$= 0.00393 / K \cdot R_{copper}$
• For aluminum	$\Delta R_{aluminum} / \Delta T$	$= 0.00377 / K \cdot R_{aluminum}$

4.7 Rated motor voltage

p0304 rated motor voltage

The rated voltage specifies the rms value of the line-to-line voltage. This data is valid for the following operating state:

- Speed of the motor shaft: Rated speed
- Power at the motor shaft: Rated power
- Current in the feeder cable: Rated current
- Temperature of the stator and rotor in induction motors:
  - S1 steady-state temperature with the specified cooling method ⇒ stator and rotor resistance in the steady-state temperature state
- Temperature of the stator in synchronous motors:
  - S1 steady-state temperature with the specified cooling method ⇒ stator resistance in the steady-state temperature state
- Without series inductance
- PWM effects are not evaluated
- Only the electrical three-phase fundamental is taken into account

Note

Rated voltage without series inductance

The rated voltage is specified without series inductance because this information

a) refers to the motor

b) refers to an idealized sinus-shaped operation in which no series inductance is necessary

Note

Electrical frequency for induction motors

For induction motors, the electric frequency is obtained from the synchronous no-load operation frequency plus the slip frequency, which is necessary to achieve the rated power with the rated current at the rated speed.

4.8 Rated motor power factor

Note

Data provided in this chapter

The data regarding the rated motor power factor provided here only apply to induction motors.

p0308 rated motor power factor

In the appropriate literature, the power factor is known as "cos φ". It specifies the ratio between the active electrical power drawn (nominator) and the apparent electrical power drawn (denominator) at the rated operating point. It is specified as a ratio and not as a percentage. This data is valid for the following operating state:

- Speed of the motor shaft: Rated speed
- Power at the motor shaft: Rated power
- Current in the feeder cable: Rated current
- Temperature of the stator and rotor: S1 steady-state temperature with the specified cooling method ⇒ stator and rotor resistance in the steady-state temperature state
- Without series inductance
- Without PWM losses
- Only the electrical three-phase fundamental is taken into account

Note

Rated efficiency factor without series inductance

The rated efficiency factor is specified without series inductance because this information

a) refers to the motor

b) refers to an idealized sinus-shaped operation in which no series inductance is necessary

4.9 Sinusoidal waveform of the EMF (quality requirement)

SINAMICS converters operate with precise, sinusoidal commutation. In this operating mode, a precise, uniform torque independent of the angle is obtained if the motor has a sinusoidal EMF (electromotive force).

Deviations from the sinusoidal EMF result in undesirable torque ripple. The harmonic content of the EMF must not be too high in order to obtain the most uniform torque that does not pulsate. It is especially the 5th, 7th and also the 11th and 13th harmonics that can generate significant torque disturbances. The following requirements are placed on the motor:

For synchronous motors:

- Acceptance condition:
  Motors are externally driven, ideally with a constant speed, with open terminals. The EMF is measured with respect to a virtual neutral point.
- Requirement:
  Compared to the amplitude of the fundamental wave, the harmonics content of the EMF (generator voltage) must not be higher than 2%. Harmonic amplitudes are squared and then summed up:
  $$a_{Total} = \sqrt{a_2^2 + a_3^2 + a_4^2 + \dots}$$

For induction motors:

- Acceptance condition:
  The motor rotates under no load conditions connected to an ideally sinusoidal, symmetrical, three-phase voltage free of harmonics. The voltage is selected so that a current is obtained that approximately corresponds to the rated magnetizing current.
- Requirement: Compared to the amplitude of the fundamental wave, the harmonics content of the current that is obtained for a sinusoidal input voltage must not be higher than 3%. Harmonic amplitudes are squared and then summed up:
  $$a_{Total} = \sqrt{a_2^2 + a_3^2 + a_4^2 + \dots}$$

Note

Deviation from the requirements for a sinusoidal EMF

A deviation from the requirements for a sinusoidal EMF is permissible, if this was explicitly agreed with the customer.

In the motor data sheet, this must be documented with the comment "Increased harmonic content of the EMF according to agreement with the customer".

4.10 Pole and slot cogging under no-load operation (quality requirement)

For synchronous motors

The pole and slot cogging torques in no-load operation (externally driven with open terminals) must not exceed 4% (peak-peak) of the rated torque. The time values as deviation from the average torque are decisive, not the spectral components.

For induction motors

- Acceptance condition:
  The motor must be in field-oriented control with encoder (p1300 = 21). The speed control gain must be parameterized to be "0" (p1460 = 0). The motor can then be externally rotated at the shaft without any opposing torque. The rotating field (magnetization) is then synchronously tracked to follow the shaft angle, without any slip and in realtime. The motor must now be externally rotated with a consistently slow speed.
- Requirement:
  In this state, the alternating components of the torque required for uniform rotation, 4% (peak - peak) must not exceed the rated torque. The time values as deviation from the average torque are decisive, not the spectral components.

Note

Deviation from the requirements relating to pole and slot cogging in no-load operation

A deviation from the requirements relating to pole and slot cogging in no-load operation is permissible if this was explicitly agreed with the customer.

In the motor data sheet, this must be documented with the comment "Increased no-load pole and slot cogging in no-load operation according to agreement with the customer".

4.11 Pole and slot cogging at the rated torque (quality requirement)

For synchronous motors

Can be considered to be fulfilled if the motor fulfills the criteria "sinusoidal EMF" and "slot cogging in no-load operation".

For induction motors

- Acceptance condition:
  The motor shaft must be clamped using a torque measuring shaft. The speed control gain must be parameterized to be "0" (p1460 = 0). Now a torque setpoint with the magnitude of the rated torque is entered with torque specification. The stator field then rotates over the rotor with the corresponding slip frequency so that irregularities of the rotating field become apparent at the torque measuring shaft.
- Requirement:
  The torque disturbances that then occur (alternating torques) must not exceed ±3% of the rated torque.

Note

Permissible deviation from the requirements relating to pole and slot cogging at rated torque

A deviation from the requirements relating to pole and slot cogging at rated torque is permissible, if this was explicitly agreed with the customer.

In the motor data sheet, this must be documented with the comment "Increased pole and slot cogging under load according to agreement with the customer".

4.12 Rated current

p0305 rated motor current

Rms value of the phase current (current in the feeder cable) that is obtained at the rated operating point.

- At the rated operating point, the rated torque is generated at the rated speed. If the motor has an internal bearing, the torque at the motor shaft that has possibly already been reduced as a result of friction (of bearing or seal) is meant.
- The motor runs at the rated operating point (rated torque at rated speed) in uninterrupted duty S1. The motor, especially the rotor, has reached the steady-state operating temperature for S1 duty. The PWM frequency is the frequency that the manufacturer has recommended or specified (see point, PWM frequency).

For synchronous motors:

- If the rated operating point is reached in field weakening, the sum of the two current components, the torque-generating current iq and the field-generating current id, is meant here. The field weakening current id is the current that compensates the terminal voltage to an rms value of 380V_{rms} (90 % of $\frac{600\ V}{\sqrt{2}}$) ($i_{Rated} = \sqrt{iq^2 + id^2}$).
  If the manufacturer specifies a series inductance, then its inductance for field weakening should be taken into account. Therefore, that field weakening current is evaluated, which, when a series inductance is being used, is required to compensate the terminal voltage (at rated torque and rated speed) to 380 V_{rms}.

For induction motors:

- The rated current specifies the total current flowing in the feeder cable, which comprises the magnetizing current id and the torque-generating current iq ($i_{Rated} = \sqrt{iq^2 + id^2}$).

The torque-generating current is calculated from the rated current p0305 and the rated magnetizing current p0320 that is required to generate the rated torque ($iq = \sqrt{i_{Rated}^2 - id^2}$).

Requirements placed on the motor

For a rotating field frequency of zero, a current of at least 80 % of the rated current must be permanently impressed in the motor, without thermally overstressing the motor.

Reason**:**
In encoderless operation (in the pre-assignment of p1612), a terminal current is impressed which corresponds to 80% of the rated current. In standby, this current flows for an unlimited time at standstill.

Use/effect of the parameter:

The rated current is used as a reference parameter to preassign a limit value.

NOTICE
Motor damage caused by overheated winding
The winding will overheat if a thermally inadmissible high current flows through the motor for a long period. In a SINAMICS converter, the average, thermally effective current is not automatically limited to the rated current. • Install a temperature sensor to reliably monitor the temperature.

Note

Temperature models

Temperature models can always be activated. However, they only provide useful thermal I2t monitoring if the correct thermal model data were appropriately entered.

However, this is generally not the case for third-party motors.

4.13 Rated torque

p0312 rated motor torque

Shaft torque which is reached at the rated operating point with rated current and at rated speed in S1 uninterrupted duty. If the motor has an internal bearing, any reduction of the torque at the motor shaft through friction (of bearing or seal) is taken into account.

For synchronous motors:

- If the rated operating point is reached with field weakening, the motor must be able to integrate the total current, which is obtained from torque-generating current iq and the field-generating current id, in S1 duty.
- If the manufacturer specifies a series inductance and the rated operating point is reached with field weakening, then its inductance must be taken into account for the field weakening current of the synchronous motor; cf. paragraph "Rated current".

Note

Parameter p0312

Parameter p0312 is only required as converter setting parameter for induction motors.

However, for synchronous and induction motors, the rated torque must be specified in the manufacturers data sheet as property that defines the motor.

4.14 Rated power

p0307 rated motor power

Shaft power that is reached at the rated operating point with rated current and at rated speed. A possible reduction of the shaft torque as a result of friction should be taken into account.

- The rated power is provided (rated torque at rated speed) in uninterrupted duty S1. The motor, especially the rotor, has reached the steady-state operating temperature for S1 duty.
- If nothing else has been agreed, the rated power should apply for a DC link voltage of 600 DC. This means that the rms terminal voltage at the rated operating point should not exceed 380 V_{rms} (90 % of $\frac{600\ V}{\sqrt{2}}$). The rated speed should be appropriately adapted so that this is complied with.
- If the motor manufacturer specifies a series inductance, then this must be taken into account in the rated power. This means that the terminal voltage specified above at the converter output applies to the motor including the series inductance. The series inductance generally reduces the rated power.

Note

Chassis drive units with an output voltage of 690 V_{rms}

The chassis drive units are also available in a version with a 690 V_{rms} output voltage.
If the motor involved is only to be used with these devices, it may make sense for the customer and motor manufacturer to both agree to use 90% of 690 V_{rms} = 620 V_{rms} as design voltage.

The design voltage must be explicitly specified in the motor data sheet.

For synchronous motors:

- If the rated operating point is reached with field weakening, then a field weakening current should be impressed which compensates the terminal voltage to an rms value of 380 V_{rms}. S1 duty must then be possible with the impressed field weakening current.

For induction motors:

- Occasionally, third-party motor manufacturers are of the opinion that for main spindle induction motor drives, a limited load duration of, for example, 10 min. is suitable for rated operation. This is not the case. The rated operating point (rated torque at rated speed) must be thermally possible in S1 duty without any interruption.
- The rated power specified in this parameter must correlate adequately well with the equivalent calculation based on the equivalent circuit diagram data. In this case, the rated current is theoretically impressed in the equivalent circuit diagram, and a stator frequency entered, which is obtained from the synchronous frequency plus the slip frequency. The slip frequency is obtained from the equivalent circuit diagram data, especially from the magnetizing current, the rated current and the rotor time constant. This procedure is described in detail in the available literature about field-orientated modes of operation.

4.15 Rated speed

The rated speed is the speed for which the motor was typically designed. It should preferably be reached without having to increase the converter output current using an additionally required field weakening current.

p0311 rated motor speed

Mechanical speed for which the rated operating point is specified. If the motor cannot rotate through a restricted angular range (e.g. a segment motor for a swivel drive), then the angular velocity at the rated operating point is converted into a speed, which would be obtained for uninterrupted rotation.

Below the rated speed, the thermally possible S1 continuous torque of the motor should not be less than the rated torque.

Note

Reduction of the S1 torque at standstill

A reduction of the S1 torque at standstill corresponding to the "stall current (Page 66)" is only permissible for synchronous motors.

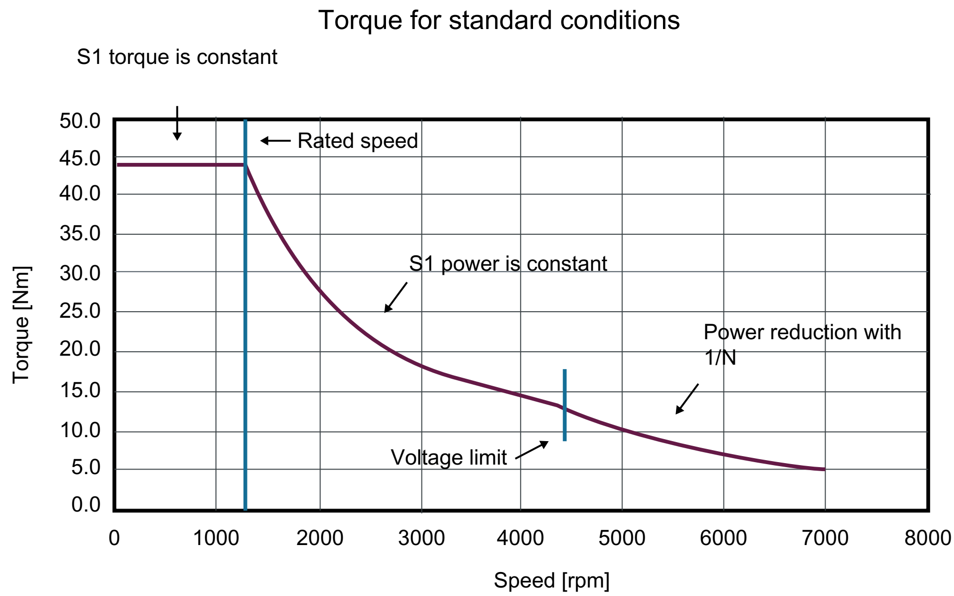


Figure 4-4 Example of a speed-torque diagram for S1 duty

Assuming that the maximum speed is greater than the rated speed, above the rated speed, the thermally possible S1 continuous power of the motor should not be less than its rated power.

It is permissible to reduce the S1 power – because the voltage limit has been reached – corresponding to the "stall torque correction factor (Page 76)". Because the level of constant power in the power and speed diagram is to have an acceptable width, the speed at which the voltage limit is reached must be at least 50% above the rated speed.

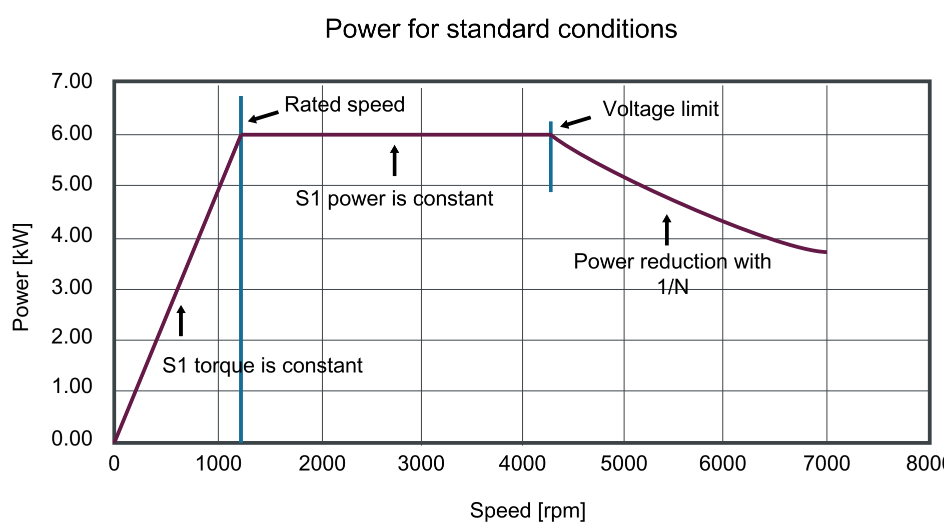


Figure 4-5 Example of a speed - power diagram for S1 duty

If nothing else has been agreed, the rated speed should apply for a DC link voltage of 600 VDC. This means that the rms terminal voltage at the rated operating point should not exceed 380 V_{rms} (90 % of $\frac{600\ V}{\sqrt{2}}$).

Note

Chassis drive units with an output voltage of 690 V_{rms}

The chassis drive units are also available in a version with a 690 V_{rms} output voltage.
If the motor involved is only to be used with these devices, it may make sense for the customer and motor manufacturer to both agree to use 90% of 690 V_{rms} = 620 V_{rms} as design voltage.

The design voltage must be explicitly specified in the motor data sheet.

For induction motors:

- In this case, the mechanical shaft speed is always meant, and not the frequency (or the associated speed) of the stator current.
- Requirement placed on the motor:
  It is not permissible that the rated speed (p0311) lies above the speed at the start of field weakening (p0348) specified in the data sheet. This means that at the rated operating point, the motor still has the full magnetization.

For synchronous motors:

- Generally, the rated speed should not be higher than the speed at the start of field weakening (p0348) specified in the data sheet.

4.16 Rated frequency

p0310 rated motor frequency

Frequency of the three-phase current that is impressed in the stator in order that the motor provides the rated torque at the rated speed.

For synchronous motors:

- The frequency is obtained from the mechanical rotating frequency of the shaft multiplied by the pole pair number (p0314).

For induction motors:

- When compared to the synchronous frequency, which is obtained from the rotating frequency of the shaft multiplied by the pole pair number, the rated frequency is increased by the slip frequency (at the rated power).

4.17 Number of pole pairs

The pole pair number does not have to be measured in reality. It is generally obtained from a theoretical analysis.

For synchronous motors:

- Number of EMF waves (360 degrees electrical), which is observed at the stator terminals with the converter disconnected, when the motor shaft is mechanically rotated through 360 degrees.
  If a rotation through 360 degrees is mechanically not possible, then rotation through a small angle is realized, where an integer number of EMF waves is obtained. The number of EMF waves contained is interpolated to a full 360 degree rotation of the motor shaft. This is especially the case for torque motor segments, which extend over less than 360 degrees.

For induction motors:

- Integer ratio between the frequency of the 3-phase current and the mechanical rotating frequency of the motor shaft in a theoretical no-load condition (with torque = 0 and slip frequency = 0).

4.18 Leakage inductance(s) and series inductance

- p0356 motor stator leakage inductance $L_{leakage\ stator}$
- p0358 motor rotor leakage inductance $L_{leakagerotor}$ (only for induction motors)
- p0353 motor series inductance L_{series}

For controlled operation of the motor at the converter, the total leakage inductance is of importance.
The total leakage inductance is the sum of the leakage inductances, which comprises those of the stator, rotor (only for induction motors) and where relevant, a series inductance.

$$L_{leakagetotal} = L_{leakagestator} + L_{leakagerotor} + L_{series}$$

The distribution between the individual components ($L_{Leakagestator} + L_{Leakagerotor} + L_{series}$) plays a minor role in this case.

Requirements placed on the parameter value:

A suitably adjusted current controller is the basis for problem-free operation of any motor at the converter. The precondition is that the current controller proportional gain p1715 matches the total leakage inductance. Because most installations take place without consulting a specialist for optimization of the current controller, a well-adjusted presetting is of crucial importance. The converter therefore adjusts the current controller proportional gain p1715 to the configured total leakage inductance during commissioning when the "Automatically calculate the motor/control parameters" function is triggered via p0340.

Note

Adapting the current controller proportional gain

The adaptation of the current controller proportional gain p1715 is triggered via p0340 for the following settings:

- 1 (Complete calculation)
- 3 (Calculation of closed-loop control parameters)
- 4 (Calculation of controller parameters)

See also: SINAMICS S120/S150 List Manual.

The party selling the motor is obligated to check and ensure that the frequency response of the current controller after automatic calculation of the current controller proportional gain, at standstill without load has an adequate bandwidth while not exceeding the 0dB line at the same time.
The appearance of a current controller frequency response that is to adapt during the process is described in the chapter "Current controller adaptation (Page 63)".

NOTICE
Thermal destruction of the magnets
In synchronous motors, a current controller with excessive gain (p1715) can result in thermal destruction of the magnets.
Make sure that the current controller does not have an excessive gain.

If the frequency response of the current controller has not been satisfactory as described above, the parameter value of the total leakage inductance must be corrected so that the desired appearance of the current controller frequency response results after triggering the automatic calculation (p0340). To do this, the two motor parameters p0356 and p0358 must be changed at the same ratio while the parameter for the series inductance remains unchanged. The motor parameters p0356 and p0358 determined this way must be saved in the data sheet for the customer.

Note

Adapting the stator leakage inductance

For synchronous motors, only the motor-stator leakage inductance p0356 is adapted when necessary.

Note

Reduction of the total leakage inductance under load

For many motors, the total leakage inductance is reduced under load.

This is why, in addition to adaptation of the basic value p1715 described here, the parameter assignment of the load-dependent adaptation is crucial to ensure current controller stability across the entire load range. See Chapter "Current controller adaptation (Page 63)".

The party selling the motor determines the three adaptation parameters.

Effect of the total leakage inductance

The total leakage inductance smooths the current so that a sawtooth current is obtained from the square wave voltage of the pulse width modulation (PWM). The ripple is defined by the magnitude of the total leakage inductance. The lower the total leakage inductance and the lower the selected PWM frequency, the higher the current ripple.

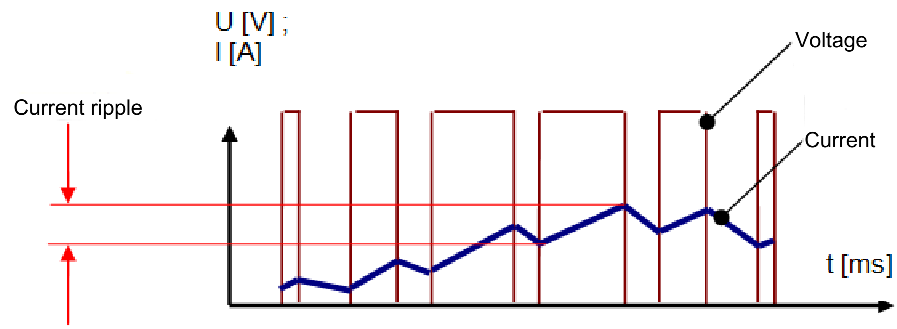


Figure 4-6 Current ripple as a consequence of PWM

Requirements placed on the motor

The physical difference of the stator leakage inductance between the field-generating and the torque-generating direction may be a maximum of 40%.

In order to guarantee uncritical operation with SINAMICS converters, the total leakage inductance must fulfill the following conditions:

- a: "mH value" stable with respect to the electrical load
- b: Adequate current smoothing in relation to the rated current ⇒ minimum value
- c: Adequate current smoothing in relation to the magnetizing current in the field weakening range (only for induction motors) ⇒ minimum value
- d: Adequate torque rate of change ⇒ maximum value

The criteria listed here regarding current smoothing should be applied to the motor including the series inductance. The required current smoothing is a minimum requirement from a closed-loop control related perspective. Whether even higher current smoothing is required from a thermal perspective depends on the motor and is exclusively the responsibility of the party selling the motor.

For a: Stability of the stator and rotor leakage inductance

The leakage inductances must be adequately stable with respect to the operating parameters:

- Torque-generating current
- Field weakening current (only for synchronous motors)
- Magnetizing current (only for induction motors)
- Speed
- Temperature

"Adequately stable" means that in the range released for operation, the leakage inductances are allowed to increase by a maximum of 10% and decrease by a maximum of 50%.
If the leakage inductance is subject to a noticeable deviation, the party that sells the motor must perform the current controller adaptation as described in chapter "Current controller adaptation (Page 63)" and save the corresponding converter parameters in the motor data sheet.

For b: Adequate current smoothing in relation to the rated current

To ensure problem-free operation of the motor on the converter from a closed-loop control perspective, the current ripple of the PWM cycle should have a reasonable relationship with the

operating currents.
The rated current is an obvious choice for reference variable. The current ripple should be a maximum of 20% of the peak value of the rated current (p0305).

As the total leakage inductance smooths the current, it is necessary to specify the minimum total leakage inductance:

For synchronous and induction motors

$$L_{StreuSumme} > \max\left(\frac{p0115[0]}{500};\frac{1}{p1800}\right)\cdot\frac{UZK}{p0305}\cdot 0{,}23 \quad [mH]$$		
With	UDC link:	DC link voltage (= 600 V if nothing else is agreed on)
	p0115[0]:	Current controller clock rate in μs
	p0305:	Rated motor current in A_{rms}
	p1800:	PWM frequency in kHz

Example:

A spindle with a rated current of 71 A_{rms} is to have

- a total leakage inductance of 0.35 mH
- and is to be operated at a PWM frequency of 8 kHz
- and a current controller cycle of 62.5 μs.

Is the total leakage inductance adequate or is a series inductance required?

$$\max\left(\frac{62{,}5}{500};\frac{1}{8}\right)\cdot\frac{600}{71}\cdot 0{,}23 = 0{,}243\,mH$$

To prevent control-related problems, the total leakage inductance must be greater than 0.243 mH.
That is the case here => no series reactor necessary.

To eliminate the need for a CU, the same spindle is now to be operated with the same pulse frequency (of 8 kHz) at the slower current controller cycle of p0115[0] = 125 μs.

Can this operation, too, be recommended without a series reactor?

$$\max\left(\frac{125}{500};\frac{1}{8}\right)\cdot\frac{600}{71}\cdot 0{,}23 = 0{,}486\,mH$$

To prevent control-related problems, the total leakage inductance must now be greater than 0.486 mH.
That is not the case here.
Control-related problems are therefore likely to occur. To achieve the recommended minimum value of the total leakage inductance, a series reactor of 0.136 mH is recommended:
0.35 mH + 0.136 mH = 0.486 mH.

for c: Adequate current smoothing in relation to the magnetizing current in the field weakening range for induction motors (not relevant for synchronous motors)

For induction motors, the magnetizing current provides the magnetization and not permanent magnets. For this reason, it is not permissible that the current ripple exceeds a certain ratio to the magnetizing current. The lowest magnetizing current that can occur in operation is used as reference value. This is obtained at the maximum speed, as the highest degree of field weakening is reached there. As the total leakage inductance also smooths the magnetizing current, it is necessary to specify the minimum total leakage inductance, which takes into account the magnetizing current.

The following condition is obtained:

For induction motors

$$L_{\text{Leakage total}} > \frac{UZK}{f_{PWM} \cdot I_{\mu}} \cdot \frac{n_{Max.}}{n_{\text{Start of field weakening}}} \cdot \frac{1}{28}\ [\text{mH}]$$

With $U_{\text{DC link}}$: DC link voltage

f_{PWM}: Pulse frequency in kHz (see p1800)

I_{μ}: Field-generating current (rms value) without field weakening p0320

$n_{\text{start of field weakening}}$: Speed at the start of field weakening p0348

n_{max}: Maximum speed

Note

Physical scope of this regulation

The physical scope of this regulation is that the current ripple must not exceed the instantaneous value of the lowest possible motor current.

The lowest possible motor current is the magnetizing current at maximum speed under no-load conditions.

---

for d: Adequate torque rate of change

In order to achieve an adequate bandwidth of the speed controller regarding its large signal behavior, the voltage that is required to change the (torque-generating) current should not be too high. This means that it is necessary to specify the maximum leakage inductance:

For synchronous motors

$$L_{\text{Leakage total}} < \frac{425\ V_{eff}}{\sqrt{3}} \cdot \frac{1}{(2\pi \cdot 60\ \text{Hz}) \cdot p0305} \cdot 1000 \quad [\text{mH}]$$

For induction motors

$$L_{\text{Leakage total}} < \frac{425\ V_{eff}}{\sqrt{3}} \cdot \frac{1}{(2\pi \cdot 60\ \text{Hz}) \cdot \sqrt{p0305^2 - p320^2}} \cdot 1000 \quad [\text{mH}]$$

If the requirements are fulfilled, at standstill, the motor is able to generate a sinusoidal alternating torque up to a frequency of at least 60 Hz. Its peak value corresponds to the rated torque.

The criterion above has been derived from wide-ranging experience involving speed- and position-controlled drive applications.

Note

Compliance with requirements

As a result of the high torque, spindle motors almost always comply with this requirement.

On the other hand, for torque motors – especially those that have been designed for slow speeds – improvement may be required as a result of the maximum leakage inductance mentioned above.

In this case, for example, the winding design must be selected for a higher rated speed, even if this rated speed is not required for the particular load profile.

Series inductance

If the motor's own leakage inductance is not sufficient to fulfill the above conditions, b) and c), regarding current smoothing, then the missing inductance must be added to the system using a series inductance.
The motor manufacturer must then specify the series inductance. It becomes part of the converter - series inductance - motor system.

A new data sheet with converter setting parameters must be generated if the series inductance changes.

As far as control behavior is concerned, in cases where the series inductance would contribute less than 20% to the total leakage inductance, the series inductance can be omitted.
If the series reactor is prescribed by the motor manufacturer for other reasons, such as heating or noise, this manual does not override the provision of the motor manufacturer.

Increasing the pulse frequency reduces the required minimum total leakage inductance according to the formulas above. Increasing the frequency may mean that it is not necessary to use a series reactor.

For thermal reasons, it is possible that the motor manufacturer dimensioned a series inductance that is higher than would be necessary according to the regulation above. This is permissible assuming that the additional voltage demand, associated with the series inductance, does not have an impermissible negative impact on the power and the torque rate of change.

4.19 Motor rated magnetizing current/short-circuit current

The meaning of parameter p0320, "Motor rated magnetizing current/short-circuit current" differs significantly between synchronous and induction motors.

4.19.1 Short-circuit motor current, p0320 for synchronous motors

For synchronous motors, this parameter involves the **short-circuit current** for an infinitely high speed and negligibly low ohmic stator resistance. For synchronous motors (in addition to the speed of the start of field weakening), it is the essential physical feature that defines the current required for field weakening (see Chapter "Speed at the start of field weakening, p0348 for synchronous motors (Page 55)").

Reason

- A synchronous motor is considered with negligibly low ohmic stator resistance.
- The motor is separately driven.

The terminal voltage is precisely zero if there is a short circuit at the converter terminals. The current that flows therefore compensates the EMF to be precisely zero, and is called the short-circuit current.
There are no losses, as there is no ohmic resistance. As a consequence, a torque is not required to rotate the motor shaft.
Because current flows without generation of a torque, the defined short-circuit current is exclusively in the d direction.

Field weakening in synchronous motor operation therefore involves the reduction of the voltage demand by compensating the EMF using the field-weakening current. As the short-circuit current completely and precisely compensates the EMF, it can be considered as the maximum value of a sensible field-weakening current.

The short-circuit current depends essentially on the total leakage inductance (in addition to the voltage constant and the motor pole pair number). The lower the total leakage inductance, the higher the short-circuit current. To reduce the necessary field-weakening current, some third-party motor manufacturers specify a series inductance. This is permissible when certain constraints are maintained. However, any series inductance then becomes a fixed component of the system:

Third-party synchronous motor ⇔ series inductance ⇔ converter

The short-circuit current specified in the data sheet should define the motor including the series inductance.

The short-circuit current p0320 is the current which, taking into account the series inductance, completely and precisely compensates the EMF.

If a series inductance is prescribed, then it must be noted in the datasheet that the specified value includes the series inductance.

4.19.2 Rated motor magnetizing current, p0320 for induction motors

For induction motors, this parameter is the magnetizing current below the speed at the start of field weakening. Above the field weakening speed, the converter reduces the magnetization with 1/speed. The rated power specified in the data sheet is applicable for the magnetizing current specified here.

Requirements placed on the motor:

- The motor is operated up to the speed at the start of field weakening with a constant magnetizing current.
- It is not permissible for the motor to be close to its thermal limit in no-load operation. Therefore, the magnetizing current must be in a reasonable ratio to the rated current.
- The motor must be designed so that the magnetizing current is a maximum of 70% of the rated current.

4.20 Speed at the start of field weakening

p0348 speed at the start of field weakening

The effect of parameter p0348 "Speed at the start of field weakening" differs significantly between synchronous and induction motors.

The practical start of field weakening depends on the magnitude of the DC link voltage. In order to avoid that one and the same motor is allocated different data sheets if it is used for different DC link voltages, to generate the motor data sheet a reference DC link voltage of 600 V DC is assumed.
In SINAMICS converters, the actual speed at the start of field weakening is automatically adapted to the current DC link voltage.

The speed at the start of field weakening should be related to a reference terminal voltage, which would be obtained for a DC link voltage of 600 V DC. The reference terminal voltage for p0348 provides a control margin of 10% so that a value of 380 V_{rms} (= 90% of $\frac{600\ V}{\sqrt{2}}$) is obtained.

It is permissible to refer the speed at the start of field weakening to a lower reference terminal voltage in order to obtain a higher control margin.

Requirements placed on an induction motor:

Induction motors should be designed so that the rated operating point is reached without field weakening. This means for a motor at operating temperature and at the rated speed and rated torque, the field-generating current specified in p0320 can be maintained without exceeding the terminal voltage of 380 V_{rms} specified above.

The effect of parameter p0348 "Speed at the start of field weakening" differs significantly between synchronous and induction motors.
For this reason, the following description differs for the two motor types.

4.20.1 Speed at the start of field weakening, p0348 for synchronous motors

Maximum voltage controller:

For synchronous motors, the EMF in the field-weakening range must be actively compensated. To do this, a current is impressed in the motor in the field-weakening direction. The converter continually monitors the output voltage. In order to avoid that the output voltage exceeds an internally defined threshold value, precisely that field-weakening current is controlled, so that the output voltage is maintained at the threshold value. In SINAMICS, this control circuit is called "Maximum voltage controller".

Description of field weakening of SINAMICS converters for synchronous motors:

The maximum voltage controller is automatically parameterized based on the entered equivalent circuit diagram data. In order to avoid that in the case of faults (for example as a result of incorrectly entered equivalent circuit diagram data), a completely inappropriate field-weakening current is controlled, the permissible field weakening current is limited (upper and lower limits).

- Upper limit:
  The short-circuit current is the current that precisely compensates the EMF, so that the voltage at the terminals disappears (goes to zero). It is known that the short-circuit current that can be physically measured increases with the speed, but it approaches the fixed end value which is saved in p0320. As a consequence, it can be considered as the maximum value for sensible field weakening.
  ⇒ p0320 forms the high limit for the field weakening current.
- Lower limit:
  The requested field-weakening current depends on the load. The higher the motor power, the higher the field-weakening current specified by the controller. If constant power is considered, then the field-weakening current follows, with a good approximation, the curve:

$$I_{Field}(N) = \begin{cases} I_{Short\text{-}circuit} \cdot \left(1 - \frac{N_{Threshold}}{|N|}\right) & \text{für } |N| > N_{Threshold} \\ 0 & \text{für } |N| < N_{Threshold} \end{cases}$$

  with N = speed
  Where $N_{threshold}$ is the threshold speed of the start of field weakening associated with the power considered. For different power ratings, different threshold speeds are obtained, and therefore different field-weakening current characteristics.
  ⇒ A theoretical field-weakening current curve, which is used for a low partial load, can be considered a suitable low limit of the field-weakening current.
  As a result of the upper and lower limits of the field weakening current, a permissible corridor is created, in which the actual, impressed field weakening current may move. In other words: If the physically necessary field weakening current is lower, the field weakening current configured with the parameters p0320 and p0348 is set.

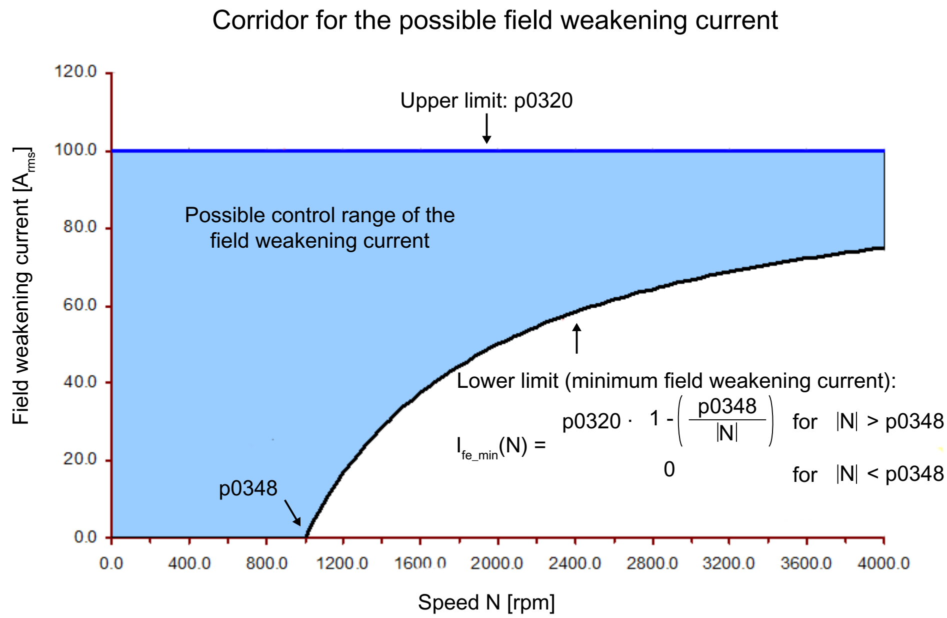


Figure 4-7 Example for a motor with p0320 = 100 A_{rms} and p0348 = 1000 rpm Permitted corridor of the field-weakening current, formed using parameters p0320 and p0348

It is permissible to refer the speed at the start of field weakening to a lower voltage.

Note

Characteristic for the lower limit

In the upper speed range, the curve of the minimum field-weakening current converges towards the short-circuit current entered in p0320. If the speed at the start of field weakening p0348 is set to a low speed, then in the lower speed range, the minimum, impressed field-weakening current increases quickly and approaches p0320. The permissible corridor of the field weakening current then constricts to a narrow strip below the short-circuit current.

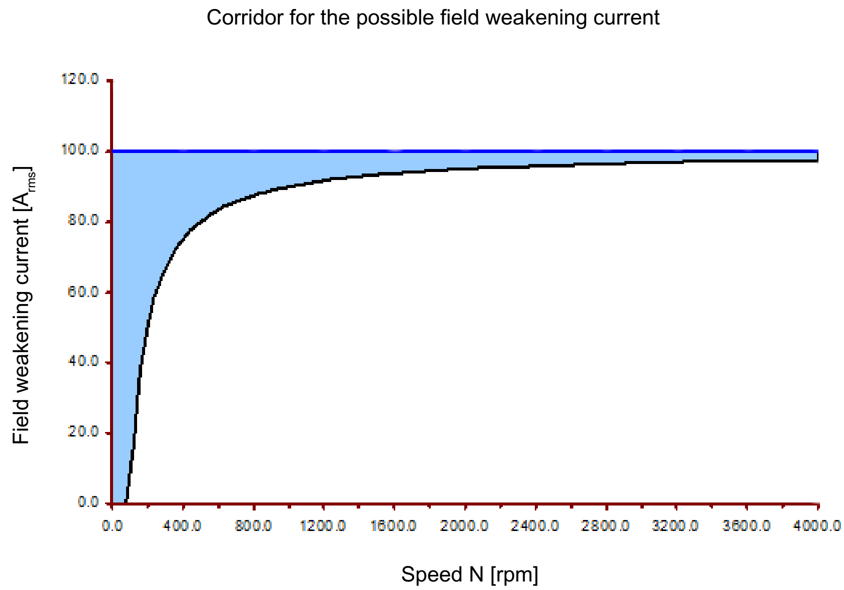


Figure 4-8 Field weakening current with significantly reduced speed at the start of field weakening, p0348

Note

Effect of the lower limit

The actually impressed field weakening current never lies below the minimum field weakening current, which is defined using p0320 and p0348.

Incorrect data sheet data for p0348:

If the speed at the start of field weakening would be set far too low as a result of incorrect data in the data sheet, then (especially in the lower speed range), the field-weakening current would be controlled to be significantly higher than would be physically necessary for compensation- (⇒ temperature rise).

Incorrect data sheet data for p0320:

If the short-circuit current would be set far too high as a result of incorrect data in the data sheet, then (especially in the upper speed range), the field-weakening current would be controlled to be significantly higher than would be physically necessary for compensation- (⇒ temperature rise).

Note

Diagnostics during commissioning

For diagnostic purposes, an (almost freely selectable) field weakening current can be impressed by drastically reducing the speed at the start of field weakening (p0348).

Impressing the field weakening current provides useful insights into the motor when these are required.

Note

Effect of the upper limit

If the short-circuit current, p0320, would be set too low as a result of incorrect data in the data sheet, then the physically necessary field-weakening current would be limited from a certain speed onwards.

When accelerating, the speed would freeze at this position.

Requirement when specifying p0348 in the motor data sheet:

The speed at which the terminal voltage has an rms value of 380 V_{rms} (= 90% of $\frac{600\ V}{\sqrt{2}}$) with 25% rated power should be specified as start speed for field weakening, p0348.

If the motor manufacturer prescribes a series inductance, then this must be taken into account in p0348. A note must then be made in the data sheet that the specified value applies with series inductance.

4.20.2 Speed at the start of field weakening, p0348 for induction motors

Threshold speed, above which the magnetization is reduced proportional to the speed. At the rated operating point, a minimum voltage margin of 10 % should remain.

The maximum speed at the start of field weakening p0348, specified in the motor data sheet, should be as high as the speed at which, at the rated current (p0305) and rated magnetizing current (p0320), the terminal voltage has an rms value of 380 V_{rms} (= 90% of $\frac{600\ V}{\sqrt{2}}$).

The speed at the start of field weakening is also applied directly from p0348 (speed at the start of field weakening for 600 V DC link) for induction motors and only adapted with the DC link voltage. An adaptation via p0353 (series inductance) does not take place automatically. However, a series inductance increases the voltage requirements.

If the motor manufacturer prescribes a series inductance, then this must be taken into account in p0348. A note must then be made in the data sheet that the specified value applies with series inductance. The value without series inductance should be entered as a note in the data sheet.

Note

Contrary to a widely established opinion, above the speed at the start of field weakening, with SINAMICS, the actual magnetic flux is reduced along a $1/_{\text{Speed}}$ characteristic, and not the magnetizing current. If the magnetizing inductance at the rated operating point manifests saturation, then the magnetizing current is reduced more significantly than the $1/_{\text{Speed}}$ dependency of the magnetic flux.

4.21 Pulse frequency

Selecting the pulse frequency represents a compromise between those aspects, which involve the motor, and those, which involve the converter. For the individual SINAMICS converter types (booksize, chassis,...), a standard pulse frequency is used as basis for dimensioning the converter. At the latest when generating the motor data sheet, the motor manufacturer and the customer must have selected the pulse frequency to be used. If an explicit agreement has not been reached then it has to be assumed that the corresponding standard pulse frequency will be used. If there is an agreement, which deviates from the standard pulse frequency, then the motor manufacturer must document this in the motor data sheet (specifying the pulse frequency parameter p1800). The pulse frequency influences the following:

- Current ripple (or current smoothing)
- Possibly the necessity to use a series inductance
- Possibly motor temperature rise
- Maximum electric three-phase frequency (refer to the List Manual)
- Continuous current and maximum current of the converter (refer to the manual)

Note

The standard pulse frequencies are listed in the SINAMICS manuals. For example, the standard pulse frequency for power units from the "Booksize" family, which extend up to an S1 current of 200 A_{rms}, is 4 kHz.

Pulse frequency switchover

SINAMICS allows the pulse frequency to be switched over in operation. For example, this can make sense if an induction motor in field weakening at high speeds requires a significantly lower magnetizing current than at the rated operating point, and at the same time, the power requirement based on the application in this speed range decreases (e.g. because a workpiece is only being finished and not roughed at the tool spindle). As a consequence, the current demand in this range significantly decreases. The reduction of the converter current, which is associated with the higher pulse frequency in the upper speed range (derating), could then be acceptable. If, from the perspective of the motor manufacturer, speed dependent switchover of the pulse frequency is required, then this must be coordinated with the customer and documented. If, in specific speed ranges, the motor may only be operated with certain pulse frequencies, then the motor manufacturer must document the speed ranges and the pulse frequencies specified for these ranges in the motor data sheet.

4.22 Conditions and criteria for using a series inductance

4.22.1 Any series inductance must be defined by the motor manufacturer

This chapter describes the conditions under which series inductance must be used.
The recommended characteristics of the series inductance (type, damping, etc.) are listed in the following chapter: "Series reactor Plus (Page 91)".

The party selling the motor is responsible for determining whether the motor requires a reactor to ensure correct operation in the intended drive configuration. If a series inductance is required, then the motor manufacturer must as a minimum list this inductance in the motor data sheet. It may be necessary to use a series inductance based on the following criteria:

- Current smoothing, you will find information on this in Chapter: "Leakage inductance(s) and series inductance (Page 48)"
- Reducing the PWM power loss in the motor
- Reducing the short-circuit current for synchronous motors

Current smoothing:

After the pulse frequency has been selected together with the customer, the motor manufacturer can then dimension the series inductance (in a clear and understandable way) that is required to maintain the necessary current smoothing according to Chapter "Leakage inductance(s) and series inductance (Page 48)". This therefore guarantees that the combination of motor and converter works from a closed-loop control perspective.

PWM power losses in the motor:

Evaluating whether the degree of current smoothing required from closed-loop control perspectives (chapter "Leakage inductance(s) and series inductance (Page 48)") is sufficient and also adequate for the thermal perspectives of the motor is the responsibility of the party selling the motor.

The motor manufacturer must dimension the motor leakage inductance and – where relevant – the series inductance so that the motor can be operated with the agreed pulse frequency with any U/f converter at the rated current and rated speed with the appropriate thermal stability.

Reducing the short-circuit current for synchronous motors:

It is a well-known fact that the short-circuit current of a permanent-magnet synchronous motor decreases with increasing total leakage inductance. Therefore, the field-weakening current required in the field-weakening range also decreases. In order to reduce the field-weakening current, it is permissible to specify a series inductance.

The field weakening current compensates the high motor EMF, so that a compatible voltage is available for the drive system at the motor terminals. For systems without any series inductance, the compensation is completely realized in the motor, so that an inadmissibly high-voltage cannot occur at any location. If a series inductance is also connected, then part of the compensation voltage is generated outside the motor in the series inductance. From the perspective of the converter, the voltage is compatible with the system. However, between the output of the series inductance and the motor terminals, the voltage, depending on the distribution of the inductances, can be significantly higher than at the converter output.

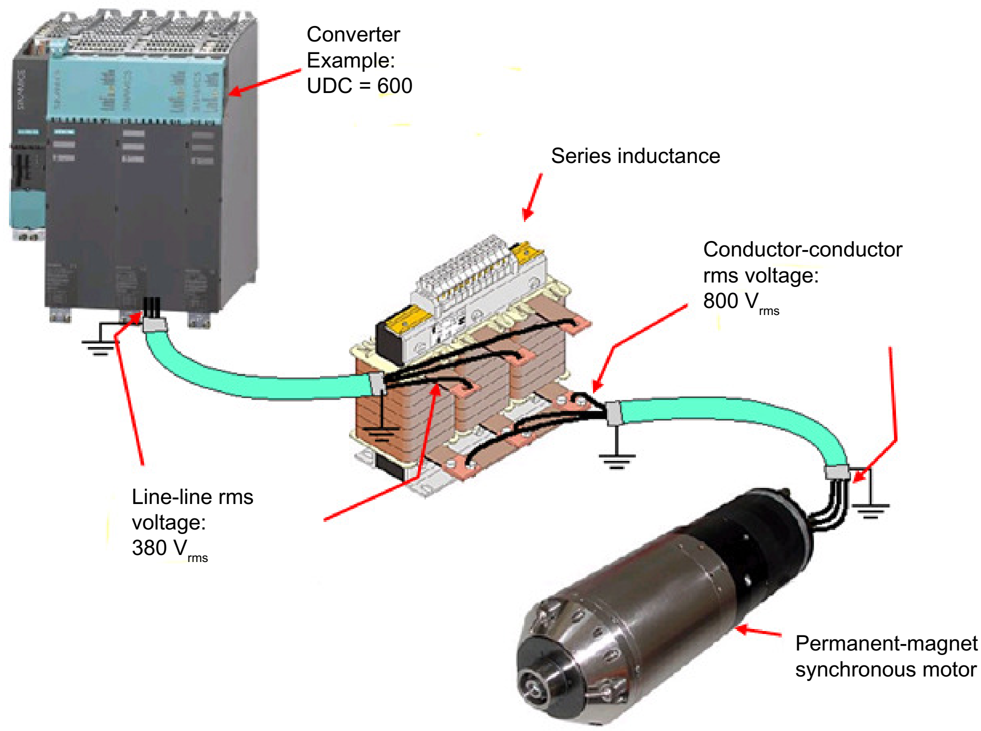


Figure 4-9 Example of voltage distribution for a significant reduction of the short-circuit current using a series inductance For reasons of transparency, the VPM is not shown here.

If the motor manufacturer prescribes a series inductance to reduce the field weakening current, they must ensure that the components used have the necessary voltage strength. The components must be designed especially for the voltage at maximum speed, which results from the selected distribution of the EMF compensation:

- the terminals and winding of the motor
- the cable between the series inductance and motor
- the terminals and winding of the series inductance

The motor manufacturer is responsible for calculating and measuring the voltage stress in the components mentioned above. The manufacturer must inform customers in the motor data sheet about the magnitude of the voltage.

4.22.2 Adapting the rated and maximum power to the series inductance

From experience, a series inductance can reduce the maximum motor power available. In addition to the properties of the motor and the series inductance, the maximum available motor power also depends on the operating voltage.

Requirements placed on the motor + series inductance:

Including the series inductance, the rms value of the terminal voltage at rated power (p0307) and rated speed (p0311) must be a maximum of 90% of $U_{ZK\_customer}/\sqrt{2}$. $U_{DClink\_customer}$ is the DC link voltage agreed with the customer. If no special agreement has been made, then a DC link voltage of 600 VDC can be assumed. The terminal voltage that should not be exceeded at the rated operating point is 380 V_{rms} in this case. If the motor data sheet specifies the maximum power, then the terminal voltage required should not exceed 95% of $U_{ZK\_customer}/\sqrt{2}$. The motor data sheet data must take into account this requirement regarding the rated and maximum power.

4.22.3 Assigning parameter p0353

The designation of a series inductance is the responsibility of the party selling the motor. If they specify a series inductance, this must be documented in the motor data sheet and the inductance value must be saved in parameter p0353.

4.23 Current controller adaptation

p0391 current controller adaptation starting point Kp

p0392 current controller adaptation starting point Kp adapted

p0393 current controller adaptation, P gain adaptation

In order to obtain the optimum bandwidth of the closed current control loop, its p gain must be in a specific relationship to the total leakage inductance. However, generally the motor leakage inductance is not constant, and decreases with increasing torque-generating current. In order to compensate for the decreasing inductance, the converter can automatically adapt the p gain using a characteristic saved in the system. The characteristic is parameterized in the converter using two interpolation points. The continuous adaptation of the current controller p gain is called "current controller adaptation". The coordinates of the two interpolation points are defined using the three parameters p0391, p0392 and p0393.

The party selling the motor is responsible for the current controller adaptation and must document the three parameters p0391, p0392 and p0393 in the data sheet.

NOTICE
Thermal destruction of the magnets For most motors, inductance decreases under load. This means that the current controller becomes unstable under load when there is no adaptation and starts oscillating at a high frequency. In synchronous motors, the high-frequency, unstable oscillation can result in the thermal destruction of the magnets. • Observe the current controller adaptation.

Note

Effectiveness of the current controller adaptation

The current controller adaptation will only become effective when it is set as generally active with parameter p1402.2, even if the parameters p0391, p0392 and p0393 were entered appropriately. You can find additional information on this in the SINAMICS S120/S150 List Manual.

- Set the current controller adaptation as generally active with parameter p1402.2.

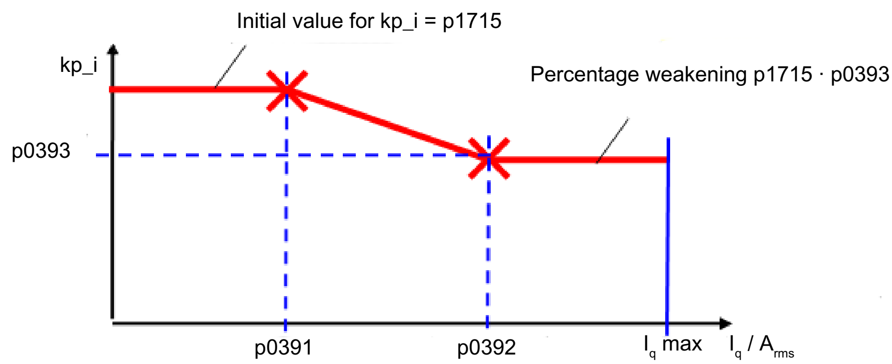


Figure 4-10 Controlling the current controller p gain using current controller adaptation

The motor manufacturer is responsible for determining the current controller adaptation characteristic. The current control adaptation is preferably determined at standstill.

The current controller adaptation parameters must be transferred to the user at the latest when the motor is shipped. They must be saved in the motor data sheet as p0391 – p0393.

If the manufacturer prescribes a series inductance, the current controller adaptation must define the system comprising a motor + series inductance.

This means that the current controller adaptation must be defined with series inductance. Therefore, the motor manufacturer must already have the series inductance as component.

Recommendation for practical implementation:

A practical method for determining the current control adaptation parameters is recommended in the following. Depending on the level of knowledge and laboratory equipment, alternative ways are possible, which will not be discussed any further here.

They all have one thing in common and that is that the current control adaptation parameters should be determined using SINAMICS converters. Preferably those sampling times for the internal control loop (p0115) and the pulse frequency (p1800) should be selected, that will also be probably used on the customer's drive system.

No external measuring equipment is required when employing the recommended technique. SINAMICS converters already have an integrated function to measure the current controller frequency response. The adaptation parameters are defined by repeatedly measuring and interpreting the current controller frequency response.

To determine the current control adaptation, the motor shaft should be clamped and the measuring series conducted as described in the following. To do this, adaptation must be deactivated (p1402.2 = 0).

For the series of measurements, increasingly higher offset currents (corresponding to the torque setpoint) are set one after the other and the "Current controller frequency response" measuring function is executed for each value of the offset current (this measuring function is already prepared for use).

For each selected offset current, the relevant kp_i (p1715) is defined, which generates the optimum bandwidth in the current controller frequency response. "Optimum" means here that the current controller frequency response should have the highest possible bandwidth without exceeding the zero dB line. For an excessively high p gain, the zero-dB line is exceeded at the end of the bandwidth. Generally, the measuring function must be repeated in order to find the optimum p gain for a specific offset current. Step-by-step (for example, in 10 % steps), the offset current setpoint is increased until the maximum permissible current is reached.

The optimum current controller p gains for the offset currents and the associated values selected in the measurement series are shown in a diagram (see also "Sample measurement for the current controller adaptation"). In the same diagram, the characteristic saved in the converter is shown, which comprises adaptation parameters p0391 – p0393.

The objective is to select adaptation parameters p0391 – p0393, so that the adaptation characteristic follows the measured values as well as possible. However, frequently it is not possible to precisely adapt all of the measuring points. In this case, the adaptation curve should not lie above the measured values, but on the average, as close as possible just below the measured values (see the diagram "Measurement example of the current controller adaptation").

If the manufacturer has still not mounted the rotor on the shaft (e.g. built-in spindle motor), then it is permissible to attach the rotor and stator using a distance sleeve so that it is torsionally stiff and free of any vibration. A dummy encoder can be used as encoder which outputs a signal in the electrically valid range (see Chapter "(Angled) position encoders (Page 159)"). For induction motors, the measurement series can be carried out using the dummy encoder without any restrictions. For synchronous motors, this is only possible, if the drive can be enabled using the inductance-based pole position identification (p1980 = 0, 1 or 4). However, this is the case for most synchronous motors. It is possible that parameter p0325 or p0329 must be temporarily changed (increased).

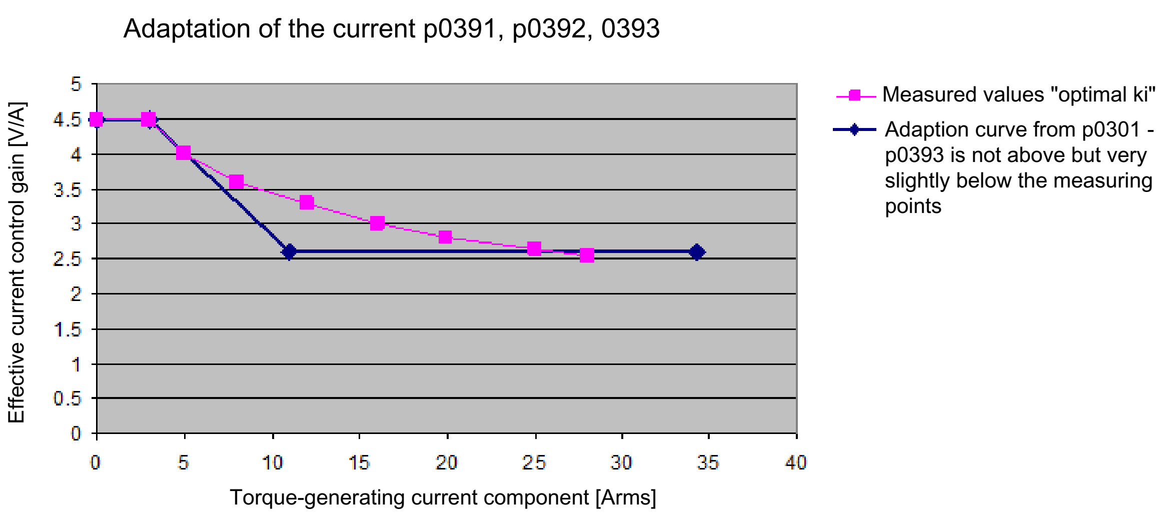


Figure 4-11 Sample measurement for the current controller adaptation

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Note

Creating the optimum bandwidth through current controller gain

The current controller gain that results in the optimum bandwidth is found by gradually increasing p1715 and each time evaluating the "Frequency response of the current controller".

The current control gain for the optimum bandwidth is the gain at which the frequency response is right at the zero dB line but does not exceed it.

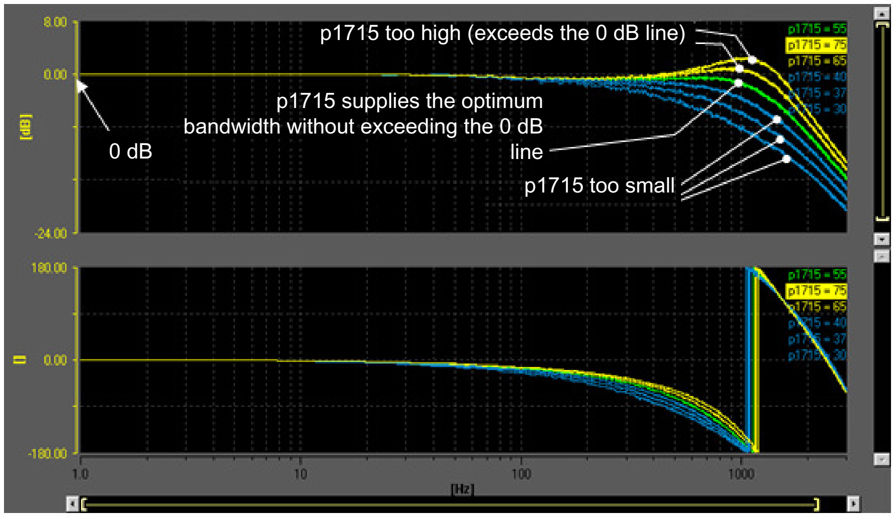

Figure 4-12 Sample measurement of the "Current controller frequency response" for various current controller gain values. Recommendation: Scale the display for +8 dB and -24 dB

4.24 Stall current

Note

The data in this chapter only apply to synchronous motors

The stall current data listed here are only applicable for synchronous motors.

p0318 motor stall current

The current that the motor can conduct as continuous current (S1) when it is at standstill (zero speed). There is no field weakening at standstill. This means that no field weakening current is impressed.

When compared to S1 duty at the rated speed, at standstill, the thermal balance can change for the following reasons, thus defining the permissible continuous current:

- Thermal stress as the phase currents are not equal
- Elimination of the thermal stress as a result of the iron losses
- Changing cooling conditions, e.g. for a shaft-mounted fan

Thermal stress as the phase currents are not equal:

At standstill, the mechanical shaft angle is stationary, and therefore also the commutation angle. DC currents then flow in the phase conductors, and not AC currents. The current distribution depends on the commutation angle. In the worst-case scenario, the current in the phase that has the highest load is greater than the three-phase rms value by a factor of $\sqrt{2}$ that would be obtained in the same phase with the same rms current but with a rotating field angle.

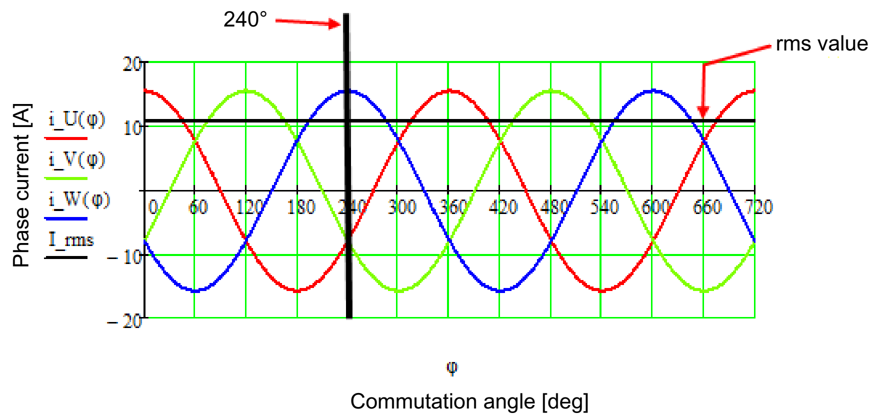

Figure 4-13 Example: Phase current distribution at standstill for a commutation angle of 240° rms current: 11 A_{rms}, peak value: 15.56 A Load in W is greater than the rms value by a factor of √2

The highest ohmic power loss is then obtained in the example above in phase W. It is twice as large as when the motor is rotating ($P_{Ohm\_loss} \sim i^2$). The stall current must be reduced, in order that the maximum permissible winding temperature is not exceeded. The extent of the reduction depends on the thermal coupling between the individual phases. In an extreme case (complete thermal decoupling), the stall current must be reduced to 71 %.

Elimination of the thermal stress as a result of the iron losses:

At standstill, the remagnetization and eddy current losses of the flux-conducting elements are eliminated (iron losses). As a consequence, for the same current, the average thermal load of the motor decreases, which provides some flexibility for increasing the current rms value.

Changing cooling conditions if a shaft-mounted fan is used:

If the coolant flow and/or the heat loss to be dissipated depends on the motor shaft speed (e.g. shaft-mounted fan), then this must be taken into consideration in the stall current.

Conclusion:

Depending on whether the unfavorable or the favorable thermal effects at standstill establish themselves more strongly, the stall current can be less, however also higher than the rated current.

- Slow running torque motors: Generally: $I_{stall} < I_{rated}$
- High-speed spindles: Generally: $I_{stall} > I_{rated}$

Using the parameter:

The parameter is used as reference variable for application-based and technological preassignments. Further, it serves as I^2t monitoring of the motor, if the model is activated per parameter.

Note

Thermal monitoring

In principle, an effective I^2t monitoring of the current in the drive can be activated via the temperature model. However, it only provides a useful protective effect – without undesirably restricting the load capability – if the appropriate thermal model data were entered. However, this is generally not the case for third-party motors. We do not recommend that the I^2t monitoring is activated for third-party motors. A temperature sensor must be used to achieve reliable thermal monitoring.

Note

Synchronous motors in the low speed range

For synchronous motors, that are subject to high loads in the low speed range, temperature monitoring is recommended that includes all three phases (preferably a PTC triplet).

4.25 Static torque

Note

The data in this chapter only apply to synchronous motors

The static torque data listed here are only applicable for synchronous motors.

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p0319 motor static torque

Shaft torque which is generated with the above specified stall current in S1 uninterrupted duty. A possible reduction of the shaft torque as a result of friction should be taken into account.

4.26 Stator resistance

p0350 motor stator resistance, cold

The stator resistance in the data sheet must be specified so that it can be directly handled as stator-related equivalent circuit diagram variable of the single-line star connection equivalent circuit diagram. The ohmic resistance at 20 °C between the terminal and neutral point must be specified. If required, the actual winding circuit should be converted into an equivalent star connection. The resistance value must be specified in the motor data sheet with at least two valid numbers (two significant positions).

4.27 Maximum speed

p0322 maximum motor speed

Maximum speed that is intended and/or permitted for the particular motor. Here, the motor manufacturer must take into account all aspects of the areas for which he is responsible. Speed-limiting variables could include:

- Centrifugal forces at the rotor
- Induced voltage in the winding
- Permissible speeds of the bearings (only if the bearings are provided by the motor supplier)
- Restrictions related to the rotary encoder (only if the rotary encoder is provided by the motor supplier)
- Restrictions related to the brake (only if the brake is provided by the motor supplier)

At the maximum speed entered in the motor data sheet, the motor must not incur any damage and must not manifest any inadmissible reduction of its service life, even under unfavorable combinations of operating states. Combinations of simultaneously occurring, unfavorable operating states, are explicitly:

- Maximum permissible temperature
- Maximum permissible current
- Vibration in the permissible range

Assuming that the motor is a subcomponent of an electromechanical system, and this system requires that the maximum permissible speed is further restricted, then the supplier of the electromechanical system must issue a new motor data sheet, where the maximum speed value has been appropriately reduced. This is frequently the case for motor spindles, where the spindle manufacturer purchases the built-in motor from a subsupplier, and then supplies the electromechanical system, namely the spindle, to the company operating the SINAMICS drive. Different maximum speeds are obtained, especially then, if the spindle manufacturer uses the same motor for different spindle types.

4.27.1 Maximum speed restrictions when operating with a SINAMICS drive

For synchronous motors: Maximum voltage with open circuit terminals

- For all drives of the voltage level "3 AC 380 ... 480 V", the peak value of the voltage that the motor generates with open-circuit terminals must remain below 2.0 $kV_{terminal\text{-}terminal}$. If it were above 2.0 kV, there is a risk of injuries in the case of a fault. Whether a higher limit may apply for chassis units of the voltage level "3 AC 500 ... 690 V" can be determined by contacting your professional Siemens retailer.
  ⇒ The rms value of the terminal voltage $U_{rms\_terminal\text{-}terminal}$ at the maximum speed must be less than 1414 V_{rms}. Therefore, that operating state should be used as a basis, where the voltage with open-circuit terminals is the highest. Generally, this when the motor is in a cold condition.
- Not below the rated speed
  The maximum speed (p0322) must not be below the rated speed (p0311) specified in the data sheet. This means that the motor must be able to be operated as a minimum up to its rated speed.

⚠ WARNING

Electric shock if there is excessive EMF peak value voltage

The risk of electric shock, which exists with a peak EMF voltage of above 2.0 $kV_{terminal\text{-}terminal}$, is not removed even when using a voltage protection function, which short-circuits the phase conductors with respect to one another (VPM, internal voltage protection, etc.).

- You must ensure that the peak EMF voltage is always below 2.0 $kV_{terminal\text{-}terminal}$ (also see above).

4.27.2 Necessity of having overvoltage protection for high synchronous motor EMFs

In the case of a synchronous motor, in order to avoid damaging charging of the DC link system by the motor operating as generator, the user must provide voltage protection if the theoretical terminal voltage generated at the maximum speed can lie above a certain threshold value. For SINAMICS applications, voltage protection is provided in the form of an armature short circuit (where the motor terminals are short-circuited). The user is responsible in ensuring that an armature short-circuit function is provided.

Note

For booksize power units, the armature short-circuit can either be implemented using an external short-circuit module, the VPM (**V**oltage-**P**rotection **M**odule) or the internal short-circuit function of the power unit.

Most synchronous motors generate a transient short-circuit current which would require an oversized power unit to use the internal short-circuit function of the power unit. The use of a VPM is therefore often the more cost-effective solution.

No external VPMs are available for chassis power units.

See Function Manual (FH1), Chapter "Internal voltage protection".

The threshold value, above which it is necessary to provide voltage protection, depends on the family of power units that is actually used.

- Booksize: 820 V
- Chassis: Depending on the voltage class (however, not below 820 V)

The motor manufacturer must check as to whether the theoretical, generated terminal voltage at the maximum speed can exceed a peak value (not rms value) of 820 V. An operating state is the basis for this check

- with open-circuit terminals
- at the highest permissible speed
- with the highest EMF constant (this is generally obtained with the rotor in a cold state)

If the peak value determined in this way can exceed 820 V, then the motor manufacturer must:

- Inform the customer that it must be assumed that a voltage protection measure is necessary.
- Specify the maximum terminal-peak voltage in the data sheet.
- Design the motor so that it can be short-circuited at the maximum speed. This aspect will be discussed in more detail in the following chapter.

Note

Peak value of the terminal-terminal voltage

The threshold value of 820 V is the peak value of the terminal-terminal voltage. This corresponds to an rms value of 580 $V_{rms\ terminal\text{-}terminal}$.

Note

Automatic limiting of the maximum speed that can be reached

Without explicit specification of the protective measure in p0643 or p1231, the maximum speed that can be reached, p1082, is automatically limited to the speed at which the peak value of the terminal voltage does not yet exceed 820 V.

Note

Intended armature short-circuit

If armature short-circuit is intended, the motor including series reactor must not generate stationary or transient power that is greater than the maximum motor current under magnetic aspects in case of a short circuit.

If necessary, the inductance of the series reactor must be increased to the extent that the permissible maximum current is not exceeded in the case of a short circuit.

4.28 Short-circuit current for a generated terminal voltage above 820 V (peak value)

Note

The information specified here is only applicable for synchronous motors.

If the check of the theoretical terminal voltage that can be reached when generating (motor in the generating mode) at the maximum speed indicates that a peak value of 820 V is exceeded, then the motor must be designed so that it is short-circuit proof.

In this case, the following requirements are placed on the motor:

- For a sudden terminal short-circuit, the (transient) phase current can exceed 180% of the steady-state short-circuit current. As a consequence, the motor must be able to withstand the phase currents that flow without incurring any damage.
- Also for the high actual operating temperature of the rotor, and for an unfavorable, transient increase in the phase currents, it is not permissible that the permanent magnets are irreversibly magnetized.

NOTICE

Power unit damage caused by overcurrent

For a winding short circuit, an excessively low inductance can result in an inadmissibly high converter current. For the case that the necessary short-circuit strength of the system, comprising a motor and converter, can only be achieved using a series inductance, then it is not permissible that the motor is operated without this series inductance.

- The use of a series reactor, and its minimum permissible value, must be very clearly specified in the manufacturer's documentation (e.g. motor data sheet).

If 820 V (peak terminal voltage) can be exceeded, then the company operating the motor must ensure adequate voltage protection. For SINAMICS converters, in the standard case, this is a device which short-circuits the motor terminals (see SINAMICS Function Manual FH1; Chapter "Armature short-circuit brake, internal voltage protection, DC brake"). To allow the user to dimension the voltage protection device, the following must be specified in the motor data sheet:

If 820 V (peak terminal voltage) can be exceeded, and the transient short-circuit current that flows exceeds the short-circuit current parameter p0320 specified in the data sheet, then

- the peak value of the transient short-circuit current and
- the decay time of the transient increase in the short-circuit current

must be specified in the data sheet. Also in this case, a possibly used series inductance must be taken into account, and a clear note must be provided in the data sheet that the specified transient short-circuit current is only applicable in conjunction with this series inductance.

4.29 Optimum load angle and reluctance torque constant

Note

The information specified here is only applicable for synchronous motors.

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p0327 optimum motor load angle (this is always 90 degrees for third-party motors without having performed a system test)

p0328 motor reluctance torque constant (this is always 0 mH for third-party motors without having performed a system test)

Background:

It is known that a current vector impressed in the stator generates the highest torque when it is at 90 degrees to the rotor field axis. The angle between the impressed current vector and the rotor field axis is called the commutation angle.

If saturation occurs at high current levels, then not only is the torque reduced, but frequently, the load angle of the torque maximum is also shifted. It is then no longer 90 degrees, but has shifted to a larger angle (see the subsequent diagram).

This effect is undesirable, which means that this shift should not exceed a certain amount. As a consequence, the following requirements are placed on the motor:

- The commutation angle, where the torque characteristic (see diagram) reaches its maximum, must lie between 90 and 105 degrees. Especially for the maximum torque-generating current permitted by the manufacturer, the shift from the ideal 90 degree value should not be higher than 15 degrees.
- The difference between the torque for a 90 degree commutation and the torque maximum (at the same absolute current) must not be more than 4% (see diagram below).

If a maximum torque is specified in the motor data sheet, then this must be referred to the maximum current, p0323 and a load angle of 90 degrees.

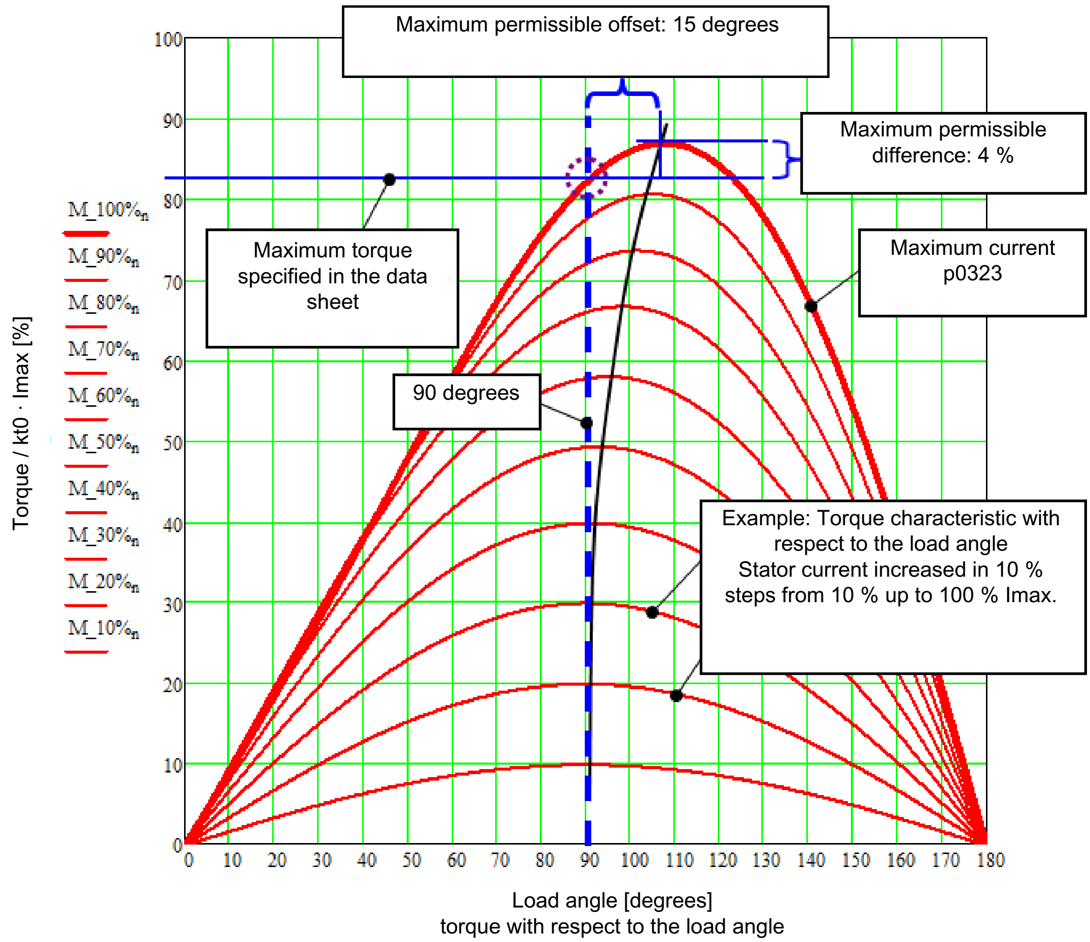


Figure 4-14 Shift of the load angle of the torque maximum current increased in 10% steps to the maximum current

Note

A typical set of characteristics showing the torque with respect to the load angle for a motor manifesting significant saturation is shown in the diagram above. An individual characteristic from the set of characteristics defines the torque, which is generated when the motor shaft is externally rotated from 0 degrees to 180 degrees. The set of curves contains 10 individual curves, where the absolute stator current is increased in 10 % steps. The torque is shown as relative torque as a %. The reference torque is the torque that would be obtained for an unsaturated torque constant kt0 and maximum current (kt0 • p0323).

For more information on kt0, see "Torque constant and voltage constant (Page 31)".

4.30 Maximum current parameters

p0323 maximum motor current (only for synchronous motors)

p0338 motor limit current (only for synchronous motors) p0640 current limit

For synchronous motors

For synchronous motors, the maximum permitted motor current is defined by the values of parameters "Maximum motor current" (p0323) and "Motor limit current" (p0338). For third-party motors, a distinction is not made between the two parameters; they are used in the same way (p0640 does not need to be listed in the data sheet).

Note

p0338 describes the maximum permissible current for third-party motors

Contrary to the List Manual of the SINAMICS parameters "SINAMICS S120/S150 List Manual", p0338 for third-party motors does not define the maximum possible current at the rated speed at the voltage limit characteristic but the maximum permitted current for the motor without any reference to speed.

For induction motors

For induction motors, the maximum permitted motor current is defined by the value of parameter "Current limit" (p0640) (p0323 and p0338 do not have to be listed in the data sheet). For induction motors, p0640 is the only parameter, which actually limits the maximum current controlled by the converter. For induction motors, the converter defines the current limit (p0640) as 1½ x the rated current (pre-assignment: p0640 = 1.5 · p0305). If the motor manufacturer wishes to use a different maximum current for the induction motor involved, then the company operating the motor should be made aware in the motor data sheet that, after executing the automatic calculation of the control parameters (using p0340 = 1 or 3 or 4), p0640 should be overwritten by the value intended by the manufacturer.

In the sense of the motor data sheet, all three parameters should be interpreted as having the same factual content. It is the maximum terminal current permitted by the manufacturer. The distribution between the torque-generating and the field-generating axis does not play any role ($i = \sqrt{iq^2 + id^2}$). The maximum current parameters listed in the motor data sheet must not be below the rated current p0305.

For the maximum current value entered in the motor data sheet, it is not permissible for the motor to incur any damage, even under an unfavorable combination of operating states. It is especially important to note that irreversible demagnetization is not permissible. Combinations of simultaneously occurring, unfavorable operating states, are explicitly:

- Maximum permissible temperature.
- for synchronous motors: Incorrect commutation (e.g. as a consequence of a rotary encoder fault). Especially when the total current vector is impressed in the field weakening direction.
- Maximum permissible speed

If the operating company wishes to further reduce the maximum current, beyond that in the motor data sheet, then parameter p0640 should be used. The two other parameters, p0323 and p0338 are intended to define the motor, and should not be changed to adapt the motor to the particular application. The value entered in p0640, limits the maximum current controlled by the converter (this is binding) ($i = \sqrt{iq^2 + id^2}$).

4.31 Stall torque correction factor

p0326 motor stall torque correction factor

The stall torque correction factor defines how far the voltage limit characteristic must be shifted in order to obtain a perfect operating behavior and response. Based on the equivalent circuit diagram data that has been entered, the converter calculates the theoretical characteristic of the voltage limit characteristic, and using a speed-dependent limiting of the torque setpoint, it ensures that no torque setpoint is entered outside the voltage limit characteristic. As a consequence, theoretically the voltage requirement should never lie above the available voltage.

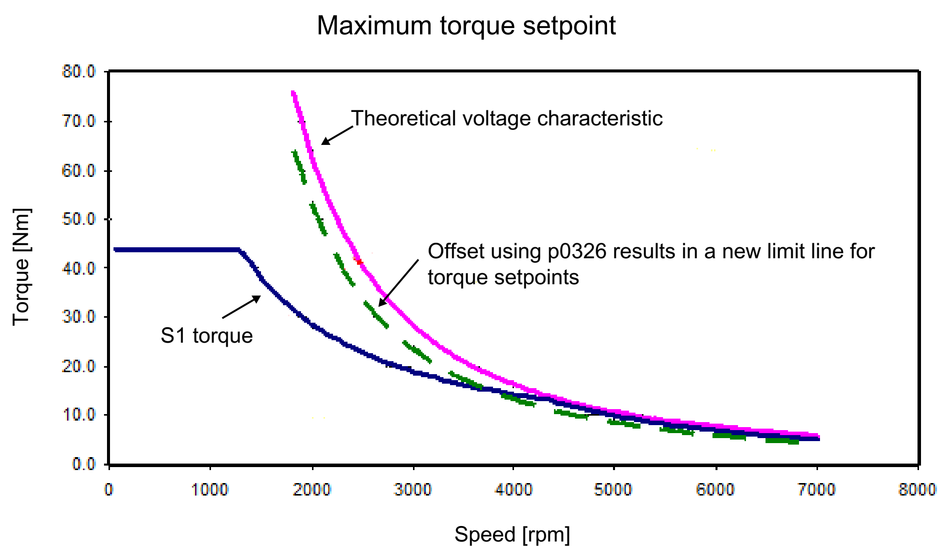


Figure 4-15 Example: Shift of the torque limit characteristic using p0326 = 85 %

However, experience has shown that for individual motors, especially motors with a high field weakening ratio, the voltage limit is reached under steady state conditions with undesirable operating behavior. These undesirable responses especially occur when braking quickly from a high-speed. The situation can be improved if the torque setpoint limit is initiated earlier than would be necessary according to the theoretical voltage limit characteristic. In this case, the torque of the theoretical voltage limit characteristic is multiplied by the stall torque correction factor (p0326), and is then used as the new limit characteristic for the torque setpoint. In the speed range, in which the voltage limit characteristic defines the maximum available torque, the stall torque correction factor acts appropriately, either decreasing or increasing the maximum torque permitted for the drive.

The stall torque correction factor compensates for a deviation between the theoretically expected drive behavior and that actually manifested in the field. As a consequence, p0326 should not be determined from theoretical preliminary calculations. It can only be determined when required, in practical operation.

As long as no adaptation has taken place in practice, the stall torque correction factor p0326 for induction motors should be 100% and 71% for synchronous motors.

Note

Pre-assignment of the stall torque correction factor

When connecting a third-party motor, the stall torque correction factor (p0326) is preassigned to a value significantly less than 100% in the converter for some software versions. This is the reason that the operating company should be made aware that they should overwrite p0326 with the value intended by the manufacturer.

A higher stall power can now be enabled via parameter p1402.6. Activating this parameter makes parameter p0326 ineffective. Parameter p0388 serves as a high limit instead which is reduced independently by an internal closed-loop controller (see r1549). A parameter assignment of the stall torque correction factor p0388 that deviates from the default value is usually no longer necessary. We therefore recommend activating p1402.6.

4.32 Pole position identification current

p0329 Motor pole position identification current

Pole position identification is abbreviated as PLI below.

Application

In synchronous motors with incremental rotary encoders, the converter must conduct pole position identification (PLI) to be able to start controlled operation.

The PLI is used to find the north pole so that the converter can lock its commutation angle onto the magnetic pole of the rotor.

Note

Unrestricted access to the motor torque is required

Even for encoders with zero mark, PLI is required during switch on because the rotor must turn mechanically to find the zero mark and therefore needs unrestricted access to the motor torque.

The party selling the motor is responsible for determining the parameters for pole position identification and noting them in the data sheet.

Because an unreliable or faulty pole position identification process is one of the most frequent causes of complaints, we are taking a closer look at the principle of operation, parameter assignment and checking the result in this chapter.

Because this chapter is only important for synchronous motors without calibrated absolute encoder, it can be skipped for the following motors:

- Induction motors
- Synchronous motors with calibrated absolute encoder

Note

Synchronous motors operated without encoder

For synchronous motors operated without encoder, the pole position identification ensures that the current vector is already aligned correctly (in field direction) when the current controller is enabled. This prevents the motor from oscillating when it is switched on.

Note

Defined series inductance

If a series inductance was defined, it must be present when the PLI parameters are determined in the circuit.

SINAMICS S120 offers several different techniques for pole position identification. They are listed in the Function Manual. In this System Manual, the focus is on the technique "Saturation-based 1st harmonics" that is selected with p1980=1.

The reason for using this technique preferably in connection with third-party motors is that the saturation-based PLI can be used relatively independently of the mechanical constraints and that the parameters, once found, remain valid even in other constellations.

If an acceptable quality and stability of the PLI technique cannot be achieved with the procedure described below, the customer must be informed that saturation-based PLI cannot be used for the specified motor.

Principle of operation

The inductance-based PLI is based on the fact that magnetic saturation shows the rotating field angle of the magnetic pole direction of the rotor at the time of the PLI. The following basic step sequence runs:

1. The converter determines the amplitude of the voltage-time area that is to be impressed to achieve the configured RLI current (p0329) theoretically (see subitem "Physical background information").
2. 60 voltage pulses with the permanently defined amplitude are then sent to the stator distributed over 360°. This means that the entire rotating field is scanned with a resolution of 6°.
   The current end value for the respective voltage pulse is saved for each voltage pulse.
3. The 60 measured values are stored in a "Current end value for angle" measurement curve.
4. The measurement curve is checked to ensure that it shows a sufficiently distinct wave contour.
5. The phase position of the shaft is detected by means of a Fourier analysis. The determined phase position is interpreted as pole position angle.

The entire step sequence takes place in fractions of a second.

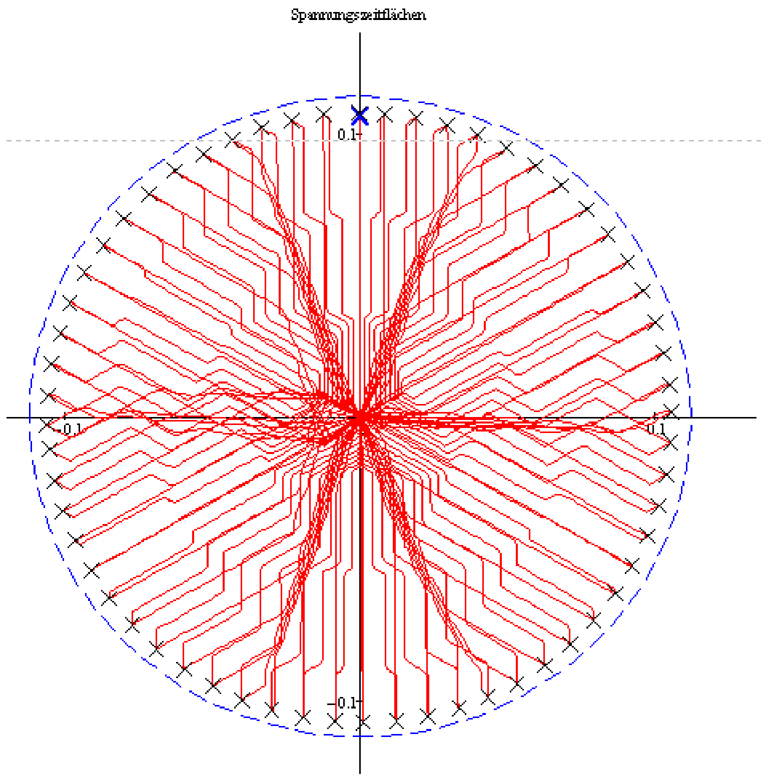


Figure 4-16 Voltage-time areas

The length of the pointers (= connected voltage-time area) is the result of the configured PLI current p0329 and the inductance.
Typical values: 1 mH · 40 A = 0.04 Vs

Parameter assignment

Using p0329, the converter is provided with the end value of the current that is to set in when a voltage pulse is connected.

Context:

Current end value = voltage-time area / total leakage inductance
=> Voltage-time area = total leakage inductance · current end value (see subitem "Physical background information")

NOTICE
Magnetic destruction of the motor through incorrectly configured total inductance
The current controller is switched off during the PLI run. Incorrect parameter assignment of the total inductance can result in an actual current end value that is significantly higher than the intended PLI current. An "incorrectly parameterized total inductance that is significantly too high" can result in the magnetic destruction of the motor. • Parameterize the total inductance correctly.

Note

Accurately described physical total inductance

The fact that the desired PLI current (p0329) only sets in when the configured total inductance accurately describes the physical total inductance can be interpreted as an indirect measuring procedure for the total inductance:

"The total inductance that results in a match between the parameterized current and the actual current during PLI is physically accurate."

Triggering the PLI test

A new PLI can be triggered at any time for a motor without load in standstill or even during slow rotation.

- Set p1983 to "1".
  The result of the currently conducted PLI is displayed in the form of the difference from the operating angle used in parameter r1984, see also "SINAMICS S120/S150 List Manual".
- However, the operating angle is not overwritten because triggering the PLI later is only used for diagnostics.
  Even if the PLI result is inaccurate due to experimentally set parameters (p0329), the performance is not affected.

Assessing the quality of the PLI result

The PLI result and thus the parameter assignment can be considered acceptable when the PolID angular difference that is shown in r1984 remains within a narrow tolerance band when the PLI test is triggered multiple times:

- For motors that are not intended for the field-weakening range: ±10°
- For motors that are operated in the field-weakening range: ±3°

When assessing the quality of the PLI result

- The PLI should be triggered at least 20 times
- All electrical angles should be run through, if possible

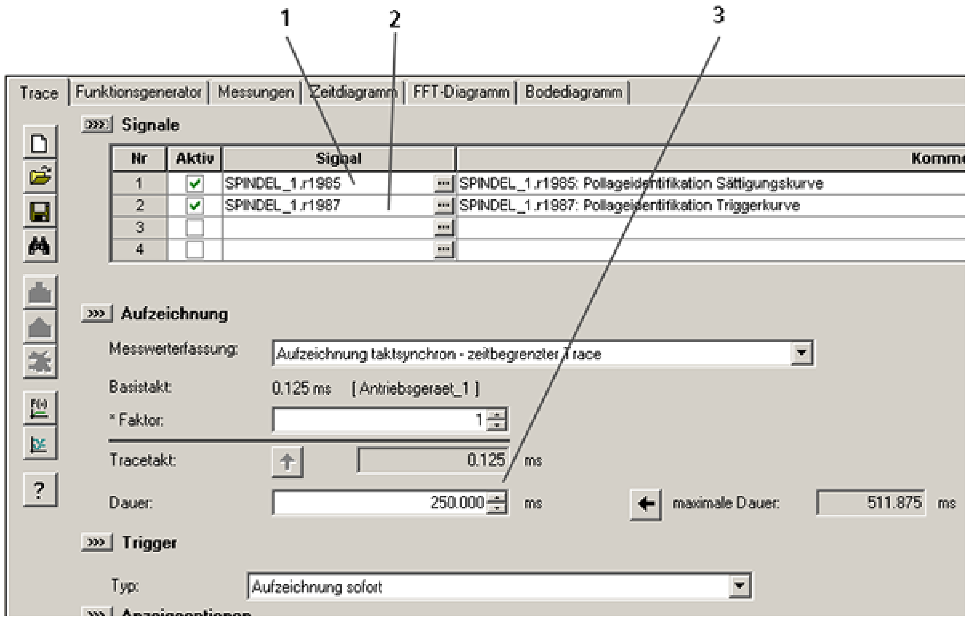
This is especially easy and quick when the motor rotates at a very slow speed, e.g. 1 rpm, and the PLI test is triggered repeatedly during the rotation.

Ensuring ruggedness

To assess the ruggedness, the "Current end value to angle" measurement curve is to be read from the measured value memory.

The current end values are stored in the read parameter r1985.

The marker that is stored in the read parameter r1987 can be consulted for additional information.
The measured value memory is read immediately after the "Measurement Start" button is pressed.
It is not necessary to set a trigger condition: "Record immediately".



1 r1985 Current end value of the 60° voltage-time area pulses

2 r1987 Marker

3 1 ms corresponds to a 6° angle step
Good legibility is achieved at 150-200 ms.

Figure 4-17 Parameter assignment for reading the measured value memory "Current end value to angle"

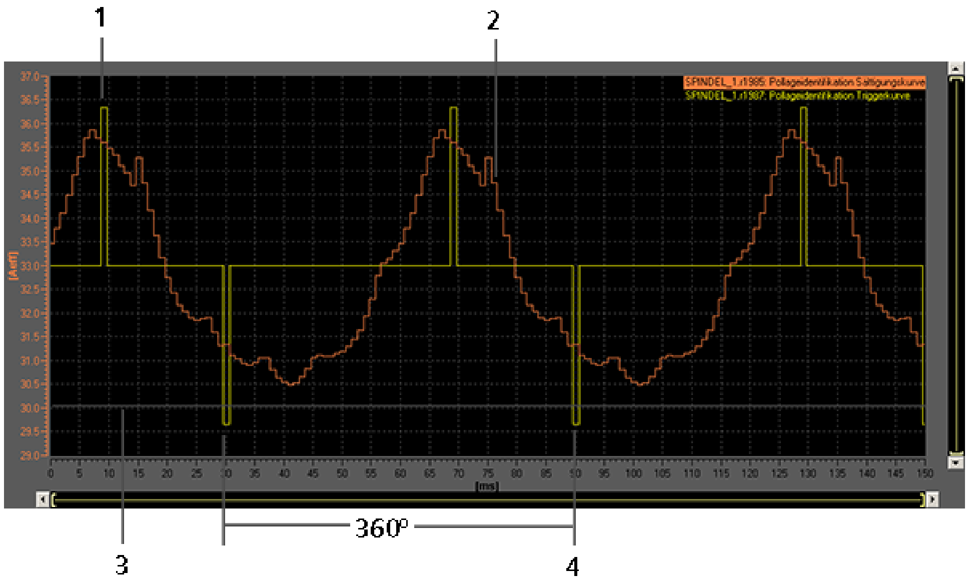
Note

Good legibility

Because an individual 6° angle step is formally addressed by a 1 ms time interval, a recording time of 60 ms would theoretically be sufficient to visualize the full 360° rotation of the voltage-time area pointer.

If a recording time of more than 60 ms is specified, the existing table content is written multiple times in a row.
The result is a repetitive, continuous representation of a wave that can be read more easily than the exact 360° (60 ms) section.

Good legibility can be achieved with a recording time of 150-200 ms.



1 Marker that shows the found focus of the current maximum

2 Current end values

3 Parameterized PLI current was 30 A_{rms} here

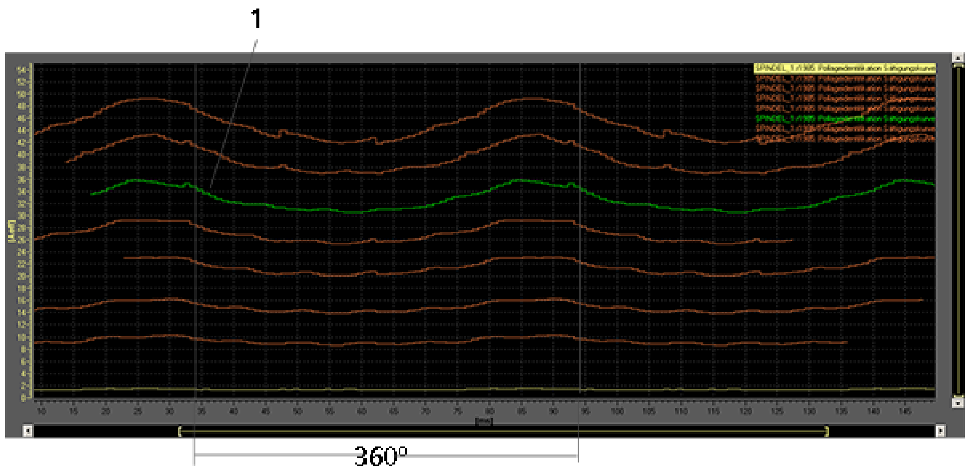
4 360° marker

Figure 4-18 Example of a measurement curve "Current end value to angle" when defining a PLI current, p0329 of 30 A_{rms}

The following two conclusions can be derived from the example above:

- The shape of the measurement curve wave is sufficiently distinct.
- The actual median current of 33 A_{rms} is about 10% above the configured current (p0329) of 30 A_{rms}. This means that the actual total inductance is about 10% less than the configured total inductance.

By comparing different measurement curves for PLI currents p0329 that were configured with different values, it becomes apparent when the relief of the trend clearly occurs. To this end, the PLI current p0329 is gradually increased, starting with a small value, and all measured value memory contents are shown in a shared diagram. See also the following figure "Example: Gradually increased PLI current". The trend for the PLI current of 30 A_{rms} that was specified as suitable for this motor is highlighted in green.



1 Adequate specification with p0329 = 30 A_{rms}

Figure 4-19 Example: Gradually increased PLI current

Note

Selection of the adequate PLI current

Higher currents usually result in a more distinct trend but also in a higher volume.

This is why this simple rule is usually applied when selecting the adequate PLI current p0329: As little as possible but as much as necessary.

Physical background information

How can the rotor angle be detected using the saturation of the inductance?

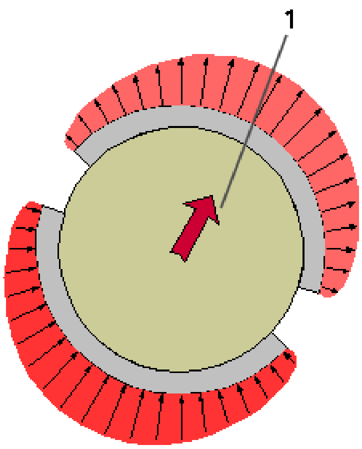
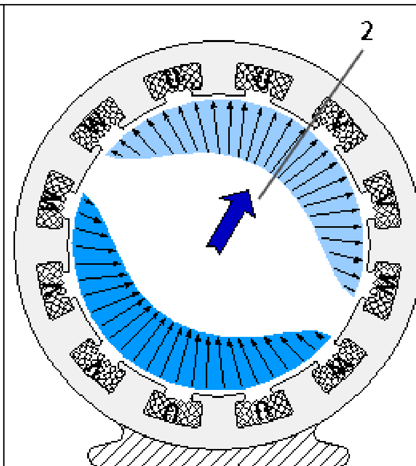
The magnetic circuit of the motor is subject to magnetic saturation. This means that the magnetic resistance increases with increasing density of field lines.
Increasing magnetic resistance results in less inductance. This effect is utilized to detect the rotating field angle of the stator in which the density of the field lines reaches its maximum.

Voltage pulses in 6° angle steps are connected to the rotor that is located at a random angle position according to the figure "Example of a recording of the voltage-time areas during the PLI".

Each electrical angle can be considered directly as an angle of the stator magnetic field. This includes angles that point approximately in the direction of the rotor magnet and others that point in the opposite direction of the rotor magnet.

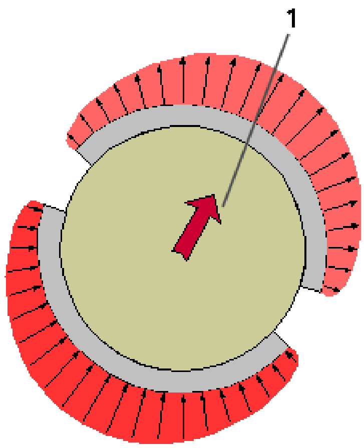
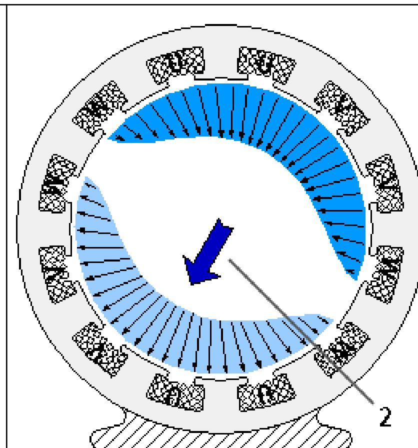
The angle that most closely matches the direction of the rotor magnet results in the greatest density of the field lines because the rotor field and the stator field combine to form a joint total field; see the figures below. Due to the magnetic saturation, the inductance has a minimum at this angle.

Table 4-6 **Rotating field angle of the stator in which the density of the field lines reaches its maximum**

 Magnetic field generated by the rotor 1 Angular position of the permanent magnet poles (rotor)	 Magnetic field generated by the stator 2 Rotating field angle of the stator
Angle of the permanent magnet poles of the rotor in an alignment that was present randomly at the time of the RLI.	The direction among the 60 voltage pulses resulting in the greatest B field is shown. Rotor field and stator field point in the same direction and combine with one another. The B field is maximum in this constellation and inductance is minimal.

Similar to the figure above, "Rotating field angle of the stator", in which the density of the field lines reaches its maximum, the angles that point in the opposite direction to the rotor magnet partially eliminate field lines (see the figure below).

Table 4-7 **Partial elimination of field lines**

 Magnetic field generated by the rotor 1 Angular position of the permanent magnet poles (rotor)	 Magnetic field generated by the stator 2 Rotating field angle of the stator
Angle of the permanent magnet poles of the rotor in an alignment that was present randomly at the time of the RLI.	Representation of the magnetic field generated by the stator in the angles under the 60 voltage pulses that results in the smallest B field. Rotor field and stator field point in the opposite direction and partially cancel each other. The B field is minimal in this constellation and inductance is maximum.

How do you recognize the inductance using a voltage pulse?

You recognize the inductance by creating a voltage-time area.

When a voltage is connected to a coil, inductance, the current increases according to an e-function that clings to an asymptote. Due to the small ohmic resistance, the asymptote would be at very high currents of several kA.

In the area of the configured PLI current under consideration, the curvature of the current increase curve can therefore be ignored.
The current increase is linear and proportional to the reciprocal value of the inductance: $\delta I/\delta t = U/L$.

For the current end value (I_{End}) at the end of the voltage connection, the result is: $\Delta I = 1/L \cdot \Delta t \cdot U$.
The product of "Voltage   connection time", ($U \cdot \Delta t$), is called "voltage-time area".

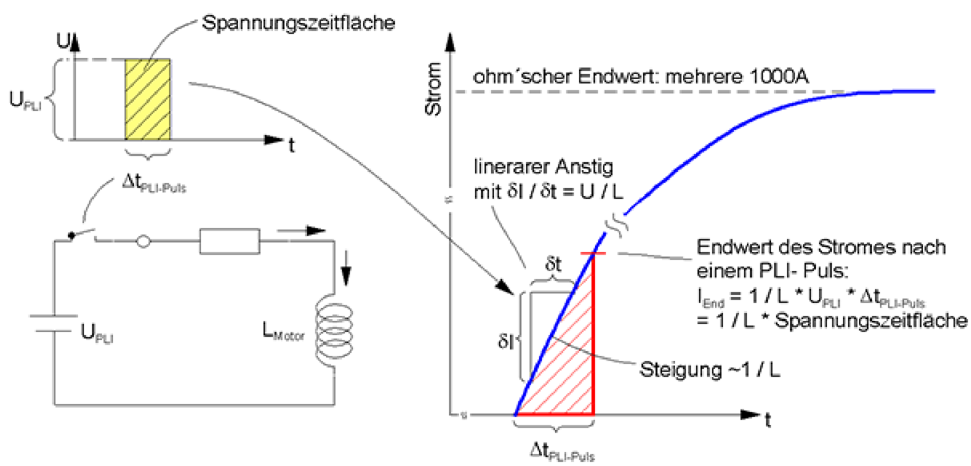


Figure 4-20 Correlation between voltage-time area and current end value

It is also apparent that the voltage pulse does not need to be square wave, but that all pulse shapes that enclose the same voltage-time area result in the same current end value. Because all 60 voltage pulses have exactly the same amount of the voltage-time area, the inductance can be derived from the current end values:

- Largest current end value → smallest inductance
  ⇒ angle of the voltage pulse points in direction of rotor magnetization
- Smallest current end value → largest inductance
  ⇒ angle of the voltage pulse points in opposite direction of rotor magnetization

4.33 Moment of inertia

p0341 motor moment of inertia

This parameter is also used to automatically assign the speed controller gain. In order to obtain a value that can be used, the total moment of inertia of the shaft must be specified here.

If the motor is being used as a subcomponent of an electromechanical system, and the moment of inertia of the motor is increased when completing the electromechanical system, then the motor manufacturer should not enter any value in p0341, but should specify the rotor moment of inertia in a separate line of the motor data sheet.

The supplier of the electromechanical system must then enter the total moment of inertia as p0341 in the data sheet. This is frequently the case for motor spindles, where the spindle manufacturer purchases the built-in motor from a subsupplier and then supplies the electromechanical system, namely the spindle, to the company operating the SINAMICS drive. In this case, the spindle manufacturer must specify the total moment of inertia in p0341.

4.34 Motor cooling method

Note

The data in this chapter only apply to induction motors

The data regarding the motor cooling method provided here only apply to induction motors.

---

p0335 motor cooling method

This parameter is used to parameterize the thermal model of the converter and to preassign the time constants of the temperature monitoring. With the prompted data input using the SINAMICS input help, "Wizard", the system prompts you to enter the cooling method for induction motors.

A distinction is made between the following cooling methods:

- Natural cooling
  There is no forced cooling
- Forced cooling
  A separately-driven/external fan pumps air through the motor, and air is exchanged with the environment
- Liquid cooling
- Natural cooling and internal fan
  - Direct heat dissipation at the housing surface to the environment by means of natural convection;
  - A fan also pumps air inside the motor,
  - No direct air exchange to the motor environment:
- Forced cooling and internal fan
  Air is driven over the housing surface and inside the motor by a fan
- Liquid cooling and internal fan

4.35 Alarm threshold for the motor temperature

p0604 Motor temperature alarm threshold

Note

See also Chapter "p0604 alarm threshold for overtemperature (Page 121)"

In this document, "motor temperature" refers to the stator winding. If an analog measuring temperature sensor or a switching temperature sensor is being used, then preferably, this should thermally correspond with the warmest point of the stator winding.

The alarm threshold is intended to maintain operation and to avoid unintended trips/shutdowns. In the application involved, for example, this is achieved by the higher-level control reducing the motor load if the detected motor temperature is above the alarm threshold.

Note

The function to reduce the load when reaching the alarm threshold is not automatically available. If a load reduction is required, and this is permissible for the particular application, then it must be explicitly implemented by the user.

In the preset parameterization of the converter, a time monitoring function is active, which switches of the motor using an OFF2 response, if the detected temperature was above the alarm threshold without any interruption for 240 s. In order to guarantee disturbance-free operation, the temperature sensing and the associated alarm threshold must fulfill the following requirements:

- The alarm threshold (p0604) must be a minimum of 5 K below the fault threshold (p0605). A possible tolerance of the switching point should be taken into account.
- With continuous operation at the rated operating point (with the specific cooling method), the temperature sensing must indicate a value below the specified alarm threshold.

Note

When using an analog temperature sensor to measure temperature, the alarm and fault thresholds are referred to one and the same measuring location.

4.36 Fault threshold for the motor temperature

p0605 Motor temperature fault threshold

Note

See also Chapter "p0605 fault threshold for overtemperature (Page 122)".

For the term "motor temperature", refer to the Chapter "Alarm threshold for the motor temperature (Page 87)".

The fault threshold is used for thermal motor protection. The temperature at which the motor can be continuously operated, without any restrictions regarding the agreed service life, should be specified as fault threshold. In order to guarantee disturbance-free operation, the temperature sensing must fulfill the following requirements:

- With continuous operation at the rated operating point (with the specific cooling method), the temperature sensing must be below the specified fault threshold.
- The temperature sensing must detect an operating state whose temperature has a negative impact on the service life by indicating a temperature value above the specified fault threshold (p0605).

When the fault threshold is exceeded, the default setting of the converter immediately initiates shutdown of the motor in the form of an OFF2 response (the pulses are immediately canceled, and the drive coasts to a stop).

NOTICE

Damage to temperature-sensitive function groups

If other temperature-sensitive function groups, such as encoders or bearings, are present in addition to the stator winding, check whether these are adequately protected by the motor temperature monitoring.

- If necessary, take additional measures to monitor the temperature of the sensitive components.

Qualitative requirements placed on a series inductance

5

The qualitative properties that a series inductance must have are described in this chapter. The necessity to use a series inductance and its value is obtained from the requirements of the previous chapter.

5.1 Integrating the series inductance into the circuit

- If a VPM is used, the series reactor must be switched between VPM and motor. This results in the following circuit:
  Converter ⇒ VPM ⇒ series inductance ⇒ motor
- Shielded power cables, with the shield connected at both ends, must be used.
  ⇒ shield support, also at the series inductance

5.2 Series reactor Plus

A number of OEMs have reported that the interaction between series inductance and motor cable has resulted in electrical oscillations with uncontrolled high voltages. This risk is eliminated by providing adequate damping of the series inductance.

The damping is generated by a transformer using an additional secondary winding with terminating resistor and has no effects on the motor operation. In connection with SINAMICS drive systems, the series inductance with secondary winding plus terminating resistor is referred to as "series reactor Plus".

The series reactor Plus reduces the conductor-earth voltage to a level that would exist without a reactor between converter and motor cable.

The concept of the series reactor Plus is an expansion of the regular series reactor by

- a secondary winding
- a damping resistor

The user is generally in charge of purchasing, installing and connecting the damping resistor. The dimensioning rules are binding and described below.

The secondary winding increases the installation space, the weight and the costs of the series reactor only slightly, because

- The number of coils of the additional winding is only one third (of the power coils).
- The wire cross-section of the actual winding is only 1 mm² - 2.5 mm² in most cases and thus many times smaller than the wire cross-section of the power coils.

Because the series reactor Plus practically completely eliminates the significant risk of electrical cable oscillation at a reasonable cost, we highly recommend only using series reactors in

SINAMICS S120 drive systems that are designed according to the guidelines of the series reactor Plus described here.

Note

Foregoing the series reactor Plus model

With an open secondary winding, the series reactor Plus becomes a conventional series reactor.

Those users who have checked by measurement that the conductor-earth voltage at the motor terminal stays within a reasonable range and that no oscillations have propagated on the motor cable even with an open secondary winding can forego using the series reactor Plus model in the specified configuration of the plant with the specified motor cables when equipping future plants and can return to using a conventional series reactor.

Note

Using a conventional reactor

You can forego using the "series reactor Plus" model for a regular reactor when the connecting cable between series inductance and motor is less than 3 m long and the rated torque of the motor is less than 10 Nm.

5.2.1 Necessity and effect

The cable between motor and series inductance represents a significant earth capacitance. The earth capacitance of the motor is also added to this capacitance.
As viewed from the converter output, a resonant circuit opens up towards the earth in combination with the series inductance. Power and motor capacitance appear as joint earth capacitance.
For cable lengths of more than 10 m and inductances of more than 0.15 mH, in particular, natural damping is not sufficient to reliably prevent electrical oscillations on the motor cable.

The following figure, VSD_Plus_A, shows the simplified resonant circuit as well as a typical, real cable oscillation. Cable oscillations are often only discovered by the end user after damage to the motor insulation has occurred frequently.

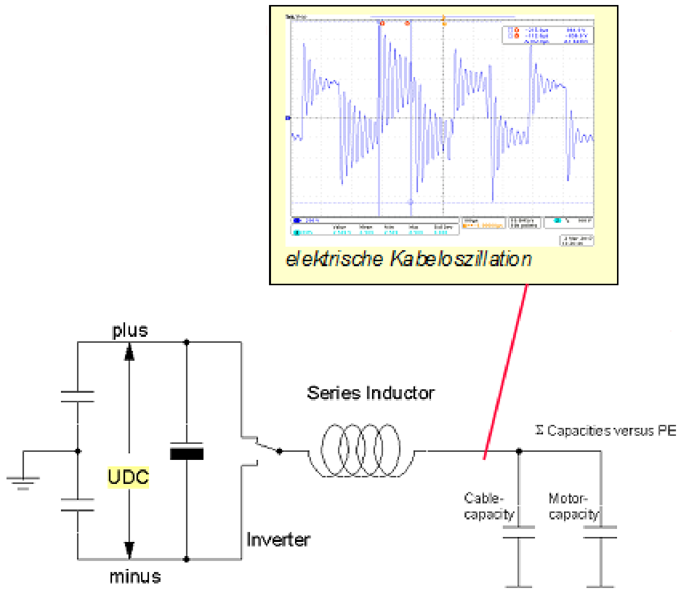


Figure 5-1 VSD_Plus_A: Resonant circuit from series inductance and earth capacitance

Replacement or retrofitting with the features of the guidelines described here for the series reactor Plus eliminates the oscillating tendency completely.

The following figure illustrates the elimination of the oscillating tendency:

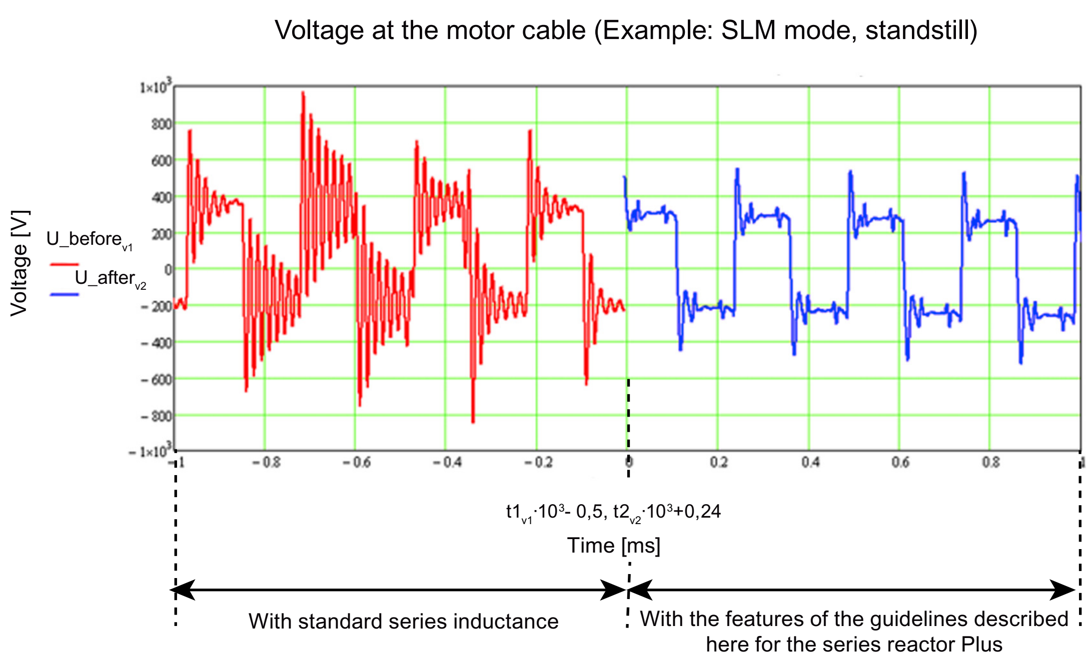


Figure 5-2 VSD_Plus_B: Elimination of the oscillating tendency with the series reactor Plus

Note

Cable oscillation

The occurrence of the cable oscillation is a characteristic of the undampened resonant circuit from series inductance and earth capacitance.

Cable oscillation is not a characteristic of the converter and occurs in converters from other brands as well.

5.2.2 Operating principle

The series reactor Plus introduces the required damping in the resonant circuit; see "Figure 5-1 VSD_Plus_A: Resonant circuit from series inductance and earth capacitance (Page 93)".

The effect can be seen in a simplified manner in the following circuit diagram:

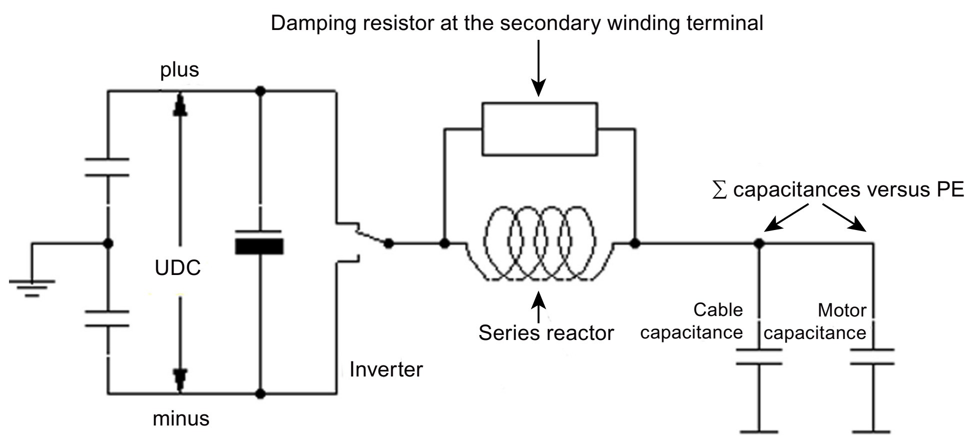


Figure 5-3 VSD_Plus_C: Representation of the damping of series reactor Plus

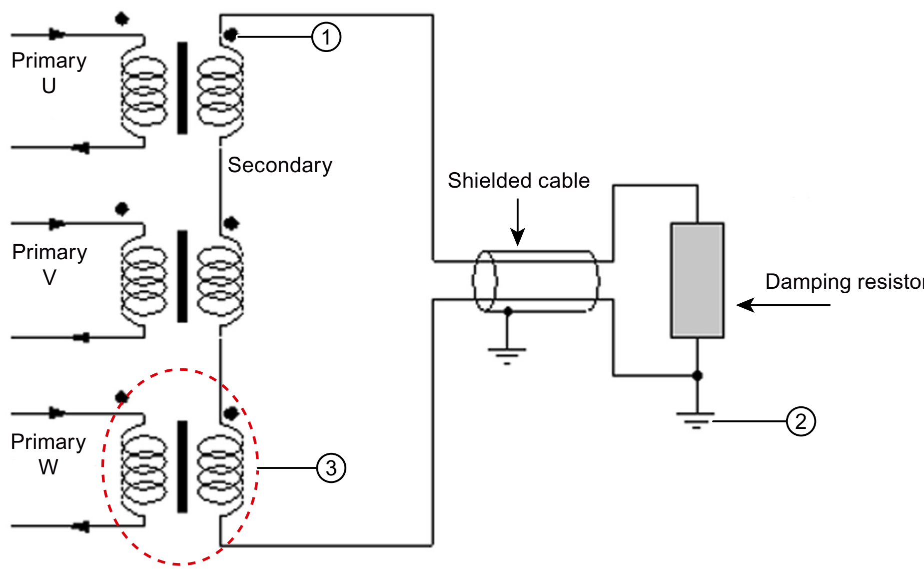
The distinction between the portions of the three-phase current and the common mode current helps us understand the effect of the reactor in:

- Three-phase current portion
  Sum of the three phase currents is always strictly zero
  → causes torque and is controlled by the converter
- Common mode current
  Current that does not add up to zero but flows down to the earth.
  → unintended "bycatch" and cannot be controlled by the converter

Exactly the same is true for voltages in the drive system. It is evident that, according to the figure above VSD_Plus_C, the oscillating current is only supplied by the common mode current portion because the oscillating charge of the earth capacitances flows to the earth. The principle of the series reactor Plus is to catch exactly those voltages that do not add up to zero (these are the common mode voltages) and guide them to the damping resistor.

In addition, each power coil of the three-phase reactor has been allocated a galvanically isolated secondary coil as transformer tap. As for the transformer with primary and secondary end, the secondary voltage is a full-scale image of the primary voltage. The series connection of the three secondary coils eliminates the three-phase current portions at the two terminals; the three-phase system sum is zero. Only the common mode portions that feed the cable oscillation remain. The resistance at the terminals of the series connection of the three secondary coils only has an effect on the current portions that connect to earth in the circuit of the figure VSD_Plus_C.

Dimensioning of the damping resistor is especially convenient with a winding number ratio of 3:1. The damping resistor with its component values transforms directly to the power side and must not be converted. This is why you should select this winding number ratio. All rules listed below are also adapted to this winding number ratio of 3:1.



① Note winding direction

② Ground damping resistor

③ Number of coils of the secondary winding
1/3 of the number of windings of the primary winding
rounded to a whole number of windings

Figure 5-4 VSD_Plus_D: Winding and connection diagram of the series reactor Plus

5.2.3 Three-legged laminated core reactor versus powder core pot design

In the version as series reactor Plus, the previous recommendation to use a three-legged laminated core reactor rather than a power core reactor no longer applies. The reason for the previous blanket recommendation in the third-party motor manual was the low loss of the core material which promoted the occurrence of the undesirable electrical cable oscillation. Because the series reactor Plus supplies the necessary damping using a resistor, the low loss of the powder core is no longer a disadvantage now but rather an advantage.

Note

Use of the powder core material

When using the low-loss powder core material, you will almost always have to use the series reactor Plus version. Without secondary winding or damping resistor, there is a considerable risk of manifestation of destructively large cable oscillation. If a series inductance in powder core material is used, measurement is essential; see Chapter "Suppression of cable oscillation (Page 104)".

5.2.4 Dimensioning the damping resistor

For optimum damping, e.g. according to "Figure 5-2 VSD_Plus_B: Elimination of the oscillating tendency with the series reactor Plus (Page 93)", the damping resistor must be matched to the circumstances of the plant.

You can find the corresponding instructions in the following chapters.

Adapting to the specific case is not complicated and also robust enough that even deviations by +50% and -40% do not have a major impact on the result. There is only a small number of influencing variables.

The following values must be defined:

- Resistance value ("Ohm value")
- Expected value of the power loss ("Watt value") of the (terminating) resistor

5.2.4.1 Resistance value

The resistance value ("Ohm value") is based on the following information:

- Inductance (mH) on the nameplate of the series reactor
- Type (three-legged reactor or single-phase design)
- Total capacitance from cable and motor against PE

There are no additional influencing factors on the resistance value. Neither infeed, power nor size of the DC link system play a role.

Inductance (mH) on the nameplate of the series reactor

The inductance is the three-phase current inductance specified on the nameplate.

Type

We distinguish between the following two types:

- Three-legged reactor
- Single-phase design

The types are briefly described below.

Three-legged reactor

① Upper common magnetic yoke for all three phases
② Return yoke for magnetic flux does not exist
③ Upper common magnetic yoke for all three phases

Figure 5-5 VSD_Plus_G

Three-legged reactors do not have a return conductor for the magnetic flow. This is why they only use a fraction of their nameplate inductance against the common mode currents that are to be dampened. They usually have a laminated core. The distinctive feature, however, is the shared upper and lower yoke that connects the three legs with one another as well as the missing leg for the return flow. The material, such as laminate, powder composite, sinter has no influence on the resistance.

Single-phase design

Separate magnetic yokes for each phase; return yoke for magnetic flux does not exist independently for each phase.

Figure 5-6 VSD_Plus_H

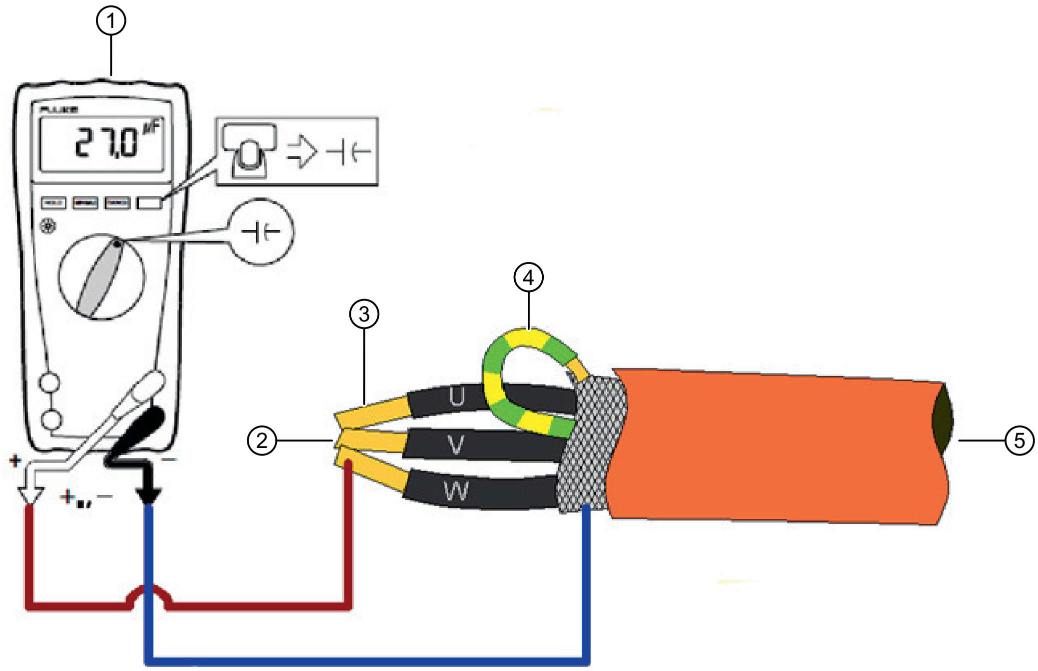
Often found in so-called "pot core design". Each phase has its own magnetic return conductor here. For those currents which result in oscillations, the nameplate value of the inductance therefore remains.

Total capacitance from cable and motor against PE

This is the capacitance of the common phase conductors against shield and PE. The total capacitance is usually not known a priori. For dimensioning the terminating resistor, the total capacitance should be available with an accuracy of ±30%.

There are two approaches to determine the total capacitance:

- Approach 1
  The information about the capacitance per meter of cable and the information about the motor capacitance is reliably provided by the manufacturers. The figure VSD_Plus_I below describes which capacitance is meant.
  - For shielded single conductors, the "meter information" of the core capacitance must be multiplied by 3. All three capacitance values are parallel.
- Approach 2
  The secure approach for determining the capacitance is the measurement. Commercial multimeters with capacitance function are suitable for this task.
  - Make sure that the entire connection is established from the series reactor all the way to the motor. The motor must be connected.
  - Remove the cable from the reactor terminal.
  - Connect the PE wire of the cable to the shield.
  - Connect the measuring instrument according to figure VSD_Plus_I.



① Usual multimeter with capacitance measurement function
② Disconnect the cable at the series reactor end
③ Join all three phase wires together
④ Connect PE wire to the cable shield
⑤ Make sure that the cable has regular connection to the motor

Figure 5-7 VSD_Plus_I: Measurement specification for measuring the relevant total capacitance

The following key points can be used to estimate the total capacitance:

- 1 meter of shielded, three-core power cable has a capacitance of ca. 0.25 nF/m to 0.8 nF/m, depending on the cross-section (mm^2 copper). A larger cross-section of the same cable series has a greater capacitance.
- Motors have a capacitance that is often linked to the rated torque. 0.1 nF/Nm can be considered as an approximate guide value.
  Example:
  A spindle with 15 Nm rated torque can show a capacitance that is close to 1.5 nF.

Depending on the cable length, cross-section and size of the motor, a total capacitance value could range from 5 nF to 80 nF. The measurement must only be conducted at the first machine. The result can be applied to the remaining plants of the series.

The Ohm value of the damping resistor is therefore derived from:

$$R_{\text{Damping}} = \text{Reactor type factor } 230 \sqrt{\frac{L_{\text{series}}}{C_{\text{total}}}} \quad [\text{Ohm}]$$

Reactor type factor	0.65 for three-legged reactor 1.0 for single-phase design (See section "Type")
L_{series}	Inductance of the series reactor in mH, not in henry (See section "Inductance (mH) on the nameplate of the series reactor")
C_{total}	Total capacitance in nF not in Farad (See section "Total capacitance from cable and motor against PE")

Example:

A total capacitance of 25 nF was measured.
The reactor is a three-legged reactor with an inductance (according to the nameplate) of 0.4 mH.

$$R_{damping} = 0.65 \cdot 230 \cdot \sqrt{\frac{0.4}{25}} = 18.9 \text{ ohm}$$

Note

Rounding of the value

Because damping is robust with regard to moderate parameter deviations, the numerical value from the equation above can be rounded up to a commercially available resistance value.

5.2.4.2 Expected value of the power loss of the damping resistor

Expected value of the power loss ("Watt value") is based on the following information:

- Total capacitance from cable and motor against PE
- Pulse frequency
- DC link voltage

There are no additional influencing factors on the resistance value. Neither the size of the DC link system, nor power or speed of the motor play a role.

The expected value of the power loss of the damping resistor is therefore calculated as follows:

Power loss = $Factor_{UDC\,link} \cdot 500{,}000V^2 \cdot C_{sum} \cdot f_{PWM}$ [W]

$Factor_{UDClink}$	1.0 for DC link voltage ≤ 600 V 1.5 for DC link voltage > 600 V
C_{total}	Total capacitance in Farad [F]
f_{PWM}	Pulse frequency (p1800) in hertz [Hz] For PWM switchover, use the highest provided PWM frequency

Example:

A total capacitance of 25 nF was measured. A DC link voltage of 650 V is intended and a PWM frequency switchover from 4 kHz to 8 kHz is set up.

Power loss = 1.5 · 500,000V² · 25 µF · 8 kHz = 1.5 · 500,000V² · 25 · 10⁹ · 8,000 Hz = 150 watts

The expected value of the power loss determined in the equation above is the basis for the balance of the control cabinet air-conditioning and dimensioning of the cable cross-section for the secondary winding and the connecting cable to the damping resistor. The expected value of the secondary current is calculated according to the following formula:

$$\text{Secondary current rms} = \sqrt{\frac{\text{Power loss}}{\text{Damping resistor}}} \quad [A_{eff}]$$

Power loss	According to result from above in [W]
Damping resistor	Numerical value according to result from above in [Ohm]

Example: With the numbers from the example above, the result is:

$$\text{Secondary current rms} = \sqrt{\frac{150}{18.9}} \quad [A_{eff}] \; = 2.9\ A_{eff}$$

For the calculated current of 2.9 A_{rms}, a copper cross-section of 1 mm² is usually considered to be adequate. The small conductor cross-section confirms the estimate that the additional workload for the series reactor Plus is moderate.

Note

Over-dimensioning of the load rating recommended

For reasons of ruggedness, we recommend a load rating that is greater by a factor of 2-3 when buying the damping resistor; see Chapter "Recommendations on the type and connection of the damping resistor (Page 102)".

5.2.5 Recommendations on the type and connection of the damping resistor

5.2.5.1 Load rating of the damping resistor

For reasons of ruggedness and service life, the load rating ("Watt value" on the nameplate) of the damping resistor should be two to three times greater than the expected value of the power loss provided above. It is not only permissible but often also useful to set up the resistance using a series or parallel connection consisting of the appropriate number of individual resistors.

Note

Recommendation on the surface for heat dissipation

Most resistors only reach their thermal load capacity when they are installed on a suitable surface for heat dissipation.

We have the following recommendations for the contact surface:

- Planar
- Good thermal conduction (e.g. aluminum, control cabinet wall, heat sink, etc.)
- Adequate size (> 3 dm^2)

If necessary, use a thermal paste during installation.

5.2.5.2 Voltage strength

Voltages up to the level of the DC link voltage can occur at the resistor.

Make sure you provide adequate clearances and creepage distances to the PE potential.

The same applies to the voltages between the connectors. The voltage strength of the resistor and its connectors should be at least 1.5 times the DC link voltage.

5.2.5.3 Parasitic inductance

The frequencies absorbed by the damping resistor are typically in the range of multiple 10 kHz. It must therefore be designed so that its parasitic inductance is as low as possible.

Suitability:

- Resistors made of wound wire are not suitable for the reasons listed above.

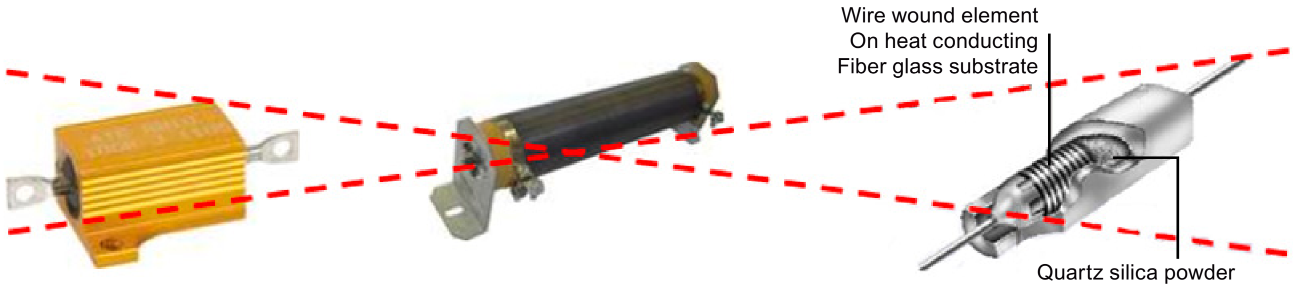


Figure 5-8 VSD_Plus_J: Examples of resistors we do not recommend made of wound wire (not recommended for this application)

- Thick-film resistors, for example, are very suitable.
  Their parasitic inductance is in the range of only a few μH.

Figure 5-9 VSD_Plus_K: Examples of well-suited resistors (well suited for this application)

5.2.5.4 Cable routing to the damping resistor

Unshielded cables are acceptable for short supply lines to the damping resistor. However, the individual wires should be twisted.

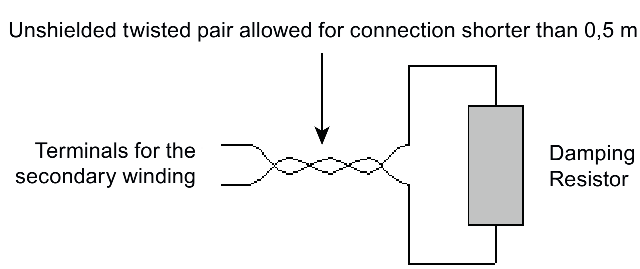


Figure 5-10 VSD_Plus_L: Cable routing to the damping resistor for short cable lengths

A two-wire, shielded cable is to be used for longer supply lines. The shield should preferably be applied at both ends. If it is not possible to apply the shield support at the terminating resistor end, it is acceptable to apply a shield at the reactor end only.

5.2.6 Control measurement of achieved damping

The procedure described here for dimensioning the resistor is permissible and reliable if the total capacitance was calculated correctly. If you are not certain, we recommend a technical measurement check during initial installation of the reactor with damper winding. The check consists of voltage measurement with an oscilloscope.

Note

Carrying out the measurement

It is sufficient to only take the measurement of the first machine in a series as a sample. Series testing is not necessary.

5.2.6.1 Suppression of cable oscillation

The following is a description of how you can determine suppression of the cable oscillation.

Procedure:

- Measuring point is the contact point between reactor output and a phase wire of the motor cable to earth. Measurement at one phase conductor is adequate.
  For additional information, see the following figure VSD_Plus_M.
- Use voltage-proof probe with an insulation capacity against PE of at least 1500 Vrms. Connect PE ground clip of the probe to PE.
- Set time basis of the oscilloscope to between 1 ms and 2 ms.
- Operating state of the drive: Speed specification zero. Set pulse enable. Regulated standstill in no-load operation is sufficient.
- The result is to be the same as seen on the right in "Figure 5-2 VSD_Plus_B: Elimination of the oscillating tendency with the series reactor Plus (Page 93)" and must not show the undampened oscillations on the left in the same figure.

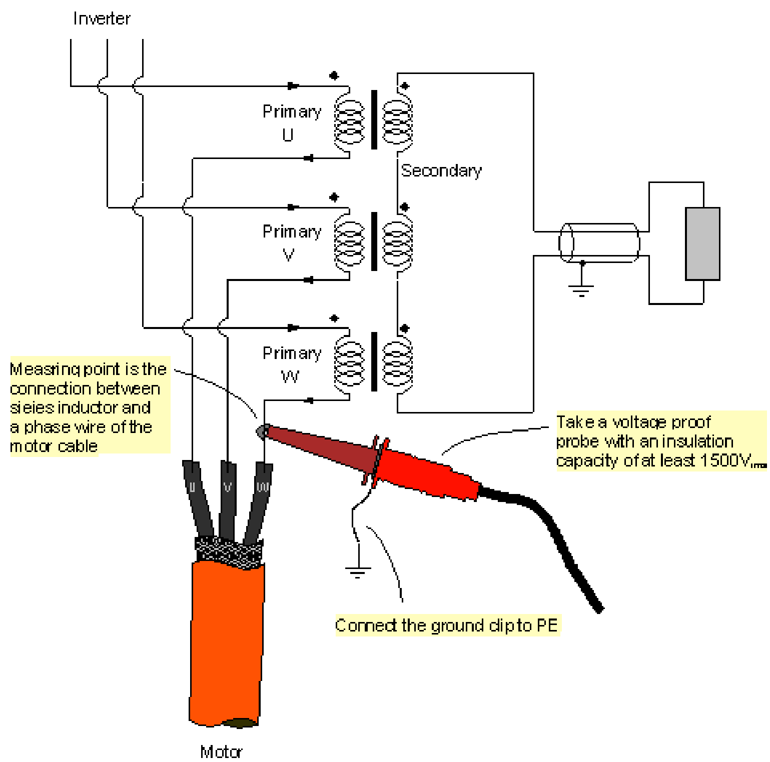


Figure 5-11 VSD_Plus_M. Measuring point for testing the damping

5.2.6.2 Safe operation of the damping resistor

Below you will find a description of how to ensure that the damping resistor is not overloaded.

Procedure:

- Operating state of the drive:
  - Speed specification zero
    (regulated standstill)
  - Set pulse enable
    (neither speed nor torque are necessary, no-load operation at standstill is sufficient.)
- Measuring the resistor temperature:
  We recommend using a cheap, commercial non-contacting thermometer.

5.2.7 Instructions for the reactor manufacturer

Forward this chapter to the reactor manufacturer.

The descriptions facilitate communication and the preparation of bids.

5.2.7.1 General electromechanical requirements

Note the following electromechanical requirements:

- Terminal board, preferably terminal strips for the required cable cross-section.
  The cable cross-section is either obtained from the rated motor current or from an agreement made with the customer.
- Shield support, preferably shield stopper plate for these cables:
  - Incoming cable
  - Outgoing cable
  - Connecting cable of the damping resistor

  For more information on the shield support, see the converter description.
- Touch protection, if there are any open live components
- Touch protection, if the user has free access to the reactor and the reactor has hot surfaces
- Shielding against electromagnetic leakage fields, if the series inductance is located close to sensitive signal paths

The paragraphs below describe those aspects that have been added in addition to the general recommendation of the Chapter "Three-legged laminated core reactor versus powder core pot design (Page 96)" due to the secondary winding.

Both types, three-legged laminated core reactor and powder pot core reactor, can be equipped with a secondary winding without any problems:

- Arrangement on a three-legged laminated core reactor

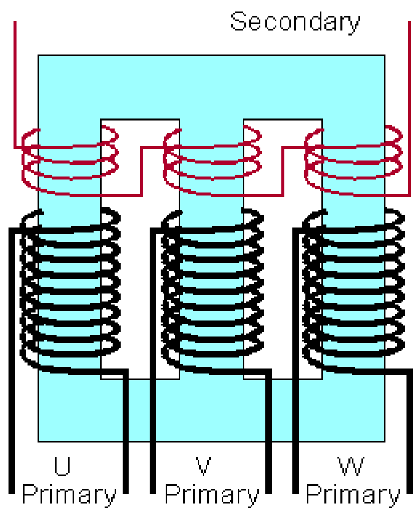


Figure 5-12 VSD-Plus_E: Basic arrangement of the secondary winding in a three-legged reactor (e.g. made of electrical steel)

- Arrangement on a powder pot core reactor

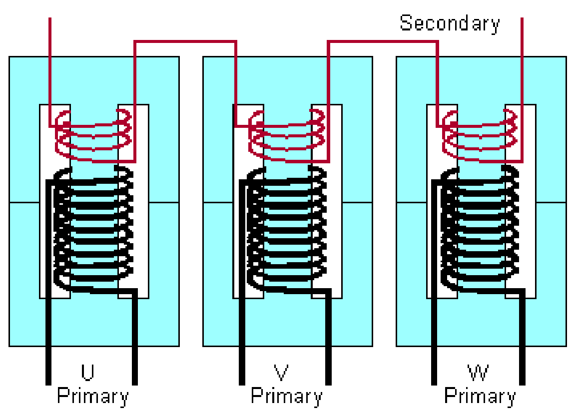


Figure 5-13 VSD-Plus_F: Basic arrangement of the secondary winding in a reactor in pot core design (e.g. made of powder core material)

5.2.7.2 Instructions on the design

The reactor manufacturer must observe the following specifications for the design:

Primary winding

Pay attention to the following specifications:

- Inductance as standard (for reactor without secondary winding)
- Core material, sheet thickness, loss factor: No restriction due to series reactor Plus type

- All three primary windings with the same number of windings (identical to one another), as standard
- Current-carrying capacity as usual
- Magnetic behavior (saturation, frequency behavior, etc.), no additional restrictions due to series reactor Plus type

Secondary winding

Pay attention to the following specifications:

- Note winding direction
- Number of coils of a secondary winding = 1/3 the number of coils of a (single) primary winding (rounded off to integer number of coils)
- Current carrying capacity:
  If the configuration is still incomplete, you can work with the following placeholders:
  - For 4 kHz PWM: 3 A_{rms}
  - For 8 kHz PWM: 6 A_{rms}
  - For 12 kHz PWM: 9 A_{rms}
  - For 16 kHz PWM: 12 A_{rms}
  - For cable lengths of more than 50 m, we recommend adding 50%.
  - For cable lengths of more than 100 m, we recommend adding 100%. Alternatively, you can contact Siemens.
- Connecting secondary winding in series U_sec – V_sec – W_sec
- Test voltage to primary winding: 2 kV_{rms}
- Test voltage to earth: Same as primary winding

Arrangement of the secondary winding

Preferably concentric design of primary and secondary winding (see sketch in figure below) to achieve a good coupling between the two windings.

For more detailed information, see the figure below.

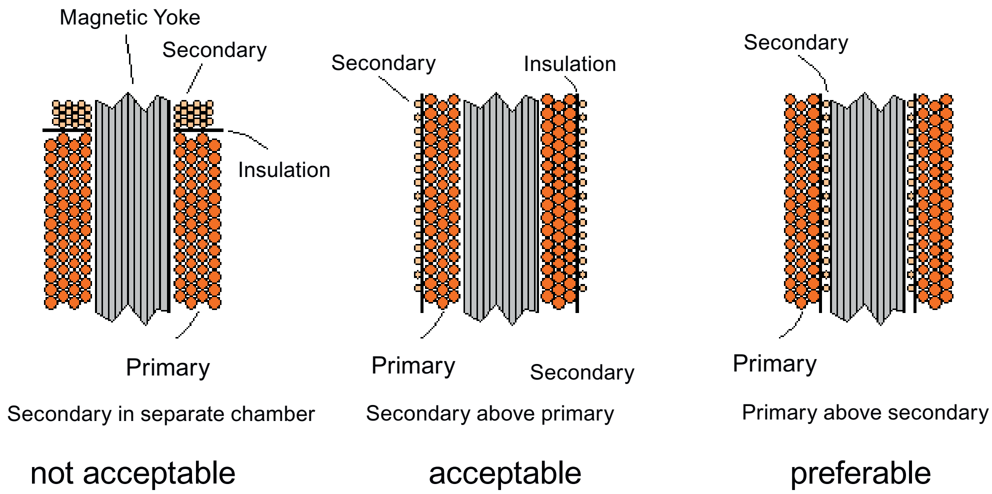


Figure 5-14 VSD_Plus_M: Arrangement of the secondary winding on the reactor yoke

5.2.7.3 Check winding direction

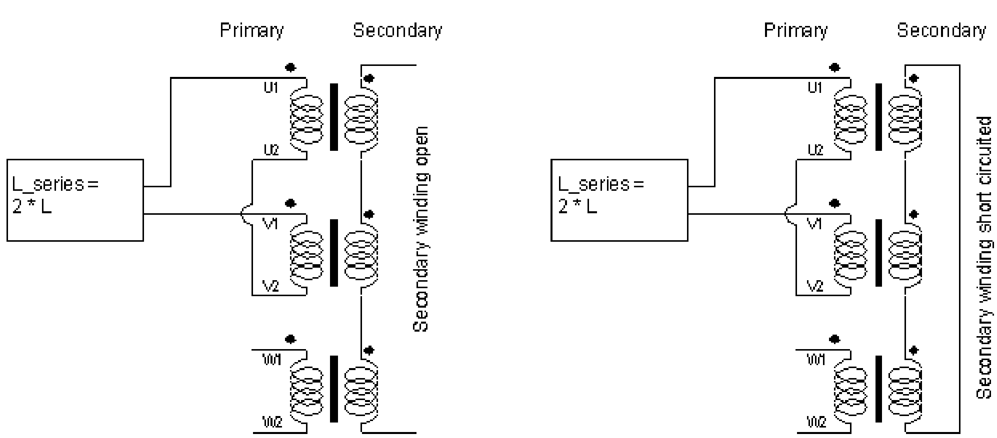
The following information refers to checking the winding direction in quality assurance.

The secondary winding only serves its intended purpose when it is poled correctly in relation to the primary winding and is connected correctly within itself in series. This is why it is important to check correct polarity. The actual function of the series reactor is its inductance in relation to the operational three-phase currents. The three-phase current inductance is not impaired by a secondary winding with correct polarity.
This characteristic can be used to very easily check the correct polarity of the secondary winding.

Note

No change of the three-phase current inductance

The three-phase current inductance must not change due to short-circuiting of the secondary winding.



Inductance must not change, when secondary winding is short circuited

Figure 5-15 VSD-Plus_N: Test instruction to ensure correct polarity of the secondary winding

Proceed as follows:

- Connect the inductance measuring instrument according to the figure above to the series connection of the primary coils U and V.
  The displayed value should be twice the inductance value given on the nameplate (two coils in series).
- Short-circuit the secondary winding.
  The displayed inductance must not change. Permissible change less than 3%.

Note

Secondary winding

The "secondary winding" always refers to the series connection of all three individual secondary coils. This means that instead of the terminating resistor, the short-circuit is switched.

- Connect the inductance measuring instrument to the series connection of the primary coils V and W.
  Repeat the procedure.
- Connect the inductance measuring instrument to the series connection of the primary coils W and U.
  Repeat the procedure.

5.3 Current and frequency-related stress

- **Maximum fundamental:**
  The series inductance must not go into saturation up to a maximum load of 110% of the maximum current (p0323 or p0338 or p0640) specified in the motor data sheet and, after this current level, must still show at least 90% of its rated inductance value (0.9 · L_reactor at 1.1 · maximum current).
  This must apply for the complete frequency range from DC up to the maximum three-phase frequency. Neglecting the slip frequency, the following applies: $f_{max\_three\text{-}phase}$ = p0322 / 60 pole pair number
- **Fundamental of the continuous current:**
  The series inductance must be able to conduct the rated current specified in the motor data sheet in S1 uninterrupted duty. It is not permissible that it overheats when it conducts this current.
  This must apply for the complete frequency range from DC up to the maximum three-phase frequency. Neglecting the slip frequency, the following applies: $f_{max\_three\text{-}phase}$ = p0322 / 60 pole pair number
- **Harmonics:**
  At the same time, and in addition to the "continuous current fundamental wave" mentioned above, the series inductance must be able to conduct a harmonic current.
  The harmonic current is generated by the pulse frequency. It is independent of the operational current and occurs even in no-load operation. It can be considered as an additional alternating current with constant rms value: Its size depends on:
  - Total leakage inductance including series inductance, see Chapter: "Leakage inductance(s) and series inductance (Page 48)".
  - Pulse frequency
  - DC link voltage

  The rms value can be estimated for dimensioning the reactor losses with the following simplified formula:

$$I_{PWM}\ \text{eff} = \frac{UZK}{45 \cdot L_{Summe} \cdot f_{PWM}}\quad [A_{eff}]$$

UDC link:	DC link voltage
L_{total}:	Total leakage inductance including the series inductance in mH, not in henry
f_{PWM}:	Pulse frequency (p1800) in kHz not in Hz
	For PWM switchover, use the lowest provided PWM frequency

Example:
Assuming a motor with a self-inductance of 0.2 mH and using the numbers of the examples above (L_{series} = 0.4 mH, UDC link voltage = 650 V and PWM switchover between 4 kHz and 8 kHz):

$$I_{PWM}\ \text{eff} = \frac{650}{45 \cdot (0{,}4 + 0{,}2) \cdot 4}\ [A_{eff}]\ = 6A_{eff}$$

The frequency of the harmonic current is twice the pulse frequency.

5.4 Voltage-related stress

If a series inductance is used, then the accumulated voltage stress, in relation to the motor terminals in Chapter "Voltage stress (Page 123)", shifts from the motor terminals to the input terminals of the series inductance. As a consequence, the voltage stress at the motor terminals will also generally change. It is the responsibility of the motor manufacturer to evaluate as to whether the voltage stress at the motor has increased as a result of using a series inductance. The motor manufacturer must then design the motor for this increased stress.

If the series reactor is used to reduce the field weakening current for synchronous motors, then the increase in the fundamental wave voltage at the reactor output should be observed, according to Chapter "Conditions and criteria for using a series inductance (Page 60)".

In general, the EMF is fed through to the motor terminals when using a series inductance. The feed-through results in increased voltage stress at the motor terminals as well as at the output terminals of the reactor. The magnitude of the additional voltage stress is described in Chapter "Line-ground voltage (Page 134)". You must ensure that not only the motor itself can withstand the increased voltage stress, but also the series inductance as well as cables and the connection system between series inductance and motor.

5.5 Sine-wave filter

Selecting, dimensioning and using sine-wave filters is extremely critical, because

- Resonance damping is generally low. The harmonics of the EMF and the side bands of the pulse frequency, in particular, can coincide with the resonance frequency of the sine-wave filter under steady-state conditions, resulting in uncontrollable overvoltages.
- The impedance present at the converter output can change significantly when using a sine-wave filter. As a consequence, the current controller can only be operated with a fraction of its usual bandwidth.
- Part of the output current flows in the shunt connection through the filter capacitors and is not available for the motor.
- The phase shift (in time) between the filter input and output causes a significant lag in the electrical rotating field angle. In synchronous motors, this can result in undesirable commutation errors.

With the exception of a few special constellations, we therefore strongly recommend that sine-wave filters are not used.

NOTICE
Motor damage caused by high voltage or converter damage caused by high currents
Generally, sine-wave filters have undampened resonance effects. If these are excited, then this results in high voltages at the motor or high currents at the converter. • Sine-wave filters in the complete system (converter, filter, motor) must be carefully checked and accepted. • It is absolutely not permissible "to market and/or commission" the system without this check having been made.

Temperature sensors 6

6.1 Function of the temperature sensors

In the following, temperature measurement involves measuring the temperature of the motor winding. It is the only reliable way to protect the winding against thermal overload. The average, thermally effective current is not automatically limited to the rated current in the drive. In order to obtain meaningful temperature monitoring, the signal of a temperature sensor must be read-in as reliable information about the thermal state of the winding, and be subsequently processed. This is the reason that we urgently recommend that the motor is equipped with one (or several) temperature sensor(s).

Note

For motors, where operation at high currents and low frequencies is not an exception, we recommend that three temperature sensors (triplet) are used.

The evaluation and the response to a temperature sensor signal can be parameterized in the SINAMICS converter in many ways. Please refer to "SINAMICS S120/S150 List Manual".

Note

For operation with SINAMICS converters, a temperature sensor is not absolutely necessary. If a temperature sensor is not available, then this can be appropriately parameterized. However, in this case, the motor winding is not directly thermally protected.

6.2 Temperature sensors that can be used

Analog temperature sensors, called "Temp-F" below, or switching temperature sensors, called "Temp-S" below, can be used for temperature protection. Both have their specific advantages and disadvantages:

- **Temp-F: Analog temperature sensor**
  Advantages:
  - Temperature is measured in °C
  - Allows the thermal utilization to be estimated
    (permits a temperature increase to be detected at an early stage and an alarm signal issued)

  Disadvantage:
  - It only detects the temperature in one of the 3 phases
  - It has a thermal lag (thermal time constant) when the winding temperature increases rapidly
- **Temp-S: switching temperature sensor (triplet)**
  Advantages:
  - It senses all 3 phases
  - It has a low thermal lag

  Disadvantage:
  - It does not allow the thermal load to be estimated, it only provides a "yes/no" response.

Using the evaluation modules available in the SINAMICS system, the two temperature sensor types – Temp-F and Temp-S – can be evaluated simultaneously.

Note

Switching temperature sensors in synchronous motors

Switching temperature sensors, which only monitor one phase, are not permissible for synchronous motors. If switching temperature sensors are used in synchronous motors, these must be triplets to monitor each phase.

Note

Especially for motors with a highly utilized winding (maximum wire load above 20 A_{rms}/mm^2), we urgently recommend that all three phases are monitored, and it is ensured that only a low thermal lag is involved.

6.2.1 Analog temperature sensor

Pt1000

The standard temperature sensor for applications with SINAMICS converters is the Pt1000. It is a component whose resistance changes as a function of the temperature and is available from several manufacturers. The component is in the form of a small glass diode. The Pt1000 is mechanically sensitive, and is completely uninsulated electrically. The following should be observed when using it as motor temperature sensor:

- The motor manufacturer must ensure suitable electrical isolation. Protective separation must be guaranteed (see Chapter "Protective separation (Page 119)").
- At the same time, the sensor must be thermally coupled to the winding as well as possible.
- For insulation tests at the motor, the two connecting cables of the sensor must also be short-circuited with one another and isolated from ground potential (also capacitively).

WARNING

Electric shock if there is no protective separation

Not only the actual temperature sensor, but also its cable routing must fulfill the requirements relating to protective separation. Otherwise, voltage flashovers to the signal electronics can occur.

- If safe electrical separation cannot be guaranteed, use a SME120 or SME125 Sensor Module External or the TM120 Terminal Module.

Note

Other temperature sensors are also supported in addition to the Pt1000. For the corresponding application and the necessary SINAMICS components, see the SINAMICS S120 manual "Control Units and Additional System Components".

6.2.2 Switching temperature sensors

PTC triplet

A PTC has a fixed temperature threshold, where the resistance transitions from a low-ohmic to a high-ohmic state. PTC triplets are available with switching thresholds in 5 °C steps. The switching threshold cannot be subsequently modified. The motor manufacturer must determine the switching threshold so that reliable thermal protection of the winding is provided. Further, the temperature threshold must be specified in the motor data sheet.

Only triplet elements should be used as PTC. For a triplet element, three individual PTCs are connected in series to form a lattice network. The lattice network has only two connecting wires (to the outside). In the high-ohmic state, the triplet element indicates that at least one individual PTC has exceeded the threshold temperature. The triplet element should be integrated in the winding, so that each phase is thermally assigned an individual PTC.

For synchronous motors, which are subject to high loads in the low speed range, we urgently recommend that a PTC triplet is used, because it detects the temperature in all three phases. It therefore reliably detects an overload in any pole position, even at standstill (see Chapter "Stall current (Page 66)").

Note

If a PTC triplet signals "overtemperature", it is not possible in the converter to evaluate how high the actual overtemperature is or at which threshold the signal occurred. Only if the PTC switching threshold is known, is it possible to conclude the minimum winding temperature.

Please note the following when selecting and integrating a PTC triplet:

- The motor manufacturer must ensure suitable electrical isolation. Protective separation must be guaranteed (see Chapter "Protective separation (Page 119)").
- The sensors must have the best thermal coupling to the windings.
- Type: PTC, thermistor triplet
  Resistance characteristic according to DIN VDE 0660 Part 303 and DIN 44082;
  Also refer to the documentation for the Siemens 3RN1 evaluation devices

---

Note

The PTC thermistors do not have a linear characteristic and are, therefore, not suitable to determine the instantaneous temperature.

Note

When selecting the PTC, it must be ensured that the required response behavior (a resistance value is exceeded at a specified threshold temperature) is applicable for the complete PTC triplet, and not only for the individual PTC.

Bimetallic triplet (NC contact)

Bimetallic triplets should be used as NC contact. Most of the properties are similar to the above mentioned PTC triplet.

- Temperature threshold: see PTC triplet
- Design as triplet: see PTC triplet
- Insulation and thermal integration into the winding: see PTC triplet
- Resistance when cold: 0 Ohm
- Resistance when hot: ∞

Note

Disadvantage of the bimetallic triplet

The disadvantage of the bimetallic triplet when compared to the PTC triplet is its larger size. As a consequence, they cannot be so closely coupled to the winding (thermally) and for fast temperature changes they have a longer lag than PTCs. Another disadvantage of the larger size is the risk of air being trapped in the winding.

Conclusion: **Bimetallic triplets should therefore only be used in exceptional cases. PTC triplets are the preferred solution.**

Note

Advantage of the bimetallic triplet

An occasional reason for using a bimetallic triplet is the fact that it can be connected in series with an analog temperature sensor. If analog temperature measurement is required in addition to the three-phase temperature monitoring, a measuring temperature sensor can be combined with a PTC triplet using the TM120 module without the need for bimetallic triplets.

6.3 Connecting

The SINAMICS drive system offers many options of reading-in temperature sensor signals. In addition to the interfaces, which can be directly assigned to the drive for motor temperature, in principle, users can also read in temperature sensor signals via the control I/O, e.g. S7 I/O. The response to an overtemperature condition to protect the motor (braking, pulse inhibit etc.) must then be implemented using suitable programming.

In this documentation, only those interfaces that can be directly assigned to the drive as motor temperature are described. The description is restricted to those aspects, which are relevant for the motor manufacturer when dimensioning the temperature sensor. Detailed descriptions of the interfaces and their functionality, which are kept up to date, are provided in the following documentation:

- SINAMICS S120/S150 List Manual
- SINAMICS S120 Manual for Booksize Power Units
- SINAMICS S120 Manual for Chassis Power Units
- SINAMICS S120 Manual for Control Units and Additional System Components

In addition, you will find recommendations on how to couple temperature sensors for built-in motors, for example, in the configuration instructions for linear and spindle motors:

- Peak and continuous load motors of the product family 1FN3 Configuration Manual
- Synchronous built-in motors 1FE1 Configuration Manual

6.3.1 Standard circuit for Siemens list motors

Pt1000 is used as temperature sensor for Siemens list motors. Inside the motor, it is connected to the 17-pin encoder connector, at pin 8 and pin 9. The temperature signal is fed to the encoder evaluation of the converter or to the SMC encoder evaluation module via the encoder cable. With the appropriate parameter pre-assignment (factory setting), a Pt1000 is expected at the pins.

In addition to the Pt1000, the KTY84 can also be evaluated with SINAMICS. If a temperature sensor other than Pt1000 is used, it must be explicitly agreed upon with the customer.

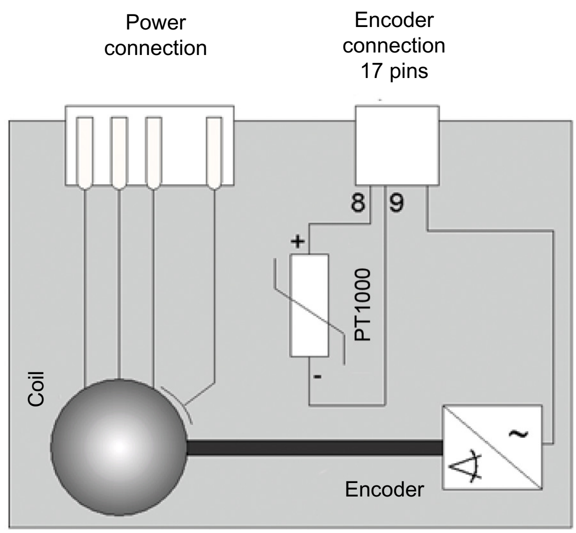


Figure 6-1 Standard temperature sensor connection for Siemens list motors

Note

Cable shield and ground potential

- Outside the immediate area around the winding, connecting cables to temperature sensors must always be routed so that they are shielded.
- The cable shield must be connected to the ground potential at both ends through a large surface area.
- Temperature sensor cables that are routed together with the motor cable must be twisted in pairs and shielded separately.

Note

Term "Siemens list motor"

In this chapter, the term "Siemens list motor" refers to a complete motor with bearings and rotary encoder.

6.3.2 Protective separation

SINAMICS converters have several temperature sensor evaluation locations. Each of these evaluation locations requires that the connected temperature sensor has "protective separation" from the winding according to the directives of DIN / EN 50178 (Protective Separation: SET).

Recommendation:

- Compliance with DIN EN 50178
- In addition to complying with design specifications (e.g. clearances and creepage distances), compliance with "protective separation" according to the standard can be proven using a routine test. We recommend conducting a surge voltage test.
- For DC link voltages up to 650 V DC: Test voltage 6 kV
- For DC link voltages above 650 V DC: Test voltage 8 kV
- The test must be performed with the temperature sensor integrated in the winding. The temperature sensor should be short-circuited, so that it is not damaged by capacitive currents during the test. There are service providers that perform this test.
- If a built-in motor is concerned, another surge voltage test must be performed after final assembly. It is permissible for the test voltage to be reduced to 80% in order to avoid shortening the service life of the insulation system.

WARNING

Danger to life due to electric shock

If a temperature sensor is connected to the standard SINAMICS temperature interface without protective separation, there is a risk of electric shock.

The standard SINAMICS temperature interface is not designed to offer protection from voltages that can occur in the motor in case of a fault. If the motor voltage were to penetrate the temperature sensor, it could propagate unchecked and spread to surfaces that can be touched.

NOTICE

Damage if there is no protective separation

Protective separation of the temperature sensor is absolutely mandatory, unless this has been expressly discussed with the customer and can then be subsequently omitted. In the motor data sheet a comment should be made that the temperature sensor has no protective separation.

NOTICE

Damage because an evaluation module is not used

If no protective separation of the temperature sensor according to DIN EN 50178 can be verified, then a suitable evaluation module of the type TM120, SME120 or SME125, for example, must be used to read the temperature signals into the SINAMICS converter.

6.3.3 Looping the temperature sensor into the 17-pin encoder connector

- This corresponds to the standard coupling for Siemens motors
- It does not require any additional hardware
- Only Pt1000, KTY84 or PTC triplet possible
- The connected temperature sensor must have safe electrical separation (protective separation required)

6.3.4 Connection at the EP terminal of the converter

The EP terminal is described in the manual for the converter.

Observe the following for the connection:

- It does not require any additional hardware
- KTY84, Pt1000, PTC triplet or bimetallic triplet possible
- For connection to the EP terminal, the connected temperature sensor must have protective separation. If the temperature sensor does not come with protective separation, an evaluation unit with protective separation function must be connected in between.

Note

Possible restrictions regarding the availability of the EP terminals for temperature sensor evaluation should be taken from the documentation listed above (see Chapter "Connection (Page 117)").

6.3.5 Connection at the Terminal Module TM120

Aside from the interface function for temperature sensors, the TM120 has no other function. It is connected to the drive lineup via the DRIVE-CLiQ bus. Details can be found in the SINAMICS S120 manual "Control Units and Additional System Components". It has integrated "protective separation", so that the requirement on the temperature sensor relating to protective separation in the motor can be ignored.

TM120:

- Represents additional hardware costs
- It allows the combination of Temp-F and Temp-S
- It allows temperature protection for stators connected in parallel (or partial winding systems)
- Pt1000/KTY84 and/or PTC triplet or bimetallic triplet possible.
- The connected temperature sensors do **not** have to comply with the requirements relating to "protective separation".

6.3.6 Connection to SME120 and SME125 Sensor Modules

The two Sensor Modules combine the encoder signal with the temperature sensor signals and convert them to comply with the DRIVE-CLiQ protocol. SME120 is for incremental encoders and SME125 for absolute (EnDat) encoders. Details can be found in the "Control Units and Additional System Components" manual. The modules have integrated "protective separation", so that the requirements on temperature sensors relating to protective separation in the motor can be ignored.

SME120 / SME125:

- Represents additional hardware costs
- It allows the combination of Temp-F and Temp-S
- It allows temperature protection for stators connected in parallel (or partial winding systems)
- Pt1000/KTY84 and/or PTC triplet or bimetallic triplet possible.
- The connected temperature sensors do **not** have to comply with the requirements relating to "protective separation".

6.4 Parameterizing alarm and fault thresholds for overtemperatures

The alarm and fault thresholds are only evaluated in the converter if an analog temperature sensor (Pt1000 or KTY84) is assigned to the drive. If only Temp-S sensors are being used, then only their "yes/no" information is applicable. Their thresholds are specified and cannot be set.

6.4.1 p0604 alarm threshold for overtemperature

If the analog temperature sensor (Temp-F) signals a temperature that is higher than that parameterized in p0604, an alarm is output. The alarm has no direct impact on the current limiting or pulse cancellation.

If, in the time parameterized in p0606 (preset default: 240 s), the temperature no longer falls back to below the alarm threshold, then the motor is shutdown as a result of overtemperature.

Note

For motors, whose temperature increases more rapidly, the time (240 seconds) pre-set as default in p0606 can be too long. It is the responsibility of the motor manufacturer to specify a shorter time when required; this must be appropriately listed in the motor data sheet.

If an analog temperature sensor is being used in the motor, the motor manufacturer must specify a value for the pre-assignment of the alarm threshold in the motor data sheet.

Note

Depending on the retraction strategy, the plant builder or the user is flexible in parameterizing the alarm threshold different than that listed in the motor data sheet, as long as it is certain that the motor is protected against overtemperature, even if the temperature rises rapidly.

6.4.2 p0605 fault threshold for overtemperature

If the analog temperature sensor (Temp-F) signals a temperature that is higher than that entered in p0605, a motor overtemperature fault is immediately generated. The default response to this fault is "OFF2".

Note

OFF2 function

- Instantaneous pulse suppression, the drive "coasts" to a standstill.
- The motor holding brake (if one is being used) is closed immediately.
- Switching on inhibited is activated.

The fault threshold must not lie below the alarm threshold.

If an analog temperature sensor is being used in the motor, the motor manufacturer must specify a value for the fault threshold in the motor data sheet.

7 Voltage stress

One of the most frequent causes of failure of electric motors is insulation failure, especially when operated from a converter. The stress caused by the voltage then destroys the insulation (at specific points). Generally, damage is identified at the following locations:

- Insulation damage with respect to the laminated core
- Insulation damage between the phases
- Insulation damage of feeder and connection conductors
- Insulation damage between the winding and temperature sensor

The sequence in which these have been listed reflects the frequency distribution in practice. In order to achieve the service life specified by customers, the insulation must sustainably and permanently withstand the stress caused by the voltage over the complete, permissible temperature range. It is the responsibility of the motor manufacturer to correspondingly design and test the installation. There are many production and test methods with which this objective can be achieved.

As a consequence, in this document, no directives regarding the design, production or testing are specified. Instead, the accumulated voltage stress is defined that is applied to the motor by the SINAMICS drive system, which the motor must be able to withstand. The accumulated voltage stress is referred to the motor terminals. The motor manufacturer takes over responsibility at the motor terminals.

In order to obtain the most transparent description of the situation, within the scope of this document, the accumulated voltage stress is described using the following three parameters:

- Voltage rate of rise dU/dt
- Line-line voltage
- Line-ground voltage

7.1 Target group

Systematic insulation failure of electric motors can cause enormous financial damage. As a consequence, the evaluation of the motor insulation is an extremely sensitive topic. For users that use Siemens components, generally there is no necessity to go into this complex topic in depth. For this group, using the catalogs or with help from Siemens personnel, it is adequate to check whether the combination of motor with the associated converter or drive system is permissible.

For projects involving third-party motors and SINAMICS drives, tests and/or mutual coordination are not necessarily a given. Applications and project partners can be very diverse. This is also true regarding experience with the service life of motor insulation, which partners, motor manufacturers and users involved in the project have. The range of experience regarding insulation stress for converter-fed motors can be covered by considering the following extreme constellations:

- Project team members with a high degree of experience
- Project team members who are being confronted for the first time with converter-fed motors

7.1.1 Project team members with a high degree of experience

The constellation is characterized by:

- Motor manufacturers who have frequently supplied motors to the customer involved.
- Customers who have frequently used the motors in applications with SINAMICS, SIMODRIVE or MASTERDRIVES converters.
- Active Line Modules are usually used for infeed to the converter drive group.
- Insulation failure for third-party motors remains in a range that can be tolerated.

An established relationship between a manufacturer of special motors and a customer from the machine tool sector can be considered as a typical example. The motor manufacturer has well-proven production and testing methods for his converter-fed motors. The fact that insulation failures do not represent a problem implies that the motor manufacturer has applied the appropriate amount of diligence to the sensitive topic of insulation stress.

Note

WEISS Spindeltechnologie

As part of the Siemens Company, WEISS Spindeltechnologie GmbH is, of course, a project partner with profound experience.

7.1.2 Project team members who are being confronted for the first time with converter-fed motors

The constellation is characterized by:

- Motor manufacturers who have either infrequently or never supplied motors for converter operation. For instance, their main motor production is for favorably-priced motors, close to the standard for line operation.
- Customers who either infrequently or never use converters to operate their electric motors. They generally use favorably-priced standard motors. Manufacturers vary depending on the quotation situation.
- There is no available experience relating to the infeed via Active Line Modules (ALM).

A manufacturer of compressor cooling units can be considered as an example. He wants to increase the energy efficiency of his products by using variable-speed motors. When using converters, he is confronted by new requirements placed on the insulation system of the motors; a topic that up until now he has not had to get involved with. In order to make it easier for this category of users to estimate whether their motors are suitable for converter operation, this document refers to widely established design features and testing methods.

Note

The notes regarding specific design features in testing techniques provided in this document are essentially in the form of examples. They should neither be considered to be mandatory nor complete. Their objective is to establish a close relationship to practice and to increase understanding of the topic. It doesn't explicitly involve regulations, which if complied with (the regulations alone), would automatically establish the required voltage strength.

7.2 Reference system

The SINAMICS S120/S150 drive system covers a huge bandwidth of

- drive power ratings (several 100 W up to several MW)
- Motor types (synchronous, induction, linear, torque, segment, etc.)
- Applications (positioning drives, main drives, pumps, etc.)
- degree of expansion (standalone up to 100 and more drives in a lineup)
- Infeed / regenerative feedback (basic diode infeed up to fully controlled, capable of energy recovery)
- Line reactor up to line filter (Clean Power Filter)
- Total cable length (10 m up to several km)

The individual versions can manifest significant differences in the voltage stress for the motor. The main factors that influence the voltage stress include:

- Magnitude of the DC link voltage (voltage stress increases linearly with the magnitude of the DC link voltage)
- Type of infeed (voltage stress increases in the following order: Basic Line Module, Smart Line Module, Active Line Module)
- Cable length of the motor involved (voltage stress is more critical for longer cables)
- Total cable length (voltage stress is more critical for longer cables)
- Type of commutation inductance
- Pulse frequencies (voltage stress is more critical for higher pulse frequencies)
- Type of line filter

It has been seen that motors that have established themselves in the market and operated from converter systems, are not tailored to a single, specific version of the drive system, but can be universally used. It is especially the operating companies that do not accept keeping a wide range of different spare parts, and therefore wish to use one and the same, standard motor for all of their various applications /Grein/.

To evaluate the voltage stress, this document is based on a configuration with Active Line Modules (ALM) as infeed. Motors, whose insulation is suitable, can then be used in conjunction with all other SINAMICS configurations.

Generally, it is not possible for users to clearly and reliably quantify factors (e.g. total cable length, line inductance,..) that influence the voltage stress. Only the DC link voltage is generally known.

As a consequence, in this document, no differentiation is made between the many possible system versions; instead, a voltage stress is specified that is obtained from the superset of the individual influencing factors. Only the DC link voltage is used as scaling factor. The following reference values should be used for the voltage stress:

- For motors connected to Booksize power units: $U_{DC\ link}$ = 720 V
- For motors connected to chassis power units: $U_{DC\ link}$ = 1035 V

Note

Booksize power units are available for rated currents up to 200 A_{rms}. For reasons of simplicity, the following classification can be assumed.

Motors up to a rated current of 200 A_{rms} are operated on Booksize power units; motors with higher rated current on chassis power units.

Only if it is explicitly agreed with a customer that the motor is operated on a lower DC link voltage is it possible to deviate from the above mentioned selection rule. The DC link voltage, used as basis to design the voltage strength, must be explicitly listed in the motor data sheet.

In addition to the high DC link voltage of 1035 V (for a 690 V line supply voltage), the chassis drive units are also available in a version with 720 V DC link voltage (=1.5 · 480 V, for a 480 V supply voltage). If the motor involved is only to be used with these drive units, then it could make sense that the customer and motor manufacturer both agree to adapt the requirements to the voltage strength. Also in this case, the DC link voltage used as basis to dimension the voltage strength must be explicitly listed in the motor data sheet.

7.3 Voltage rate of rise du/dt

With fast switching of converters, a wave propagates in the motor cable that is reflected at the end of the cable where it occurs as a short oscillation package. This phenomenon is known as cable reflection; see: Figure "Example of a line-to-line voltage at 720 V (Page 132)". The end of the cable is also the motor terminal. The voltage rate of rise that the wave can transport is often less than the voltage rate of rise directly at the converter output. Only in exceptional cases with a high frequency of cable reflection (> 2 MHz) are voltage rates of rise found which are similar to (or even higher than) those of the converter, even at the motor terminal.

The fast switching operation of the converter that arrives at the motor terminal as a wave with a sharp rise is already flattened within the motor after a few coil turns. This is because, compared to the cable, the inductances of the motor are several times larger. The voltage rate of rise therefore can be considered as the cause of insulation damage only if the damage is located within the coils located near the motor terminals.

Strictly speaking, the insulations of turns do not fail due to an excessively fast voltage change, but rather, always fail because of a voltage difference. This voltage difference between the individual turns of a winding occurs only because, like any signal, the voltage requires a certain amount of time to propagate in the winding (wave travel time).

In practice, due to the existing damping, the individual coils of a motor winding, which also always have a capacitance to ground, can be regarded as PT2 filters.

An input signal is filtered by the property of the PT2 element. This means that a jump becomes visible at the output only after a certain period of time.

In the worst case, the first turn of the first coil at the motor terminal input lies directly next to the last turn of the same coil ("random winding"). As a result, the two turns are isolated from each other only by their wire enamel. While the terminal voltage is applied on the first turn, the voltage applied on the last turn results from the PT2 filter behavior of that coil (with parasitic capacitance).

Note

Additional insulation in the winding overhang

If turns of different coils touch each other, in an extreme case, a wire which is near the motor terminal may be located next to a wire that is near the neutral point. In such a case, the motor is not suitable for converter operation.

- Make sure that no turns of different coils touch each other by providing additional insulation in the winding overhang.

The output voltage on the first coil is the input voltage of the next coil of the motor winding.

The output voltages of the individual coil sections can be determined approximately by simulating an LC chain link. To do this, check the voltage at each output over time.

The voltage at the input is strongly filtered already after the first LC link (see the following figure). This continues up to the neutral point. A certain amount of time elapses until the voltage changes at all at the respective output.

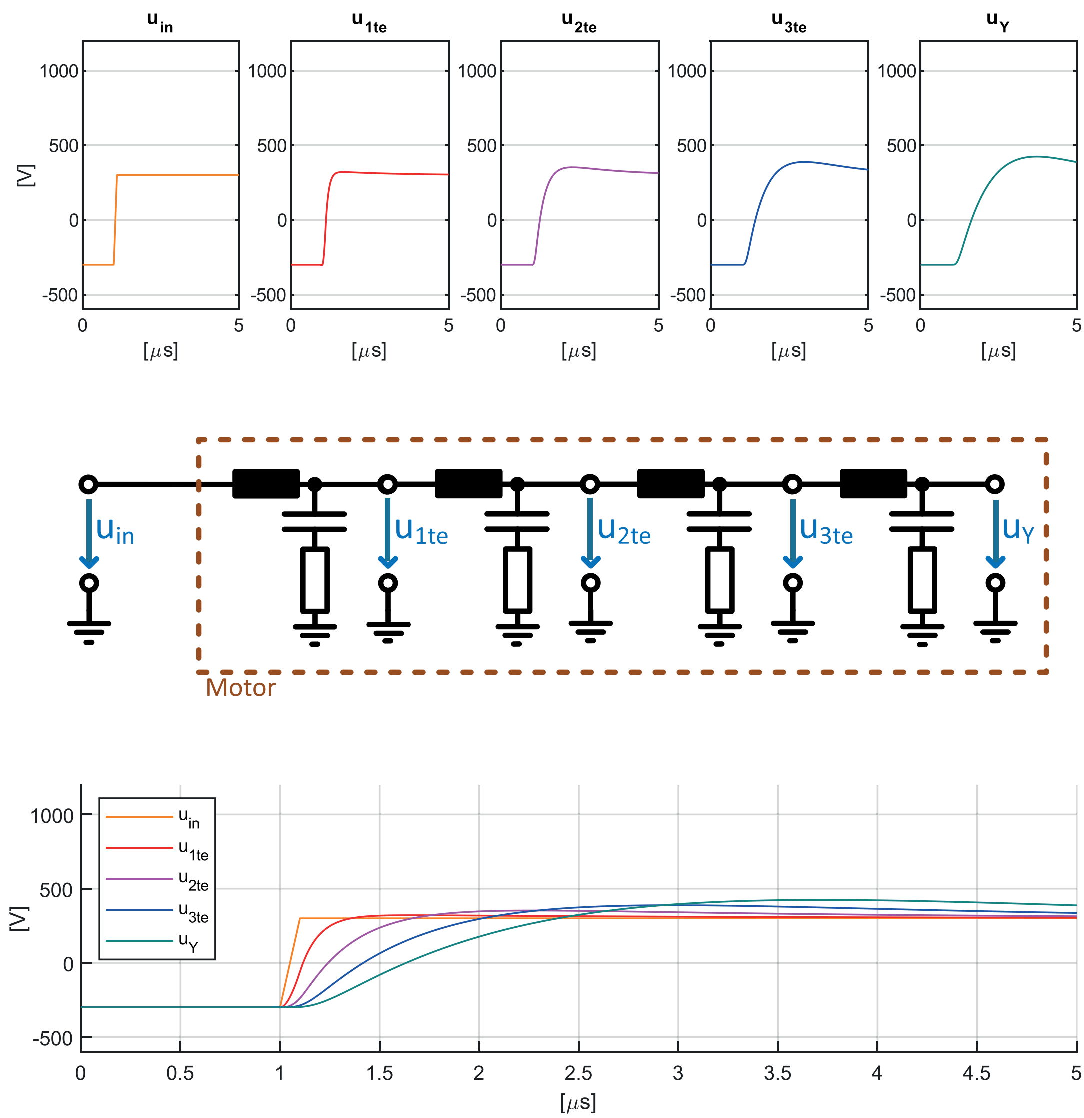


Figure 7-1 Almost ideal jump (ramp) without cable reflection; voltages at every coil output

In the worst case, the insulation stress between turns equals the difference resulting from the input voltage minus the output voltage of the first coil located directly at the motor terminal input. At the beginning (almost) the entire voltage excursion is present above the coil, and therefore also between the first and last wire of the coil. With time, this difference disappears (see the following figure).

The steeper the jump at the input is, the more voltage is applied above the first coil. For this reason, dv/dt is often referred to, even though it is the voltage difference that stresses the turn insulation.

However, it also follows that: As long as the voltage difference of a switching operation at the input is less than the insulation strength of the enameled wire, the voltage rate of rise (dv/dt) can theoretically be infinitely high without resulting in any damage to the turn insulation.

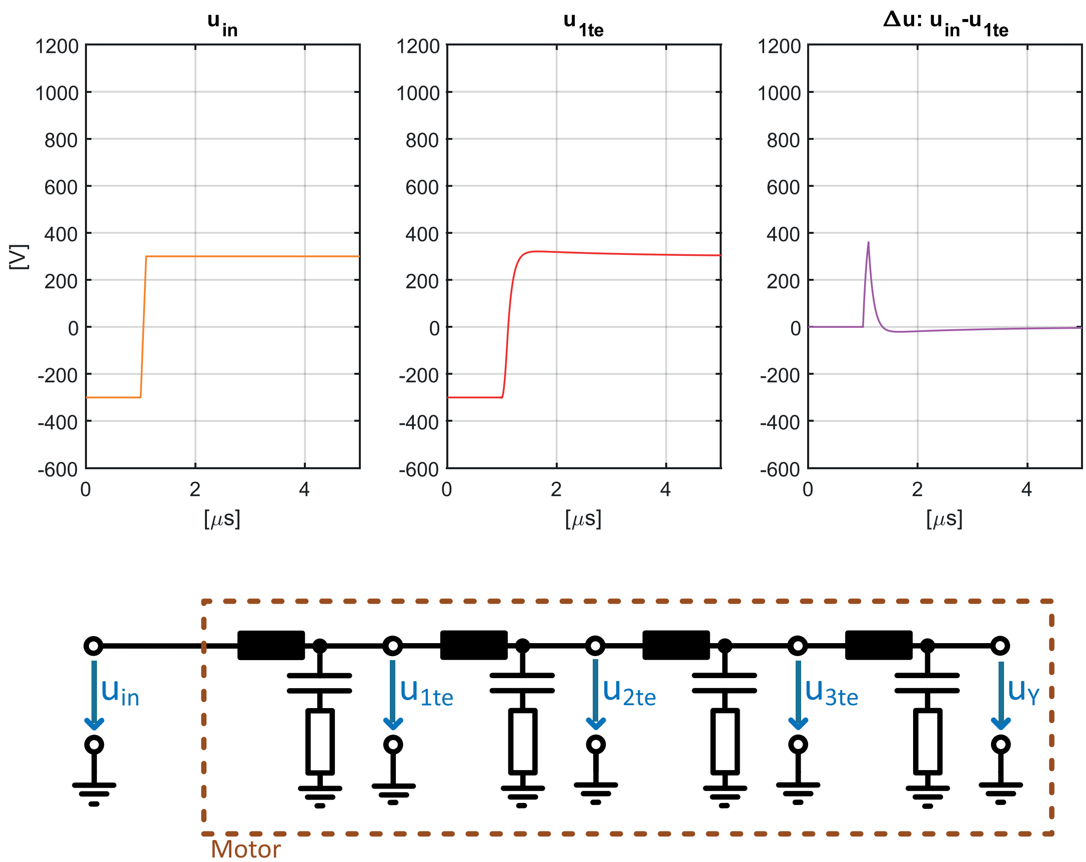


Figure 7-2 Almost ideal jump (ramp) without cable reflection; voltage difference above first coil

In reality, there are, however, also reflection processes at the motor terminal and at the converter output. The voltage jump generated by the converter leads to a traveling wave process on the cable between the converter and the motor terminal. A voltage oscillation with a frequency dependent on the length of the cable occurs at the motor terminal.

An extreme example of this is an oscillating frequency of more than 3 MHz (1 MHz is typical).

The voltage difference also can be calculated here (see the following figure).

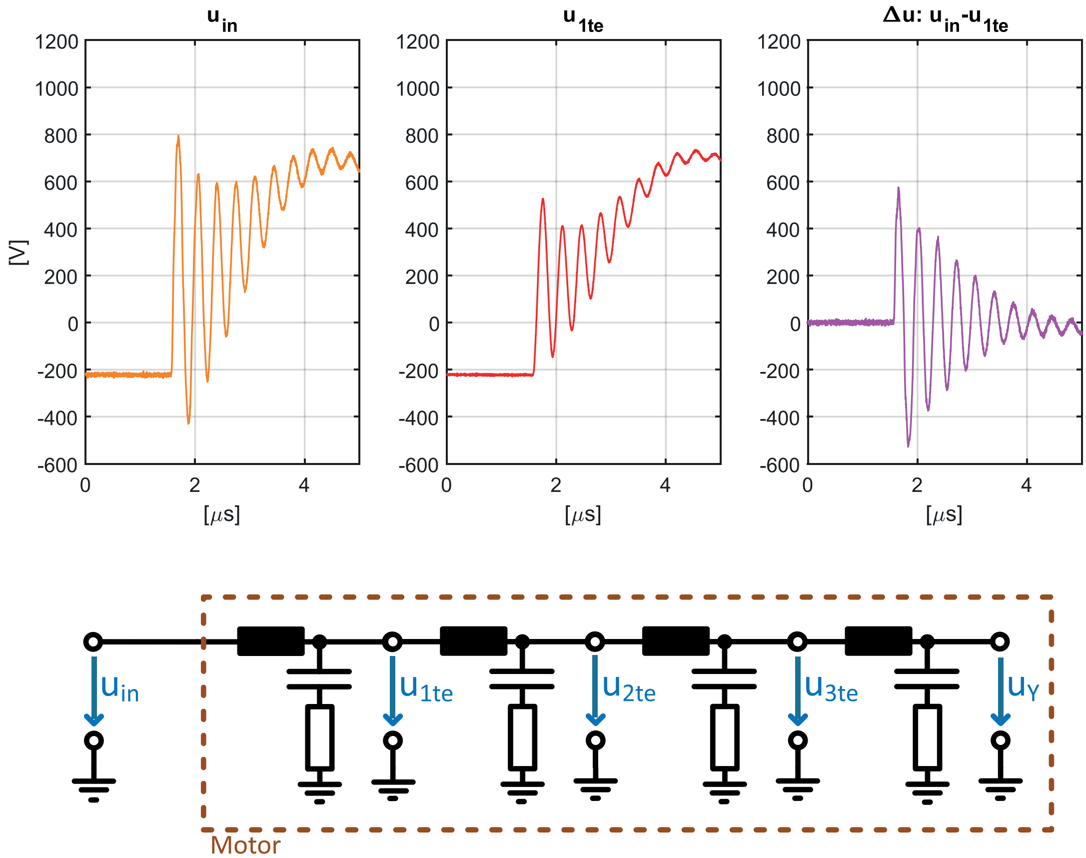


Figure 7-3 Real switching edge with cable reflection, voltage difference above first coil

In the end, the actual motor design is decisive for the maximum occurring or permissible voltage difference between the first and the last turn of the first coil. This means that the same input voltage can destroy one motor, but leave another motor undamaged (even with the same dialectric strength to ground).

In order to enable the motor manufacturer to dimension its insulation so that its motors can be reliably operated with converters, typical guide values are specified for SINAMICS converters. These values take into account that the stress for the motor winding not only depends on the switching speed, but also on the step height. The line-ground voltages at the motor connections are in this case relevant. These values, which can occur in the SINAMICS drive system under worst case practical conditions at the motor terminals, take into account the following:

- Fully formed reflection
- Frequency of cable reflections up to 2 MHz
- Weak damping of the electrical system oscillations of the DC link (to ground)

The insulation in the motor must therefore be dimensioned so that, when operated with SINAMICS converters, it can permanently withstand voltage rise times in the line-ground voltage at the motor for step heights at least corresponding to those listed in the following table:

Rated converter voltage	Time window 100 ns	Time window 200 ns	Time window 400 ns
3 AC 200 ... 230 V	-	-	-
3 AC 400 ... 480 V	900 V	1050 V	1260 V
3 AC 500 ... 690 V	1425 V	1660 V	2000 V

The following voltage changes result from the table per time window:

- For a DC link voltage U_{ZK} **= 720 V**

9 kV/µs	for steps up to 900 V	in a time window of 100 ns
5.25 kV/µs	for steps up to 1050 V	in a time window of 200 ns
3.15 kV/µs	for steps up to 1260 V	in a time window of 400 ns

- For motors connected to chassis power units, with $U_{DC\ link}$ **= 1035 V**

14.25 kV/µs	for steps up to 1425 V	in a time window of 100 ns
8.3 kV/µs	for steps up to 1660 V	in a time window of 200 ns
5 kV/µs	for steps up to 2000 V	in a time window of 400 ns

Here, the designation kV/µs is only the result of the division and the voltage changes in the specified time window and does not indicate a maximum voltage gradient. I.e. the dv/dt in 100 ns may very well exceed 9 kV/µs. It is only decisive that the voltage does not change by more than 900 V within 100 ns.

In case of doubt, a measurement of the actual voltage stress is always recommended in order to make sure that it is not too high due to the specific setup.

7.3.1 Widely established design-based countermeasures

Widely established design-based countermeasures

Especially those windings located close to the motor terminals are affected by a high voltage rate of rise (voltage gradient). For the winding areas that are located "further downstream" in the motor, the inductance of the first coils (together with the parasitic capacitances to ground) acts like a lowpass filter; this significantly reduces the voltage rate of rise. This is the reason that measures to protect motors against the voltage rate-of-rise especially involve the area of the first coils:

- Sturdy, insulated connection wires are used instead of simply extending the copper enamel wires to the terminals
- Phase segregators
- Double-enamel insulation of the coil wires
- Generously dimensioned clearances and creepage distances in the area of the connections (also behind the terminal board) and clearance to conductors associated with other voltage systems (temperature sensors)
- Windings are impregnated or encapsulated in resin

7.3.2 Known countermeasures as part of the drive application

- Series reactor between the converter and power cable
- Inductance values lie between 10 and 50 µH
- Technical requirements placed on the reactor, see Chapter "Qualitative requirements placed on a series inductance (Page 91)".

7.4 Line-line voltage

In steady-state converter operation, the line-line voltage can only assume three states: 0 V, $+U_{DC\ link}$ and $-U_{DC\ link}$. The switching pattern between these states is given by the pulse frequency, the modulation depth and the modulation type. The switching is associated with cable reflection. The extent of this also depends on the cable length. At the motor terminals, the reflection takes on the form of a decaying oscillation. The maximum theoretical overshoot can be as high as the step height itself (generally however, up to a maximum of 90%).

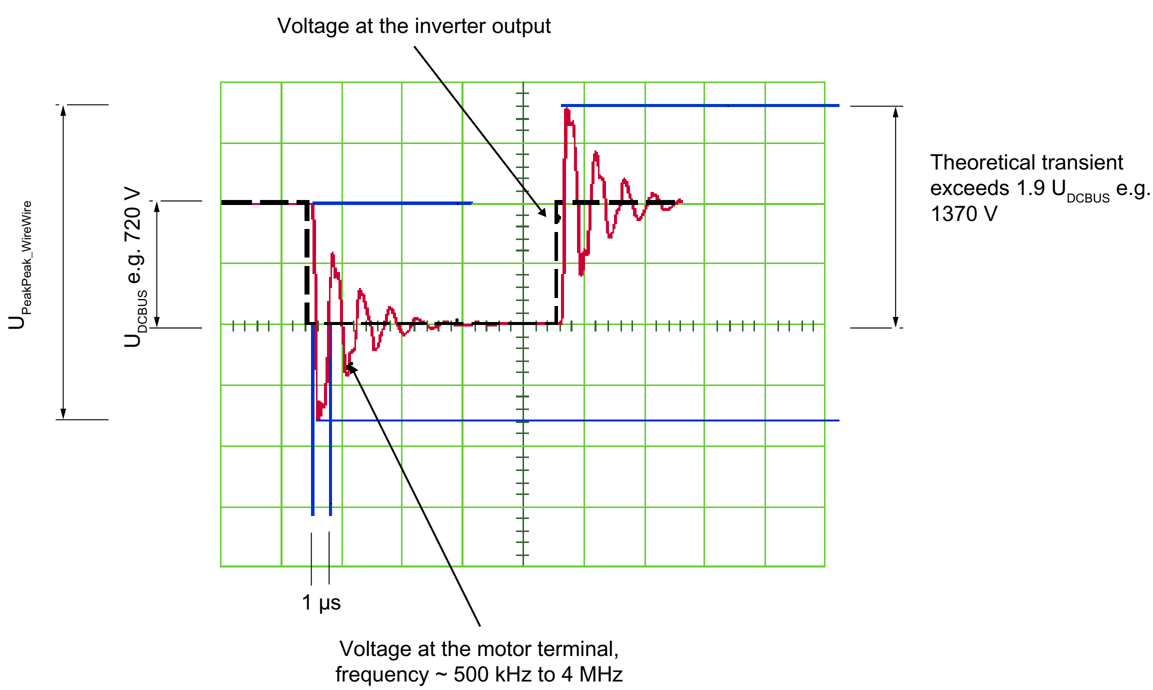


Figure 7-4 Example for line-line voltage at the motor terminals for a 720 V DC link voltage;overshoot caused by reflection at a long cable

The following permanent line-line stress occurs at the terminals with overshoots of $1.9 \cdot U_{DC\ link}$ and settling times with 2 – 8 periods in the frequency range 0.5 – 4 MHz:

1370 V transient overshoot magnitude for $\mathbf{U_{DC\ link} = 720\ V}$

The transient overshoot magnitude can be linearly converted for other DC link voltages.

For motors connected to chassis power units, the following is therefore obtained:

1970 V transient overshoot magnitude for $\mathbf{U_{DC\ link}}$ **= 1035 V**

Note

The insulating capability of insulation systems presently commercially used for low-voltage motors significantly decreases as the temperature increases. As a consequence, the insulating capability at the motor operating temperature is lower than at room temperature. This effect is frequently taking into account by increasing the required voltage strength at room temperature. Further, it has been shown to be practical that the peak-to-peak band that the line-line voltage assumes over a longer period of time is evaluated instead of the transient overshoot magnitude of an individual step. As a consequence, the following practical requirement is obtained regarding the line-line voltage strength (withstand voltage):

Upk,pk,LL = 2800 V at $\mathbf{U_{DC\ link}}$ **= 720 V**

Upk,pk,LL = 3800 V at $\mathbf{U_{DC\ link}}$ **= 1035 V**

7.4.1 Widely established design-based countermeasures

Overshoot caused by reflection – and its associated decay curve – predominantly occur in the high frequency range. This is the reason that here, just the same as for the voltage rate of rise, winding areas are predominantly involved, which are located close to the motor terminals. As a consequence, essentially the same countermeasures can be listed.

7.4.2 Widely established test methods

As a result of the galvanic coupling between the terminals, only transient test methods can be used. The surge voltage test is the most well known. In this test, the surge voltage is impressed in pairs with respect to the phase conductors. Several manufacturers offer surge voltage test units for 3-phase coils, which also supply information regarding the partial discharge strength.

Note

The result of the surge voltage test is only of real value, if it also supplies information regarding the partial discharge strength. A statement that the test object successfully passed the test procedure without any arcing is not sufficient. Suitable testing equipment must therefore also include a device to detect partial discharge.

A routine test is recommended.

7.4.3 Known countermeasures as part of the drive application

Countermeasures as for the topic of the voltage rate of rise, see Chapter "Known countermeasures as part of the drive application (Page 126)".

7.5 Line-ground voltage

The line-ground voltage is that element of the accumulated voltage stress, which places the highest demands on the motor insulation. It is the most frequent reason for insulation failure.

Contrary to the line-line voltage, the line-ground voltage depends significantly on the inductive and capacitive coupling between the DC link and ground. Frequently, no simple step patterns, which can be immediately identified, are formed; instead voltage characteristics that appear to be completely unorderly and without any clear association.

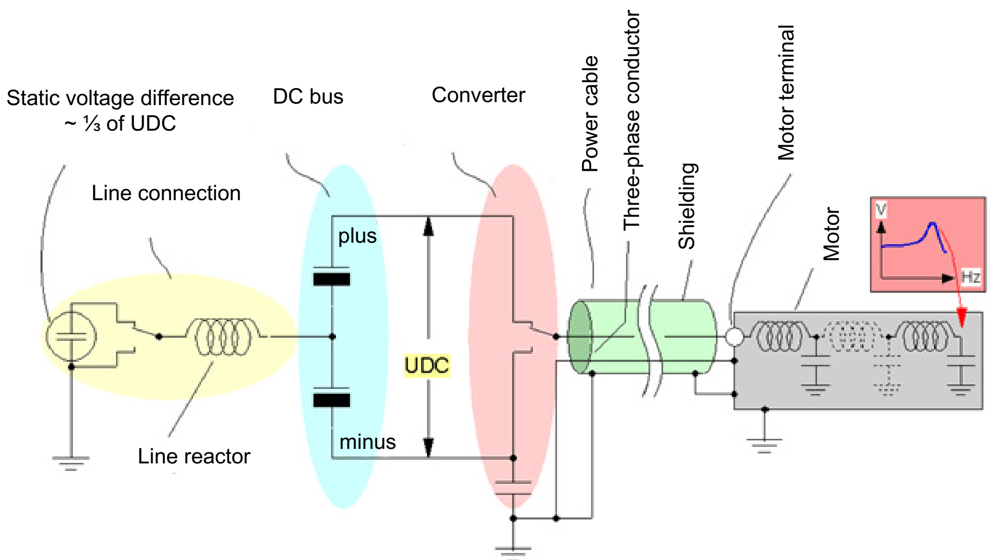


Figure 7-5 Simplified equivalent circuit diagram to explain the line-ground voltage

The highest amplitudes of the overshoot with respect to ground occur when all three phases switch simultaneously. This is the case for a low modulation depth; i.e. if the motor is stationary, or if it generates a low EMF. The simplified equivalent circuit diagram shown above describes the voltage excitation in this operating states for a system equipped with ALM. As all three phase conductors of the motor switch simultaneously, the conductors as well as also the switches can be merged to create a single element.

In a system equipped with ALM, a DC link is not rigidly connected to ground; however it can manifest oscillations with respect to ground through the commutation inductance and the parasitic capacitances to ground. In so doing, the voltage difference between the plus and minus busbars of the DC link remains constant. The voltage system of the DC link oscillates with respect to ground as a "single entity". This is why the oscillations are called "system oscillations". Frequently, they represent a large portion of the line-ground voltage stress.

The frequency of the system oscillation is essentially obtained from the commutation inductance and the total capacitance of the parasitic capacitances to ground. For a SINAMICS drive system, it lies in the range from 20 kHz – 200 kHz. Configurations with high natural frequencies of the system oscillation, frequently have a higher damping (attenuation), and manifest low oscillation amplitudes.

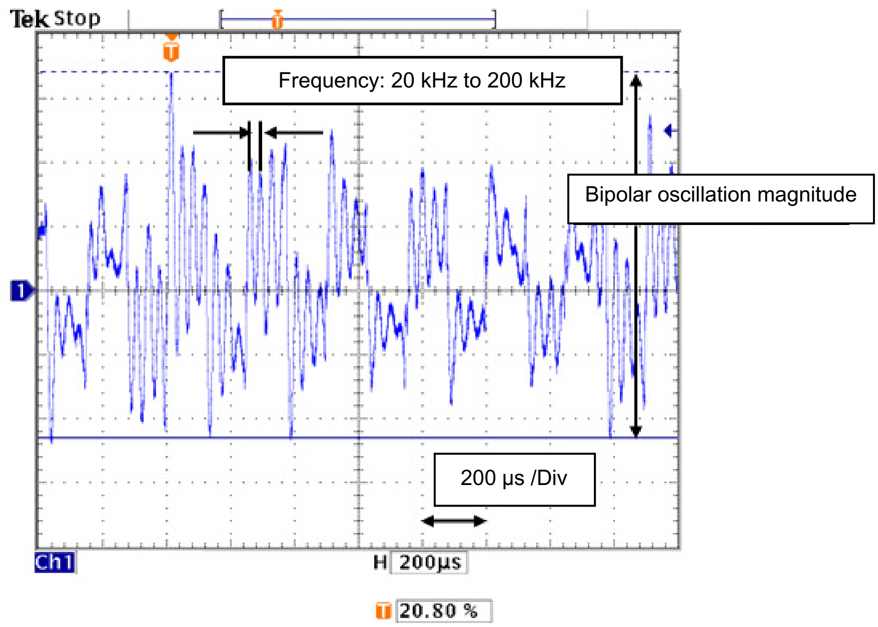
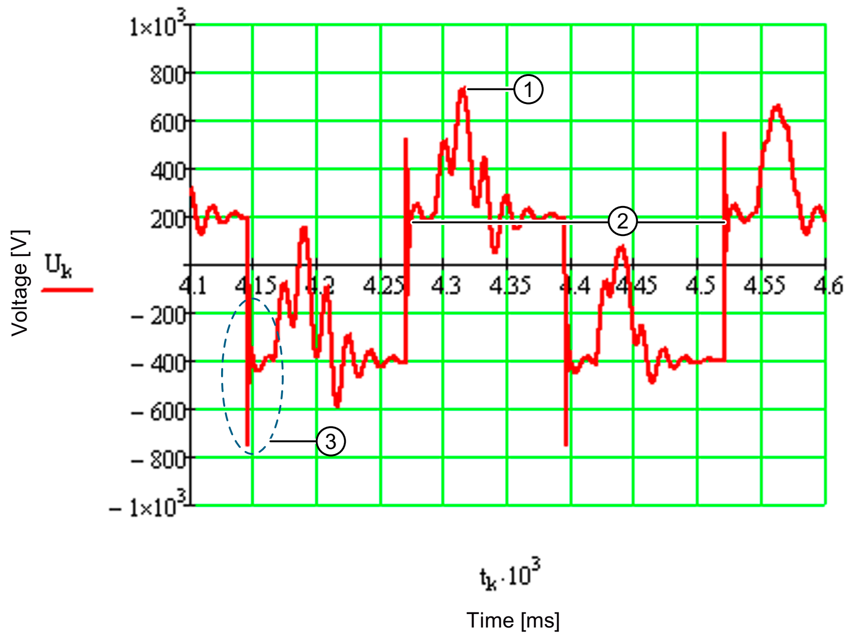


Figure 7-6 Example of a line-ground voltage at the motor terminals for a 720 V DC link voltage; system oscillation of the DC link (in this example) with a frequency of 27 kHz

The diagram above shows the low-frequency component of the line-ground voltage, which is generated by the system oscillation.

It has been seen that the clearance between the positive and negative maximum values of the system oscillation represent a significant influencing quantity when it comes to evaluating the voltage load. This influencing variable is called "bipolar oscillation amplitude" in this document.



① Peak of the low-frequency system oscillation
Typical frequency 20 ... 200 kHz

② PWM cycle

③ Cable reflection (for magnification, see figure below)
Typical frequency 0.5 ... 5 MHz

Figure 7-7 Example of the line-ground voltage at the motor terminal with UDC link voltage = 600 V
Active increase with ALM and AIM shown here

The figure above shows that a specific frequency occurs again and again. It is the preferred frequency with which the DC link system shifts in relation to the ground potential. The frequency is therefore referred to as "system frequency". It is determined by the sum of earth capacitances and the (common mode) inductance of the network connection whereby the earth capacitances are mainly determined by the total cable length. The amplitudes of the high-frequency oscillation packages of the cable reflection are added to the low-frequency system oscillations, see figure below.

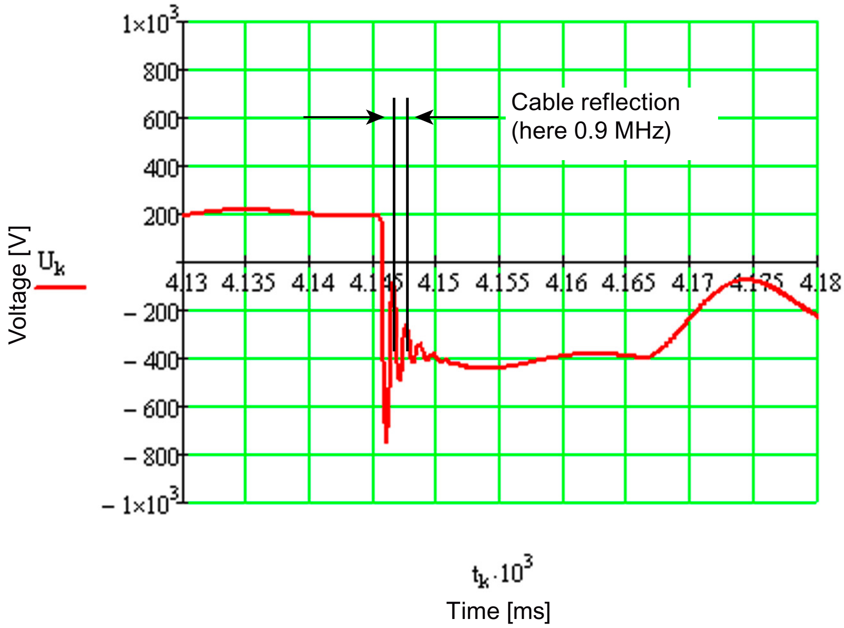


Figure 7-8 Magnification of the cable reflection from the figure above

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Note

Oscillation packages

Because the high-frequency oscillation packages of the cable reflection are shown as peaks rather than resolved oscillation packages in the unfocused time resolution of the voltage curve according to the figure "Example of the line-earth voltage at UDC link voltage = 600 V", they are often referred to as "voltage peaks" in the discussion. However, oscillation packages remain that occur in a justifiable manner as reactions of switching actions, though they may look like random peaks when viewed superficially.

In drive systems with ALM, the system oscillations can show greater amplitudes than the oscillation packages of the cable reflection if the system is strongly excited and only weakly dampened.

There, it has been seen that the following simplifications can be made to evaluate the line-ground voltage stress of commercially available, organic, low-voltage insulation systems:

When evaluating the line-ground voltage stress

- the bipolar oscillation amplitude is an informative quantity. Half of this value can be used as amplitude of periodic voltage stress with respect to ground.
- the high-frequency oscillation packages of the cable reflection can be ignored unless the first windings directly behind the motor terminals showed a ground fault during a damage analysis.

As a consequence, a value that is simple to handle can be derived from a somewhat confusing characteristic of the line-ground voltage.

Note

For all generally available low-voltage insulation systems, the voltage at the start of partial discharge decreases significantly as the temperature increases. A decrease of 30 ... 45% can generally be expected for a 100 K temperature rise. This must be considered when dimensioning and testing the insulation system.

Note

System oscillations can be significantly increased as a result of unfavorable properties of the commutation inductance – or inadmissibly long power cables. Especially the damping (attenuation) of the commutation inductance plays a decisive role. The values of the line-ground voltage stress mentioned above are only valid,

- if only the permitted line connection components for the particular configuration are used (commutation inductance, filter, etc.),
- if neither the permissible total cable length nor a permissible single cable length is exceeded
- if only connected to the permitted line supplies (TN, TT and IT line systems, however no line systems with grounded line conductor).

Motors with/without series inductance

For motors without series inductance:

In SINAMICS drive systems, the line-ground voltage stress measured over a longer period of time (≥ 100 ms) typically corresponds to a peak-to-peak value of:

- Upk, pk, LG = 1960 $V_{peak\text{-}peak}$ at UDC link = 600 V
- Upk, pk, LG = 2350 $V_{peak\text{-}peak}$ at UDC link = 720 V
- Upk, pk, LG = 3200 $V_{peak\text{-}peak}$ at UDC link = 1035 V

The amplitude can be converted approximately linearly for other DC link voltages.

In the end, the actual voltage stress depends on the real setup. Thus, for instance, the line and the motor itself (keyword "wave impedance") have a considerable influence. In case of doubt, the voltage stress must be determined on the actual setup and applicatively reduced if necessary.

For motors with series inductance:

The EMF is fed through to the motor terminals when using a series inductance. The EMF feed-through increases the values of the line-ground voltage stress mentioned above. The EMF is no longer fully broken down in the motor but is fed through to the motor terminals in the voltage distribution ratio of external series inductance (L_{Series}) to total leakage inductance ($L_{LeakageTotal}$). The EMF feed-through is independent of current and torque.

Note

EMF feed-through

The EMF feed-through is the immediate physical consequence of the use of a series inductance. The EMF feed-through is not influenced by the converter, the make or the type of modulation, or other technical properties of the converter. The effect behind it is explained in appendix "EMF feed-through (Page 203)".

$$EMF\_feed\text{-}through = 2 \cdot \frac{Max\_Peak\_EMF}{\sqrt{3}} \cdot \left(\frac{L_{Series}}{L_{Leakagetotal}} \right) \qquad [V_{peak\text{-}peak}]$$

Max_Peak_EMF:	Peak value of the maximum EMF terminal-terminal
L_{series}:	Series inductance in mH
$L_{Leakagetotal}$:	Total leakage inductance (see Chapter "Leakage inductance(s) and series inductance (Page 48)") $= L_{Leakagestator} + L_{Leakagerotor} + L_{series}$

The formula above shows immediately that the EMF feed-through disappears when there is no series inductance ($L_{Series} = 0$ mH). In the limit value of a very large series inductance, the voltage distribution ratio ($L_{Series} / L_{LeakageTotal}$) is approaching 1. This means that:

When the series inductance is considerably greater than the self-inductance of the motor, a large portion of the EMF of the motor is fed through to the terminals and thus increases the line-ground voltage stress significantly.

Induction motors/synchronous motors

In terms of the maximum EMF, there is an important difference between induction motors and synchronous motors:

For induction motors:

Max_Peak_EMF = UDC [V]

The peak value of the maximum EMF (terminal-terminal) does not exceed the DC voltage of the DC link.

For synchronous motors:

Max_Peak_EMF = p0317 · $\sqrt{2} \cdot N_{max}$ [V]

N_{max}:	Maximum speed intended for the respective motor
p0317:	Voltage constant [$Vrms_{terminal\text{-}terminal}$/1000 rpm]

For synchronous motors, the EMF increases proportionally to the speed and reaches its maximum value at the maximum speed. If an additional speed range with constant power is required, the respective synchronous motor is usually designed so that the peak value of the maximum EMF (terminal-terminal) approaches 2 kV. Because of the potential risk of injuries, a permissible design must not exceed 2 kV, see Chapter "Maximum speed restrictions when operating with a SINAMICS drive (Page 70)".

Example for synchronous motor

We are assuming a synchronous motor spindle with the following data:

p0317:	67 V_{rms} / 1000 rpm
N_{max}:	20000 rpm
$L_{Leakagestator}$:	0.3 mH
L_{series}:	0.5 mH

$$\text{Max\_Peak\_EMK} = \frac{67\text{ V}}{1000\text{ Ump}} \cdot \sqrt{2} \cdot 20\,000\text{ Upm} = 1895\text{ V}$$

$$\text{EMF\_feed-through} = 2 \cdot \frac{1895\text{ V}}{\sqrt{3}} \cdot \left(\frac{0{,}5\text{ mH}}{0.3\text{ mH} + 0.5\text{ mH}}\right) = 1370\text{ V}_{\text{peak-peak}}$$

If the DC link voltage is 600 V, for example, the expected line-ground voltage stress increases from 1960 $V_{peak-peak}$ to 3330 $V_{peak-peak}$ by using the 0.5 mH series inductance.

Example for induction motor

We are assuming an induction motor spindle (600 V DC link) with the same performance characteristic as in the example above and the same inductances:

$L_{Leakagestator}$:	0.3 mH
L_{series}:	0.5 mH

$$\text{EMF\_feed-through} = 2 \cdot \frac{600\text{ V}}{\sqrt{3}} \cdot \left(\frac{0.5\text{ mH}}{0.3\text{ mH} + 0.5\text{ mH}}\right) = 433\text{ V}_{\text{peak-peak}}$$

Conclusion

The examples show: For synchronous motors with a broad constant performance range, the EMF feed-through can be three times that of induction motors with comparable performance characteristic.

Note

Observe the voltage stress

The basic insulation of the winding in the series inductance as well as the cable routing between series inductance and motor including installation technology must also be able to withstand the increased voltage stress.

Note

EMF feed-through

The EMF feed-through for synchronous motors does not just start at the point of active field weakening but is present throughout the entire operating range.

7.5.1 Widely established design-based countermeasures

Contrary to the voltage rate-of-rise or cable reflections, the line-ground voltage not only stresses the winding areas close to the motor terminals, but also propagates into the complete motor. Only the high-frequency components are already absorbed in the winding areas close to the terminals. Suitable motors frequently have the following features:

- Adequately dimensioned main insulation
- High-quality impregnation or resin casting
- Avoiding lattice network resonance effects inside the motor
  (see diagram "Simplified equivalent circuit diagram to explain the line-ground voltage")

7.5.2 Widely established test methods

As the line-ground stress mainly occurs in the low-frequency range, applying a 50 Hz AC voltage (with respect to the grounded motor frame) to the motor terminals is a widely established test method. The main insulation must be able to withstand a specified amplitude, without partial discharge occurring.

In addition to the "50 Hz method", a surge voltage applied to the motor terminals with respect to ground is another common test alternative.

Note

The result of the AC voltage test is only of real value, if it also supplies information regarding the partial discharge strength. A statement that the test object successfully passed the test procedure without any arcing is not sufficient. Suitable testing equipment must therefore also include a device to detect partial discharge.

Note

The expected decrease in the voltage at which partial discharge occurs at the rated operating temperature must be taken into account. The general procedure involves the test object being subject to an appropriately increased test voltage amplitude.

A routine test is recommended.

7.5.3 Known countermeasures as part of the drive application

- Operating Active Line Modules only together with a suitable commutation inductance (Active Interface Module).
- From the commutation inductance alternatives permitted, select the one with the highest damping (attenuation), (e.g. HFD)
- Replace ALM by a non-pulsing infeed module (Basic Line Module or Smart Line Module).

7.6 Neutral-point oscillation

With operation on converters, insulation damage that shows a ground fault close to the neutral point is of particular significance. The effect behind this damage pattern is therefore discussed in more detail in its own chapter. The term "Operation on converters" is kept intentionally vague because the damage pattern is not tied to devices from specific converter manufacturers.

Quick changes in voltage at the motor terminals do not spread immediately across the entire conductor as with a hard copper bar, but are transmitted over a chain of inductances and capacitances to the end of the ladder network. The neutral point is the end of the ladder network.

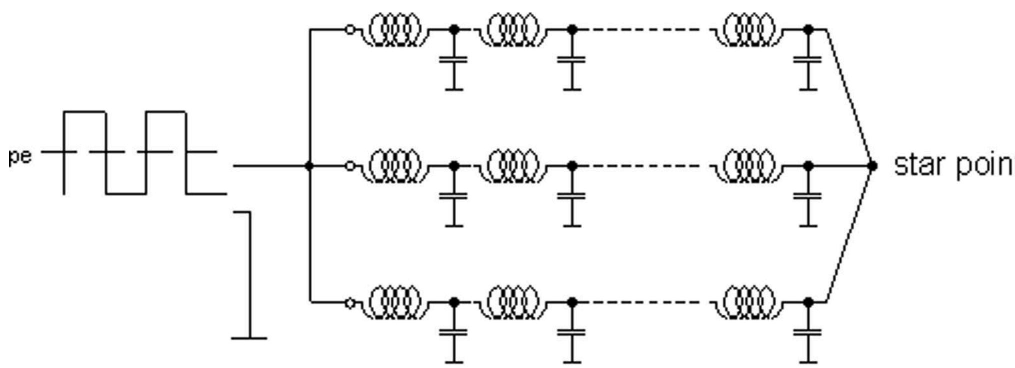


Figure 7-9 (1) Three-phase ladder network consisting of inductances and capacitances

The ladder network shown above represents the high-frequency behavior of an electric motor.

Note

Application

The effect described here is not limited to motors in star connection. For motors in delta connection, this is the area of the winding series connection that is located furthest away from the motor terminals, electrically speaking.

The neutral-point oscillation is strongest when all three phases switch at the same time. This is the case at standstill. In this case, the three waves arrive at the neutral point at the same time. To enable better understanding of neutral-point oscillation, the three-phase circuit diagram can be converted into a simple single-phase circuit diagram:

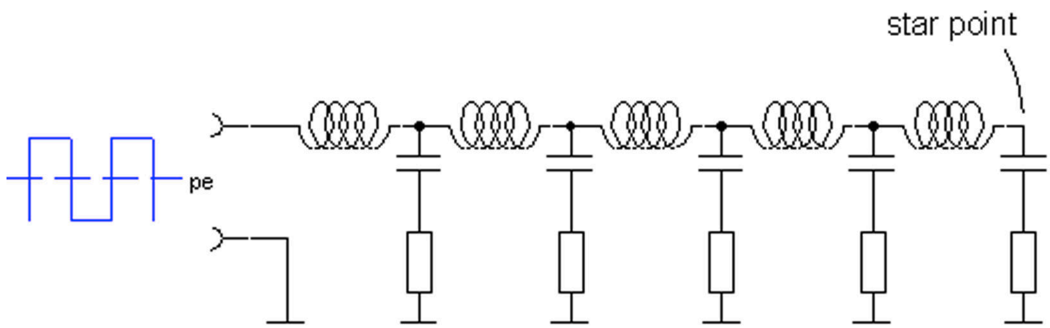
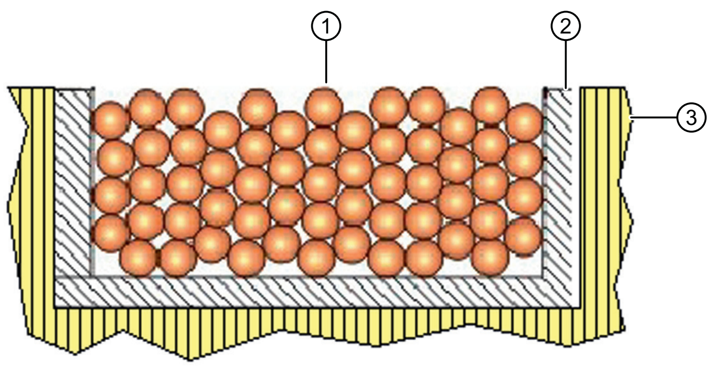


Figure 7-10 (2) Simplified single-phase circuit diagram

The origin of the inductances in the figure above (2) is obvious as these are the inductances of the motor coils. The origin of the capacitance is an inevitable consequence of embedding the coils in the sheet metal body of the motor.



① Coil
Internal conductor of the capacitor

② Insulating material
Dielectric of the capacitor

③ Sheet metal body
External conductor of the capacitor

Figure 7-11 (3) Typical capacitor: Conductor - Insulator - Conductor

With the insulating material as dielectric, the coil has the typical structure of a capacitor with respect to the ground potential: Two conductive surfaces that are separated from each other by a thin dielectric.

The transmission behavior of the lattice network as seen in figure (2) from the terminal to the neutral point can be interpreted as lowpass. Depending on the motor type and the winding design, the transition from the passband to the stopband is typically between 20 kHz and 200 kHz. This means that the cable reflection in the frequency band around 1 MHz can no longer reach the neutral point because its frequency is located too far in the stopband. This means that insulation damage close to the neutral point cannot be caused by the cable reflection or the voltage rate of rise.

A fundamental challenge of a lowpass in which energy storage (in this case inductances and capacitors) is involved is the frequency band in the transition from passband to stopband. Without sufficient damping, frequencies in this band are reinforced and only decay slowly. In figure (2), damping through resistors is symbolized. It is given through the natural loss mechanisms of the iron and the dielectric. Natural damping is often not strong enough to completely avoid voltage peaks. In the limit value of very weak damping, a square wave voltage jump is inflated by factor 2 and remains as oscillation for many periods at the neutral point.

If different winding versions are offered within a motor size, the individual winding versions can exhibit significant differences in the expression of the neutral point resonance. The higher the torque constant, the more windings are connected in series. A high torque constant therefore promotes the expression of the neutral point resonance.

Note

Suitability

Synchronous motors with a torque constant above 3 N/Arms and an inductance of more than 5 mH at the same time are candidates for a strong neutral point resonance.

If both of these features are present, we recommend you bring out the neutral point for the first motor and measure the neutral point voltage in typical operating states. If the neutral point voltage is evaluated as non-critical, the brought out neutral point can be omitted in the subsequent motors of the series.

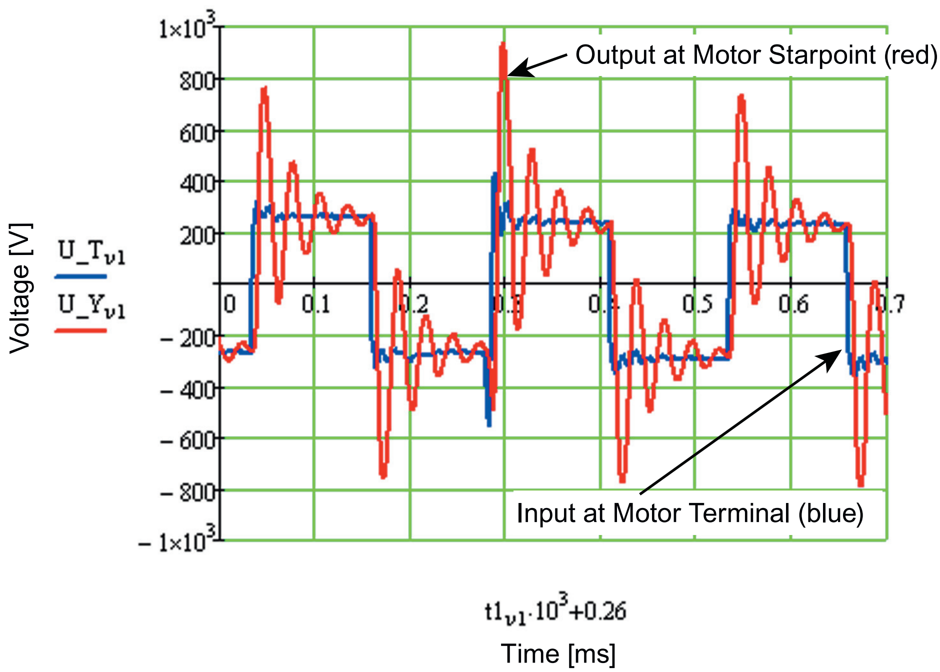


Figure 7-12 (4) Measurement result of a neutral-point oscillation

The measurement result above represents a problematic neutral-point oscillation at standstill. Third-party motor at SLM DC link (UDClink = 550 V)

Even though the voltage arrives as a relatively accurate square wave at the motor terminal, as can clearly be seen in Figure (4), the neutral point is flooded with oscillations. The oscillation amplitudes increase at both ends to twice the input step height and only decay slowly. It is clearly evident that the oscillations at the neutral point according to Figure (4) always have the same frequency. This is the natural frequency of the internal motor lattice network system according to the figures (1) or (2).

The insulation of motors with such a strong neutral-point resonance can fail even in smart mode DC links. If the DC link voltage is put into active mode, the DC link system shifts periodically against the ground potential, whereby the typical frequency of this offset motion is in the same characteristic frequency band as the neutral-point oscillations, that is, between 20 kHz and 200 kHz. This means the neutral-point oscillation is not only fueled by the square wave steps, as shown in Figure (4), but also by the system oscillation (see Figure "Line-ground voltage at UDC link voltage = 600 V" (Page 134)), if the frequencies of system oscillation and neutral-point oscillation are close enough to each other.

In discussions that are started because the insulation close to the neutral point failed, motor manufacturers often state that voltage peaks have resulted in an overload of the insulation. The term "voltage peak" for the oscillation package of the cable reflection from Figure "Line-ground voltage at UDC link voltage = 600 V" (Page 134) is still relatively understandable. However, calling the low-frequency neutral-point oscillation in Figure (4) a "voltage peak" is completely inappropriate and confusing. The waves of the neutral-point oscillation are not peaks but rather the systematic result of the motor characteristic to have used its own internal electrical energy store to compensate for insufficient damping.

Note

Rating of the insulation strength

The interface to the motor manufacturer for rating the line-ground insulation strength is represented by the voltage specifications from Chapter "Line-ground voltage (Page 134)". The binding maximum voltage that is to be expected in the SINAMICS drive system must be specified here. It is the responsibility of the motor manufacturer to rate the insulation so that it can withstand the expected maximum voltage. If the motor multiplies the external voltage internally, this is neither the responsibility of Siemens nor of the user.

Compared to a voltage package of the cable reflection, the amplitudes of a strong neutral-point resonance do not decay in a few microseconds but remain for several tens up to a hundred microseconds. The impact time and the local impact depth of the neutral-point resonance cannot be compared to the rather limited effect of the cable reflection.

There are known application-based countermeasures to increase the damping of the neutral-point resonance that can be applied if the motor manufacturer has failed to provide the adequate insulation to do so. The motivation to present the principle of two proven application-based countermeasures in this manual is to show that the topic of neutral-point oscillation can be addressed by the motor manufacturer. Because the application-based solution takes time and money, here is the order of preference:

- First preference:
  Motor lattice network is well dampened naturally and forms the neutral-point resonance only to a very limited extent.
  → No risk
- Second preference:
  Neutral-point resonance is strong but insulation is adequately dimensioned.
  → To date, it is only possible to see during operation whether the rating of the insulation is truly adequate.
- Third preference:
  Neutral-point resonance is strong and insulation is not adequate
  → Application-based countermeasures create adequate damping.
  Disadvantages:
  - Early detection necessary before damage occurs
  - Complicated
  - Adaptation to the motor and the cable, if necessary
  - Tests necessary

7.6.1 Application-based countermeasure: Neutral-point termination

The lattice network circuit diagram of the neutral-point resonance according to "Figure 7-10 (2) Simplified single-phase circuit diagram (Page 143)" not only has a similar structure to the equivalent circuit diagram of an electric line, but many results from the description of a line can also be applied to the phenomenon of neutral-point resonance. The following issue is of great practical importance:

The lattice network cannot be considered a closed line; see "Figure 7-9 (1) Three-phase ladder network consisting of inductances and capacitances (Page 142)" and "Figure 7-10 (2) Simplified single-phase circuit diagram (Page 143)". In this case, the neutral-point resonance can be interpreted as oscillation package of the cable reflection, see "Figure 7-8 Magnification of the cable reflection from the figure above (Page 137)". A wave impedance is to be allocated to the lattice network according to the familiar rules. If the lattice network is closed with the resistive wave impedance, the reflection and thus also the neutral-point resonance disappears.

By knowing the resonant frequency and the earth capacitance of the motor, the wave impedance can be estimated:

$$R_{Wave} = \frac{159000}{C_{Motor} \cdot f_{Star}} \quad [\text{Ohm}]$$

C_{Motor}	Earth capacitance of the motor alone without line All three phases together in nF not in Farad
$f_{neutral\ point}$	Frequency of the neutral-point resonance in kHz not in Hz Take out of the measurement

Example

A motor capacitance of 7.5 nF was measured. To take the measurement, the line was disconnected and a short, unshielded line was connected to the motor terminals. The three phases of the line were combined during the measurement, see figure below. The frequency of the neutral-point resonance was determined with the cursor to be 55 kHz.

$$R_{Wave} = \frac{159000}{7{,}5 \cdot 55} \text{ [Ohm]} = 385 \text{ Ohm}$$

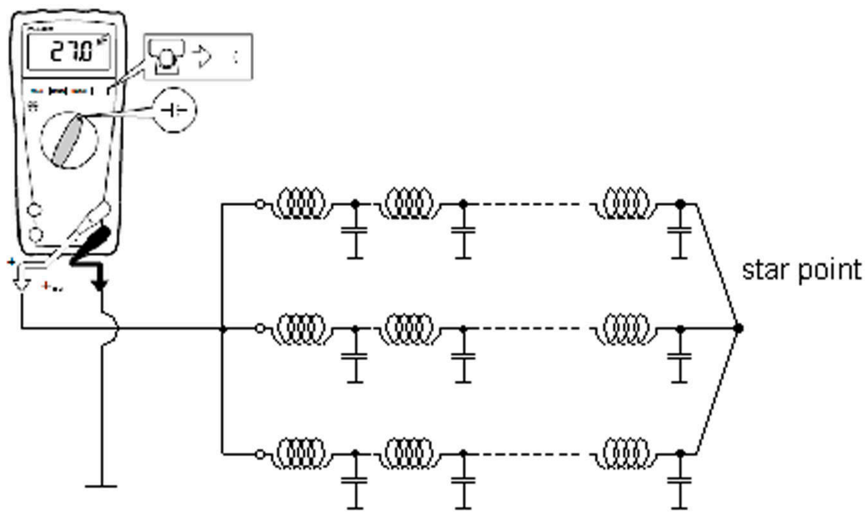


Figure 7-13 Measuring the motor-earth capacitance

If the terminating resistor were to be switched close to the neutral point, it would create a heat loss of several 100 Watts. Especially when the earth capacitance of the motor is large or the frequency of the neutral-point resonance is high. This is usually not desirable. The function of the terminating resistor is to be effective in the frequency band around the frequency of the neutral-point resonance. It is therefore permissible to connect the terminating resistor not directly but over a small network that is only conductive in the necessary frequency band.

As is well known, a series resonant circuit has a very low resistance in the environment of the resonant frequency and a high resistance outside of it. The bandwidth should not be too narrow so that it is sufficiently robust against frequency shifts. The terminating resistor, $R_{Terminator}$, does not change because of the network. When implementing the inductance, make sure that the magnet core can still be used in excess of 100 kHz. The core cross-section must be large enough that it does not reach magnetic saturation at maximum damping current.

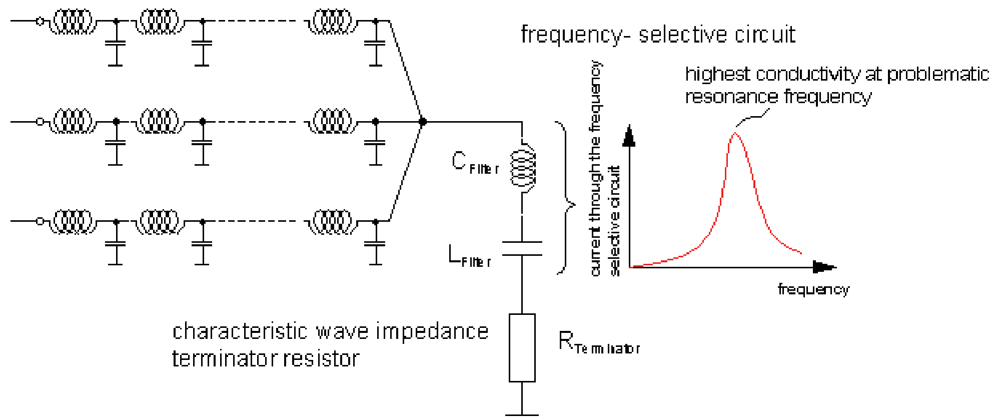


Figure 7-14 LC circuit for frequency-selective connection of the terminating resistor

If the inductance of the series resonant circuit is to be omitted for cost reasons, a capacitor can also block a large portion of the undesirable power loss:

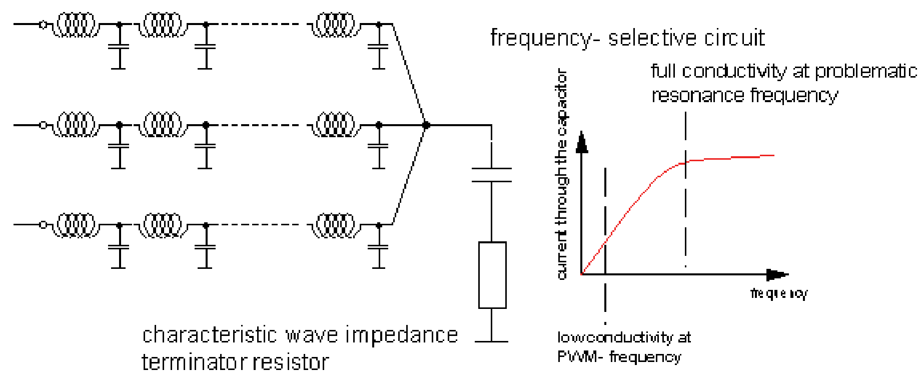


Figure 7-15 Capacitor for frequency-selective connection of the terminating resistor

The capacitor should preferably be selected so that its impedance at the neutral-point resonant frequency is less than 1/5 of the wave impedance. This is the case when the capacitor for connection of the terminating resistor is at least five times the size of the motor earth capacitance calculated above.

A variety of third-party motors serve as neutral point for damping networks, known as "snubbers". Whether they are set up according to the rules introduced here or are operating on a different principle cannot be evaluated in the scope of the third-party motor manual. However, the following always applies when using any neutral-point networks:

- The neutral point must be brought out of the motor. If it is not brought out, the measure cannot be retrofitted.
- The line from the neutral point to the damping network must be shielded and be suitable for the frequency range of the neutral-point resonance. The rms currents of the network are usually only a few amperes strong so that a small cable cross-section is sufficient.
- The effect of the network must be tested. This means that a measurement at the neutral point is necessary for the first plant.

Note

Insulation strength

A neutral-point network generally represents a current path to the earth. It must have at least the same insulation strength as the main motor insulation. The grounding conductor from the neutral point must not be removed from the ground terminal during operation.

7.6.2 Application-based countermeasure: Damping transformer

The best technical solution for damping the internal motor neutral-point resonance is an upstream damping transformer.

- Retrofittable, even if the neutral point is not brought out
- Behaves completely neutral with respect to the earth potential → no earth currents
- Requires core material of very high quality → this is a cost factor for rated current of more than 30 A_{rms}

The neutral-point oscillation periodically discharges the internal capacitances of the motor at the rate of the resonant frequency, whereby the discharge current is supplied by the motor cable. With strong resonance, the series resistors from "Figure 7-10 (2) Simplified single-phase circuit diagram (Page 143)" are too small to cause a loss of energy that would be necessary for adequate damping. The damping transformer acts as an additional series resistor with regard to the neutral-point resonance. The discharge current of the neutral-point oscillation must overcome this additional resistance and loses energy. The series resistor can be selected so that an almost aperiodic transient response with hardly any overshoot occurs at the neutral point. This measure can be retrofitted because the intervention occurs on the input side of the motor (motor terminals) and not by connecting the neutral point.

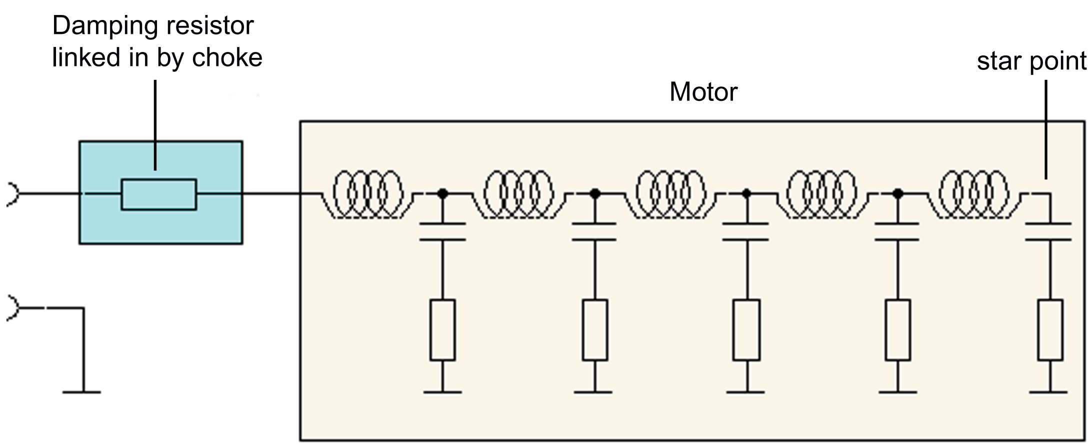


Figure 7-16 Effect of the input resistor

Depending on the frequency and capacitance of the respective motor, the typical series resistors are between 20 ... 1000 Ohm. It goes without saying that a series resistor of this size cannot be simply connected into the motor cable because it would stop the current flow required for operation. This resistor can be inserted by using a common mode transformer so that it only inhibits the discharge current of the internal capacitances but remains invisible in the path of the current flow required for operation.

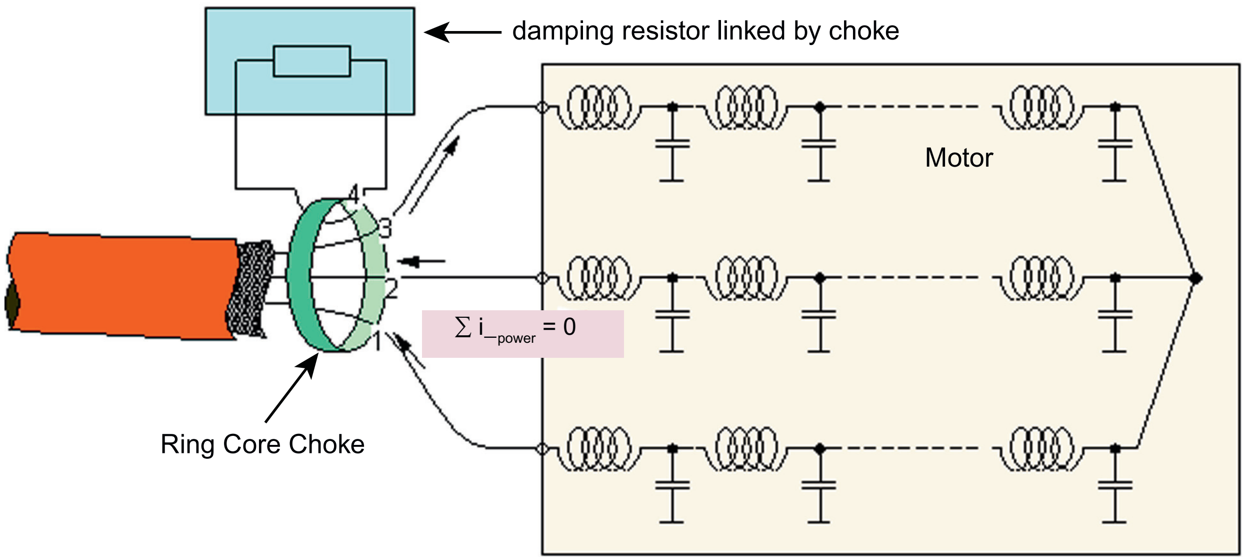


Figure 7-17 Inserting the damping resistor using a common mode transformer

Explanation of the figure:

- To aid understanding, the damping transformer is displayed with only one winding. The number of windings is usually around 20.
- No connecting cable between the symbolic damping transformer and the motor is shown. In almost all cases, the damping transformer does not have to be installed directly in front of the motor. The damping transformer can almost always be placed in the control cabinet behind the converter output. Only in the case of very long cables in which the cable capacitance is several times greater than the motor capacitance does the damping transformer need to be installed closer to the motor to keep the connecting cable relatively short.

The effect of the common mode transformer is based on the fact that the operating current of the three phases strictly adds up to zero and therefore has no effect in the common ring core. A common mode transformer according to the figure above is not visible for three-phase current. The discharge current of the internal motor capacitors, on the other hand, flows back outside of the ring core (via earth) and takes full effect in the transformer. The resistance in the fourth current loop therefore only has an effect on the discharge current (as intended) and does not exist in the three-phase circuit. The effect of this damping measure is dramatic:

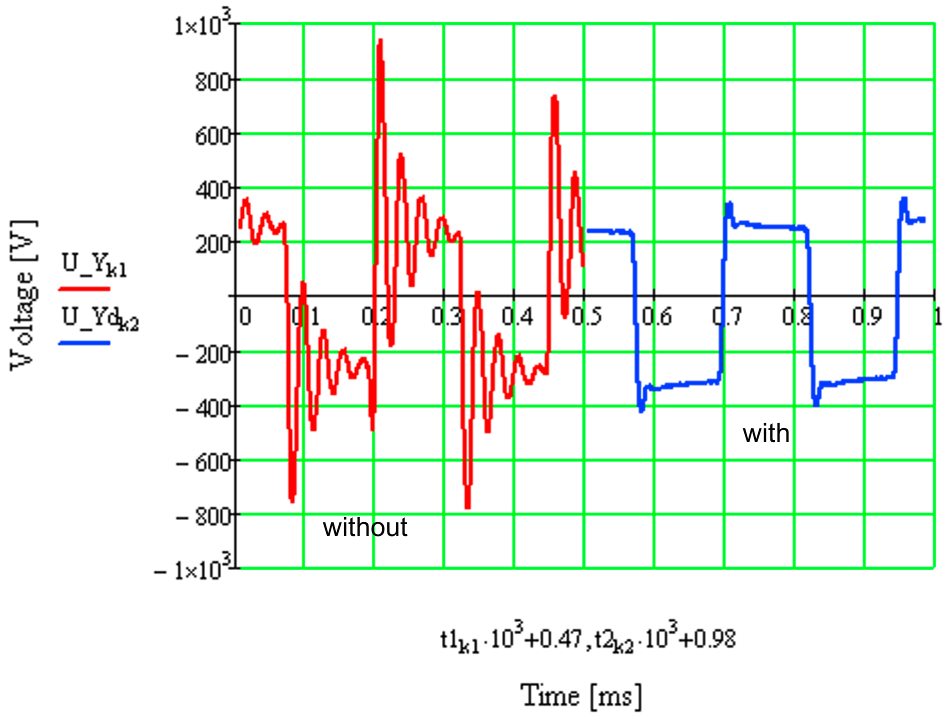


Figure 7-18 Measurement result after eliminating the neutral-point resonance of the third-party motor using a damping transformer

The figure relates to "Figure 7-12 (4) Measurement result of a neutral-point oscillation (Page 144)" using a damping transformer.

Note

Design

On request, Siemens can design this damping measure as part of an engineering service.

7.6.3 Diagnostics of insulation failure close to the neutral point

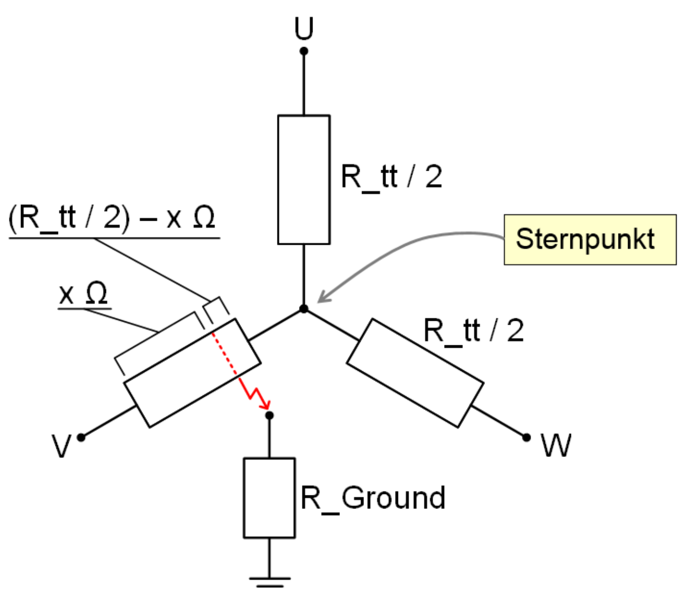
To implement a targeted countermeasure after ground fault insulation failure, knowing the position of the ground fault along the lattice network is of crucial importance; see
"Figure 7-14 LC circuit for frequency-selective connection of the terminating resistor (Page 148)",
"Figure 7-15 Capacitor for frequency-selective connection of the terminating resistor (Page 148)" and
"Figure 7-16 Effect of the input resistor (Page 149)".

We are therefore describing a simple process here that can be used to determine the position of the ground fault through measurement in a non-destructive manner, if the ground fault is low-resistance enough even in the case of extra-low-voltage. This is often the case.

In the case of a ground fault, we highly recommend that you perform the measurement described here before the motor is opened up for further analysis or even scrapped. Once the motor is opened up, the analysis described here is no longer possible.

Note the following:

The ground fault is located by measuring the resistance of the terminals to the ground fault. The symmetry or asymmetry of the individual resistances can be used to determine the proximity to the neutral point. The assumption here is that the ground fault is a single, conductive contact point between the winding wire and the motor body. The resistance along the coil wire, i.e. from terminal to terminal, is not affected by the ground fault. The electrical circuit diagram for this fault is shown in the figure below. The resistance R_Ground symbolizes the ohmic resistance of the ground fault contact point. It is quite possible that this resistance is as strong as the regular line resistance.



R_tt: Terminal-terminal resistance

Figure 7-19 Resistance relationships in case of ground fault

The extreme cases (for a low-resistance ground fault) are:

- Exact same resistance from terminal to earth in all three phases
  → Ground fault is in close proximity to the neutral point.
- Resistance from terminal to ground in one phase is close to zero, in the other phases it is about the size of the regular terminal-terminal resistance:
  → Ground fault is in close proximity to the terminal that shows the low resistance.

Below are instructions for basic measurement and calculation based on an example. The ground fault is in phase V in this case. If the actual ground fault is in a different phase, the phase labels have to be renamed accordingly for the analysis:

1. Measuring the resistance of each phase to ground (e.g. grounding conductor of the motor cable)
   → The phase with the lowest resistance has the ground fault.
   Example:
   $R_{U\text{-}PE}$ = 0.31 Ohm; $R_{V\text{-}PE}$ = 0.27 Ohm ; $R_{W\text{-}PE}$ = 0.32 Ohm
   The ground fault is in phase V.
2. Measuring the resistance of the "ground fault phase" to one of the other two phases
   Example:
   The "other phase" is phase U in this case.
   $R_{V\text{-}U}$ = 0.42 Ohm
   Result:

$$X = \frac{R_{V\text{ - }PE} - R_{U\text{ -}PE} + R_{V\text{ - }U}}{2} \quad \text{[Ohm]}$$

$$R_{Ground} = \frac{R_{V\text{ - }PE} + R_{U\text{ - }PE} - R_{V\text{ - }U}}{2} \quad \text{[Ohm]}$$

With numerical values:

$$X = \frac{0{,}27\ \Omega - 0{,}31\ \Omega + 0{,}42\ \Omega}{2} = 0{,}19\ \Omega$$

$$R_{Ground} = \frac{0{,}27\ \Omega + 0{,}31\ \Omega - 0{,}42\ \Omega}{2} = 0{,}08\ \Omega$$

3. Determining the ground fault position along the coil wire:
   The resistance of a phase to the neutral point is mathematically exactly half the value of the terminal-terminal resistance.
   $R_{U\text{-}Y} = R_{V\text{-}Y} = ½ \cdot R_{U\text{-}V}$.
   In this example, $R_{U\text{-}Y} = 0.21\ \Omega$.
   According to the result above, the ground fault is 0.19 Ohm away from terminal V (value "X"). Because the resistance distance from terminal V to the neutral point is 0.21 Ohm, the resistance distance from the neutral point to the ground fault is only 0.02 Ohm. By using the numbers and transforming the equation, the proximity to the neutral point can be specified:

$$\text{Neutral point proximity} = \left(\frac{R_{V-PE} - R_{U-PE}}{R_{V-U}} + 1\right) \cdot 100\ \%$$

Note

Repeat with phase W

Steps 2 and 3 are now repeated with phase W as the reference to phase V remains because it had the ground fault.

Note

Selection of the reference phase instead of phase V

If phase U were to be selected as reference phase instead of the faulty phase V in the example above, the value of the neutral point proximity would increase from 90.5% to more than 100%. This means that the ground fault as seen from phase U is behind the neutral point and therefore not in phase U.

$$\text{Neutral point proximity} = \left(\frac{0.27\ \Omega - 0.31\ \Omega}{0.42\ \Omega} + 1\right) \cdot 100\ \% = 90.5\ \%$$

100% = Ground fault is directly at the neutral point
0% = Ground fault is directly at terminal V

4. Measuring the resistance of the "ground fault phase" to remaining phase
   Example: The "remaining phase" is phase W in this case.
   $R_{V\text{-}W} = 0.44\ \Omega$
   Result:

$$X = \frac{R_{V\,-\,PE} - R_{W\,-\,PE} + R_{V\,-\,W}}{2} \quad [\text{Ohm}]$$

$$R_{Ground} = \frac{R_{V\,-\,PE} + R_{W\,-\,PE} - R_{V\,-\,W}}{2} \quad [\text{Ohm}]$$

   With numerical values:

$$X = \frac{0{,}27\ \Omega - 0{,}32\ \Omega + 0{,}44\ \Omega}{2} = 0{,}195\ \Omega$$

$$R_{Ground} = \frac{0{,}27\ \Omega + 0{,}32\ \Omega - 0{,}44\ \Omega}{2} = 0{,}075\ \Omega$$

5. Determining the ground fault position along the coil wire:

$$\text{Neutral point proximity} = \left(\frac{R_{V\,-\,PE} - R_{W\,-\,PE}}{R_{V\,-\,W}} + 1\right) \cdot 100\ \%$$

$$\text{Neutral point proximity} = \left(\frac{0.27\ \Omega - 0.32\ \Omega}{0.44\ \Omega} + 1\right) \cdot 100\ \% = 88.6\ \%$$

Because the defective phase (the one with the ground fault) is the reference phase and the calculation using one of the other two phases already returns a valid calculation result, there are two numerical values for each of the required variables. If the results from the two different calculations do not clearly contradict each other, you can use the mean value from both calculations. In addition to the proximity to the neutral point, the calculation also provides a result for the resistance of the ground fault location (R_{Ground}). The results shown above should be considered possibly inaccurate when this resistance is several times greater than the phase-phase resistance.

The measuring current that is used in the 4-wire method should be at least 100 mA. It can be supplied with power by a battery, a small power supply unit or even a USB socket. The series resistor is important because, without it, the voltage source would be overloaded immediately. After specifying the voltage source, the resistance is selected using Ohm's law so that you will have the desired measuring current. The motor resistance can be left out when specifying the series resistor.

Note

Method of resistance measurement

The resistances are to be measured exclusively using the 4-wire method shown below. Measurements with the ohmmeter are useless unless the motor winding has such a high resistance that the phase resistance is more than 5 Ohm.

Note

Resistance measurement from the control cabinet side

It is permissible to measure the resistance from the control cabinet side via the motor cable. To do this, the cable must be separated from the converter.

Note

Measuring the resistance with parallel connection of the winding systems

If the motor contains multiple winding systems in parallel, the arithmetic shown here does not apply in this form. It must be replaced with a calculation method that takes the parallel connection into consideration. However, we recommend here too that you determine the resistances to the ground fault exactly (according to the instructions below) and contact Siemens. Parallel winding systems are usually only used in high-performance motors so that the method described above can be applied to a wide majority of motors.

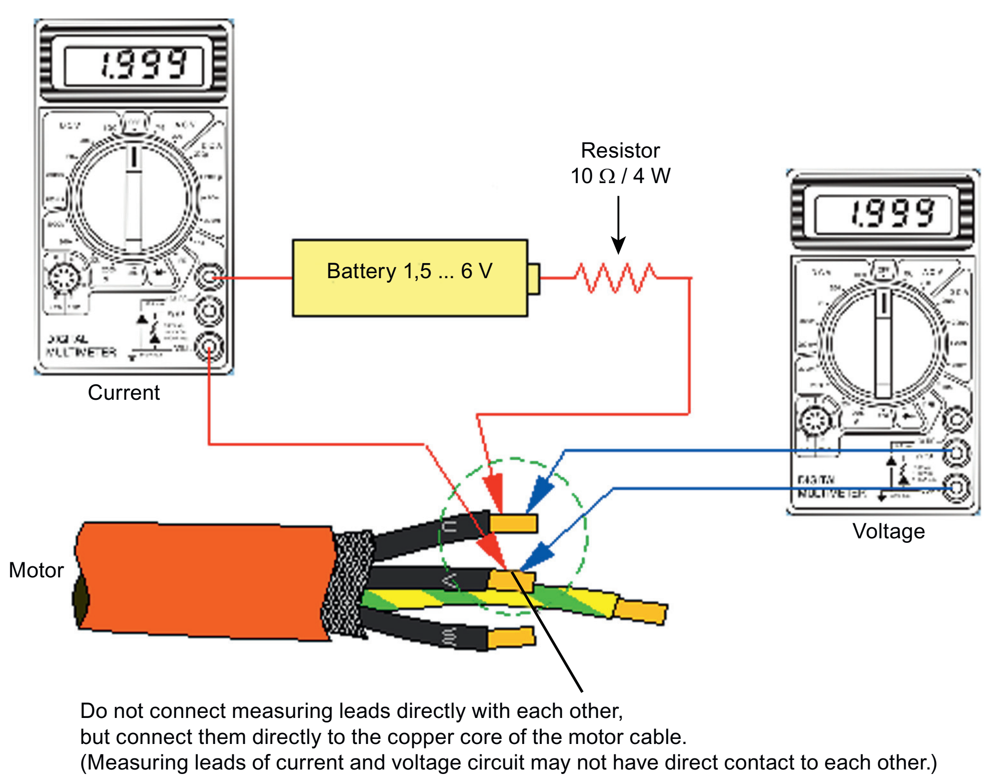


Figure 7-20 Four-wire measurement to determine the phase-phase resistance

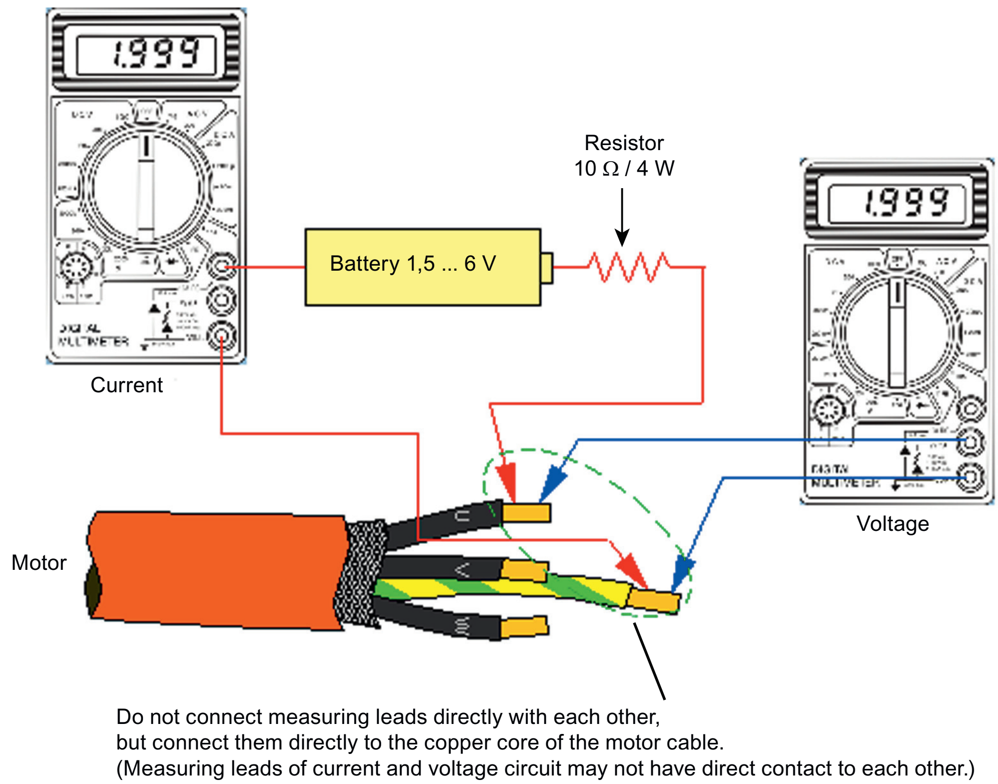


Figure 7-21 Four-wire measurement to determine the phase-ground resistance

7.7 EMC aspects

Also in converter operation, the motor must comply with the relevant EMC directives.

- When operated with the voltage characteristics described above, it is not permissible that it emits electromagnetic interference.
- Its function must not be disturbed or its service life shortened (temperature sensor, encoder, bearing currents..) – neither by externally generated nor by its own electromagnetic influences.

In order to guarantee this, as a minimum, it must have one of the following design features:

- Electrically conductive, EMC-sealed enclosure with adequate wall thickness and conductivity (with the exception of built-in motors).
- If a power connector is being used, then its housing must be manufactured out of conductive material, and it must be electrically connected to the motor enclosure. The electrical connection between the motor enclosure/frame and the connector housing must not be obstructed by paint or other coatings.

- Any terminal box must be manufactured out of electrically conductive material. Also the cover must be electrically connected to the terminal box through a wide surface area. Bare metal contact surfaces must be provided between the cover and the main terminal box assembly. The seal must not obstruct the electrical connection between these bare metal surfaces (i.e. it should not act as spacer).
- If terminal box or direct cable outlet: A cable gland must be used in order to connect the power cable shield through 360 degrees. The shield must represent an EMC-compliant "extension" of the housing.

(Angled) position encoders

8

The DRIVE-CLiQ interface is the encoder interface of the SINAMICS drive system. To a large extent, Siemens list motors are already equipped with this interface. They can be directly connected to the drive lineup. A Sensor Module is required for non-DRIVE-CLiQ encoders to convert the encoder signals to the DRIVE-CLiQ interface.

Siemens has authorized the marketing of DRIVE-CLiQ encoders. This means that they are automatically compatible to SINAMICS drive systems. This is the reason that only non-DRIVE-CLiQ encoders are discussed in this document. The following encoder types can be connected:

- Incremental encoders
- EnDat absolute encoders
- Resolvers
- TTL-/HTL encoders
- SSI absolute encoders

8.1 Incremental encoders

A general description of the mode of operation of incremental encoders is available, for example, in publications from the Heidenhain company. There, the same designations are used as for Siemens, except Heidenhain calls the C and D track the "Z1 track".

Definition of "signal track"

When electrically transferring encoder signals, the signal content is formed from the difference between two individual electrical signals. In conjunction with position encoders, the signal content is frequently called "track". In this document, the signal content derived by obtaining the difference is therefore called "track" or "signal track". The individual signals are in opposition with one another. In this document they are designated "+" and "-". As the electrical signals are in opposition with one another, the amplitude of the track signal when generating the difference is doubled. The benefit when generating the difference is that the (common mode) noise is suppressed.

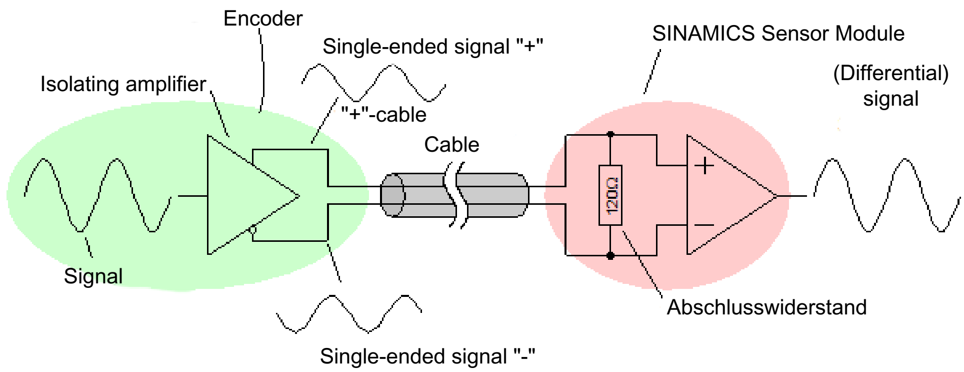


Figure 8-1 Signal transfer using opposing individual signals

8.1.1 Incremental tracks A B

The differential signals A and B contain the position information. They have sinusoidal or cosinusoidal waveforms. Their properties have a direct influence on the quality and precision of the position actual values sensing:

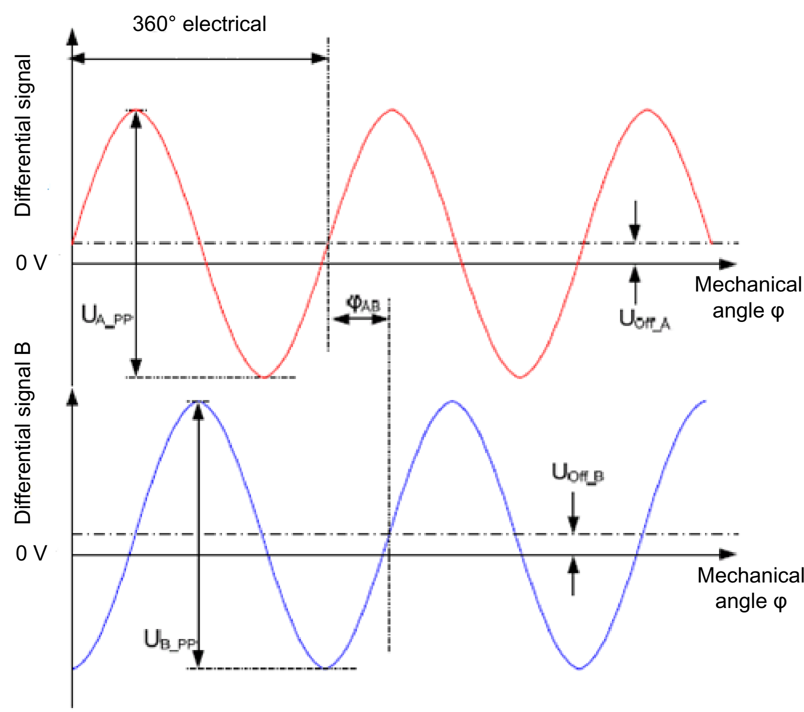


Figure 8-2 Typical signal characteristic of the A and B tracks (differential signals)

The signals of the A and B incremental tracks, should fulfill the following conditions:

- **Signal amplitude, U_{X_PP}: 1 $V_{peak-peak}$**
  Recommended tolerance range: 1.2 $V_{peak-peak}$ .... 0.75 $V_{peak-peak}$
  For the maximum possible input frequency fin_AB_max, it must be ensured that the amplitude of the encoder does not fall below the recommended range of U_{X_PP}.
- Maximum **difference** between the A and B tracks (in a signal period):

  $$\frac{2(U_{A\_PP} - U_{B\_PP})}{(U_{A\_PP} + U_{B\_PP})} \leq 10\ \%$$

- **Dynamic amplitude change** between two adjacent signal periods: ΔU_{A_PP} or ΔU_{B_PP} **≤ 0.6 mV**
- **Degree of modulation** of the amplitude envelope curve through one revolution
  $m = (U_{X\_PP\_max} - U_{X\_PP\_min}) / U_{X\_PP\_min}$ **≤ 0.1**
- Signal sequence: For a positive direction of rotation, track A leads the track B by 90°.
- **Angle between track A and B, $_{\varphi X\_PP}$: 90°**
  Recommended tolerance range: **±3 °**
- **Offset, U_{Off_X}: 0 V**, recommended tolerance range: **±50 mV**
- **Maximum frequency** at maximum speed: **500 kHz**
- **dynamic offset change**: U_{X_off} ≤ 1 mV amplitude between two adjacent signal periods
- **Distortion factor ≤ 0.5 %**

  $$k = \sqrt{\frac{U_2^2 + U_3^2 + U_4^2 + \ldots}{U_G^2 + U_2^2 + U_3^2 + U_4^2 + \ldots}}$$

  U_G: Amplitude of the basic fundamental
  U_2; U_3; ...: Amplitude of the corresponding harmonic

8.1.2 Reference track

In this document, the formal conditions are described, which the reference track signal must fulfill in order to be identified as a valid reference mark. It remains open as to whether the reference track of the encoder includes one or several reference marks per revolution. One reference mark per revolution is usual for standard encoders.

The reference pulse must lie in a specific angle window with respect to the A and B tracks. This means that its signal voltage, within a minimum permissible angle window, must have exceeded the level U_{RS_min}, and outside a maximum permissible angle window, must lie below the level $U_{quiescent\_max}$. The two threshold levels are called "active level" and "quiescent level" hereafter.

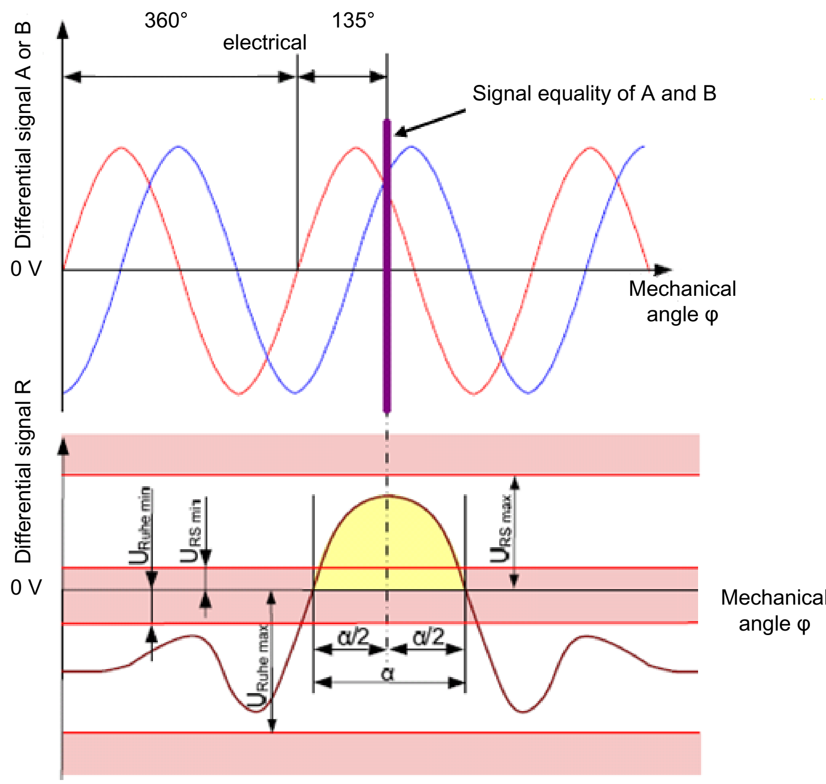


Figure 8-3 Typical cyclic characteristic of the R track (differential signal)

- Active level: U_{RS_min} = 200 mV; U_{RS_max} = 700 mV
- Quiescent level: $U_{quiescent\_max}$ = -200 mV; $U_{quiescent\_min}$ = -700 mV
- Minimal angle window: | α/2 | ≥ 50° (refers to one signal period of the A/B track)
- Maximum angle window: | α/2 | ≤ 225°
- The angle window does not have to be symmetrical;
  $\alpha/2_{left}$ does not have to be equal to $\alpha/2_{right}$

The accuracy of the referencing does not depend on the waveform or the position of the referencing pulse. If the reference pulse does not fill the conditions mentioned above, then it is not identified, or an error signal is generated.

8.1.3 C D track signals

For rotating motor encoders, absolute signals C, D are used for commutation. They emulate the angular position of the motor shaft with precisely one sinusoidal-cosinusoidal period per mechanical revolution.

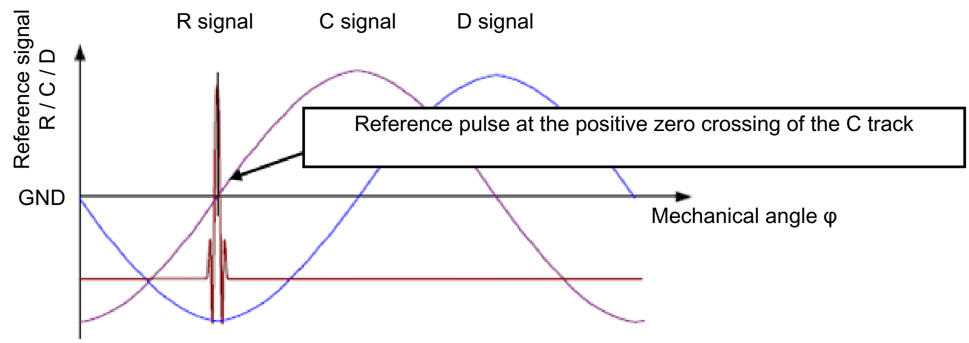


Figure 8-4 Typical signal characteristic of the C and D tracks (differential signal)

The requirements placed on the signal quality of the C and D tracks is the same as the requirements placed on the A and B tracks described above. Further, the tracks must manifest a certain alignment regarding the reference track:

- For a positive direction of rotation, the positive zero crossing of the C track must appear in an angle window of ±5° with respect to the reference pulse (refer to the figure above).

8.1.4 Individual electrical signals

The individual signals move symmetrically around a center voltage. The center voltage can be interpreted as an average value formed from the maximum and an associated adjacent minimum of the sinusoidal voltage of an individual signal.

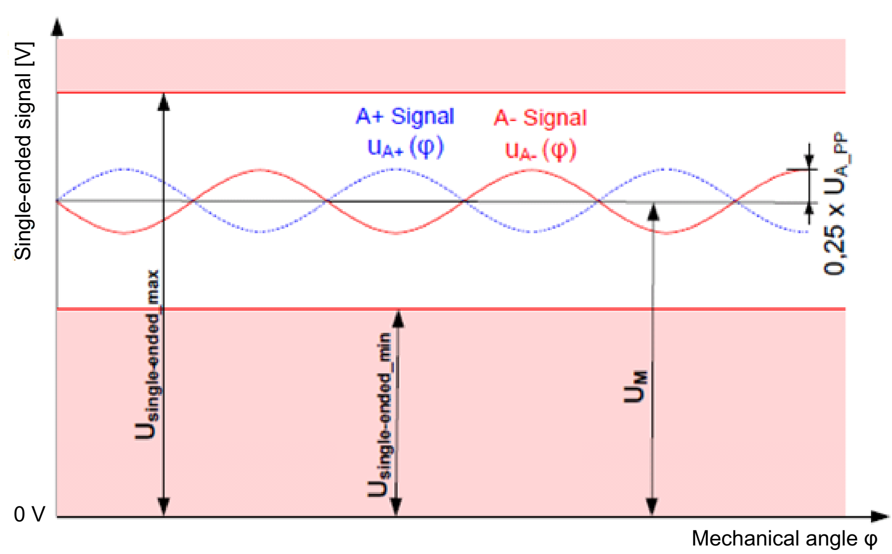


Figure 8-5 Individual electrical signals of a signal track, e.g. A track; The ground of the encoder power supply is the reference potential (M_encoder).

The individual electrical signals should fulfill the following conditions:

- The center voltage should be equal to half the supply voltage.

  $$U_M = \frac{P\_Geber - M\_Geber}{2}$$

  with P_encoder: = positive encoder supply (nominal value: 5 V)
  and M_encoder: negative encoder supply (nominal value: 0 V)
  results in a nominal value of 2.5 V for the center voltage. The center voltage must not be a fixed value, but must be linked to (half) of the encoder power supply voltage.
- The center voltage must be the same for the two individual signals of a track. If the center voltage is not equal for both tracks, then this would immediately lead to an undesirable offset of the signal track involved.
- For a nominal encoder power supply value of 5 V, the individual electrical signals must lie within a voltage window of 2.0 V ... 3.0 V, relative to the ground of the encoder power supply (M_encoder).
- The ohmic cable termination is, seen from the encoder, at the end of the cable (in the Sensor Module). Correspondingly, it is 120 Ω between the "+" and the "-" individual signals.
- Fig. "Signal transfer using individual signals that are in opposition with one another": The cable drivers of the encoder must be in a position to drive this signal, with respect to this load, over the complete frequency range. There is no low-ohmic termination with respect to the signal ground in the Sensor Module.
- If not agreed differently with the customer, the permissible length of the encoder cable must be at least 50 m. The cable driver of the encoder must be in a position to drive this signal, with respect to the capacitive load of the cable, over the complete frequency range. It is absolutely not permissible that the cable driver has a tendency to oscillate.

The requirements placed on the individual signals listed above, also apply to all signal tracks: A, B, C, D and R.

Note

In the applicable literature, the individual electrical signal is frequently called "single-ended signal".

Note

For the SINAMICS encoder evaluation, the individual electrical signals are separately sensed and digitized. The differential signal is derived by forming the digital difference from the two individual signals. This is the reason that each of the two individual electrical signals of a signal track must lie within the permissible voltage window.

8.2 Encoder supply

8.2.1 Function of the sense line

The nominal value of the encoder power supply (P_encoder – M_encoder) is 5 V. For longer cables, the ohmic voltage drop along the encoder cable can result in a noticeable voltage reduction. This means that the supply voltage at the encoder is lower than the supply voltage provided by the Sensor Module.

The voltage controller of the Sensor Module compensates this voltage drop, so that the supply voltage actually received at the encoder is kept constant at the nominal value of 5 V. To achieve this, the supply voltage received at the encoder is tapped (high ohmic tap) using the sense line. This is then fed back to the voltage controller of the Sensor Module. The voltage controller ensures that the voltage is maintained at the nominal voltage of 5 V. The precondition to achieve this is that the supply voltage that is received at the encoder is connected to the sense line.

Note

The cable length within the motor/spindle mounting space is generally relatively small. This means that the sense line can be jumpered at one of the encoder connectors at the motor enclosure.

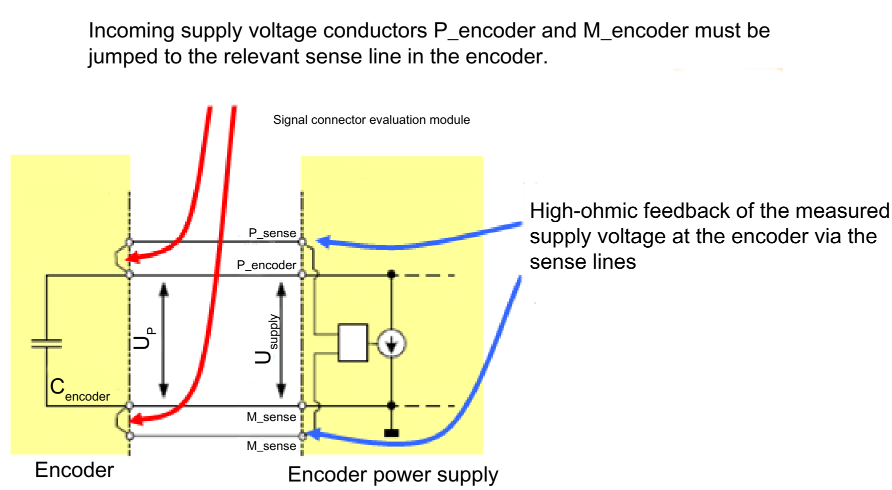


Figure 8-6 Sense line to control the encoder supply

- To guarantee the function of the voltage controller, a maximum capacitance of 1000 μF is permissible in the encoder input circuit.

Note

For the names of the individual conductors of an encoder cable,
P_sense is often called 5 V_{sense}; M_sense often 0 V_{sense}

8.2.2 Voltage ripple on the encoder supply

A high-frequency ripple can be superimposed on the supply voltage that the Sensor Module connects to the encoder (see the following figure). The encoder must be designed so that this ripple does not negatively impact the track signals.

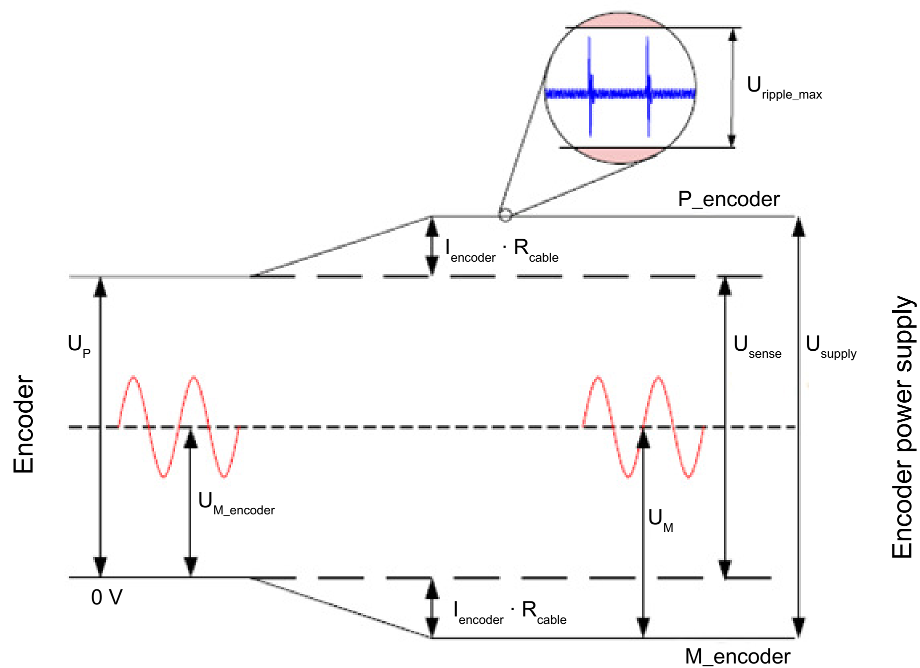


Figure 8-7 Voltage relationships and ripple voltage at the encoder

- The maximum high-frequency ripple voltage on the encoder power supply is 200 mV. The ripple voltage frequencies lie above 100 kHz. The encoder must have sufficient noise suppression with respect to the differential signals. The distortion factor or the noise/interference voltage component of the differential signals, even if there is a high frequency voltage ripple, must not exceed the above mentioned limit value of 0.5 %.

8.2.3 Overload behavior of the encoder power supply

- Maximum continuous current: 300 mA
- Short-circuit proof, maximum short-circuit current 2 A (for 0 V)

8.2.4 Encoder power supply

- Nominal value: 5 V ±5% (only when the sense lines are correctly connected)
- Sense lines must be connected to the power supply cables at the encoder
  P_encoder ⇔ P_sense and M_encoder ⇔ M_sense
- Maximum transient supply voltage: 10 V
  This voltage peak can be present for 50 ms with a maximum short-circuit current of 2 A if the remote sense function is used and the encoder cable is pulled and inserted impermissibly during operation. The encoder must be designed to tolerate this for reasons relating to ruggedness.

8.2.5 Switch-on phase

The ramp-up of the power supply voltage, depending on the load that the encoder represents, can be realized more or less continuously.

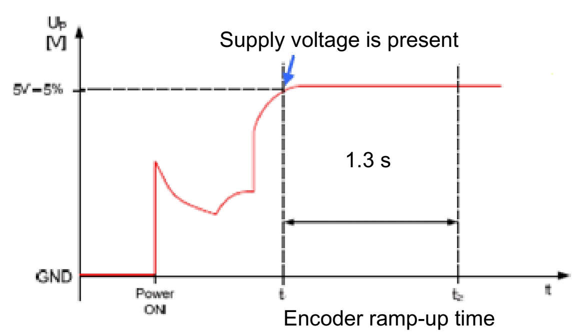


Figure 8-8 Typical ramp-up of the encoder voltage

- After connecting the operating voltage U_P, the encoder must have ramped up within 1.3 s. This means that valid encoder signals must be present after this time (see the above diagram).
- The encoder must be able to handle a non-uniform ramp-up of the power supply voltage (see the above diagram).

8.3 EMC aspects

The encoder must be shielded using a metallic, conductive housing. It should encompass the encoder just like a "can". The can should, if possible, only have an opening, where it is absolutely necessary for the function of the encoder, for instance for the encoder shaft or at the window to magnetically or optically scan the measuring standard. It should be mechanically mounted so that the encoder (or its conductive enclosure) is electrically connected to the motor enclosure through the largest possible surface area. The outer shielding of the cable must be conductive, and must be connected at the can through the largest surface area so that it can be considered as an (EMC) sealed extension of the can.

The encoder cable set is routed to the encoder connector on the motor side. The housing of the encoder connector must be metallic and conductive. The shield of the cable set must be connected to the metal housing of the encoder connector. The following also applies to this shield connection: Through the largest possible surface area, so that the shield can be considered as an extension of the metal encoder connector housing.

In addition to the overall shielding of the cable set, the individual electrical signals of tracks A, B, and R should be twisted in pairs, and the pairs should also be shielded. The shield, which encompasses the individual signal pair, is called the inner shield. Inner shields may only be connected at one end. At the encoder connector on the motor side, they should be connected with the electronics ground potential (M_encoder). The inner shield can be omitted for short cable sets.

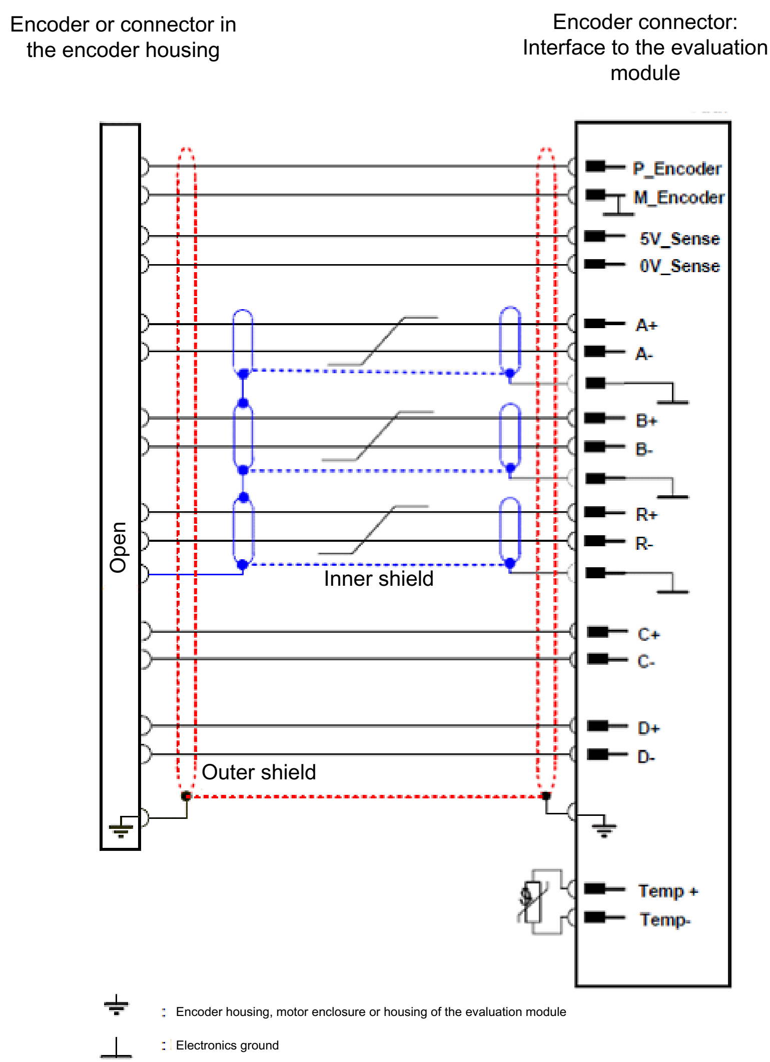


Figure 8-9 Shield concept for connecting the encoder to the encoder connector on the motor side

The following rules must be observed:

- It is not permissible to connect the electronics ground to the housing or outer shield.
- A conductive connection of the encoder housing with a large surface area to the mounting flange (bearing shield) must be guaranteed using the appropriate design.

- The overall shield must be connected at the encoder through a large surface area onto a metallic surface.
- The outer and inner shields should be braided.

Widely established test method:

Interference immunity to electrostatic discharge (ESD EN61000-4-2):

- Direct discharge, contact discharge to bare or metal surfaces of component enclosures coated with non-insulating material (e.g. paint) with 9 kV.
- Acceptance criteria of the operating behavior to be complied with:
  Category A according to EN 61800-3 (usual operating behavior, no malfunction).

8.4 EnDat absolute encoders

The EnDat interface is the bidirectional interface for measuring systems from the Heidenhain company. In the case of an EnDat encoder, the SINAMICS Sensor Modules expect signals according to the EnDat 2.1 interface definition.

Principle of operation of the EnDat 2.1 interface

In addition to the digital position values, two analog incremental tracks, A and B, with 1 $V_{peak-peak}$ are transferred. The analog tracks are generated by scanning a grid. The digital position values have a resolution of ¼ grid spacing of the analog track. The fine resolution of the position value is realized by interpolating analog tracks A and B.

With reference to the encoder power supply, the same specifications apply as for the incremental encoder type discussed above.

8.5 TTL-/HTL encoders

You can find a summary of the requirements placed on the encoder signals in the manual "Control Units and Additional System Components", chapter "Sensor Module Cabinet-Mounted SMC30".

8.6 Resolvers

You can find a summary of the requirements placed on the encoder in the manual "Control Units and Additional System Components", chapter "Sensor Module Cabinet-Mounted SMC10".

8.7 SSI encoders

You can find a summary of the requirements placed on the encoder signals in the manual "Control Units and Additional System Components", chapter "Sensor Module Cabinet-Mounted SMC20", subitem "Technical specifications".

- Gray or binary-coded encoders are permissible.
- Error bit/alarm bit is the LSB. If, in addition, a parity bit is transferred, then this is the next to last bit. If an alarm bit is not transferred, then the parity bit is the LSB.
- The net (useful) information - also as parity or error bit/alarm bit - are either gray or binary-coded - but never mixed.
- Telegram length (including alarm and/or parity): 13 to 25 bits
- Transfer frequency, f: 100 or 500 kHz
- Monoflop time:
  - at 100 kHz t_m min 12 µs
  - at 500 kHz t_m min 2.4 µs

DC-Link Smoothing Filter

9

9.1 Function of the DC-Link Smoothing Filter

The DC-Link Smoothing Filter is primarily used to solve problems during operation of third-party motors. The filter consists of the components

- SF Choke Module
- SF Capacitor Module

The documentation of the filter is integrated in this manual. The description is not included in the SINAMICS S120 manual for "Booksize Power Units". Because of its close relationship to third-party motors, there is no separate documentation for the DC-Link Smoothing Filter.

9.1.1 Description

A failure of the motor insulation often causes damage far exceeding the cost of replacing the actual motor. They range from assembly costs to production failures due to machine standstill. With the aim of protecting the insulation of third-party motors, requests are made for Siemens to reduce the voltage stress by means of system expansions.

The DC-Link Smoothing Filter has been developed as an additional component for the SINAMICS Booksize system. In ALM mode, the filter largely filters out the switching stages of active increase from the DC link potential.
The DC link potential in ALM mode is thus approximately equivalent to the uniformity of open-loop control operation.

The following diagram shows the voltage of the two DC link busbars DCP and DCN against earth. On the left without DC-Link Smoothing Filter, on the right with filter. You can easily see the effect of the DC-Link Smoothing Filter.

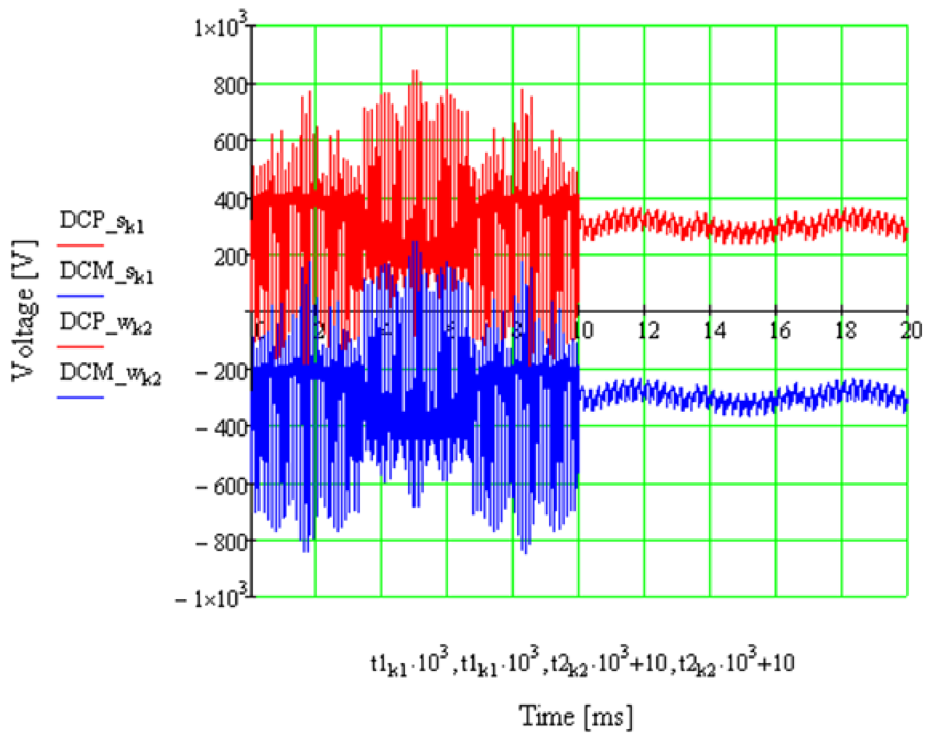


Figure 9-1   ALM step-up mode U_{Line} = 400 V AC; UDC = 600 V

The diagram above shows that the DC-Link Smoothing Filter significantly reduces the periodic movement of the DC link relative to the earth. See also Chapter "Line-ground voltage (Page 134)".
The reduction of the voltage stress achieved at the DC link is applied to all drives of the DC link system.
Siemens system motors are designed for the standard ALM step-up mode without additional measures. This can be seen in the left half of the diagram above.
The DC-Link Smoothing Filter is an option for operators using third-party motors to reduce the risk of insulation failure.

The DC-Link Smoothing Filter can also be used in DC link systems without third-party motors. For example, if large earth capacitances have added up due to long cables with large cross-sections in case of single-wire routing.

9.2 Using the DC link smoothing filter

9.2.1 Combination with additional voltage-reducing measures

The DC-Link Smoothing Filter can be combined with the motor-related measures for reducing the voltage stress. The measures are described in the Chapter: "EMC aspects (Page 157)".
For motors exhibiting neutral-point resonance, the effects of the individual measures, motor-related + DC-Link Smoothing Filter, add up at the neutral point. The following distinction makes for easier understanding:

- The damping measures in the chapter "EMC aspects" are motor-related. They turn the poorly dampened motor into a motor with good internal damping. See also Chapter "Example of the line-earth voltage with UDC link voltage = 720 V (Page 135)".
- The DC-Link Smoothing Filter leaves the motor in the natural state of its existing damping, but reduces the incoming load at its input terminals.

9.2.2 Effect at the neutral point

Function

The most frequent insulation failures occur close to the neutral point. For this reason, the effect of the DC-Link Smoothing Filter is important for the amplitude of the neutral point voltage.

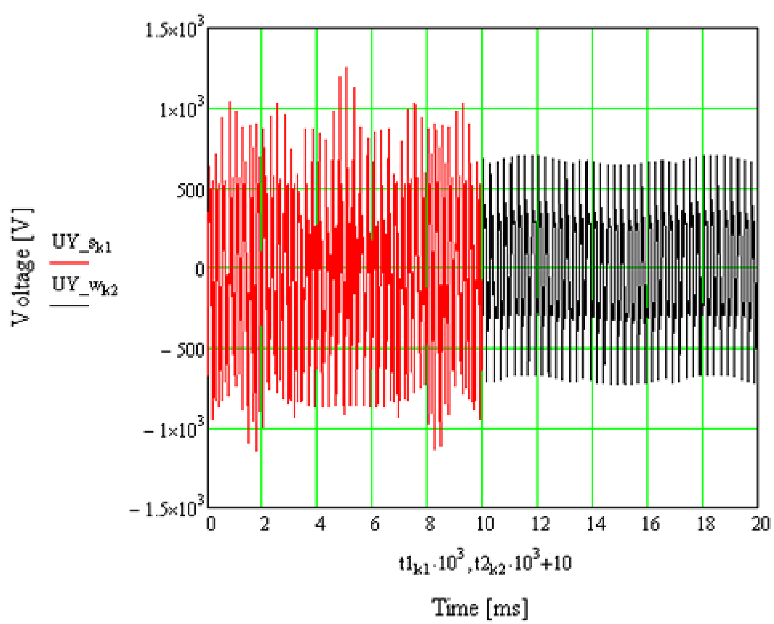


Figure 9-2 Typical voltage at the neutral point with respect to PE in the standard (red) and with DC-Link Smoothing Filter improvement (black) at the neutral point approx. 900 $V_{peak\text{-}peak}$

A significant improvement can be seen at the DC link system, see figure above. This improvement is passed on to the neutral point.

The detailed view shows that the tendency of the neutral point to oscillate remains the same because it is a motor property.
The improvement at the neutral point results from the improvement at the motor input that was achieved by smoothing the ALM switching stages using the DC-Link Smoothing Filter. See the detailed figure below.

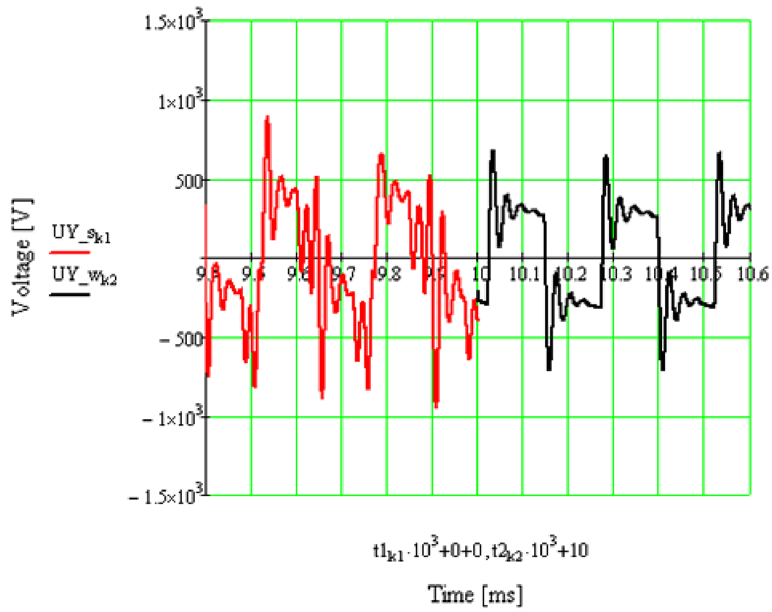


Figure 9-3 Detail from figure above: Tendency of the motor to oscillate at the neutral point remains the same, the improvement is achieved by smoothing the motor input voltage using a DC-Link Smoothing Filter (standard = red, smoothing = black).

Note

Insulation failure close to neutral point already during uncontrolled SLM operation

There are motors on the market whose neutral-point resonance is so severe that the insulation failure occurs already during uncontrolled SLM operation close to the neutral point.

These motors cannot reach their expected service life through installation of a DC-Link Smoothing Filter alone. In cases such as these, consider taking motor-related damping measures. You can find details in the Chapter "Neutral-point oscillation (Page 142)".
In combination with a motor-related damping measure with the DC-Link Smoothing Filter, the necessary safety can almost always be achieved.

Retrofitting

The DC-Link Smoothing Filter can be retrofitted. If the DC-Link Smoothing Filter and ALM are from the same performance class, the system performance is not limited. In the case of a retrofit into an existing system, neither a new network identification nor a parameter change of the ALM or a Motor Module are necessary.

Stability and control quality of the DC link voltage

Even though the DC-Link Smoothing Filter has a significant effect on the DC link voltage with respect to PE (line-earth), the stability of the DC link voltage (line-line) is not affected.
When using the DC-Link Smoothing Filter, the DC link voltage (mostly 600 V DC) is available at the same level, power and stability as without the filter.

9.3 Components

The DC-Link Smoothing Filter consists of two components. Both components must always be connected correctly.

Note

Operation with only one of the two components

Operation with only one of the two components is **not** permissible.

SF Choke Module

The SF Choke Module is currently offered in the following versions:

- 55 kW, AC-side connection
- 120 kW, DC-side connection

The power loss depends on the specified ALM power and the degree of increase.

SF Capacitor Module

The SF Capacitor Module is available in the versions "Booksize" and "Top-Hat Rail".

- The power loss is negligible.
- The SF Capacitor Module can be easily integrated.
  - No 24 V connection
  - No fan
  - No signaling contacts
  - No displays via LED
    If LED is present, it has no function

Note

Confusing the SF Capacitor Module with the Capacitor Module

Do not confuse the SF Capacitor Module with the Capacitor Module (6SL3100-1CE14-0AA0). In particular, the Capacitor Module does not replace the SF Capacitor Module.

The SF Capacitor Module and the Capacitor Module are not mutually exclusive. The SF Capacitor Module of the DC-Link Smoothing Filter does not interact with any potentially installed Capacitor Modules.

9.3.1 SF Choke Module 55 kW

9.3.1.1 Interface description

Interface overview

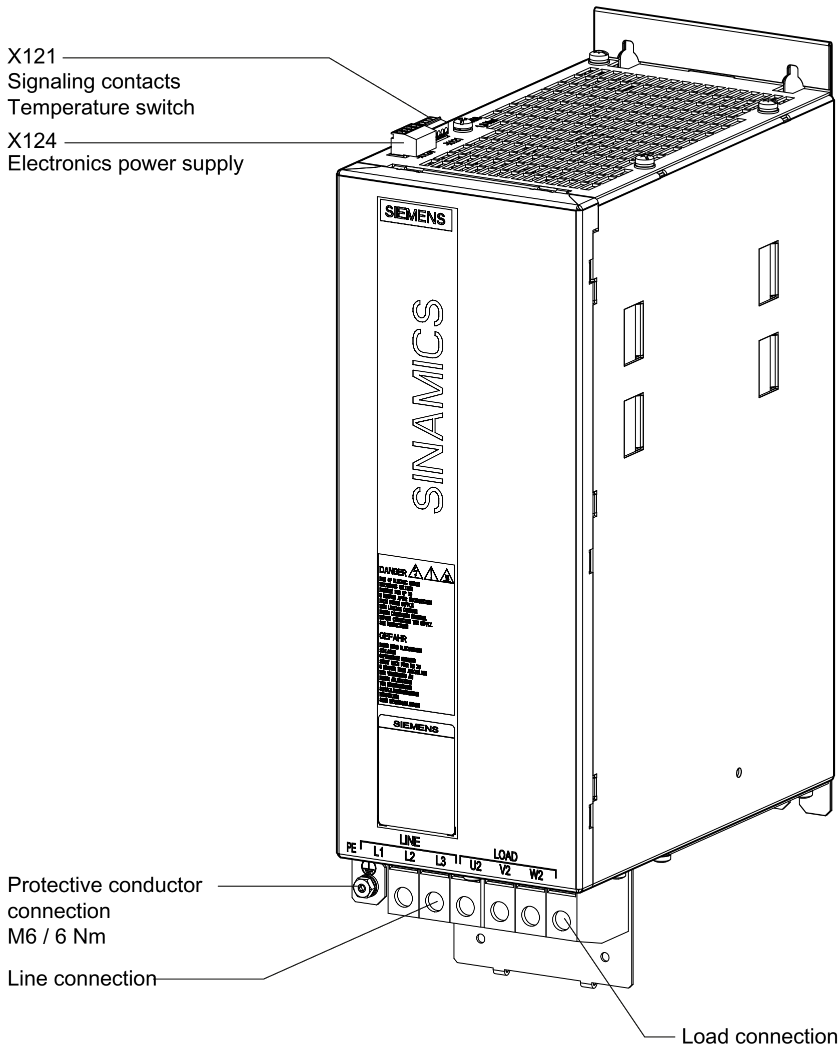


Figure 9-4 SF Choke Module interface overview (55 kW)

Line/load connection

Table 9-1 Line supply and load connection SF Choke Module 55 kW

	6SL3100-0DC25-5AA0
Power	55 kW
Line supply connection L1, L2, L3	Screw terminal 50 mm² end sleeve 6 Nm
Load connection U2, V2, W2	
Tool	Flat-head screwdriver 1.2 x 6.5 mm

> **Note**
>
> **Observing the touch protection with SF Choke Module 55 kW**
>
> The connection terminals of the SF Choke Module 55 kW are only certain to have touch protection IPXXB according to IEC 60529 if cables with a minimum cross-section of 25 mm² and insulated end sleeves are used.

X121 temperature sensor and fan control

Table 9-2 Plug-in screw terminal X121

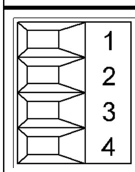
	Terminal	Designation	Technical data
	1	+Temp	Output temperature switch Must be connected to interface X21 of the Active Line Module.
	2	-Temp	Temperature switch output
	3	+24 V power supply for digital inputs	Current carrying capacity: 500 mA
	4	Disable Fan	The fan can be disabled. The fan may be disabled only while the Active Line Module is disabled. The fan will, however, be forcibly activated if the internal temperature of the module exceeds approx. 75°C.

Table 9-3 Connectable conductor cross-sections and tightening torques for the screw terminal

Connectable cable cross-sections	Rigid, flexible With end sleeve, without plastic sleeve With end sleeve, with plastic sleeve AWG / kcmil	0.08 ... 1.5 mm² 0.25 ... 1.5 mm² 0.25 ... 0.5 mm² 28 ... 14
Stripped length	7 mm (0.28 in)	
Tool	Flat-head screwdriver 0.4 x 2.0 mm	
Tightening torque	0.22 ... 0.25 N (1.9 ... 2.2 lbf in)	

> **Note**
>
> If terminal X121.4 is not connected (or connected with low level), the fan will run in the continuous mode.

X124 electronics power supply

Table 9-4 X124 electronics power supply

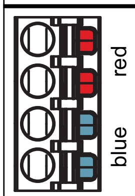
	Terminal	Function	Technical specifications
	+	Electronics power supply (24 V)	Voltage: 24 V DC (20.4 to 28.8 V) Current consumption: max. 1.6 A Max. current via jumper in connector: 20 A at 55°C
	+	Electronics power supply (24 V)	
	M	Electronics ground (0 V)	
	M	Electronics ground (0 V)	

Table 9-5 Connectable cable cross-sections for the spring-loaded terminal

Connectable cable cross-sections	Rigid, flexible With end sleeve, without plastic sleeve With end sleeve, with plastic sleeve AWG / kcmil	0.2 ... 2.5 mm^2 0.25 ... 2.5 mm^2 0.25 ... 1.5 mm^2 24 ... 12
Stripped length	8 mm (0.31 in)	

> **Note**
>
> The two "+" and "M" terminals are bridged in the connector. This ensures that the supply voltage is looped through.

9.3.1.2 Dimension drawing

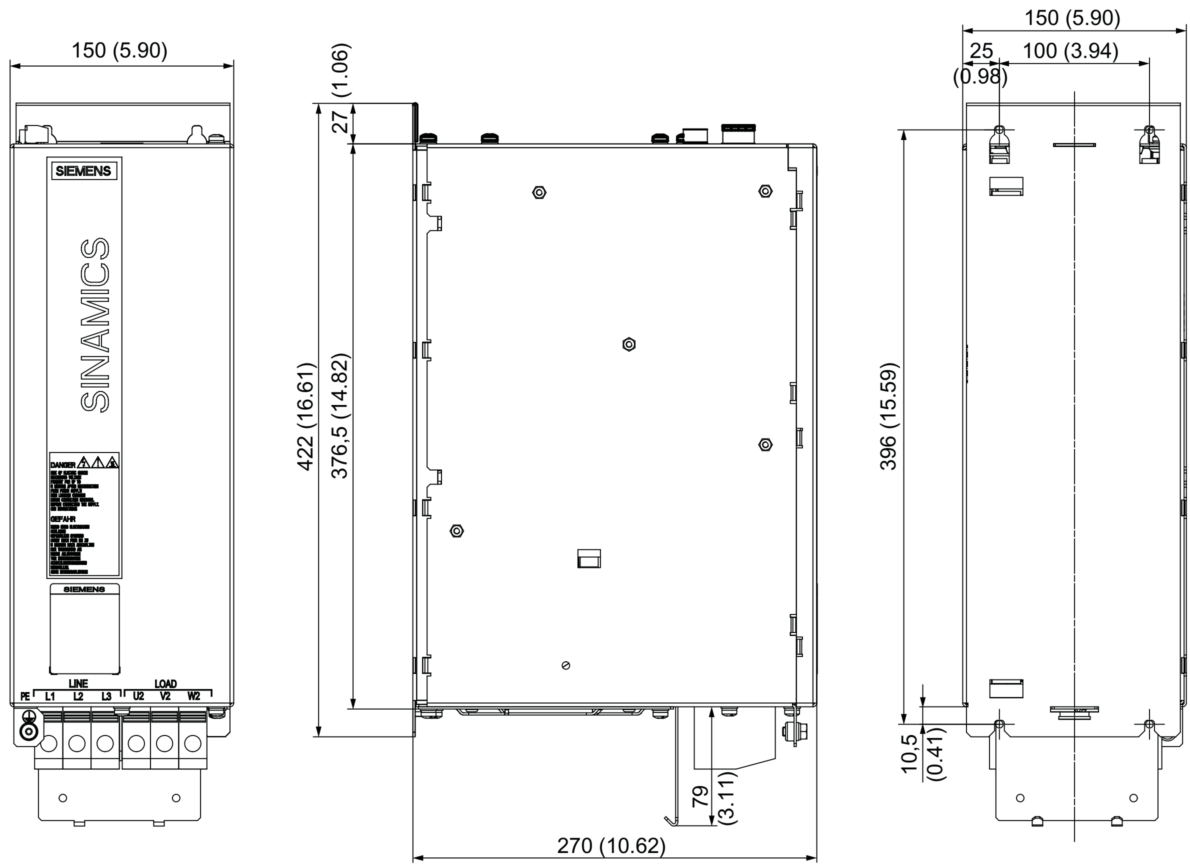


Figure 9-5 Dimension drawing of the SF Choke Module 55 kW, all dimensions in mm and (inches)

Mounting

Screws	M6 (no hexagon-head screws)
Tightening torque	6 Nm (53.1 lbf in)

9.3.1.3 Technical specifications

Table 9-6 Technical specifications of the SF Choke Module

SF Choke Module		6SL3100-0DC25-5AA0
P_{rated} 1)	kW	55
P_{Max} 1)	kW	128
Maximum DC link voltage without derating	V_{DC}	650
Maximum DC link voltage with derating	V_{DC}	720
I_{rated}	A	88
I_{max}	A	176
Current requirement of the 24 V electronics power supply	A	0.49

SF Choke Module		6SL3100-0DC25-5AA0
Line voltage	V	3 AC 380 V ... 480 V ±10% (-15% < 1 min)
Line frequency	Hz	47 ... 63
Cooling air requirement	m^3/h	160
Power loss	W	350
Weight	kg	29

1) The specified power ratings apply to the line voltage range from 380 V to 480 V AC with simultaneous DC link voltage up to 650 V DC

9.3.1.4 Derating

The power loss of the SF Choke Module depends on the specified ALM power and the degree of increase. For the power consideration, the rated power depending on the DC link voltage used is considered more exactly.

Derating of the effective power

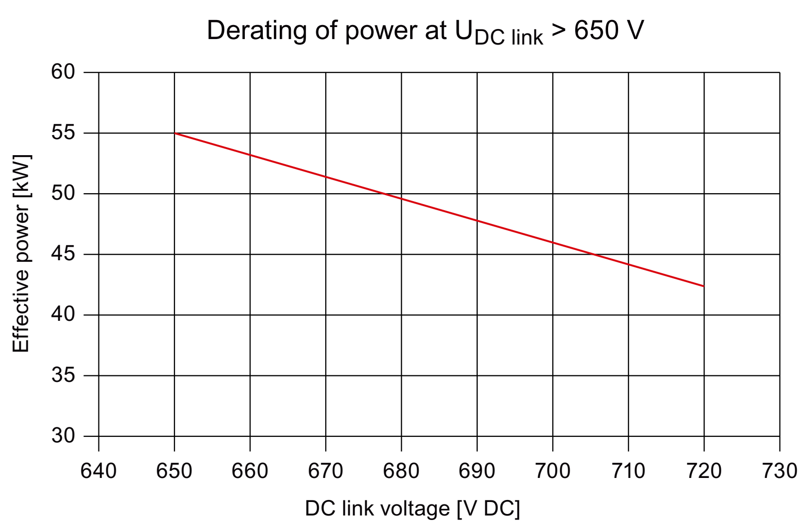


Figure 9-6 Power derating of the 55 kW module with a DC link voltage of more than 650 V

The effective power here is the root mean square value of the power over a time period of more than one hour. If a DC link voltage of more than 650 V DC is required, the effective power is reduced.

Reason for derating:

- The heat loss of the damping rises with the increasing degree of increase.

Prevention of the power increase derating

To prevent derating of the effective power, the DC link can be operated at a higher line voltage, for example, by using a series transformer. The minimum line voltage required to prevent power derating is shown in the diagram below.

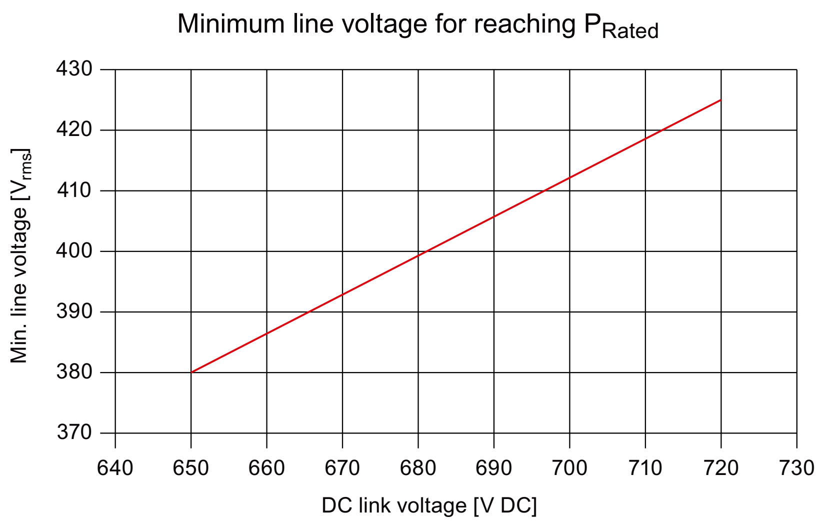


Figure 9-7 Necessary line voltage (SF Choke Module 55 kW)

Example: With a line voltage of 400 V_{rms}, a DC link voltage of 683 V DC without power derating can be extracted.

9.3.2 SF Choke Module 120 kW

9.3.2.1 Interface description

Interface overview

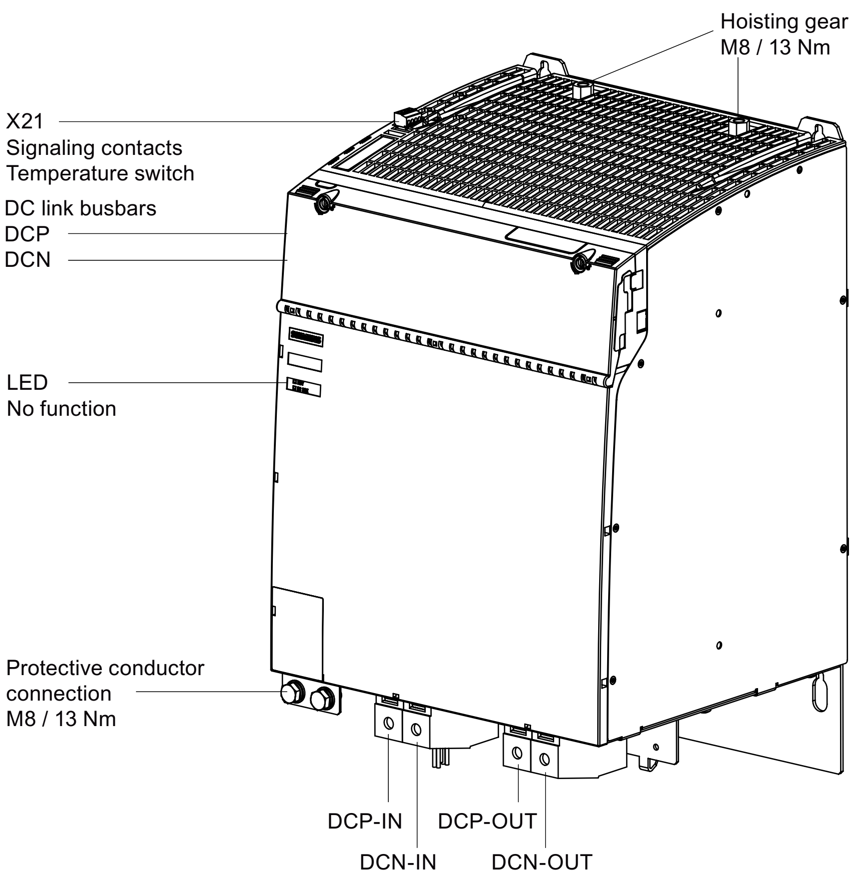


Figure 9-8 SF Choke Module interface overview (120 kW)

Line/load connection

Table 9-7 Line and load connection with SF Choke Module

Article number		**6SL3100-0DC31-2AA0**
Power [kW]		120
ALM-side DC connection	DCP-IN, DCN-IN	Connection via DC link busbar using a DC link bridge (front busbars)[1]
	DCP-OUT, DCN-OUT	
Tool		8 mm Allen key

[1] Alternative connection:
Screw terminal 35 ... 95 mm^2
End sleeve
15 ... 20 Nm

Note

Observing the touch protection with SF Choke Module

Touch protection IPXXB according to IEC 60529 is provided for the connection terminals of the SF Choke Module 120 kW only under the following conditions:

- The lines have a cross-section of at least 35 mm^2.
- The end sleeves used are isolated.

Note

Unused terminal connections are covered.

Close any unused terminal connections for DCP-IN/OUT and DCN-IN/OUT in the terminals with the supplied dummy covers.

X21 temperature sensor and fan control

Table 9-8 Plug-in screw terminal X21

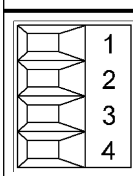
	Terminal	**Designation**	**Technical data**
	1	+Temp	Output temperature switch Must be connected to interface X21 of the Active Line Module.
	2	-Temp	Temperature switch output
	3	+24 V power supply for digital inputs	Current carrying capacity: 500 mA
	4	Disable Fan	The fan can be disabled. The fan may be disabled only while the Active Line Module is disabled. The fan will, however, be forcibly activated if the internal temperature of the module exceeds approx. 75°C.

Table 9-9 Connectable conductor cross-sections and tightening torques for the screw terminal

Connectable cable cross-sections	Rigid, flexible With end sleeve, without plastic sleeve With end sleeve, with plastic sleeve	0.08 ... 1.5 mm^2 0.25 ... 1.5 mm^2 0.25 ... 0.5 mm^2
	AWG / kcmil	28 ... 14
Stripped length	7 mm (0.28 in)	
Tool	Flat-head screwdriver 0.4 x 2.0 mm	
Tightening torque	0.22 ... 0.25 N (1.9 ... 2.2 lbf in)	

Note

If terminal X21.4 is not connected (or connected with low level), the fan will run in the continuous mode.

Electronics power supply

The electronics power supply is provided via the electronics current busbars.

You must use a 24 V terminal adapter for horizontal installation of the 120 kW Choke Module.

9.3.2.2 Dimension drawing

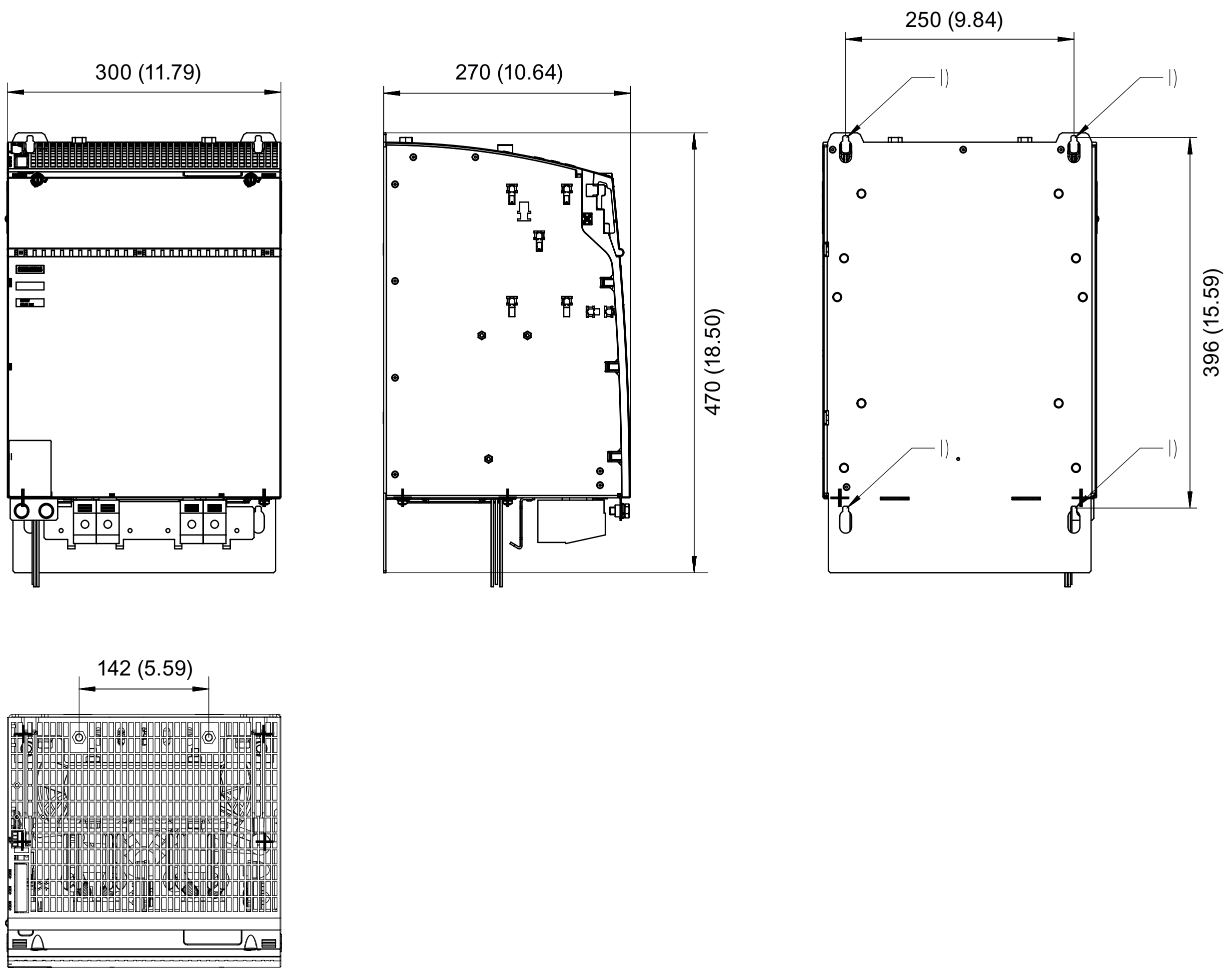


Figure 9-9 Dimension drawing of the SF Choke Module 120 kW, all dimensions in mm and (inches)

Mounting

Screws	M6 (no hexagon-head screws)
Tightening torque	6 Nm (53.1 lbf in)

9.3.2.3 Technical specifications

Table 9-10 Technical specifications of the SF Choke Module 120 kW

Article number		6SL3100-0DC31-2AA0
P_{rated} 1)	kW	120
P_{Max} 1)	kW	175
Minimum DC link voltage without derating	V_{DC}	600
Minimum DC link voltage with derating	V_{DC}	560
I_{rated}	A	200

Article number		6SL3100-0DC31-2AA0
I_{max}	A	294
Current requirement of the 24 V electronics power supply	A	1.3
Line voltage	V	3 AC 380 V ... 480 V ±10% (-15% < 1 min)
Line frequency	Hz	47 ... 63
Cooling air requirement	m³/h	320
Power loss	W	500
Weight	kg	41

1) The specified power ratings apply to the line voltage range from 380 V to 480 V AC with simultaneous DC link voltage up to 650 V DC

9.3.2.4 Derating

The power loss of the SF Choke Module depends on the specified ALM power and the degree of increase. For the power consideration, the rated power depending on the DC link voltage used is considered more exactly.

Derating of the effective power

The permissible rated power decreases depending on the DC link voltage used according to the following diagram. From 600 ... 720 V DC, the SF Choke Module reaches its maximum rated power of 120 kW.

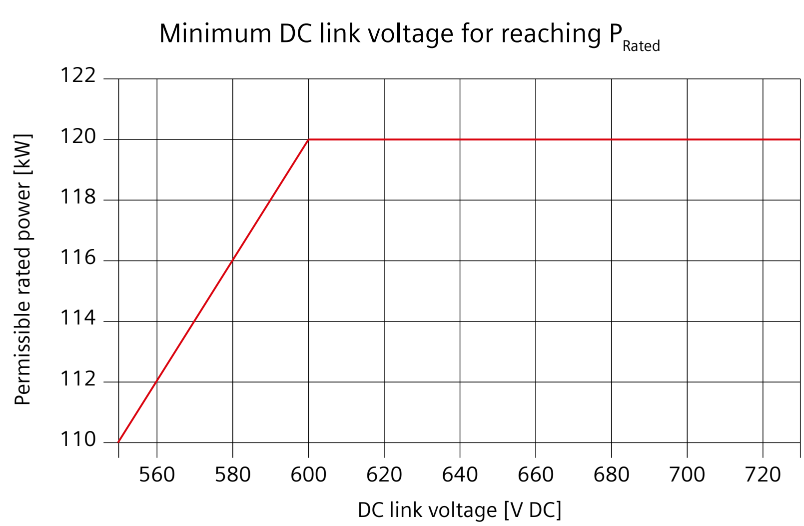


Figure 9-10 Minimum DC link voltage for the SF Choke Module 120 kW

The effective power here is the root mean square value of the power over a time period of more than one hour.

Reason for derating:

- The copper losses of the winding increase as the DC link voltage decreases.
- The heat loss of the damping rises with the increasing degree of increase.

Prevention of the power increase derating

The minimum line voltage required to prevent power derating is shown in the diagram below.

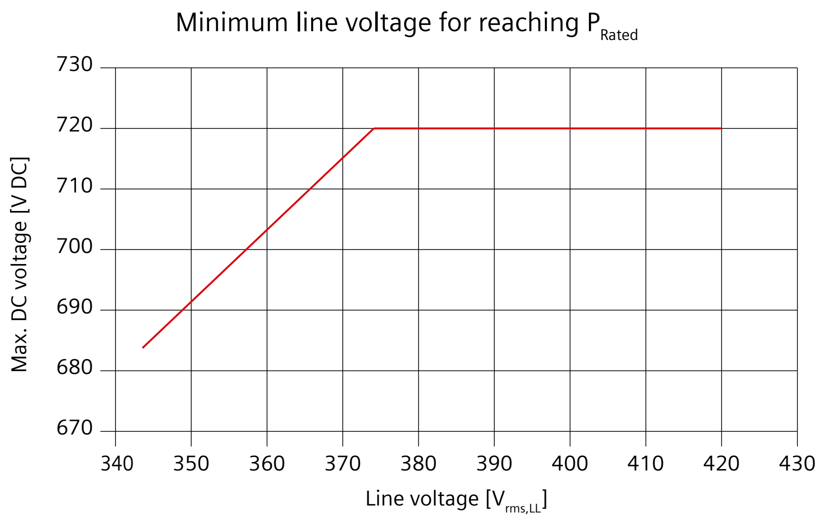


Figure 9-11 Maximum DC voltage (SF Module 120 kW)

Example: With a line voltage of 370 V_{rms}, a DC link voltage of 714 V DC without power derating can be extracted.

9.3.3 SF Capacitor Module, Booksize

9.3.3.1 Description

The SF Capacitor Module in the SINAMICS Booksize version has a 50 mm wide SINAMICS housing. The module participates in the DC link busbars via DCP/DCN.

Arrangement in the SINAMICS drive line-up

Install the SF Capacitor Module Booksize as the last module in a row so that it terminates the line-up. See also the figure "Figure 9-17 Simplified circuit of the DC-Link Smoothing Filter (55 kW, AC-side) (Page 195)" and the figure "Grounding recommendation for the SF Capacitor Module" in this chapter.

A connection over a DC link rectifier adapter (6SL3162-2BD00-0AA0) is permissible.

Grounding of the SF Capacitor Module

The circuit of the DC-Link Smoothing Filter closes over the ground connection of the line filter. Route the ground connection of the SF Capacitor Module so that its leakage current flows as directly as possible to the ground connection of the line filter; see figure below. The conductor cross-section of the ground connection must be at least 2.5 mm².

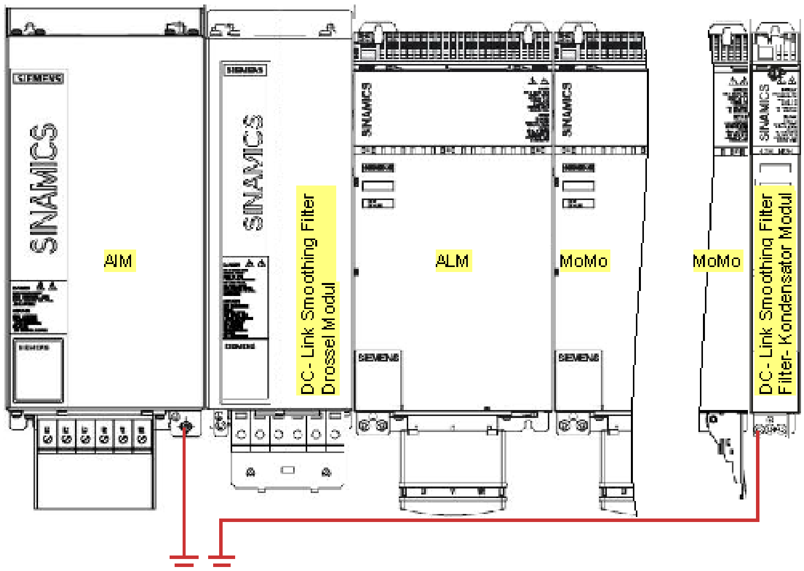


Figure 9-12 Grounding recommendation for the SF Capacitor Module using the example of the SINAMICS Booksize version

The AIM has an integrated line filter. The grounding conductor of the SF Capacitor Module should therefore be routed as directly as possible to the ground connection of the AIM on the mounting plate.

9.3.3.2 Interface description

Overview

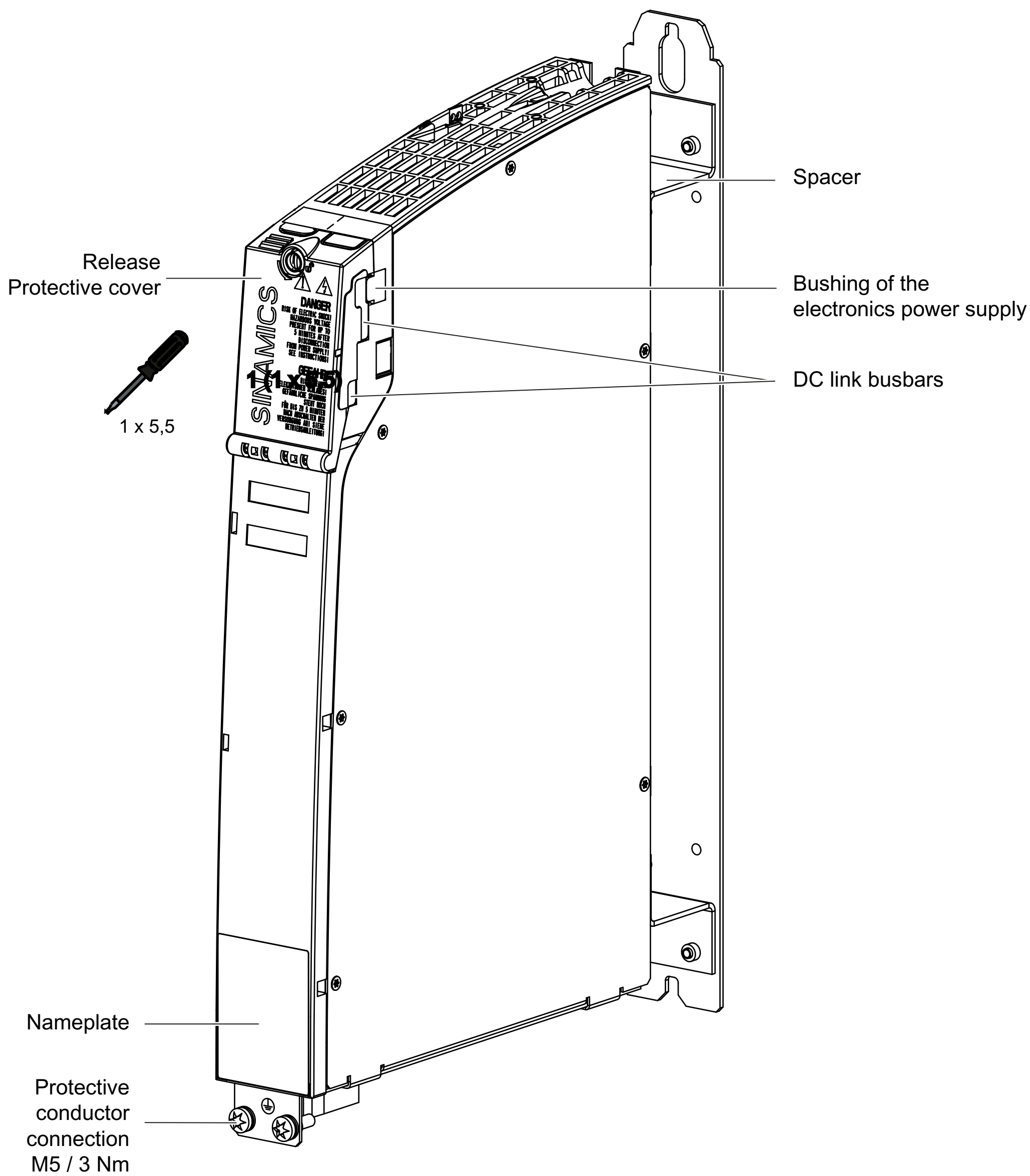
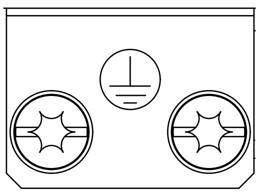


Figure 9-13 Overview of interfaces of the SF Capacitor Module

Protective conductor connection

Table 9-11 Protective conductor connection

	Terminal	Technical data
	Protective conductor connection	M5 screw / 3 Nm at the housing

9.3.3.3 Dimension drawing

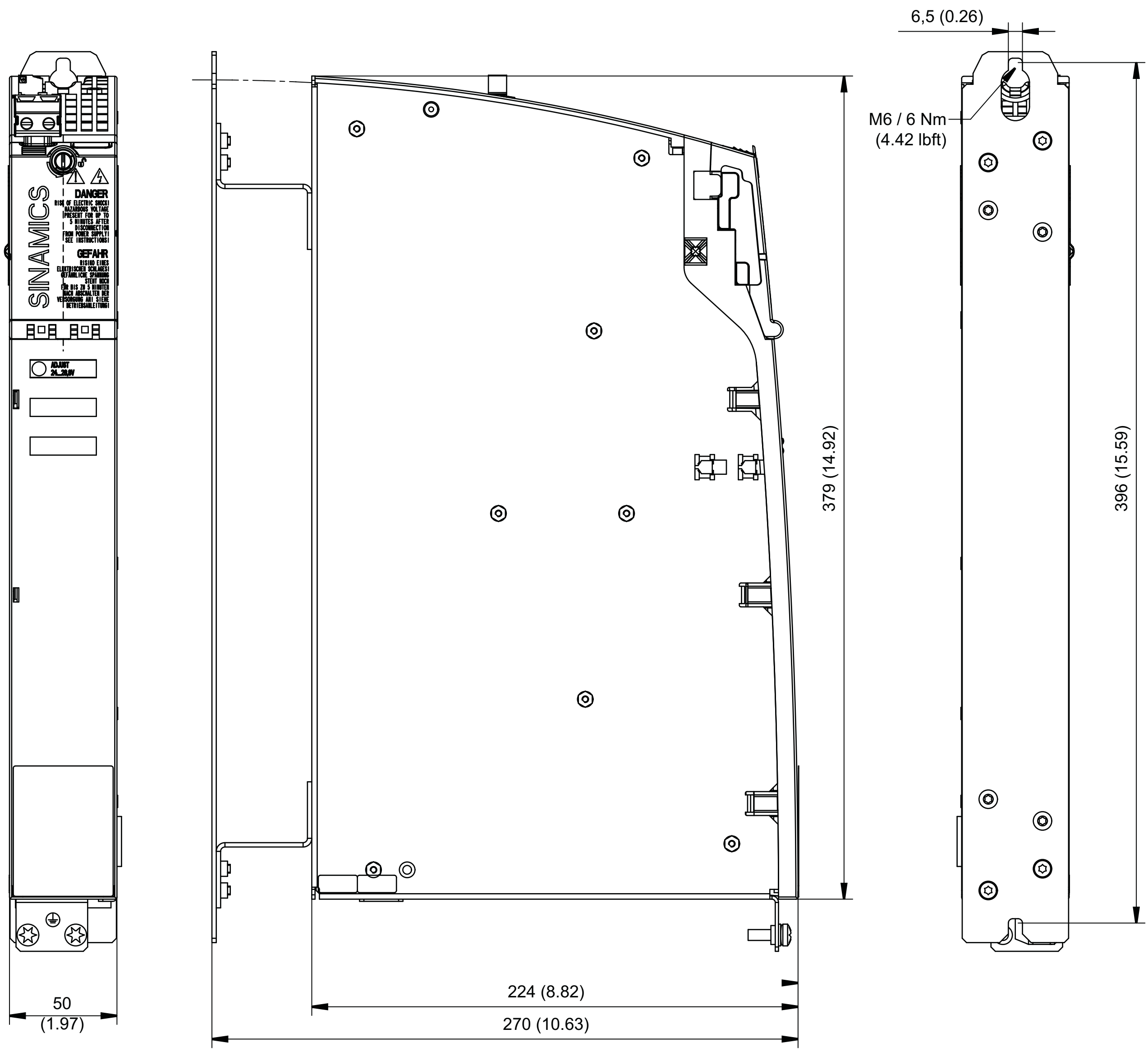


Figure 9-14 Dimension drawing of the SF Capacitor Module Booksize, all dimensions in mm and (inches)

9.3.3.4 Technical specifications

Table 9-12 Technical specifications of the SF Capacitor Module Booksize

SF Capacitor Module	6SL3100-1DC01-0AA0
Conductor cross-section	1.5 ... 2.5 mm^2
Capacitance	400 nF DCP<->PE 400 nF DCN<->PE
U_{max}	Same as SINAMICS system

9.3.4 SF Capacitor Module, Top-Hat Rail

9.3.4.1 Description

The SF Capacitor Module, Top-Hat Rail is usually a retrofit part. It is mounted onto a top-hat rail.

① DCP (Direct Current Positive)
② DCN (Direct Current Negative)
③ Functional ground

Figure 9-15 SF Capacitor Module, Top-Hat Rail

DC link connection

- Use a DC link rectifier adapter for connection to the DCP and DCN terminals, e.g. "6SL3162-2BD00-0AA0".
- Use a two-wire, shielded cable.
- Apply the shield at both ends close to the module, close to the top-hat rail module as well as close to the Motor Module at the mounting plate.
- Use mechanically rugged cables.
- For an unshielded cable, twist both wires together.
- Use a cable cross-section of at least 1.5 mm^2.

For SF Capacitor Module, Top-Hat Rail, mixing up the DCP and the DCN has no consequences. All components are designed for alternating voltage.

Protective ground and functional grounding

The SF Capacitor Module, Top-Hat Rail has a plastic housing. Therefore, protective ground must not be connected.

Install the grounding conductor of the functional grounding preferably close to the line filter grounding conductor at the mounting plate. See also the figure "Grounding recommendation for the SF Capacitor Module using the example of the SINAMICS Booksize version".

9.3.4.2 Dimension drawing

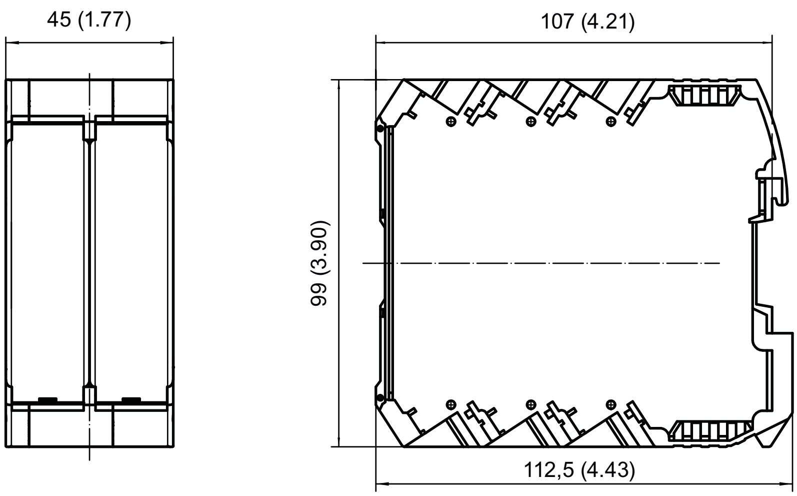


Figure 9-16 Dimension drawing of the SF Capacitor Module Top-Hat Rail, all dimensions in mm and (inches)

9.3.4.3 Technical specifications

Table 9-13 Technical specifications of the SF Capacitor Module, Top-Hat Rail

SF Capacitor Module	6SL3100-1DC02-0AA0
Conductor cross-section	1.5 ... 2.5 mm^2
Capacitance	400 nF DCP<->PE 400 nF DCN<->PE
U_{max}	Same as SINAMICS system

9.4 Use and load spectrum

The power of the DC-Link Smoothing Filter is matched to the respective Active Line Module. It is currently available in the sizes 55 kW and 120 kW.

Many machines require peak performance for the infeed. The rated power of the infeed usually greatly exceeds the actual demand.
It is permissible and practical in this case to select the performance class of the DC-Link Smoothing Filter one level less than the performance class of the infeed.

Example for combination in design for peak performance:

- 55 kW DC-Link Smoothing Filter at 80 kW ALM and 80 kW AIM

The DC-Link Smoothing Filter can easily withstand a temporary overload. The rated power of the ALM can also carry the DC-Link Smoothing Filter, dimensioned one level smaller, for several minutes.

9.5 Intended use

The DC-Link Smoothing Filter is inserted into the DC link in addition to the existing line connection.

- It is intended for SINAMICS S120 DC link systems in Booksize design with active infeed (ALM).
- It has been adapted to the fixed ALM PWM of 8 kHz.
- It has been adapted to the fixed flat top type of modulation.
- In the switching topology, the SF Choke Module must be connected between line filter and ALM.
  A connection between line and line filter, e.g. AIM, Wideband, Line Filter, Basic Line Filter, is not permitted.
- The DC-Link Smoothing Filter does not replace the filters on the line side.
  If the DC-Link Smoothing Filter is installed, all line filters that were necessary without DC-Link Smoothing Filter are still necessary.
- It is not permissible to use the SF Choke Module without also using the SF Capacitor Module at the same time.
- It is not permissible to use the SF Capacitor Module without also using the SF Choke Module at the same time.
- The temperature sensor of the SF Choke Module must be connected to the EP terminal (X21) of the ALM.
  When using an AIM, the temperature sensor of the SF Choke Module must be connected in series to the temperature sensor of the AIM. Disabling the trip function is not permissible.
- Operation of the SF Choke Module without 24 V supply (at X124) is not permissible (fan power supply).

9.6 System compatibility

See the following notes regarding system compatibility of the DC-Link Smoothing Filter:

- The DC-Link Smoothing Filter is suitable for retrofitting. You can find additional information in the Chapter "Using the DC link smoothing filter (Page 173)".
- The SLM mode of the ALM is permissible for the 55 kW variant. Derating depending on the DC link voltage results with the 120 kW variant.
- The DC-Link Smoothing Filter can be used at DC links with AIM and at DC links with HFD reactor. The usual system environment is AIM.

- Permitted mounting positions:
  - Hanging (top/bottom ventilation clearance ≥ 80 mm)
    55 kW Module: Line connection, bottom
    120 kW Module: Line connection via DC link busbars
  - Horizontal with rear panel at bottom (ventilation clearance ≥ 80 mm from the ventilation grilles)
    120 kW Module: Line connection via terminals in bottom plate
- The DC-Link Smoothing Filter can be used for Active Line Modules with smaller rated power than the rated power on the nameplate without any restrictions.
- The DC-Link Smoothing Filter can be used for Active Line Modules with greater rated power than the rated power on the nameplate with restriction of the continuous power.
- For Motor Modules, there are no restrictions of pulse frequencies due to the DC-Link Smoothing Filter.
- Sporadic failures with fast slope 70%, 500 ms is possible between phases.

9.7 Principle of operation

The DC-Link Smoothing Filter can be interpreted as LC lowpass that filters out the switching edges of the ALM of the DC link system in relation to PE.

The following figure shows the simplified electric circuit for the 55 kW DC-Link Smoothing Filter.

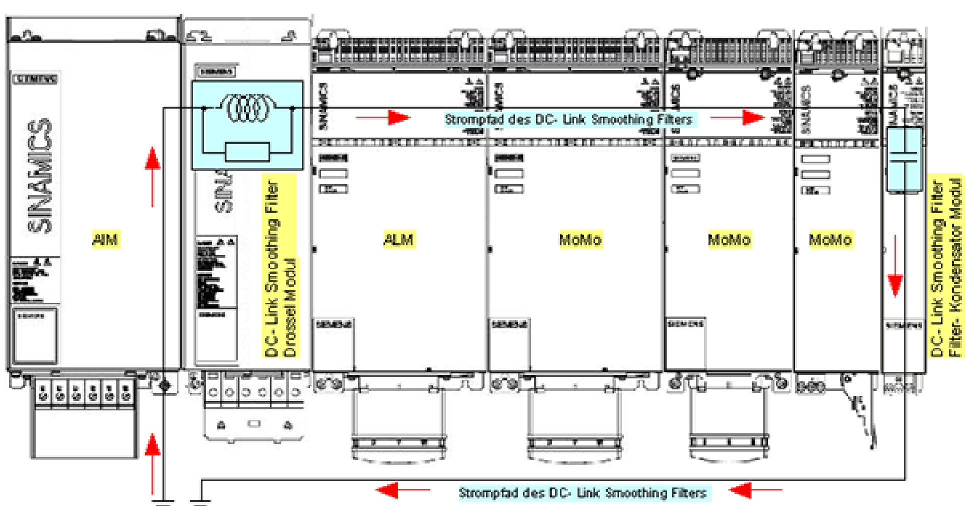


Figure 9-17 Simplified circuit of the DC-Link Smoothing Filter (55 kW, AC-side)

SF Choke Module and SF Capacitor Module have the following functions here:

- The SF Choke Module makes the DC link system sufficiently elastic toward PE.
- The SF Capacitor Module fixes the DC link system toward PE.

This distribution of tasks means that the two modules may only be operated together.

- SF Choke Module without SF Capacitor Module
  The DC link system loses its hold with regard to the ground potential. The reaction of the converters causes an unpredictable drifting and pulsing.
- SF Capacitor Module without SF Choke Module
  The elasticity with regard to the ground potential is missing. The ground currents of the SF Capacitor Module will become inadmissibly high. A smoothing effect as seen in figure "Function of the DC-Link Smoothing Filter (Page 171)" does not occur.

The necessary damping of the LC lowpass is shown by a damping resistor parallel to the reactor in the figure above.
The damping resistor is housed in the SF Choke Module with an electric steel quality of the reactor core material perfectly matched to the damping requirements.
The heat loss of damping requires heat dissipation by the fan. The amount of heat loss of the damping rises with the degree of increase. Therefore, a derating depending on the DC link voltage must be considered if necessary, see SF Choke Module for this. For the DC version with 120 kW, there is a derating depending on the DC link voltage (copper losses).

Therefore, a derating should be considered as of an increase from 380 V AC input to > 650 V DC.

During smoothing according to "Function of the DC-Link Smoothing Filter (Page 171)", the SF Capacitor Module absorbs currents and discharges them to the PE.
The circuit that is created this way closes over the line filter. In the figure above, the line filter is integrated into the AIM. To close this circuit most effectively, the grounding conductor of the SF Capacitor Module should be mounted as close as possible to the grounding conductor of the line filter at the mounting plate, see the Chapter "Description (Page 187)".

The ground currents that the SF Capacitor Module discharges to the PE close within the DC link system and are therefore outside the control cabinet. In particular, they are not visible at the grounding conductor to the mains connection.
Because the SF Capacitor Module smooths the DC link voltage, the converters emit fewer capacitive ground currents into the motor cables than without smoothing, see also: "Function of the DC-Link Smoothing Filter (Page 171)".
The DC-Link Smoothing Filter therefore absorbs a portion of the capacitive motor currents before they leave the control cabinet.

9.8 Topology of the power connection

9.8.1 Topology DC-side 55 kW

Connect the SF Choke Module of the DC-Link Smoothing Filter between line filter and ALM.

- In the DC link with AIM, connect the SF SF Choke Module directly in front of the ALM; see also the figure "Connection of the SF Choke Module directly in front of the ALM".
- In the DC link with HFD and external line filter, connect the SF Choke Module also directly in front of the ALM.

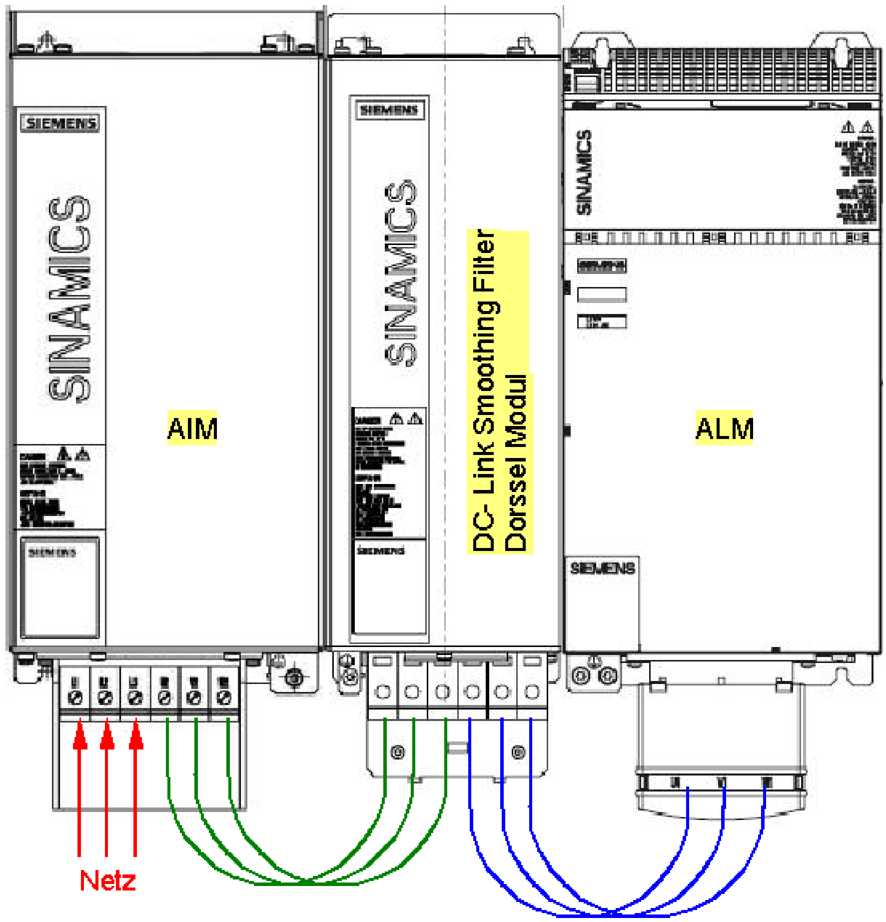


Figure 9-18 Connection of the SF Choke Module directly in front of the ALM

In the figure above, the power connections of the ALM are connected directly to the power connections of the SF Choke Module.

NOTICE

Device damage due to incorrect integration of the SF Choke Module

When you integrate the SF Choke Module at a different location than between line filter and ALM, this may damage the DC link components. See also the following figure.

- Always install the SF Choke Module between line filter and ALM.

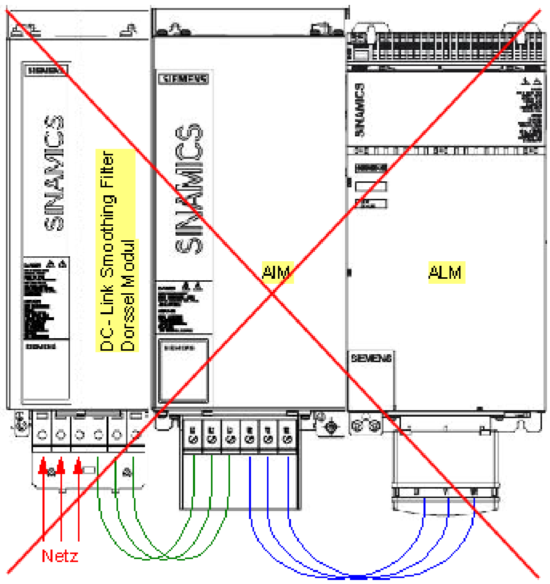


Figure 9-19 Impermissible connection of the line filter with the ALM without intermediate connection of the SF Choke Module

The connection topology shown in the figure above is not permissible because the line filter is integrated into the AIM.

The connections of the SF Choke Module are referred to as Line L1, L2, L3 (mains connection) and as Load U2, V2, W2 (load connection).
With the SF Choke Module, the connections are equivalent so that they may be swapped.
Example:

- In the figure "Connection of the SF Choke Module directly in front of the ALM", the mains connection of the SF Choke Module is connected to the load connection of the AIM, and the load connection of the SF Choke Module is connected to the ALM.
- The connections can be swapped: Connect the load connection of the SF Choke Module to the load connection of the AIM and the mains connection of the SF Choke Module to the ALM.

This degree of freedom can be helpful in case of horizontal installation or when retrofitting the DC-Link Smoothing Filter.

To comply with EMC limits, you must use shielded cables (preferably MOTION-CONNECT cables).

Because only the correct wiring of the modules with each other is important (see figure above), the SF Choke Module can also be installed at a different location in the control cabinet.

WARNING

Fire due to overheating resulting from excessively long power cables

Excessively long power cables can cause overheating of components with resulting fire and smoke development.

- The total cable length between an Active Interface Module, SF Choke Module and Active Line Module as well as between an Active Interface Module and Basic Line Filter must not exceed 10 m.

9.8.2 Topology DC-side 120 kW

Connect the SF Choke Module of the DC-Link Smoothing Filter between the ALM and the first DC link component (typically Motor Module).

- In the DC link with the ALM, connect the SF Choke Module directly behind the ALM; see also the figure "Connection of the SF Choke Module directly behind the ALM".

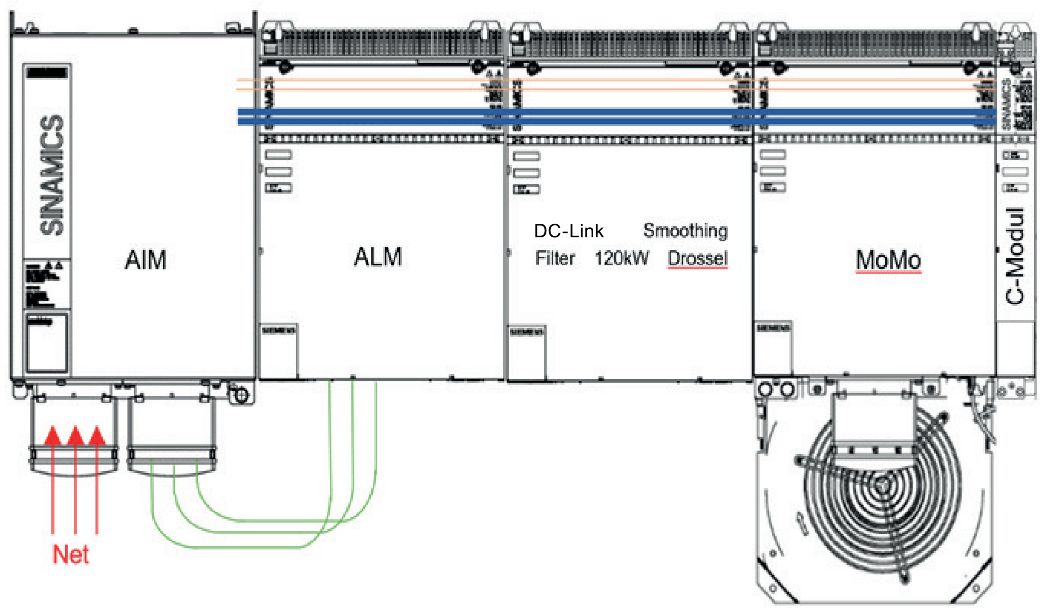


Figure 9-20 Connection of the SF Choke Module 120 kW

In the representation above, the DC link connection goes directly from the ALM via the SF Choke Module to the loads in the DC link. The SF Capacitor Module must always be located behind the SF Choke Module 120 kW on the DC link. This means that the ALM comes first, followed by the SF Choke Module 120 kW, and then (after a random number of Motor Modules) the SF Capacitor Module.

NOTICE

Device damage due to incorrect integration of the SF Choke Module

If you integrate the SF Choke Module 120 kW at a different location than between the ALM and the SF Capacitor Module, this may cause damage to the DC link components. See also the following figure.

- Always install the SF Choke Module between the ALM and the SF Capacitor Module.

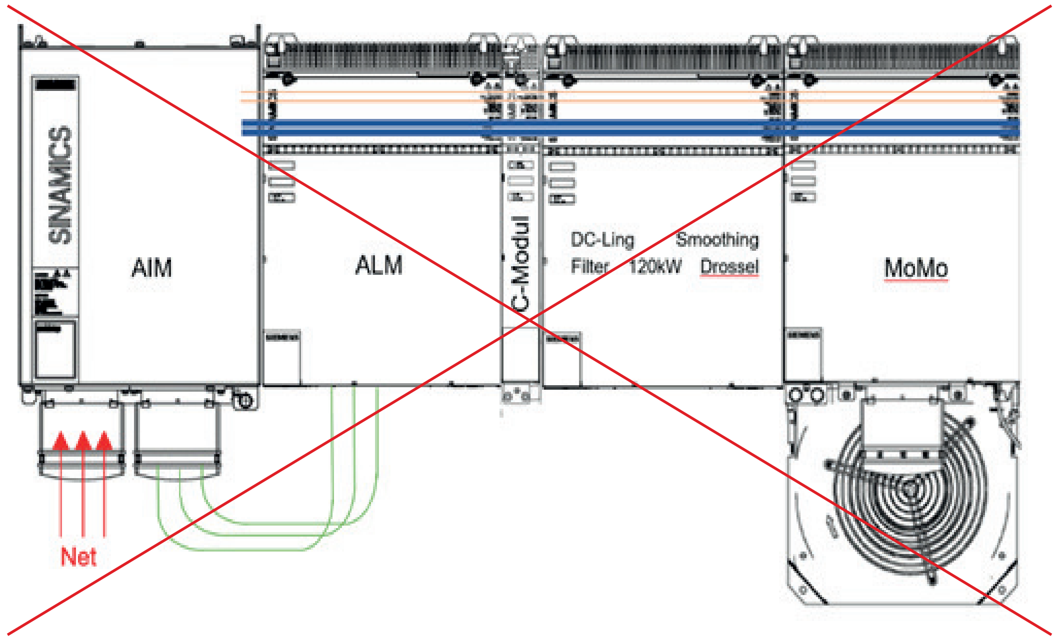


Figure 9-21 Inadmissible connection topology for the SF Choke Module 120 kW

The illustrated connection topology is not admissible because the SF Capacitor Module is located in front of the SF Choke Module when viewed from the ALM.

If the DC link goes to the left from the ALM as is also permitted, the add-on array of SF modules must also be replaced. However, it is also important here that, from the ALM (or viewed from the line) the ALM comes first, followed by the SF Choke Module 120 kW, and then the SF Capacitor Module.

With a shared DC link (DC link goes to the left and to the right from the ALM), two DC-Link Smoothing Filters are also required for the DC version in order to filter both sides of the DC link (if this is required).

To comply with EMC limits, you must use shielded cables (preferably MOTION-CONNECT cables).

9.9 Temperature sensor and fan control of the SF Choke Module

Temperature sensor

Consider the following points when connecting the temperature sensor to the SF Choke Module:

- In the DC link with AIM, connect the temperature switch of the SF Choke Module in series to the temperature switch of the AIM.
- In the DC link with HFD and external line filter, connect the temperature switch of the SF Choke Module to the connectors 1 and 2 of the ALM terminal X21.

Disabling the trip function of the ALM terminal X21 is not permissible.

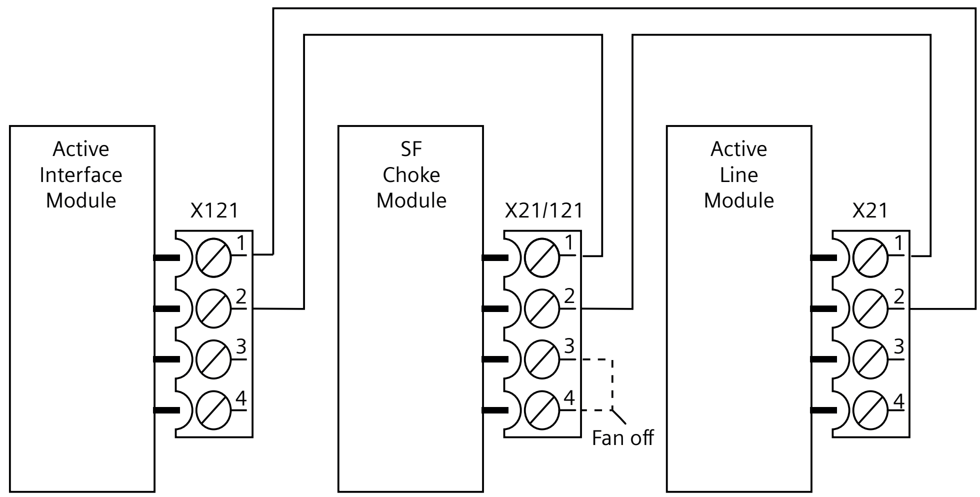


Figure 9-22 Connection example for the temperature switch of the SF Choke Module

Fan control

Due to the damping effect of the DC-Link Smoothing Filter, the SF Choke Module also generates heat during no-load operation.
The amount of heat depends on the degree of increase. You can find additional information on this in Chapter "Requirements regarding motor quality (Page 30)".
Only disable the fan over the fan control input, terminal X121, pin 4, when

- the setpoint of the DC voltage does not exceed 600 V and
- the effective ALM power is below 10 kW at the same time.

In all other cases, enable the fan permanently as follows:

- Connect pin 4 of terminal X121 permanently to pin 3.

X124 electronics power supply

You can find information on this in the SINAMICS S120 "Booksize Power Units" manual, chapter "Active Interface Module; X124 Electronics power supply".

Note

The fan is supplied over the 24 V connection of the terminal X124. Continuous operation (for more than 15 minutes) is not permissible without a proper 24 V connection.

Appendix A

A.1 EMF feed-through

EMF feed-through is explained below using a synchronous motor as an example.

To explain the effect clearly, we are assuming the following idealized conditions:

- The DC link is connected symmetrically and rigidly toward the earth using a DC-Link Smoothing Filter.
- The cable reflection is suppressed by the series inductance. Waveguide effects are not taken into account.
- No common mode voltages are propagating in the system.
  (No neutral-point oscillation, etc.)
- The Ohmic resistance was left out.
- We are using a star connection for the analysis.
  The result is also valid for delta connection.

Note

EMF feed-through under normal conditions

EMF feed-through occurs in the same way and in the same size even without idealized conditions.

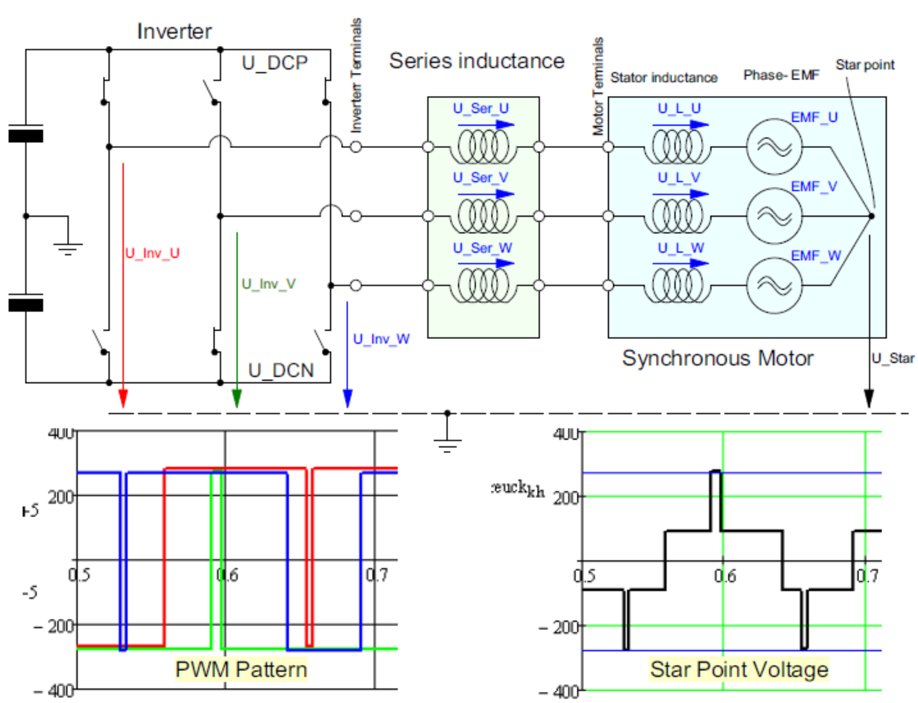


Figure A-1 Neutral-point voltage = average of the three phase voltages

It can be shown that, in the absence of common mode voltages, the neutral point voltage in the three-phase current system is identical to the average of the three phase voltages. This is illustrated by the two voltage progression charts in the figure above.

$$U\_Star = \frac{1}{3} \cdot \sum_{U,\,V,\,W} U\_Inv$$

In the absence of common mode voltages in the three-phase current system, the sum of the voltage drops as well as the sum of the currents is equal to zero at each three-phase current element:

$$\sum_{U,\,V,\,W} U\_Ser = 0; \quad \sum_{U,\,V,\,W} U\_L = 0; \quad \sum_{U,\,V,\,W} U\_EMF = 0$$

Note

Three-phase current element

A "three-phase current element" can be the series inductance, the motor leakage inductance or the regenerative system of the motor.

Of particular importance are those time segments in which all three bridges are located on the same potential: All three bridges are located on U_DCP, or all three bridges are located on U_DCN. We are going to look at the state: "*All three bridges on U_DCP*". The neutral point is also on U_DCP in this case.

In the figure below, the numbers from the Chapter "Line-ground voltage (Page 134)" have been applied.

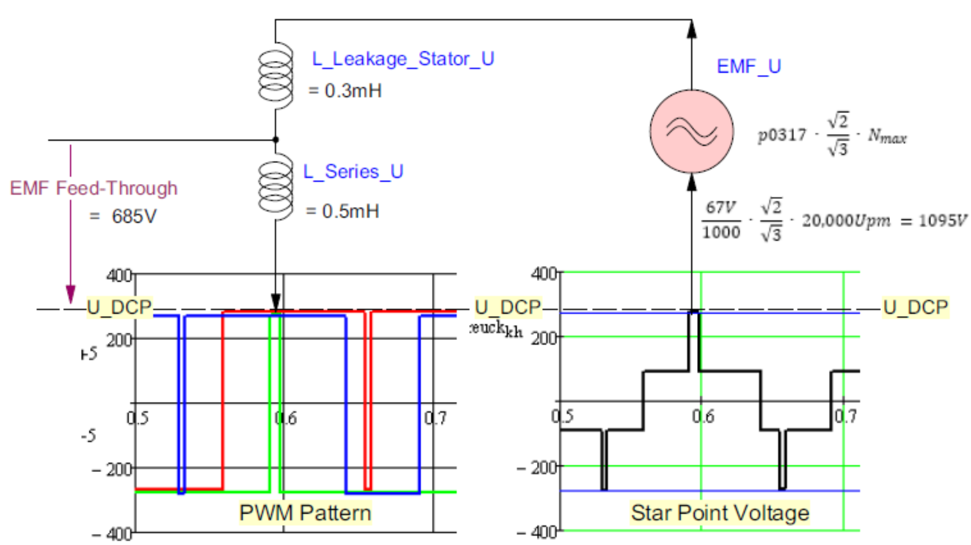


Figure A-2 Neutral-point voltage = average of the three phase voltages / the U phase is under consideration

Explanation of the figure:

- The PWM switching status at which all three bridges are located on the same potential, on U_DCP, occurs only once in each PWM cycle.
- The PWM cycle (p1800) is significantly faster than the EMF cycle. The PWM pattern in the figure above will therefore agree with any EMF phase position, including the positive peak value of the EMF phase (terminal-neutral point).
- The voltages between the neutral point and the converter terminals that are all located on U_DCP in the time segment under consideration must be identical. To create identical voltages, the EMF peak value, which is 1095 V in this example, must be broken down again in the series connection of the two inductances. To do this, a corresponding phase current occurs which results exactly in the necessary voltage equality.
- In the motor, only the fraction that corresponds to the voltage distribution ratio is broken down. The rest appears as voltage drop over the terminals of the series inductance. According to the numbers of the example from the figure above, the voltage drop over the series inductance is 685 V. This voltage drop increases the terminal potential of the motor in relation to PE.
- Because the inverse switching status exists in the same way in which the neutral point as well as all bridges are on U_DCN and which coincides with the negative peak value of the EMF, the EMF feed-through moves periodically (with the electrical frequency) between +685 V and -685 V.
  The peak-peak value is twice the size of the individual maximum.
- In a circuit without series inductance, the entire EMF would be broken down in the motor. In the same way as the EMF is induced coil-for-coil into the winding, it is broken down coil-for-coil in the self-inductance of the motor through the phase current so that voltage does not accumulate at any part of the winding. The series inductance breaks down this balance in the motor winding and increases the voltage in the motor.

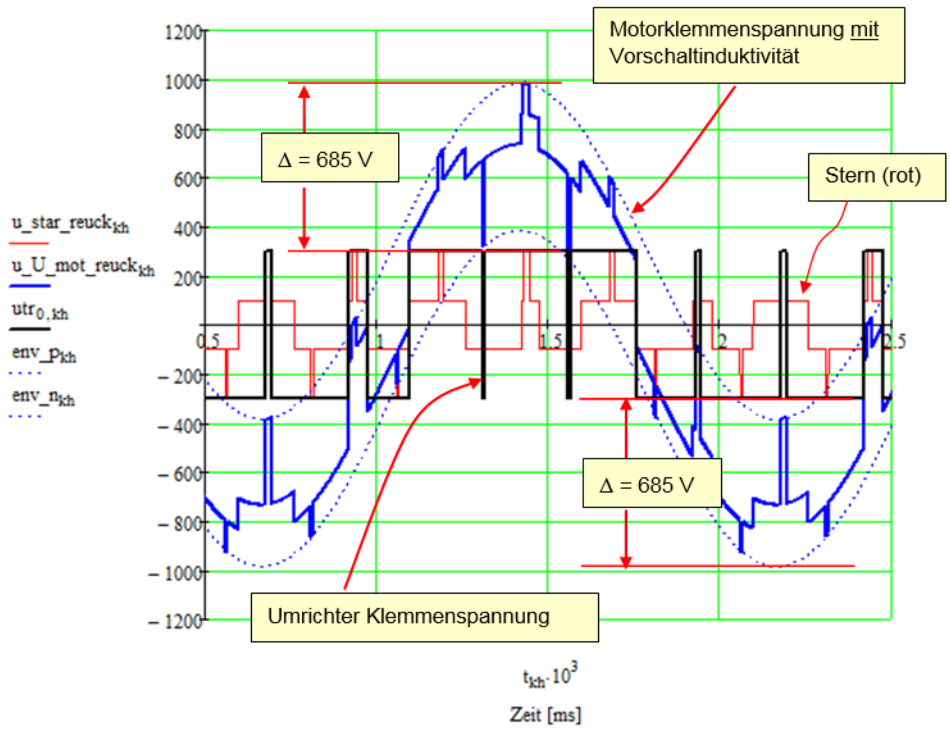


Figure A-3 Motor terminal voltage and converter terminal voltage of phase U at maximum speed (20000 rpm) (terminal to PE; PWM frequency = 4 kHz)

Without series inductance, the voltage at the converter terminal would be identical to the voltage at the motor terminal (in the context of this derivation). This means that the voltage curve shown in black in the diagram above would occur at the motor terminal. The voltage drop that must occur over the series inductance moves the motor terminal voltage against the converter terminal voltage, increases it, and imprints the wave shape of the EMF; see blue voltage curve in the diagram above.

A.2 List of abbreviations

Abbreviation	Meaning
AIM	Active Interface Module
ALM	Active Line Module
ASM or induction	Induction motor
BLM	Basic Line Module
DCN	Direct Current Negative
DCP	Direct Current Positive
EMF	Electromotive force
p	Parameters
PEM or. sync	Permanent-magnet synchronous motor
PLI	Pole position identification
PTC	Positive Temperature Coefficient (standard type of a switching temperature sensor)
PWM	Pulse Width Modulation
SET	Protective separation
SLM	Smart Line Module
SMC	Sensor Module Cabinet
SME	Sensor Module External
TE	Partial discharge
Temp-F	Analog temperature sensor
Temp-S	Switching temperature sensor
TM	Terminal Module
$U_{DC\ link}$ or Vdc	DC link voltage
VPM	Voltage Protection Module

/Grein/H. Greiner, H. Dorner / Danfoss: Converter-fed three-phase motors EP2906

/61800-8/IEC/TS 61800-8 Adjustable speed electrical power drive systems - Specification of voltage on the power interface

/SINAMICS S120 Manual, "Control Units and Additional System Components"

/SINAMICS S120 Manual, "Booksize Power Units"

/SINAMICS S120 Function Manual, "Drive Functions"

/SINAMICS S120/S150 List Manual

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Additional information

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