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# Tractors and machinery for agriculture and forestry — Electrical high-power interface 700 V DC / 480 V AC —

## Part 4:
## AC operation mode



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# Foreword

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This document was prepared by Technical Committee ISO/TC 23, *Tractors and machinery for agriculture and forestry*, Subcommittee SC 19, *Agricultural electronics*.

This document is intended to be used in conjunction with ISO 23316-1, ISO 23316-2, ISO 23316-3, ISO 23316-5, ISO/FDIS 23316-6:— and ISO 23316-7.

A list of all parts in the ISO 23316 series can be found on the ISO website.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

# Introduction

The purpose of the ISO 23316 series is to provide design and application standards covering implementation of electrical high-power interface with a nominal voltage of 700 V DC/480 V AC for agricultural and forestry machinery. The ISO 23316 series specifies the physical and logical interface requirements that provide interoperability and cross compatibility for systems and equipment.

In order to state compliance to the ISO 23316 series, all applicable requirements from ISO 23316-1 to ISO 23316-7 shall be met.

It is permitted for partial systems or components to be compliant to the ISO 23316 series by applying all applicable requirements e.g. for the plug, receptacle or inverters, on a tractor or implement.

NOTE For example, if a DC-mode only HPI is provided, it is not necessary to comply with this document describing AC-mode, as it is not applicable. If an AC-mode only HPI is provided, it is not necessary to comply with ISO 23316-5 describing DC-mode, as it is not applicable.

The following are not within the scope of the ISO 23316 series:

— service, maintenance, and related diagnostics;

— functional safety;

— control strategies for high-power supplies and loads;

— application-specific strategies and operational modes;

— component design;

— energy storage systems, e. g. supercapacitors or batteries;

— multiple electrical power supplies to a common DC-link.

# Tractors and machinery for agriculture and forestry — Electrical high-power interface 700 V DC / 480 V AC —

# Part 4: AC operation mode

## 1 Scope

This document specifies required measures applicable to the HPI AC Interface between a supply system (typically located on an agricultural tractor) and detachable electrical consumer system (typically located on an agricultural implement).

This document covers the following:

— HPI system topologies;

— interface relevant characteristics of the HPI providing AC or combined AC and DC;

— interface relevant characteristics of the HPI AC load (for relevant characteristics of a DC load, see ISO 23316-5);

— logical, operational and electrical characteristics of the HPI:

  — operating mode aspects, and

  — communication parameters

NOTE This document contains simplified electrical diagrams showing specific aspects of the required functionality.

## 2 Normative references

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

ISO 23316-1:2022, *Tractors and machinery for agriculture and forestry — Electrical high-power interface 700 V DC / 480 V AC — Part 1: General*

ISO 23316-2:2023, *Tractors and machinery for agriculture and forestry — Electrical high-power interface 700VDC / 480-VAC — Part 2: Physical interface*

ISO 23316-5:2023, *Tractors and machinery for agriculture and forestry — Electrical high-power interface 700VDC / 480-VAC — Part 5: DC operation mode*

ISO//FDIS 23316-6:—[1)], *Tractors and machinery for agriculture and forestry — Electrical high-power interface 700VDC / 480-VAC — Part 6: Communication signals*

IEEE 802.3-2018, *Physical Coding Sublayer (PCS), Physical Medium Attachment (PMA) sublayer and baseband medium, type 100BASE-T1 (100 Mb/s Ethernet full duplex local area network over a single balanced twisted pair)*

1) Under preparation: Stage at the date of publication: ISO/FDIS 23316-6:2023.

## 3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 23316-1 and the following apply.

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

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at http://www.electropedia.org

**3.1**
**AC-load**
**ACL**
device capable of utilising AC voltage

EXAMPLE 3-phase motor, heat resistor, linear actuator.

**3.2**
**actual value**
feedback values of the electric drive's control within the agricultural application/process

Note 1 to entry: In torque control mode, it is an estimation based on current and electric machine's model.

**3.3**
**application control**
**APP-C**
control means to monitor and control the consumer system, typically located on the implement

**3.4**
**combined AC and DC interface**
interface be able to provide AC Mode or alternatively DC Mode functionality

**3.5**
**DC-load**
**DCL**
device capable of utilising DC voltage (e.g. power converter with inductive/resistive/capacitive load)

**3.6**
**EtherCAT**
industrial communication network according to IEC 61158 Type 12

Note 1 to entry: All uses of the term "fieldbus" in ISO23316 refer to this definition.

Note 2 to entry: EtherCAT is an Ethernet based fieldbus technology widely used for real-time distributed control applications. EtherCAT uses Ethernet frames according to IEEE 802.3. The frames are sent by the EtherCAT MainDevice, which typically also is the application controller. The frames contain process data and parameter data for the distributed nodes such as drives, sensors and general input/output devices which are called EtherCAT SubDevices. Each EtherCAT SubDevice reads the output data intended for it from the frame and writes the input data to be sent to the MainDevice into the frame. This is done on-the-fly in hardware with minimum delay while forwarding the frame to the next SubDevice. Due to this functional principle, switches are omitted, and the protocol overhead is minimized.

**3.7**
**EtherCAT MainDevice**
device integrated within inverter onboard supply system, controls actively the communication within the EtherCAT network and requests/receives data to/from the EtherCAT SubDevice in a cyclically and time-wise deterministic manner



**3.8**
**EtherCAT SubDevice**
device integrated within LLB on-board consumer system receives data (e.g. requests) from and provides data (e.g. feedback) to the EtherCAT MainDevice passively

**3.9**
**fundamental component**
sinusoidal component of the Fourier series of a periodic quantity (e.g. sinusoidal current or PWM voltage) having the frequency of the quantity itself

[SOURCE: IEC 60050-103]

**3.10**
**induction machine**
**IM**
asynchronous machine of which only one winding is energized

[SOURCE: IEC 60050-411]

**3.11**
**load logical box**
**LLB**
collects and transfers sensor data and specific parameters from the load to the PC/S via EtherCAT

Note 1 to entry: electronical device connected to EtherCAT as SubDevice and optionally topic electrical load internal communication bus; intended use as memory of load specific data (e.g. electric machine specific data) and load sensor electronics (e.g. for processing of temperature, speed, or position sensor signal).

**3.12**
**permanent magnet synchronous machine**
**PSM**
machine in which the field system consists of one or more permanent magnets

[SOURCE: IEC 60050-411]

**3.13**
**reluctance synchronous motor**
**RSM**
synchronous motor with an unexcited rotor carrying a number of regular projections which may or may not have a cage winding for starting

[SOURCE: IEC 60050-411]

**3.14**
**switched reluctance machine**
**SRM**
type of stepper motor with isolated windings, but it contains a smaller number of poles

Note 1 to entry: The applied voltages are not sinusoidal; it is controlled by switched voltage blocks.

Note 2 to entry: Similarly, to the RSM, the SRM has only salient poles without magnetic excitation measures.

**3.15**
**target value**
commanded value for the controlled quantity of the electric drive within the agricultural application/process

Note 1 to entry: other commonly used terms like command value, set value (point), reference value, demanded or desired value are not used therefore within this document.

**3.16**
**tractor implement management**
**TIM**
operator assistance system that enables clients to request the control of certain functions (for example speed, steering, hitch, PTO, hydraulic valves, etc.) from servers

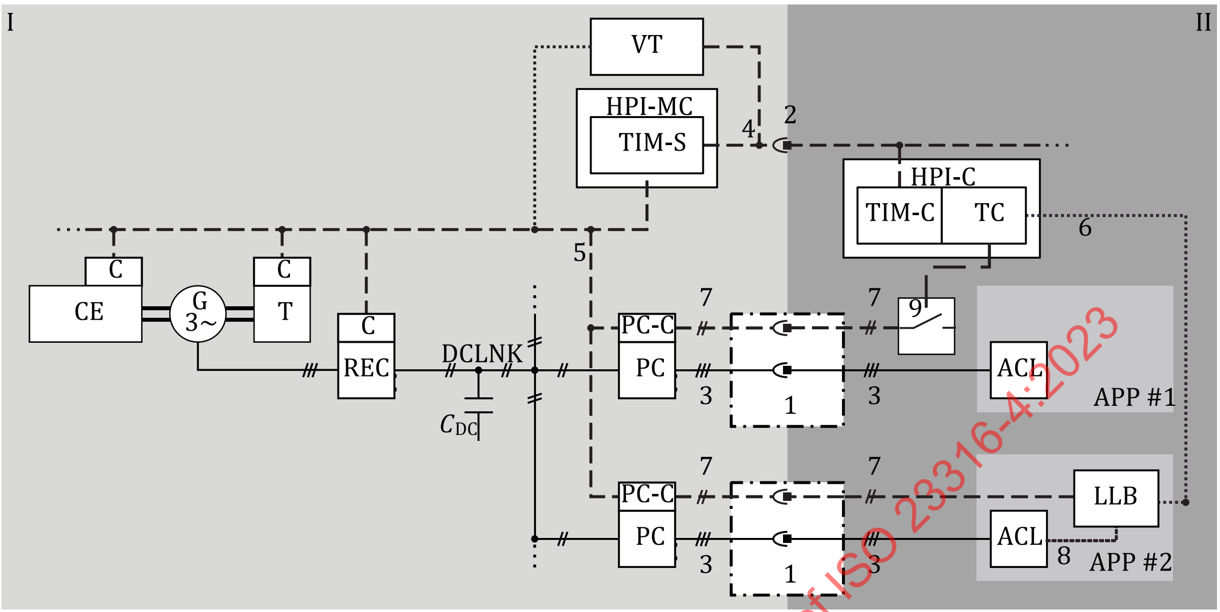
**3.17**
**tractor implement management client**
**TIM-C**
operator assistance system which represents TIM functions for the process optimization in the use of tractor implement combinations based on the ISOBUS communication protocol

**3.18**
**tractor implement management server**
**TIM-S**
participant that provides TIM functions or settings and is able to share these with TIM clients

# 4 AC System overview

## 4.1 Basic AC system topology

Figure 1 describes the basic AC system topology with two AC drives.




**Key**

| | | | |
|---|---|---|---|
| ——— | power connection | C | controller of a device |
| – – – | signal/bus connection | $C_{DC}$ | DC link capacitor |
| ........... | optional signal connection | CE | combustion engine |
| I | supply system | DCLNK | DC link |
| II | consumer system | HPI-C | HPI - control |
| 1 | HPI (high-power interface) | HPI-MC | HPI – master control |
| 2 | ISOBUS connector | LLB | load logical box |
| 3 | power lines | PC | power converter |
| 4 | ISOBUS | PC-C | power converter controller |
| 5 | supply system communication bus (e.g. tractor bus) | REC | rectifier (AC/DC power converter) |
| 6 | consumer system communication bus (e.g. implement bus) | T | transmission |
| 7 | EtherCAT/interlock signal | TC | task controller |
| 8 | feedback signal (e.g. sensor signal) | TIM-C | TIM (tractor implement management) - client |
| 9 | interlock signal line breaker | TIM-S | TIM - server |
| ACL | AC load (e.g. electric motor) | VT | virtual terminal (user interface, e.g. display) |
| APP | application | | |

**Figure 1 — AC topology example with two loads**

A power supply provides at least one HPI.

A typical electric AC drive consists of one 3-phase inverter on the side of the power supply that is connected with at least one AC load on the side of an implement via one high power connector.

**4.1.2** Rationale for basic AC-system topology:

— ISOBUS and EtherCAT are mandatory for closed-loop AC modes.

— ISOBUS is intended for application-specific communication, e.g. values for working process data between implement and tractor.

— HPI-MC and supply system communication bus are typically used for connection of the inverters to the ISOBUS. However, this is not mandatory for the functionality of the HPI.

— EtherCAT is intended for load specific communication, e.g. AC-load identification and sensor-signal feedback data.

— EtherCAT is a 1:1 connection and enables the unambiguous communication between inverter and LLB.

— The LLB is a logical representative of AC-load (ACL).

— HPI with ACL are identified via EtherCAT communication by related PC. The mapping of the ACL (LLB address) and the PC (ISOBUS and supply system communication bus addresses) shall be performed -as described by the handshake sequence given in ISO/FDIS 23316-6:—, Clause 5.

— EtherCAT shall also be used for supervision of plugged power connector (interlock loop functionality).

— The optional consumer system communication bus connects the HPI-C with the LLBs and optional other controllers onboard the consumer system.

— Pure AC topology as well as mixed DC and AC topology is possible.

## 4.2 Load configurations

Figure 2 presents examples for possible loads. The typical ACLs are 3-phase electric machines but can also be general electric impedances (3-phase and 1-phase).

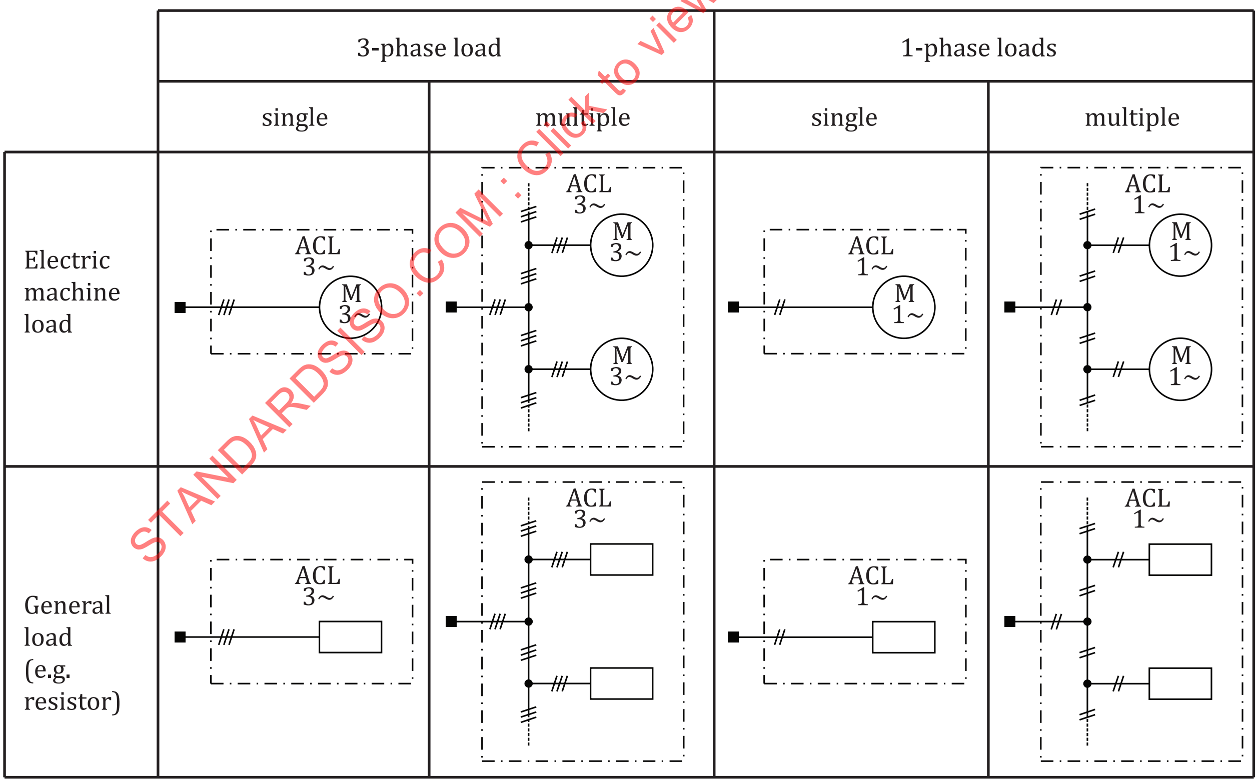



**Figure 2 — Examples for ACL configurations**

The ACL may consist of multiple loads connected in parallel (e.g. several induction electric machines in parallel on a single output as displayed in Figure 2).



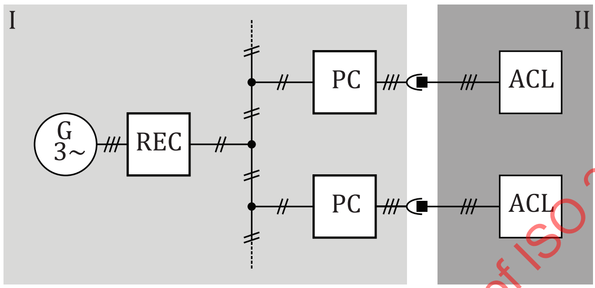
Parallel use of two HPI sources into a single load circuit shall not be allowed.

## 4.3 Consumer system configuration

### 4.3.1 Operation with single consumer system

A single consumer system may contain one or more independent electric loads; such a configuration is shown in Figure 3 and is the basis for the following figures with multiple ACLs.

The consumer system may contain one common HPI-MC or separated HPI-MC's related to the different ACLs.




**Key**

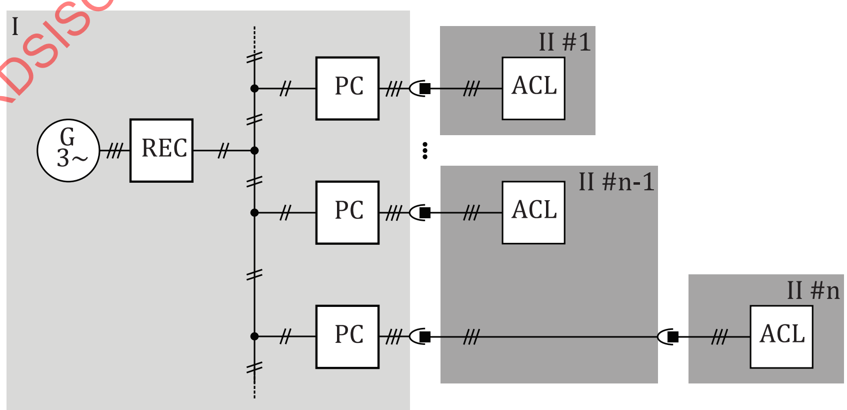
| | | | |
|---|---|---|---|
| I | supply system | II | consumer system |
| ACL | AC load (e.g. electric motor) | REC | rectifier (AC/DC power converter) |
| G | generator | PC | power converter |

**Figure 3 — Single consumer system schematic**

### 4.3.2 Operation with multiple consumer systems

In this subclause, some but not all possible configurations with more than one ACL are shown.

Figure 4 shows a configuration with exclusively ACLs. As shown with the ACL on consumer system #n, it is not necessary to have direct connection to a supply system; a consumer system attached in between (see Figure 4 #n-1) may be used similar to an "extension cable".




**Key**

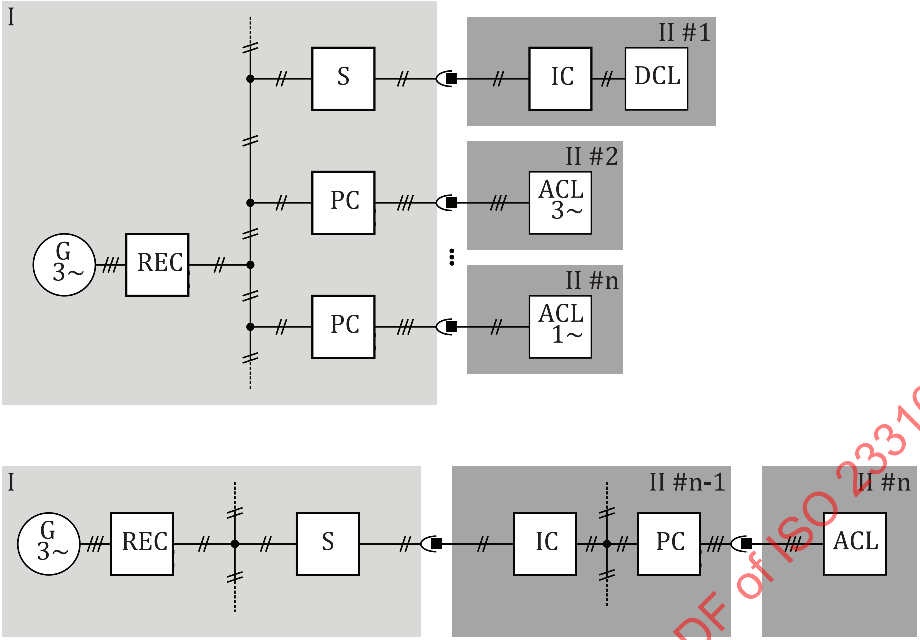
| | | | |
|---|---|---|---|
| I | supply system | II | consumer system |
| ACL | AC load (e.g. electric motor) | REC | rectifier (AC/DC power converter) |
| G | generator | PC | power converter |

**Figure 4 — Multiple consumer system schematic with pure AC-topology**



Figure 5 shows configurations with mixed AC and DC topology (a system topology using AC-HPI and DC-HPI in the same system).




**Key**

| | | | |
|---|---|---|---|
| I | supply system | PC | power converter |
| II | consumer system | DCL | DC load (e.g. inverter and electric motor) |
| ACL | AC load (e.g. electric motor) | REC | rectifier (AC/DC power converter) |
| IC | input circuit of a consumer system with DCL (e.g. pre-/discharge unit including filter) | G | generator |
| S | switch (contactor or solid state switch, including pre- and discharge unit) | | |

**Figure 5 — Multiple consumer system schematics with mixed AC and DC topology**



## 4.4 Control modes

### 4.4.1 Closed-loop control modes

**4.4.1.1** The following closed-loop control modes shall be supported:

a) torque control (see 4.7.2.1), and

b) speed control (see 4.7.2.2).

**4.4.1.2** The following electric machine types shall be supported in the closed-loop control modes:

a) induction machine (IM, squirrel cage machines);

b) permanent-magnet synchronous machine (PSM), and

c) reluctance synchronous machine (RSM).

NOTE 1 RSM does not mean switched reluctance machine (SRM) and has different control strategy than SRM.

NOTE 2 The necessary parameters used for setting the electric machine type are listed in ISO/FDIS 23316-6:— , Table A.11.

NOTE 3 Configurations with multiple electric machines which are used in parallel at one AC-interface are not supported in closed-loop control modes.

### 4.4.2 Open-loop control modes

The following open-loop control modes shall be supported:

a) voltage-frequency characteristic control (see 4.7.3.2),

b) independent voltage and frequency supply (see 4.7.3.3), and

c) variable DC chopper supply (see 4.7.3.4).

NOTE 1 The open-loop control modes enable the flexibility to operate single or multiple general ACLs or DCLs.

NOTE 2 IEC TS 60034-25 and IEC TS 61800-8 can be used as a reference for design of inverters and electric machines. The necessary parameters used for setting the control mode are listed in ISO/FDIS 23316-6:—.

## 4.5 AC voltage and current

### 4.5.1 AC voltage

#### 4.5.1.1 Voltage range

The following AC output voltage range shall be applicable: 0 V to 480 V RMS.

RATIONALE The AC output voltage of up to 480 V RMS (phase to phase) is related to the maximum applicable fundamental AC voltage with inverter modulation based on DC-link nominal voltage of 700 V DC.

NOTE 1 The AC output voltage is always a PWM voltage, modulating the DC-link voltage. An RMS voltage value is meant as the fundamental component of the PWM voltage, which is relevant for powering the motor. The RMS value of the complete PWM voltage can be significantly higher.

NOTE 2 Special working points with over-modulation can provide a higher fundamental output voltage.

#### 4.5.1.2 Voltage quality

The LLB shall be able to request a minimum switching frequency.

In closed-loop control modes (torque and speed control), there are no requirements concerning voltage quality.

In open-loop “variable DC chopper supply” mode, there are no requirements concerning voltage quality.

In “voltage-frequency characteristic control” and “independent voltage and frequency supply” mode, the voltage quality shall be ensured by following measures:

a) controlling of output voltage in order to compensate variation in DC-Link voltage;

b) sinusoidal waveform with a minimum of 10 samples per period for the fundamental frequency range below 500 Hz;

c) minimum switching frequency of 5 kHz for a fundamental frequency at and above 500 Hz.

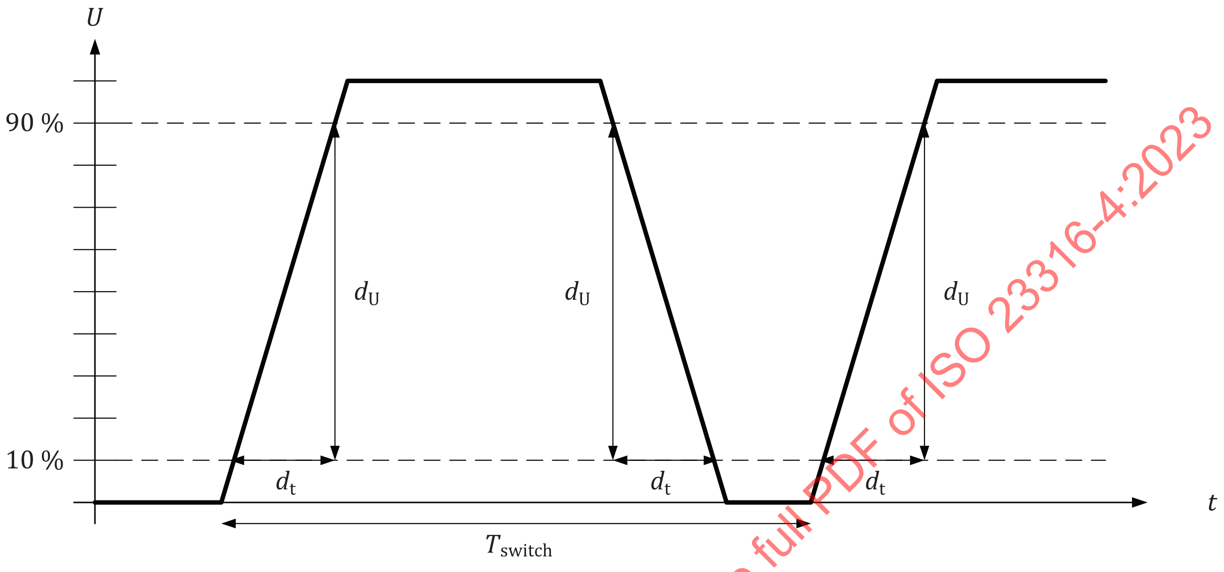
#### 4.5.1.3 Transient threshold

The allowed maximum voltage slope ($dU/dt$), as a transient between 10 % and 90 % of switched DC-link voltage (as shown in Figure 6) of the PC PWM output voltage shall be sent by the LLB to the PC (see

ISO/FDIS 23316-6:—, Annex A). The value sent by the LLB and the dU/dt value of the PC shall be sent by the PC to the HPI-C. The HPI-C shall decide whether a reliable operation is possible.

NOTE 1 The allowed maximum voltage slope is considered as a maximum requirement for the inverter and as a minimum requirement for the electrical machine.

NOTE 2 The current benchmark of $d$U/dt is 5 kV/µs to 10 kV/µs. However, technology developments might improve on this leading to higher values.




**Key**

$d$U voltage difference

$d$t time difference

$T_{switch}$ time period of PWM voltage

**Figure 6 — Detail of a PWM voltage**



### 4.5.1.4 Over-voltage protection

The inverter shall limit the voltage according to ISO 23316-1:2022, Clause 5.

In both torque control and speed control mode, this can be achieved by limitation of the generated torque. If this measure is not sufficient or any open-loop control mode is used, the PC shall switch off its power stage. For this, two different over-voltage switch-off modes should be available (voltage levels according to ISO 23316-1):

— open terminal outputs (typically used e.g. for induction motors): All IGBTs are switched off;

— active terminal short-circuit in field weakening range (typically used for PSM, if considered in components design): The upper IGBTs are switched off, the lower IGBTs are switched on or vice versa.

The over-voltage-switch-off mode for field weakening range for PSM shall be sent as initialization parameter via EtherCAT (see ISO/FDIS 23316-6:—, Table A.15).

NOTE If there is a need for a permanent magnet synchronous motor to be switched-off because of a fault while it is operating in field weakening condition at high speed, an over-voltage condition is likely to result because of the high back-EMF voltage. The over-voltage can be avoided by active terminal short-circuit of the PC. This measure can be considered in the design of the motor to avoid demagnetization of the permanent magnets and to limit the short circuit current to a value which do not exceed the current capability of the PC.

### 4.5.2 AC current

#### 4.5.2.1 Current capability and requirement

Each supply system interface (limited by PC output, cable and connector) has its individual current capability (continuous and peak), which is valid under normal conditions.

The supply system shall inform the HPI-C about transient limitations of the current capability under special conditions (e.g. derating due to under-voltage or over-temperature) in accordance with ISO/FDIS 23316-6:—.

The HPI-C shall only start operation if the current and power capability of the supply system can cover the minimum requirements of the load for a reliable operation of the application.

NOTE The peak current is characterized by a certain value exceeding the continuous current for a limited time.

If the current capability of the supply system only allows a limited operation, this can be indicated to the operator by the application ECU.

#### 4.5.2.2 Over-current protection

##### 4.5.2.2.1 Supply system

Current limitations for protection of the PC/S and HPI (PC, cable and connector) are part of the particular inverter design, thus are out of scope of this document.

##### 4.5.2.2.2 Load

In both torque control and speed control mode, definitions of continuous and peak current limitations necessary for protection of the ACL shall be part of the initialization process.

In general, the HPIC shall perform the necessary protection measures for itself, e.g.- $i^2t$ limitations. Therefore, the load current shall be limited by the HPI-C via communication to the HPI-MC independent of the application control type (see ISO/FDIS 23316-6:—, Annex A).

The related actual current information shall be transmitted from the inverters to the HPI-C and TC.

NOTE Independent of these protection measures of the load, the supply system components (e.g. inverter) protect themselves, e.g. by a component specific $i^2t$ limitation.

## 4.6 Cable length

Related to cable length, voltage peaks at the electric machine terminals can be twice the PC output voltage.

IEC/TS 61800-8:2010, Clause 9 gives guidance for the design of an electric drive system including wiring.

## 4.7 Basic control modes

### 4.7.1 General

#### 4.7.1.1 Control mode selection

The PC shall provide at least the basic control modes listed in 4.4. The control mode shall be selected by the HPI-C/TC.

NOTE The typically required signals are listed in the tables of ISO/FDIS 23316-6:—, Annex A.



Further application-specific controls (e.g. process control) may be realized by the HPI-C using one of the basic control modes as subordinated control (for some specific applications the tractor provides these modes as tractor-controlled application). Any kind of derating functionality (e.g. temperature management of electric machine) shall be the responsibility of the HPI-C/TC.

This document specifies the basic functionality; additional features may be provided by the PC.

#### 4.7.1.2 Application

##### 4.7.1.2.1 General

There are two different groups of applications, so-called supply system controlled applications (e.g. by an agricultural tractor) and consumer system controlled applications (e.g. by an agricultural implement). The kind of application relates finally to the certain controlling application ECU, which can be either on the supply system or on the consumer system.

The application control type shall be set during initialization by using the control parameter "Control type" (see ISO/FDIS 23316-6:—, Annex A).

##### 4.7.1.2.2 Consumer system-controlled applications

The majority of the applications are controlled by an ECU of the consumer system, which takes the responsibility of application/process control functionalities. All user inputs are driven by the TIM function of the consumer system. The communication of control data (such as parameters and set values) is between the HPI-C and the PC via HPI-MC .

The HPI-C/TC of the consumer system shall enable and completely control these electric drives (including corresponding operator interaction).

Each control mode has a required set of parameters, which shall be transferred during the initialization phase from the HPI-C/TC to the PC via ISOBUS. In order to allow parameter adaptation (parameter scheduling), the relevant parameters (as defined in ISO/FDIS 23316-6:—) shall be adjustable during operation.

NOTE The signal transmission between HPI-C/TC and PC will always be routed via the source bus, the HPI-MC, and the ISOBUS.

##### 4.7.1.2.3 Supply system controlled applications

Some applications, such as traction assist systems, need to be controlled by an ECU of the supply system. In this case, the communication of control data (such as parameters and set values) is between the responsible supply system ECU and the PC.

For these specific applications, the application/process control functionalities shall be completely in the responsibility of the supply system, except certain load protection functions which resides on the consumer system (e.g. over-temperature protection since the supply system isn't aware of design details of the ACL).

The HPI-C / TC at the consumer system shall only enable / disable the general usage of these electric drives (including corresponding operator interaction) by setting the controlbyte- (see ISO/FDIS 23316-6:—, Annex A) accordingly. In addition, the HPI-C/TC shall send required configuration parameters and provide load specific protection measures (e.g. against over-temperature).

An HPI-C shall not send control commands for this kind of application.

#### 4.7.1.3 Control values

The following definitions shall apply:

— the torque and speed quantities refer to the electric machine's shaft;



— the torque refers to the applied electromagnetic torque;

— the torque quantities are in relation (percent value) to the torque reference value;

— the speed quantities are in relation (percent value) to the speed reference value;

— the directions of rotation are defined in ISO 23316-1;

— the same kind of referencing as above applies also to the following quantities: Voltage, current, power and frequency.

### 4.7.2 Closed-loop control modes

#### 4.7.2.1 Torque control

##### 4.7.2.1.1 General

Torque control mode is an indirect control of electric machine shaft torque based on the mathematical model of the electric machine.

Torque control shall be based on the electric machine characteristics data only. Parameters should not be dependent on the application.

NOTE The necessary parameters used for the torque control mode are listed in ISO/FDIS 23316-6:—, Annex A.

##### 4.7.2.1.2 Speed-dependent torque limitation

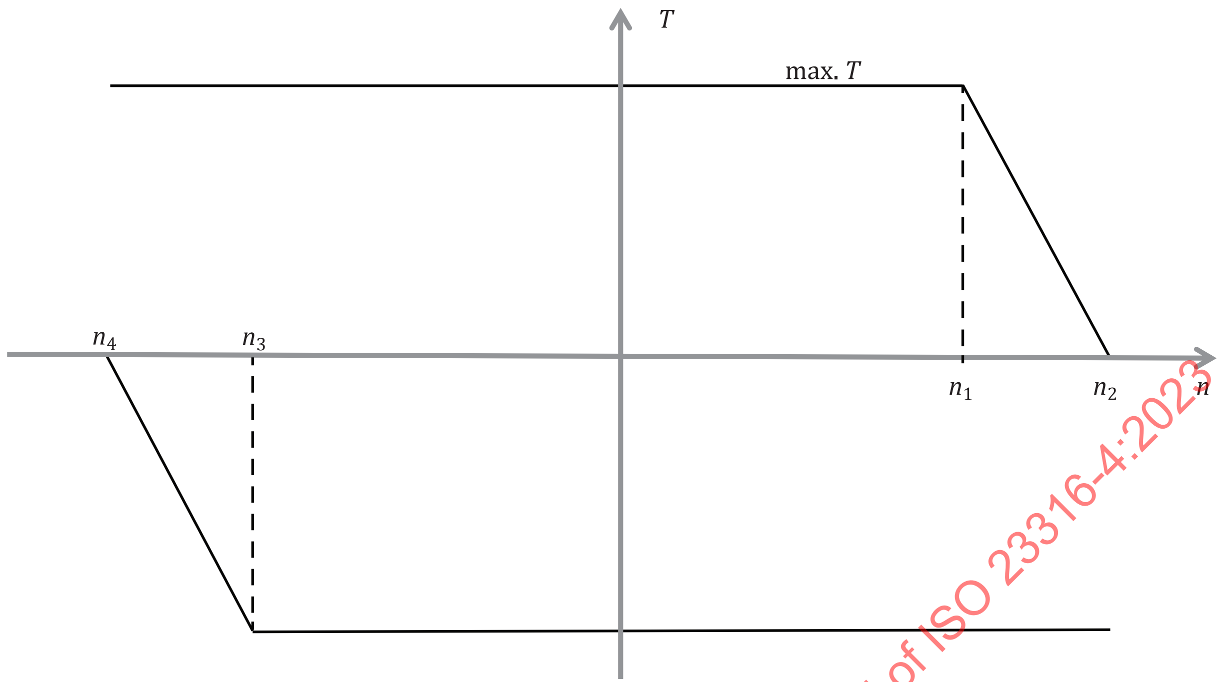
To protect against over-speed, the motoring torque shall be limited dependent on the actual speed.

Thus, if the actual speed is below the “torque ramp down” speed there shall be no speed-dependent limitation active. While the actual speed exceeds the “torque ramp down” speed but is still below the speed limitation threshold, the torque shall be linearly ramped down according to Figure 7.

If the actual speed is above the speed limitation threshold, the torque shall be reduced to 0 %.






**Key**

| | | | |
|---|---|---|---|
| *n* | speed | *T* | torque |
| *n*1 | positive torque ramp down speed | *n*3 | negative torque ramp down speed |
| *n*2 | positive speed limitation threshold | *n*4 | negative speed limitation threshold |

**Figure 7 — Speed dependent torque derating**

#### 4.7.2.2 Speed control

Speed control shall be a superordinate control of the torque control. The application ECU shall set the parameters of the speed controller, since they are assumed application-specific (influenced by e.g. the drive's inertia). The controller structure shall be of Proportional-Integral (P-I) in parallel configuration (see Figure 8); its transfer function is defined in Formula (1) and Formula (2). See also Table 1.

NOTE The necessary parameters used for the speed control mode are listed in ISO/FDIS 23316-6:—, Table A.7.

#### 4.7.2.3 P I-controller description (in Laplace domain)

$$y = \left( k_P + k_I \cdot \frac{1}{s} \right) \cdot e \qquad (1)$$

$$e = n_{target} - n_{actual} \qquad (2)$$

**Table 1 — Controller characteristics**

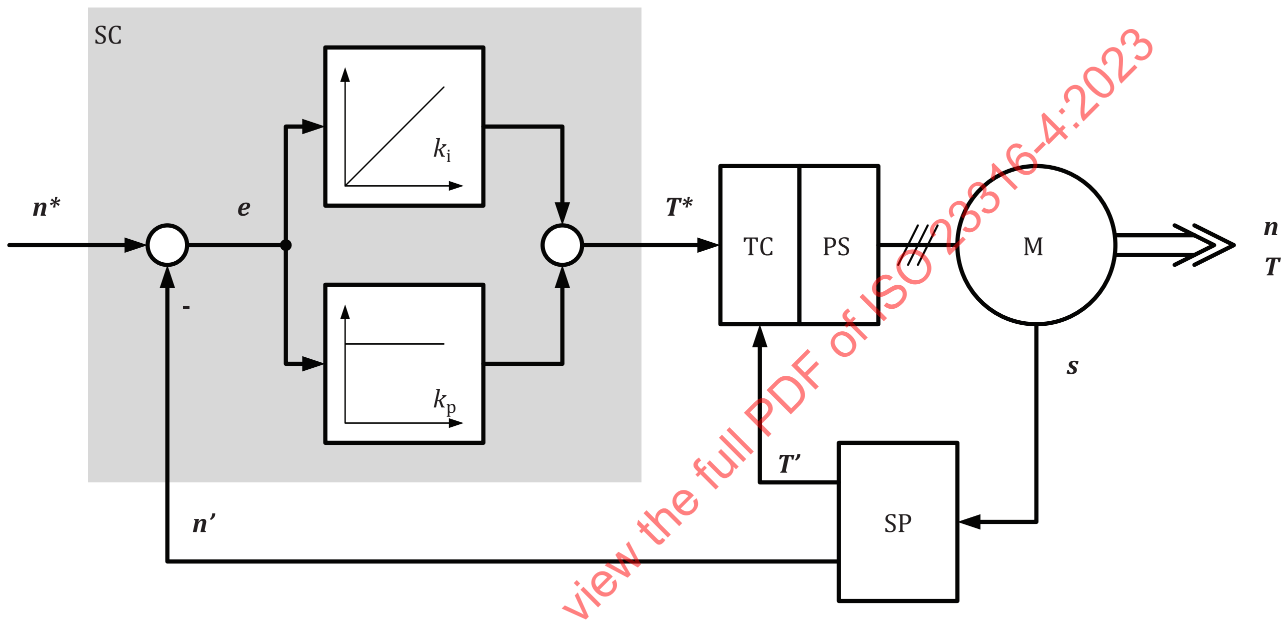
| Symbol | Unit | Quantity | Description/remarks |
|---|---|---|---|
| $e$ | % of reference speed | Control deviation (error) | Difference of target and actual value |
| $y$ | % of reference torque | Controller output variable | Target value as input for torque controller. |
| $n$ | % of reference speed | Actual speed | |
| $k_P$ | See ISO/FDIS 23316-6:—, Table A.2 | Proportional controller gain | See ISO/FDIS 23316-6:—, Table A.7 |



**Table 1** *(continued)*

| Symbol | Unit | Quantity | Description/remarks |
|---|---|---|---|
| $k_I$ | See ISO/FDIS 23316-6:—, Table A.2 | Integral controller gain | See ISO/FDIS 23316-6:—, Table A.7 |
| $s = \sigma + j\,\omega$ | $s^{-1}$ | Complex Laplace transformation operator | Includes damping ($\sigma$) and oscillating ($\omega$ → angular frequency) term with $j = \sqrt{-1}$ as imaginary unit. |






**Key**

n speed
n* target speed
n' calculated actual speed
e speed error
Kp proportional gain
Ki integral gain
M motor
T torque
T* target torque
T' calculated actual torque
SC speed controller
TC torque controller
PS power stage
SP signal processing
s feedback signal

**Figure 8 — Speed controller**

### 4.7.3 Open-loop control modes

#### 4.7.3.1 General

In order to provide the flexibility of operating general single or multiple AC or DC loads, the open-loop control modes (without control feedback) specified by 4.7.3.2 to 4.7.3.4 shall be implemented.

The output voltage shall be independent of the DC-Link voltage.

The maximum AC output voltage (fundamental) shall be 480 V RMS at nominal DC-Link voltage of 700 V.

The inverter shall support a fundamental frequency range between 0 Hz and at least 700 Hz.

NOTE 1 Consider that single-phase loads as defined in 4.2 lead to current flow only in two phases (line and return).

NOTE 2 Consider the DC-link voltage definitions given in ISO 23316-1 regarding maximum voltage transients.

#### 4.7.3.2 Voltage-frequency characteristic control

The V/f characteristic control shall automatically adjust the output voltage to a given target frequency value according the V/f characteristics.

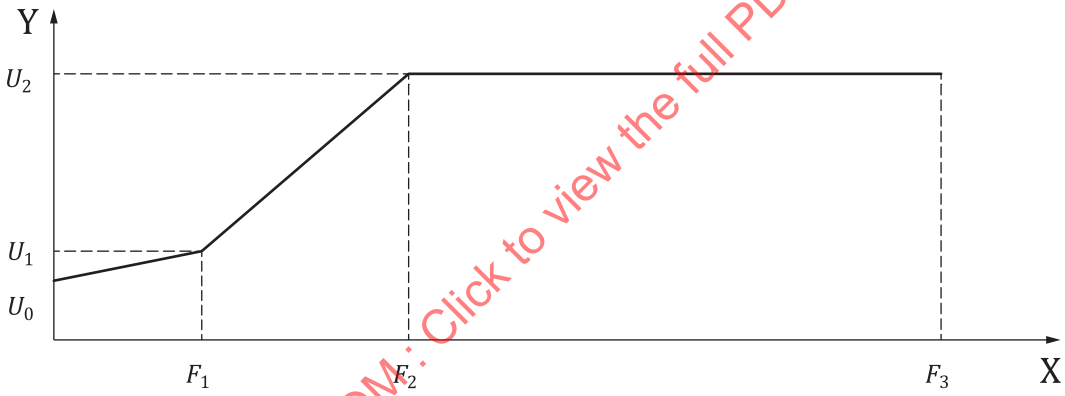
The V/f characteristics shall be specified with parameters used in Figure 9.

In the case that parameters do not follow the useful order (F1 < F2 < F3), the output voltage shall be always 0 V.

NOTE 1 This mode is typically used for electric drive applications with induction motors (including in parallel configuration) and low performance requirements.

NOTE 2 The necessary parameters are listed in ISO/FDIS 23316-6:—, Annex A.

NOTE 3 The characteristics are related to absolute frequency values. This means that the same curve is related to positive and to negative output frequencies.




**Key**

| | | | |
|---|---|---|---|
| X | frequency | Y | voltage |
| U0 | output voltage at f=0Hz | F1 | frequency definition point 1 |
| U1 | output voltage for f=F1 | F2 | frequency definition point 2 |
| U2 | output voltage for f>=F2 | F3 | maximum output frequency |

**Figure 9 — V/f characteristic**



#### 4.7.3.3 Independent voltage and frequency supply

In this mode, frequency and voltage shall be controlled independently within the limits illustrated by Figure 9.

NOTE The necessary parameters are listed in ISO/FDIS 23316-6:—, Annex A .

#### 4.7.3.4 Variable DC chopper supply

In this control mode, the inverter shall provide a variable PWM DC voltage to the phase contact pins as defined in ISO/FDIS 23316-6:—, 4.5. The maximum available voltage shall be the DC-link voltage.

NOTE 1 The necessary parameters are listed in ISO/FDIS 23316-6:—.