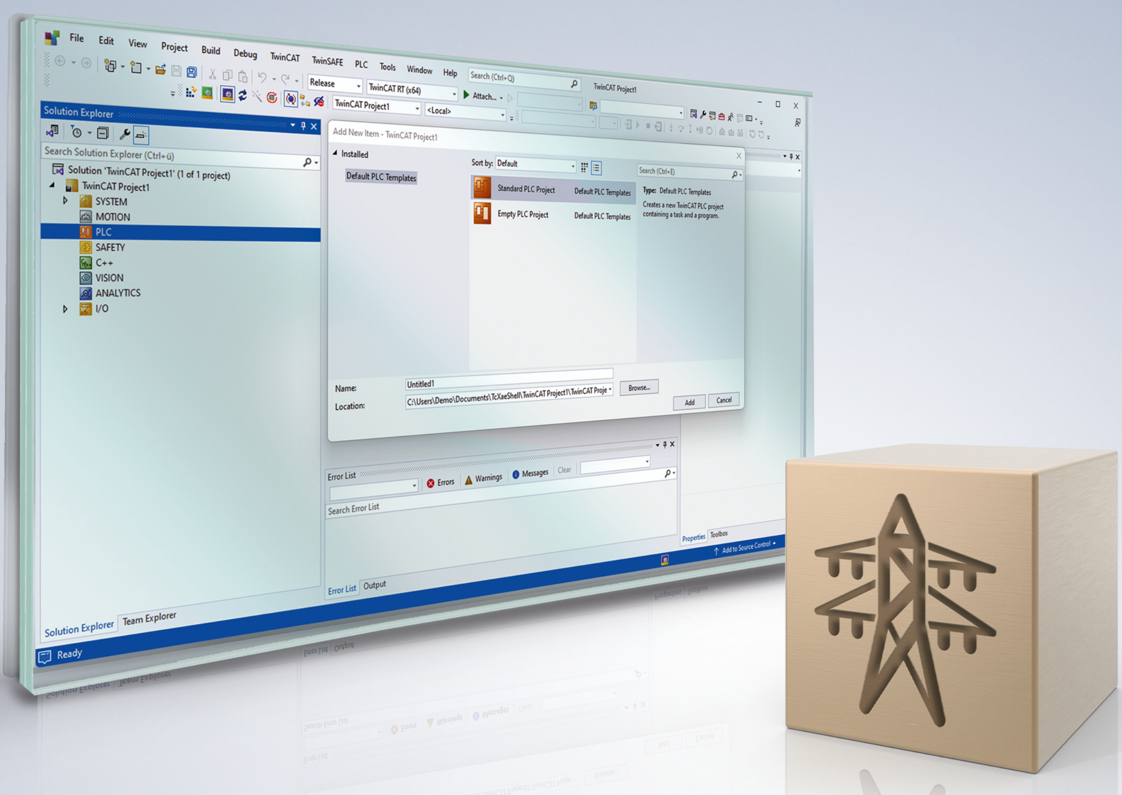
BECKHOFF New Automation Technology

Manual | EN

TF8360

TwinCAT 3 | Power Control



2025-09-29 | Version: 0.1.0

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1 Foreword

1.1 Notes on the documentation

This description is intended exclusively for trained specialists in control and automation technology who are familiar with the applicable national standards.
The documentation and the following notes and explanations must be complied with when installing and commissioning the components.
The trained specialists must always use the current valid documentation.

The trained specialists must ensure that the application and use of the products described is in line with all safety requirements, including all relevant laws, regulations, guidelines, and standards.

Disclaimer

The documentation has been compiled with care. The products described are, however, constantly under development.
We reserve the right to revise and change the documentation at any time and without notice.
Claims to modify products that have already been supplied may not be made on the basis of the data, diagrams, and descriptions in this documentation.

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1.2 For your safety

Safety regulations

Read the following explanations for your safety.
Always observe and follow product-specific safety instructions, which you may find at the appropriate places in this document.

Exclusion of liability

All the components are supplied in particular hardware and software configurations which are appropriate for the application. Modifications to hardware or software configurations other than those described in the documentation are not permitted, and nullify the liability of Beckhoff Automation GmbH & Co. KG.

Personnel qualification

This description is only intended for trained specialists in control, automation, and drive technology who are familiar with the applicable national standards.

Signal words

The signal words used in the documentation are classified below. In order to prevent injury and damage to persons and property, read and follow the safety and warning notices.

Personal injury warnings

⚠ DANGER
Hazard with high risk of death or serious injury.

⚠ WARNING
Hazard with medium risk of death or serious injury.

⚠ CAUTION
There is a low-risk hazard that could result in medium or minor injury.

Warning of damage to property or environment

NOTICE
The environment, equipment, or data may be damaged.

Information on handling the product

This information includes, for example:
recommendations for action, assistance or further information on the product.

1.3 Notes on information security

The products of Beckhoff Automation GmbH & Co. KG (Beckhoff), insofar as they can be accessed online, are equipped with security functions that support the secure operation of plants, systems, machines and networks. Despite the security functions, the creation, implementation and constant updating of a holistic security concept for the operation are necessary to protect the respective plant, system, machine and networks against cyber threats. The products sold by Beckhoff are only part of the overall security concept. The customer is responsible for preventing unauthorized access by third parties to its equipment, systems, machines and networks. The latter should be connected to the corporate network or the Internet only if appropriate protective measures have been set up.

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To stay informed about information security for Beckhoff products, subscribe to the RSS feed at https://www.beckhoff.com/secinfo.

1.4 Documentation issue status

Version	Changes
0.1.0	First release with TF8360 in version 0.1.0

2 Overview

The *TwinCAT 3 Power Functions* provide software in the form of TwinCAT modules for use in electrical power systems. These are divided into three *TwinCAT Functions* with corresponding licenses:

- **TF8330 | TwinCAT 3 Power Collector**
  Functions for power measurement using EtherCAT Terminals of the EL34xx series.
- **TF8350 | TwinCAT 3 Power Technologies**
  Functions for power measurement using EtherCAT Terminals of the EL37x3 and ELM3xxx series.
- **TF8360 | TwinCAT 3 Power Control**
  Functions for the control of power generating plants.

3 Functions

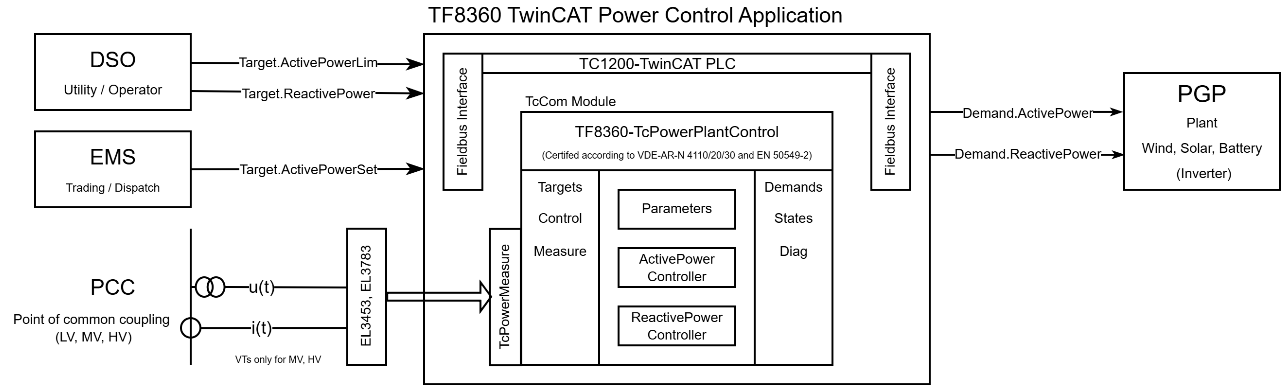
The *TF8360 | TwinCAT 3 Power Control* is a modular software solution for controlling and regulating electrical energy systems, especially for grid-connected power generating plants (PGP). This TwinCAT function provides special software blocks for this purpose, including for implementing a standard-compliant PGP controller. Such a controller is required for the operation of power generating plants in order to comply with the technical connection conditions of the respective grid operator - in Germany, for example, in accordance with VDE-AR-N 4110 (medium voltage) or VDE-AR-N 4120 (high voltage).

3.1 PGP controller

TwinCAT Power Plant Control is a TwinCAT module for use as a controller for power generating plants (PGP controller).

The technical connection rules VDE-AR-N 4110, VDE-AR-N 4120 and VDE-AR-N 4130 define the requirements for the grid connection and operation of power generating plants to the medium, high and extra-high voltage grid in Germany. A component certificate in accordance with these standards is mandatory for the use of a PGP controller.

TwinCAT Power Plant Control has been certified by the FGH for use as a PGP controller for selected hardware components (see Certification [▸ 11]). The certification procedure is based on measurements, evaluations and the assessment of the controller functions in accordance with the requirements of FGW TR3.



A Beckhoff PGP controller consists of the embedded PC and the grid data acquisition (see Grid data acquisition [▸ 17]), as well as the *TwinCAT Power Plant Control* as the controller kernel in the form of the TwinCAT module `TcPowerPlantControl`. This module is integrated into a TwinCAT 3 project and provides all the necessary interfaces (see Interfaces [▸ 17]) and control functions (see Functions [▸ 13]).

Grid data is referred to as `Measure` and is recorded using suitable measurement technology at the point of common coupling (PCC):

- The interface for grid data acquisition is referred to in the system as `Measure` and is typically implemented via EtherCAT Terminals.

Setpoints are referred to as `Target` and are typically received by the controller via two interfaces, which must be implemented on a project-specific basis:

- The telecontrol interface to the grid operator is referred to in the system as `Operator`. It transmits the active power limitation (`fActivePowerLim`) and the reactive power setpoint (`fReactivePowerSet`). Depending on the grid level, the grid operator can be a Distribution System Operator (DSO) or a Transmission System Operator (TSO). This interface is used to regulate the frequency and voltage on the grid side to ensure stable grid operation.
- The interface to the plant operator's energy management system (EMS) is referred to in the system as `Marketer`. It transmits the active power setpoint (`fActivePowerSet`). The connection is made to a higher-level system for marketing or aggregating the feed-in, for example through a direct marketing company, electricity trader or operator. In an international context, this role is also referred to as the Balancing Responsible Party (BRP).

Control values are referred to as `Demand` and are transmitted from the controller to the power generating plant or its units via a communication interface. This interface must also be implemented on a project-specific basis:

- The interface to the power generating plant (PGP) or its power generating units (PGU) is referred to as `Plant` in the system. The control values for active power (`fActivePowerDmd`) and reactive power (`fReactivePowerDmd`) are transmitted to wind, photovoltaic (PV) or storage systems, or directly to the inverters if necessary.

A model of the controller core (see Model [▸ 37]) and an application example are provided to demonstrate the use of the controller in a closed simulation environment.

3.1.1 Certification

The certification of TwinCAT Power Plant Control as a PGP controller confirms conformity with the following standards (see References [▸ 62]):

Standard	Description	Certification
VDE AR-N 4110:2023	Technical requirements for the connection of customer installations to the medium voltage network (TAR medium voltage).	Pending Expected Q3/2025
VDE AR-N 4120:2018	Technical requirements for the connection and operation of customer installations to the high voltage network (TAR high voltage).	Pending Expected Q3/2025
VDE AR-N 4130:2018	Technical requirements for the connection and operation of customer installations to the extra high voltage network (TAR extra high voltage)	Pending Expected Q3/2025
EN 50549-2:2019	Connection to a MV distribution network - Generating plants	Pending Expected Q4/2025
PPPiREE, V1.3: 2024	Technical implementation of (EU) 2016-631 for Poland.	Pending Expected Q4/2025

Regulatory principles

The EU Regulation (EU) 2016/631 is also known as the Network Code Requirements for Generators (NC RfG) and forms the legal framework for the grid connection conditions for power generating plants in Europe. The EN 50549-2 standard specifies these requirements by describing detailed technical requirements for the connection.

In addition, national regulations, such as VDE-AR-N 4110, 4120 and 4130 in Germany, close the gap between the Europe-wide specifications of the NC RfG and the technical specifications of the EN standards. They thus create binding rules for grid integration at national level.

The FGW TR3 (Technical Guideline 3 of the Fördergesellschaft Windenergie und andere Dezentrale Energien e.V.) describes the determination of electrical properties of power generating units and plants within the scope of type and component certifications. It specifies the methods and test procedures used to verify electrical behavior in relation to the grid.

PPPiREE (Polskie Porozumienie Producentów i Rozdzielców Energii Elektrycznej) is the Polish industry organization for electricity producers and distributors that, among other things, coordinates the technical implementation of EU Regulation (EU) 2016/631 (NC I RfG) in Poland. It establishes guidelines and technical specifications that convert European grid connection requirements into national regulations.

These documents are closely linked:

- The NC RfG specifies the requirements that must be met.
- EN 50549-2 defines how these requirements are to be implemented in practice.
- VDE-AR-N 4110, 4120 and 4130 define this implementation for Germany
- The PPPiREE defines this implementation for Poland
- FGW TR3 defines how the requirements are to be tested and certified.

3.1.1.1 Validity

The TwinCAT Power Control product with the product number TF8360 was tested as part of the certification process. The controller core is implemented by the TwinCAT Power Plant Control module, which is named TcPowerPlantControl in TwinCAT.

Certification in accordance with VDE-AR-N 4110, 4120 and 4130 took place in September 2025 and was published with version 0.1.0 of TwinCAT Power Plant Control. The tested functions and components are described in the following sections.

The use of TwinCAT Power Plant Control as an PGP controller is only permitted in the combinations of hardware and software covered by the type test. In addition, the general conditions (e.g. measuring transformer accuracy, communication interfaces, operating environment) of the components must be complied with and verified during commissioning. See Components [▶ 13].

License-based restriction of the platforms

TwinCAT Power Plant Control may only be executed as an PGP controller on certified Beckhoff Embedded PCs. This is checked by licensing the product *TF8360 | TwinCAT Power Plant Control*:

- The license is limited to TwinCAT platforms 20, 30, 40 and 50.
- These platforms represent the devices approved in the component certificate.
- Execution on other platforms or third-party systems is prevented by the TwinCAT license mechanism.

3.1.1.2 Functions

The following table shows a summary of the controller functions with references to chapters of VDE AR-N 4110/20/30 and EN 50549-2:

Description	Name	VDE 4110/20/30	EN 50549-2	FGW TR3
Setpoint specification of a max. active power	Setpoint specification of the active power controller [▶ 25]	10.2.4.1 / 10.2.4.2 / 11.2.7	4.11.2	6.1.3.6
Frequency-dependent active power control P(f)	Frequency-dependent active power adjustment [▶ 27]	10.2.4.3 / 11.2.8	4.6.1 / 4.6.2	6.1.4.5
Provision of primary control power	Frequency-dependent primary control of the active power [▶ 26]	10.5.3 / 11.2.8.3 (only VDE 4110)	N/A	6.1.7
Active power gradient after voltage loss	Setpoint specification of the active power controller [▶ 25]	11.3.2	4.10.2	6.1.11
Voltage related active power reduction	Voltage related active power reduction [▶ 28]	-	4.7.3	-
Reactive power control with constant setpoint	Reactive power control with constant setpoint [▶ 32]	10.2.2 / 11.3.2	4.7.2.3.2	6.1.4.1
Reactive power control with displacement factor CosPhi	Reactive power control with CosPhi displacement factor [▶ 32]	10.2.2.4 / 11.3.2	4.7.2.3.2	6.1.4.2
Reactive power control with voltage limitation	Reactive power control with voltage limiting function Q(Ulim) [▶ 34]	10.2.2.4 / 11.3	-	6.1.4.3
Reactive power-voltage characteristic curve Q(U)	Reactive power control with voltage characteristic curve Q(U) [▶ 33]	10.2.2.4 / 11.3	4.7.2.3.3	6.1.4.4
Reactive power-active power characteristic curve Q(P)	Reactive power control with active power characteristic curve Q(P) [▶ 35]	10.2.2.4 / 11.3	4.7.2.3.4	6.1.4.5
Behavior in the event of communication errors	Behavior in the event of communication errors [▶ 21]	10.2.2.4 / 11.3	-	6.1.8.2
Behavior in the event of a power supply / UPS failure	Behavior in the event of a power supply failure [▶ 22]	10.2.2.4 / 11.4.21	-	6.1.8.1
Controller bypass (slave mode)	Operating states of the controller [▶ 20]	11.3.2	-	6.1.9
Automatic activation after protective tripping	Automatic reconnection after protective tripping [▶ 22]	10.4 / 11.2.11	4.10.2	6.1.12
Switching behavior during operation	Switching operation modes during operation [▶ 32]	-	-	6.1.5
Prioritization with multiple setpoint specifications	Setpoint specification of the active power controller [▶ 25]	11.3.2	-	6.1.10

3.1.1.3 Components

Depending on the plant configuration, a PGP controller using *TwinCAT Power Plant Control* can consist of selected components covered by the certificate.

Certified for use on embedded PCs based on Arm® Cortex® processors such as the CX8200, CX8290 and CX9240, as well as Intel Atom® processors from the Elkhart Lake series such as those installed in the CX5330 and CX5340. The EtherCAT Terminals from the series for power measurement were validated for grid data acquisition, in particular the use of the EL3453 and EL3783, as well as their variants EL3453-0100 and EL3783-0100.

These components are produced under a quality management system certified according to ISO 9001.

Overview of embedded PCs:

Component	Description	Reference
CX8200 CX8290	Arm® Cortex® A53 CPU 2 cores, 1.2 GHz, 1 GB RAM	WWW, PDF WWW, PDF
CX9240	Arm® Cortex® A53 CPU 4 cores, 1.2 GHz, 2 GB RAM	WWW, PDF
CX5330	Intel Atom® x6214RE CPU 2 cores, 1.4 GHz, 4 GB RAM	WWW, PDF
CX5340	Intel Atom® x6425RE CPU 4 cores, 1.9 GHz, 8 GB RAM	WWW, PDF

Overview of EtherCAT Terminals for grid data acquisition:

Component	Description	Reference
EL3453 EL3453-0100	EtherCAT Terminal 130 / 690 V AC, 1 / 5 A, 24 bits	WWW, PDF WWW, PDF
EL3783 EL3783-0100	EtherCAT Terminal 130 / 690 V AC, 1 / 5 A, 16 bits, 20 ksps	WWW, PDF WWW, PDF

3.1.2 Agreements

The following sections define key terms and basic principles for using *TwinCAT Power Plant Control* as a PGP controller. The terms and designations described are used both in the *TwinCAT Power Plant Control* software modules and in this documentation. In addition, the terms and abbreviations from VDE-AR-N 4110, VDE-AR-N 4120 and VDE-AR-N 4130, hereinafter referred to as VDE standards, as well as EN-50549-2 and derived standards, hereinafter referred to as EN standards, apply (see References [▶ 62]).

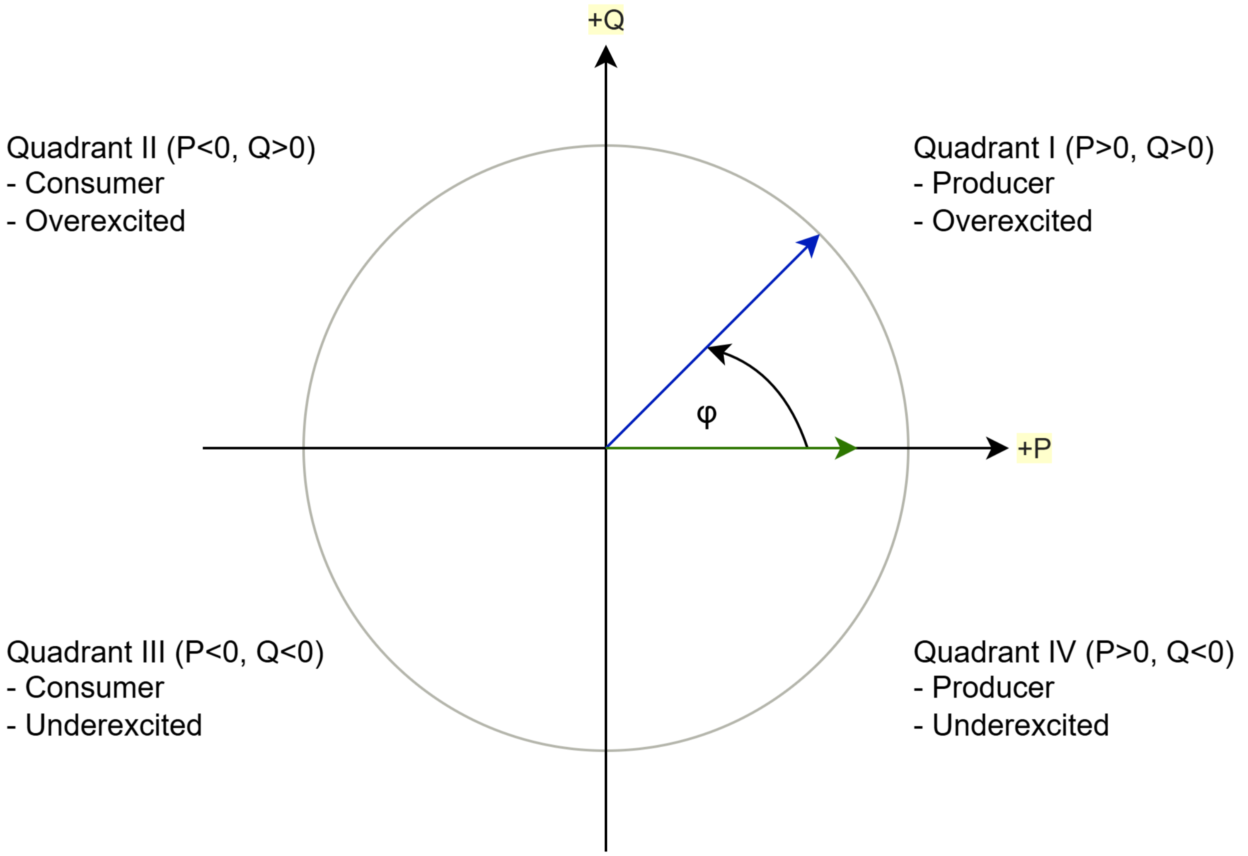
3.1.2.1 Nomenclature

TwinCAT Power Plant Control is integrated as a controller kernel via several interfaces of the TwinCAT module. Operating states, control commands and setpoints are transferred via these interfaces, and control states, control values and diagnostic information are read. The data points in the respective interfaces are structured into categories and are described using the following terms.

Name	Description
Target(s)	Process data input for specifying setpoints of the application to the controller.
Control	Process data input for transferring application states and commands to the controller.
Demand(s)	Process data output for the output of the controller control values.
Status	Process data output for the output of the controller operating states.
Diagnostic(s)	Process data output for the output of internal controller variables for diagnostics. Is added to the Process data output module in TwinCAT via Module tab->Data Area. Internal controlled variables are output in [pu] scaling.
Measure(s)	Process data input for grid data acquisition. Can be added to the process data of the module in TwinCAT via the *Data Areas*. The controller requires an average voltage value U123 over 3 phases and a total active and fundamental reactive power value with sign.
Operating state	Internal operating state of the controller. Indicated by flags in *Status*
(e)ActiveMode	Operation mode of the active power controller
(e)ReactiveMode	Operation mode of the reactive power controller
Active Power Control	Active power controller of the *TcPowerPlantControl* module
Reactive Power Control	Reactive power controller of the *TcPowerPlantControl* module
Fallback Control	A *FallbackMode* configures the behavior of the controller if communication with the energy provider fails, if communication with the direct marketing company fails, if communication with the power generating plant fails or if grid data acquisition fails.
Persistent Control	File-based storage and restoration of the last valid setpoints and parameters of a *TcPowerPlantControl* or a *TcPowerMeasure* module.
Overexcited operation	A positive reactive power (direction from the power generating plant to the grid) increases the voltage at the point of common coupling of the power generating plant. *OvExt* is used as an abbreviation for parameters and process data. The controller requires setpoint and actual values with a sign in order to correctly map the underexcited and overexcited operation in the power generating plant (see Reference arrow system [▶ 16]).
Underexcited operation	A negative reactive power (direction from the grid to the power generating plant) reduces the voltage at the power generating plant. *UdExt* is used as an abbreviation for parameters and process data. The controller requires setpoint and actual values with a sign in order to correctly map the underexcited and overexcited operation in the power generating plant (see Reference arrow system [▶ 16]).

3.1.2.2 Reference arrow system

TwinCAT Power Control uses the generator reference arrow system as shown in the figure below. The generator reference arrow system is also used by the EN standards. In contrast, the VDE standards use the load reference arrow system. This means that all the characteristic curves and parameters listed there can be transferred to the generator reference arrow system for comparison with *TwinCAT Power Plant Control*.



Sign convention for Q and cos φ in the generator reference arrow system

The following sign convention applies to the reactive power (Q):

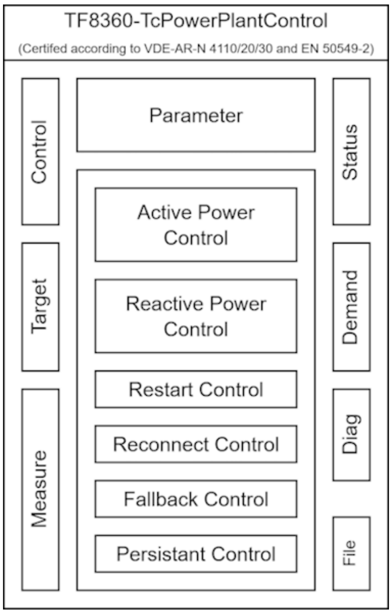
- Q > 0: Plant feeds reactive power into the grid
- Q < 0: Plant absorbs reactive power from the grid

As the power factor (cos φ) is by definition unsigned, its sign is derived from the reactive power:

- cos φ > 0: Plant feeds reactive power into the grid (Q > 0)
- cos φ < 0: Plant absorbs reactive power from the grid (Q < 0)

3.1.3 Interfaces

TwinCAT Power Plant Control calculates the active power and reactive power control values as *demands* based on the measured actual values from *Measure*, the transferred specifications in *Controls* and the setpoints in *Targets*. The *Targets* are transferred scaled to their nominal values or calculated by the module as Demand. The *parameters* of the module are preconfigured via the *Parameters (Init)* tab. The active power controller is described at Active power controller [▸ 23] and the reactive power controller at Reactive power controller [▸ 30]. The names and agreements used by *TwinCAT Power Plant Control* and this documentation, as well as their meaning, are listed at Nomenclature [▸ 15]. Lists of the enumeration definitions and data structures for the controller interfaces can be found at Data types [▸ 60]. There is also a parameter list for the controller with minimum, maximum and default values with a description at Parameter [▸ 48].



3.1.3.1 Grid data acquisition

The EtherCAT Terminals for grid data acquisition tested as part of the certification process are listed below (see also Components [▸ 13]):

Component	Description
EL3453 EL3453-0100	EtherCAT Terminal 130 / 690 V AC, 1 / 5 A, 24 bits • Voltage/current accuracy ≤ 0.3 % • Power accuracy ≤ 0.6 % • Frequency accuracy ≤ 5 mHz • Update rate = 10 ms
EL3783 EL3783-0100	EtherCAT Terminal 130 / 690 V AC, 1 / 5 A, 16 bits, 20 ksps • Voltage/current accuracy ≤ 0.2 % • Power accuracy ≤ 0.4 % • Frequency accuracy ≤ 5 mHz • Update rate = 1 ms

A *TwinCAT Power Measure* module from the *TF8330* | *TwinCAT Power Collector* or the *TF8360* | *TwinCAT Power Technologies* is used for the acquisition and calculation of grid data. These modules are used in connection with EtherCAT Terminals for grid data acquisition.

- EL3453: The grid data of the EL3453 terminal is retrieved via the `TcPowerMeasureEL3453` module. In this case, grid analyses and evaluations of the measured voltages and currents are carried out directly in the EtherCAT Terminal. The results are taken from the *TwinCAT Power Measure*.
  See also TcPowerMeasureEL3453.
- EL3783: The grid data of the EL3783 terminal is read via the `TcPowerMeasureEL3783` module. The terminal provides instantaneous values of voltages and currents, which are then evaluated by the *TwinCAT Power Measure*.
  See also .

The standard variants of the EL3453 and EL3783 are used for direct measurement in the low-voltage network up to 690 V. The *-0100 variants* of both terminals are optimized for use with voltage transformers and enable the measurement of medium or high voltage via their 100 V secondary side. Technically, they only have different input wiring, while the firmware and software for processing the measured values are identical.

For the use of *TwinCAT Power Plant Control* as a PGP controller in extra-high voltage grids, the EL3783 with the `TcPowerMeasureEL3783` must be used in order to meet the higher requirements.

The *TF8330* licenses for integrating the *EL3453* using the `TcPowerMeasureEL3453` module are included in the *TF8360* license. To integrate the *EL3783* using the `TcPowerMeasureEL3783` module, the *TF8350* license must also be purchased.

The data of the respective `TcPowerMeasure` module is transferred via an interface pointer directly into the `TcPowerPlantControl`, without the detour via the explicit mapping of inputs and outputs of the process data. The measured values are transferred to the controller in SI units. For further internal processing, the controller scales these values into the per-unit representation (pu) to enable a normalized evaluation relative to the respective nominal value.

The controller uses the symmetrical three-phase average value U123 for voltage control. The phase-to-phase voltages U12, U23 and U31 are used to monitor the connection conditions during the *Restart* and *Reconnect* operating states. To calculate the active and reactive power, the controller uses the fundamental values of the fundamental as signed total power across all three phases.

External devices for grid data acquisition

If external devices other than the supported EtherCAT Terminals are used for grid data acquisition, the measured values must meet the following requirements and be made available to *TwinCAT Power Plant Control* in a suitable form.

Measured value	Accuracy	Update rate
Voltage	≤ 1.0 %	≤ 100 ms
Current	≤ 1.0 %	≤ 100 ms
Power	≤ 1.0 %	≤ 100 ms
Frequency	≤ 10 mHz	≤ 100 ms

The use of the PGP controller in extra-high voltage grids is subject to extended requirements for grid data acquisition. These must be taken into account when selecting and connecting external devices for grid data acquisition.

Measured value	Accuracy	Update rate
Voltage	≤ 0.5 %	≤ 100 ms
Current	≤ 0.5 %	≤ 100 ms
Power	≤ 0.5 %	≤ 100 ms
Frequency	≤ 5 mHz	≤ 100 ms

3.1.3.2 Setpoint specifications

The following products and protocols can be used to implement the interfaces for receiving setpoint specifications and sending control values to power generating plants, among others.

A transmission accuracy of at least 1 % of the nominal value and a maximum delay time of 100 ms should be guaranteed.

Product /Reference	Interface
EL1002 EL2002	Digital signals 0..24 V, 0..12 V, 0..10 V, 0..5 V
EL3022 EL4022	Analog signals 4..20 mA, 0..20 mA, 0..10 V, +/- 10 V
TF6500	IEC 60870-5-101 IEC 60870-5-104
TF6510	IEC 61850 IEC 61400-25
TF6250 EL625x	Modbus TCP
TF6255	Modbus RTU
TF6100	OPC UA Server/Client
TF6105	OPC UA Pub/Sub
TF6270	PROFINET RT
EL6633	PROFINET IRT
TF628x EL665x	EtherNet/IP
EL673x	PROFIBUS
EL675x	CAN, CANopen

3.1.3.3 Scaling

The following section describes how units and scaling are used and configured in *TwinCAT Power Plant Control*.

All power values in *Target* and *Demand* as well as parameters associated with power control are expected by the controller as a percentage of the nominal value. The nominal value is defined by the parameter `ActiveNominal` (in watts) and corresponds to $P_{b\ inst}$ according to VDE standards or P_{Max} according to EN standards. User-specific scaling can be configured for *Target* and *Demand* power values using the *ActiveScale* parameter (default=100.0) for active power values and *ReactiveScale* (default=100.0) for reactive power values. If *Scale* = 1.0, per-unit scaling is set. The default setting is *Scale* = 100, which corresponds to the percentage scaling.

Incoming grid data is received in SI units (such as V, A, W) and scaled internally to per-unit with corresponding parameters such as *VoltageNominal* . The parameters assigned to the voltage are given as a percentage, as in the VDE and EN standards.

The frequency is not standardized and is expected by the controller in Hertz.

3.1.3.4 Step sizes

All analog signals and measured values are transmitted in the „floating point“ data type with single precision in accordance with IEEE 754. More than six significant digits are available when transferring data to the controller. This ensures high accuracy and precise value transfer to the controller. The accuracy limits are defined by the specification of the IEEE 754 standard.

The step size when setting parameters depends on the data type used:

- **BOOL**: Boolean value that only allows two states (TRUE, FALSE).
- **ENUM**: Enumeration that only allows predefined states.
- **TIME**: Numerical value that represents durations in milliseconds.
  This means that time periods from 0 seconds to approx. 49 days are available.

- **REAL**: Floating point number with single precision in accordance with IEEE 754.
  This means that more than six significant decimal places are available.

3.1.4 Operation modes

The following section describes the possible states of the controller during operation. This explains how the controller responds to different specifications and grid conditions.

3.1.4.1 Operating specifications of the controller

The controller takes operating states of the application into account via *Control* process data (see DataAreas [▶ 56]).

Variable	Description
`bEnable`	Enable the controller with reset of all timing elements, filters and integrations.
`bSupplyError`	External UPS is active due to power supply failure. Signal to the controller to save internal states via a controlled switching off and restart.
`bMeasureError`	Communication error to the grid data acquisition device at the `Measure` interface. The controller goes into the *bypass* state for the duration of the error and uses the setpoints selected by the *Fallback Control* parameters and the *FallbackMode*.
`bPlantError`	Communication interruptions to a connected power generating plant. Affects the control values from the *Demand* interface. The controller goes into the *bypass* state for the duration of the error.
`bOperatorError`	Interruption of communication to the telecontrol interface of the grid operator. The controller uses the setpoints selected via the `OperatorFallbackMode` parameter for the targets `fActivePowerLim`, `fReactivePowerSet` and `fCosPhiSet`. After the fault has been cleared, a restart delay applies in accordance with the `OperatorFallbackDelay` parameter.
`bMarketerError`	Interruption of communication with the energy management system of the direct marketing company. For `fActivePowerSet`, the controller uses the setpoint that was selected via the `MarketerFallbackMode` parameter. After the fault has been cleared, a restart delay applies in accordance with the `MarketerFallbackDelay` parameter.
`bVoltageProtection`	Voltage protection triggered by external device. Concerns the *Reconnect* function of the controller.
`bFrequencyProtection`	Frequency protection detected by external device. Concerns the *Reconnect* function of the controller.

3.1.4.2 Operating states of the controller

The controller recognizes the following operating states as part of the Data Area *Status* (see DataAreas [▶ 56]).

The operating states *Normal, Critical, Restart, Reconnect* are used to select the rise limit of the active power setpoint.

Variable	Description
`bValid`	The controller is correctly configured via parameters and targets and can be started with *Enable* = TRUE. The *Demand* control values can be used.
`bStart`	The controller is enabled by *Enable* and ready to operate. The connection conditions for *Restart* or *Reconnect* have been met and the waiting time for switching on the power generating plants has expired.
`bNormal`	The controller is in a normal operating state. Grid-critical operation is not active. All conditions for a *Restart* or *Reconnect* are also fulfilled and no waiting time is active.

Variable	Description
bCritical	The controller detects the grid-critical state by continuously monitoring the frequency during the frequency-dependent active power adjustment P(f). The diagnostic information provides further details about the connection conditions that were not met.
bRestart	Start-up of the power generating plant is active. The diagnostic information provides further details about the connection conditions that were not met.
bRestartWait	Enabling conditions are met and the waiting time for enabling power generation is active.
bReconnect	Reconnection of the power generating plant after protective tripping is active. The *Reconnect* is disabled at the end of the start-up ramp. The diagnostic information provides further details about the connection conditions that were not met.
bReconnectWait	Enabling conditions are met and waiting time for automatic reconnection after shutdown is active.

3.1.4.3 Enabling power generation

Enabling power generation after a start-up is a function in accordance with EN standards. This function is particularly relevant for decentralized power generating plants in order to avoid a disorderly restart after a grid failure and to ensure system stability in accordance with grid connection guidelines. In *TwinCAT Power Plant Control*, this function is referred to as `Restart` and is configured via parameters in the `Restart` group (see Restart [▶ 49]).

The function is enabled with the parameter RestartAutomatic = `TRUE`. After a grid restoration event, the restart mechanism monitors the grid frequency and grid voltage during startup to check the release conditions defined in the standard. The following status signals are available:

- `bRestartWait`: Indicates that the technical release conditions (frequency, voltage) have been met, but the configured waiting time (`RestartDelay` parameter) is still running.
- `bRestart`: Indicates that the waiting time is complete and the power generating plant is starting up.
- `bStart`: Serves as an enable signal for power generation (e.g. to control a circuit breaker), provided the restart function is enabled.

3.1.4.4 Behavior in the event of communication errors

An individual *Fallback* mode with restart *delay* can be configured for setpoints, measured values and control values of the power generating plant via the parameter group `Plant` (see Plant [▶ 49]). This function is anchored in the requirements of the VDE and EN standards.

Function of the Fallback mode

The Fallback mode defines the behavior of the controller in the event of communication failures with the following components:

- the grid operator (`Operator`) - concerns setpoints from the grid control system
- the direct marketing company (`Marketer`) - concerns setpoints from marketing
- the power generating plant (`Plant`) - concerns the feedback and control of the units
- the grid data acquisition (`Measure`) - concerns measured values at the point of common coupling (PCC)

A failure of the respective communication connection is detected via assigned status flags of the control interface (see Operating specifications of the controller [▶ 20]) and signaled to the controller.

Available Fallback modes

Depending on the configuration, the controller responds as follows in the event of an error:

- `Default`: The default configured as a parameter is used as the setpoint
- `Last`: The last valid setpoint will continue to be used

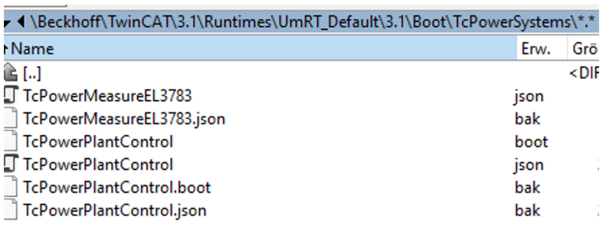
This is also saved and restored via the *Persistent Control* when the system is restarted. This *Fallback* logic is also active when the controller starts up after activation via `bEnable = TRUE`, even if there is no valid communication at this time.

3.1.4.5 Behavior in the event of a power supply failure

After a power supply failure, the PGP controller should automatically restore its last valid state with the corresponding setpoints and parameters. This requirement is defined in the VDE standards.

For implementation, *TwinCAT Power Plant Control* saves the current parameters and setpoints in JSON format in the TwinCAT boot directory at startup (transition from Config to Run): `%TWINCAT3DIR%/Boot/TcPowerSystem`.

When the system stops (transition from Run to Config), these values are restored from the saved JSON files. If the files do not exist or are incorrect, the initial values are left as they are.



3.1.4.6 Automatic reconnection after protective tripping

Automatic reconnection after a (protective) shutdown is a requirement of the VDE and EN standards. The *Reconnect* function ensures that an unplanned reconnection of the power generating plant only takes place under stable grid conditions in order to make a key contribution to system security in the distribution and transmission system. It prevents the risk of grid interferences or instabilities following grid faults or island grid operation. In *TwinCAT Power Plant Control*, this function is implemented under the name *Reconnect* and configured via parameters of the *Reconnect* group (see Reconnect [▶ 50]).

Activation and basic function

The reconnect function is activated by setting the parameter `ReconnectAutomatic = TRUE`. In the active state, the function continuously monitors compliance with the reconnection conditions defined in the standard during start-up:

- the grid frequency (F)
- the phase-phase voltages (U12, U23, U31)

A status indicator is provided by the `Status` flags:

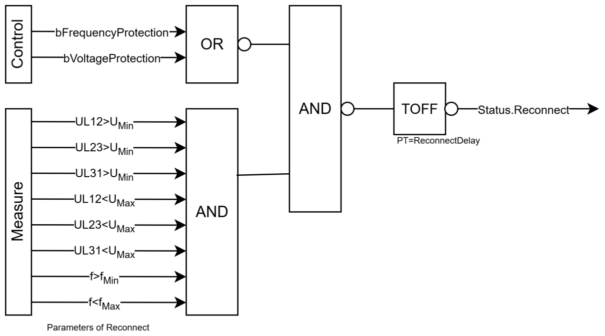
- `bReconnectWait`: The reconnection conditions are met, but the reconnection delay (`ReconnectDelay`) is still running.
- `bReconnect`: The waiting time has expired - the system is starting up.
- `bStart`: The enable signal for power generation (e.g. to control the circuit breaker) when *Reconnect* is active.

Optional integration of external protective devices

Protective tripping from external protective devices can also be taken into account via the flags `bVoltageProtection` and/or `bFrequencyProtection`

Functional principle in the block diagram

The functional block diagram of the *Reconnect* function in accordance with the requirements of the VDE standards:



3.1.5 Active power controller

The active power control of a power generating plant is configured via the parameters of the `ActivePower` group (see ActivePower [▶ 50]). It adapts flexibly to the characteristics of the connected power generating units and meets the requirements of VDE and EN standards.

Initialization

The controller is enabled by setting `bEnable = TRUE` in the `Control` input process data (see DataAreas [▶ 56]).

At startup, all integrator states and filters are adjusted or reset to the current input values to ensure a clean start of control.

Limiting the active power

The maximum available active power of the connected power generating plant (PGP) is defined in two stages:

- Static via parameters: `ActiveMaximum`, `ActiveMinimum`
  - Values in [%] relative to plant output, with sign according to the generator reference arrow system.
- Dynamic via setpoint inputs (*Targets*):
  - Two separate external setpoint inputs can be used for dynamic limitation (e.g. by grid operators or direct marketing companies).

Frequency-dependent demand response

The frequency-dependent active power control (*ActiveByFrequency*), which cannot be disabled, is carried out in accordance with the specifications of VDE 4110/4120 and is described in the chapter Frequency-dependent active power adjustment [▶ 27].

The optionally switchable primary control power (*ActiveByPrimary*) in accordance with VDE-AR-N 4120 is described in chapter Frequency-dependent primary control of the active power [▶ 26].

Signal filtering

The following parameters are used to filter the measured active power:

- `ActualFilterTime` (Default: 10 ms)
- `ActualFilterType` (Default: PT1)

As well as the following parameters for filtering the measured frequency:

- `FrequencyFilterTime` (Default: 10 ms)
- `FrequencyFilterType` (Default: PT1)

Controller structure

The active power controller is designed as a classic PI controller:

- `ControlGain`: Gain
- `ControlIntegration`: Integration time constant

Predictive control (optional)

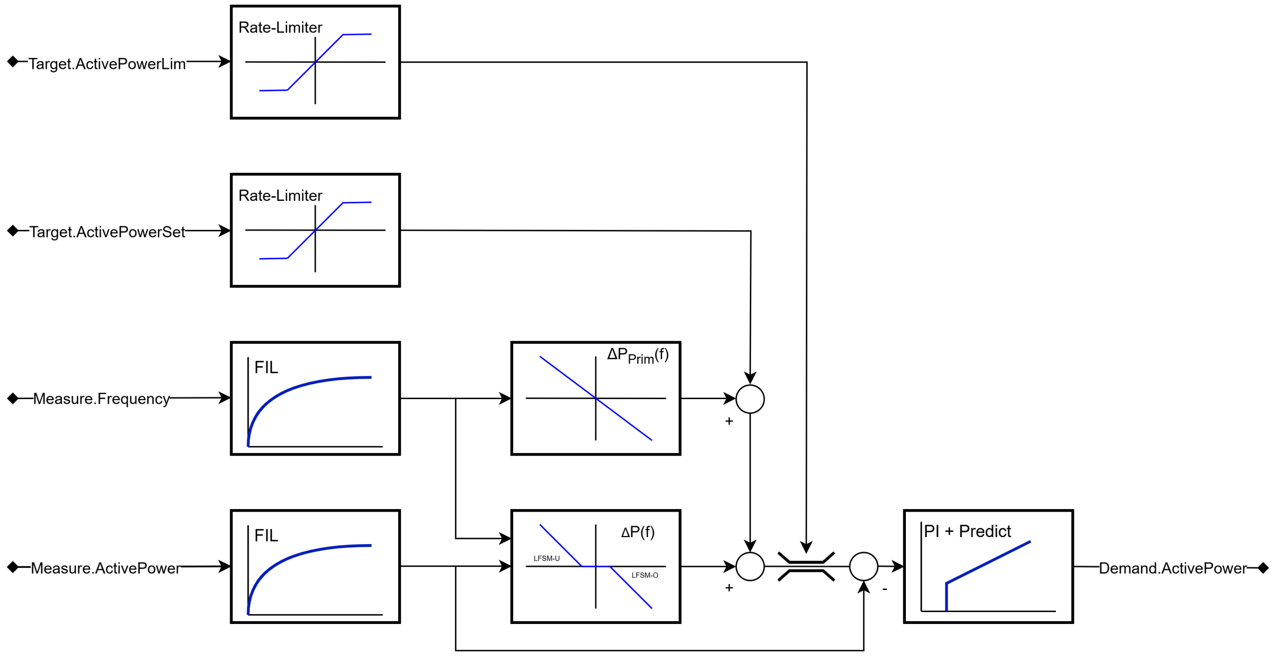
The typical dynamic response of a PGP according to VDE can be described by a simple PT1 behavior with characteristic values of delay time and dead time. If the actual characteristics of the plant are known, the control behavior can be improved by the following parameters.

- `PredictDeadtime`: Mapping the dead time of the track
- `PredictFilterTime`: Mapping of the PT1 delay

These values are taken into account by the PI controller in order to optimize the transient response - especially in systems with a significant dead time compared to the controlled system.

Block diagram

The following figure shows the basic structure of the active power controller:



3.1.5.1 Operation modes of the active power controller

The process data input `eActiveMode` under *Targets* controls the switchover between different operation modes of the active power controller (see DataAreas [▶ 56]). The following modes are available:

- `Default`:
  The setpoint is specified by the statically defined `ActiveTargetDefault` parameter.
- `Normal`:
  The setpoint comes dynamically from `fActivePowerSet` and is processed by the controller.
- `Slave`:
  In `Slave` mode, the active power controller works as a subordinate controller. The `fActivePowerSet` setpoint is passed directly to the PI controller and bypasses the rise limitation so that the specification is implemented without delay.
- `Bypass`:
  In `Bypass` mode, the active power controller including rise limitation is bypassed.

This switchover can take place during operation and enables flexible adaptation to different application scenarios.

3.1.5.2 Setpoint specification of the active power controller

The setpoints of the active power controller are defined via the input process data in the `Targets` structure (see DataAreas [▶ 56]), whereby the parameters of the ActivePower group are used for setting (see ActivePower [▶ 50]).

The PGP controller processes setpoints according to the priorities defined in the standards:

- Network operator (Operator): The target `fActivePowerLim` acts as a limit.
- Direct marketer (Marketer): The target `fActivePowerSet` acts as a setpoint.

In the event of conflicting specifications, the smaller target value is used. This means that the direct marketer's specifications are only implemented within the limit defined by the grid operator.

Network-specific requirements

The prioritization of the active power specifications is set standard specific via the `ControllerMode` parameter (see Plant [▶ 49]):

- `DE_VDE4110_2023` for medium-voltage grid
- `DE_VDE4120_2018` for high-voltage grid
- `DE_VDE4130_2018` for extra-high voltage grid

By selecting the appropriate `ControllerMode`, the prioritization of the active power specifications for the respective grid is automatically applied as described below.

- Medium and high-voltage grid (VDE-AR-N 4110 / 4120):
  - The active power output of the controller to the generating units is limited to the maximum value specified by the grid operator.
- High-voltage grid (VDE-AR-N 4130):
  - In the event of an increase in power as a result of an underfrequency event, the automatic grid protection measure (e.g. frequency-dependent active power control P(f)) has has priority and may exceed the limit specified by the grid operator.

Rise limitation of the setpoints

The setpoints are adjusted with a slope limitation depending on the operating status, which is configured using the following parameters:

- `ActiveTargetSlopeNormal` for normal operation
- `ActiveTargetSlopeCritical` for critical state
- `ActiveTargetSlopeRestart` for restart phase
- `ActiveTargetSlopeReconnect` for reconnect phase

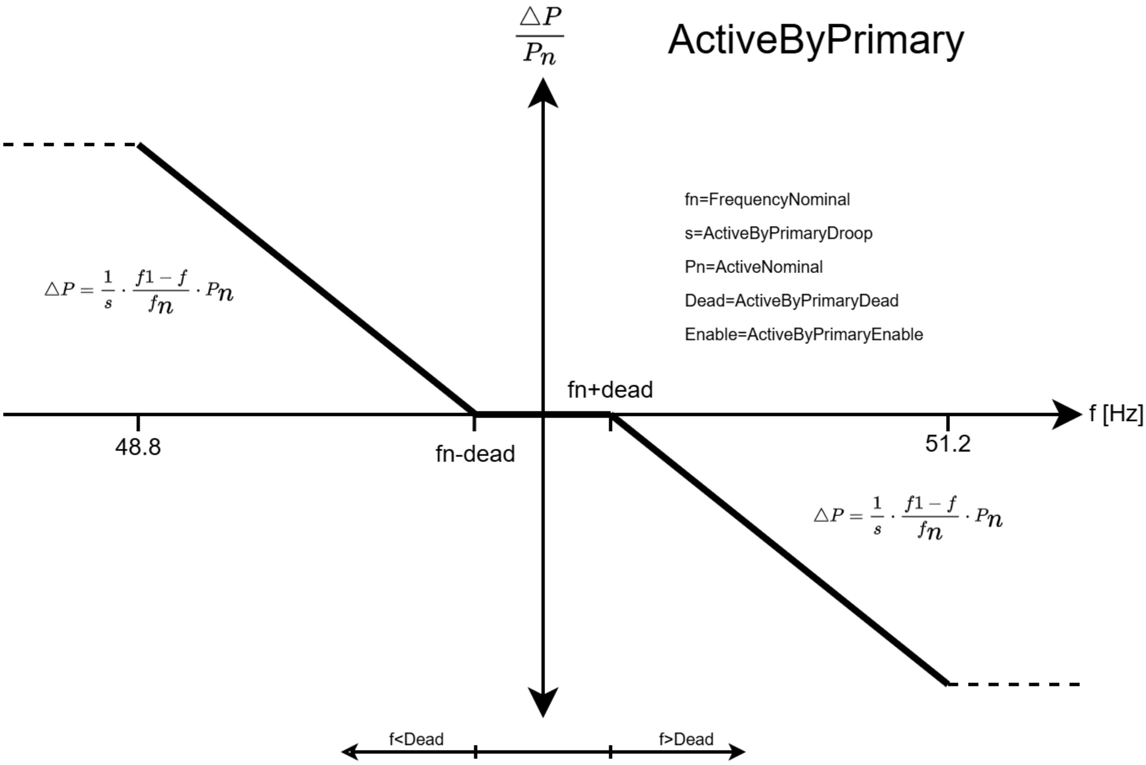
This differentiated slope limitation ensures a safe and stable adjustment of the setpoints, taking into account the grid situation and the system operating states.

3.1.5.3 Frequency-dependent primary control of the active power

The characteristic curve in the `ActiveByPrimary` parameter adjusts the active power of the power generating plant depending on the grid frequency. This function must be implemented in accordance with VDE standards. Control is based on the `ActiveByPrimary` parameter group and is enabled by the `ActiveByPrimaryEnable` parameter (see ActiveByPrimary [▶ 51]).

In the EN standards, this operation mode is also referred to as *Frequency Sensitivity Mode (FSM)*.

The associated characteristic curve forms a frequency-dependent demand response using the `ActiveByPrimaryDroop` parameter with the configurable deadband around the nominal frequency using the `ActiveByPrimaryDeadband` parameter. By default, the deadband is pre-set to ±10 mHz in order to map the required insensitivity of 10 mHz.



3.1.5.4 Frequency-dependent active power adjustment

The characteristic curve in the `ActiveByFrequency` parameter adjusts the active power of the power generating plant depending on the grid frequency as soon as a transition to a grid-critical operating state occurs. This function is part of the requirements of the VDE and EN standards. It covers both overfrequency (*LFSM-O*) and underfrequency (*LFSM-U*). Configuration is carried out via the `ActiveByFrequency` parameter group (see ActiveByFrequency [▶ 51]).

In the EN standards, this operation mode is also referred to as *Limited Frequency Sensitive Mode (LFSM)*.

A non-critical grid condition exists if the grid frequency is within the permissible limits. If a frequency limit is exceeded and the configured delay time (`StrDelay`) expires, the critical operating state is activated (*LFSM-U* or *LFSM-O*). This state is signaled in the *Status* via `Critical`.

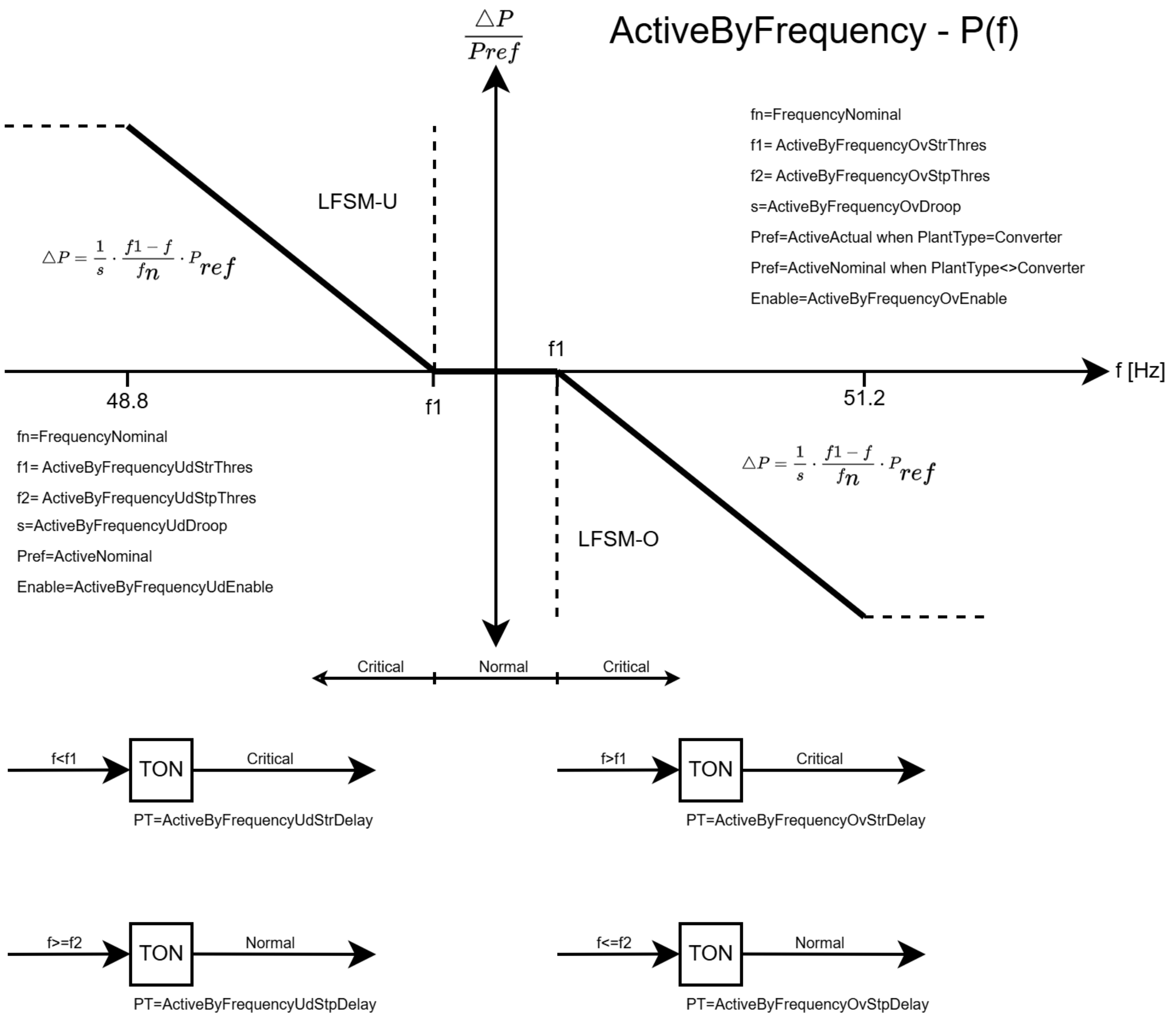
- *LFSM-U* (underfrequency operation): The power adjustment ΔP is calculated using the reference value P_{Ref} = `ActiveNominal` and the `UdDroop` parameter.
- *LFSM-O* (overfrequency operation): The reference value P_{Ref} depends on the plant type. For plants with `PlantType = Converter`, `ActiveActual` is used, otherwise `ActiveNominal`. The power is then reduced via P_{Ref} and `OvDroop`.

The system returns to the non-critical state when the frequency is back within the permissible range and the release delay (`StpDelay`) has expired.

The reference value P_{Ref} must be set via the `ActiveNominal` parameter according to the nominal output of the generation system (see parameter [▶ 50]).

Frequency measurement, pre-filtering and control are optimized in terms of propagation delay. Delays can also be deliberately configured to avoid unwanted switching frequencies.

In the critical operating state, the slope limitation `ActiveTargetSlopeCritical` (see ActivePower [▶ 50]) takes effect for the `fActivePowerSet` setpoint.

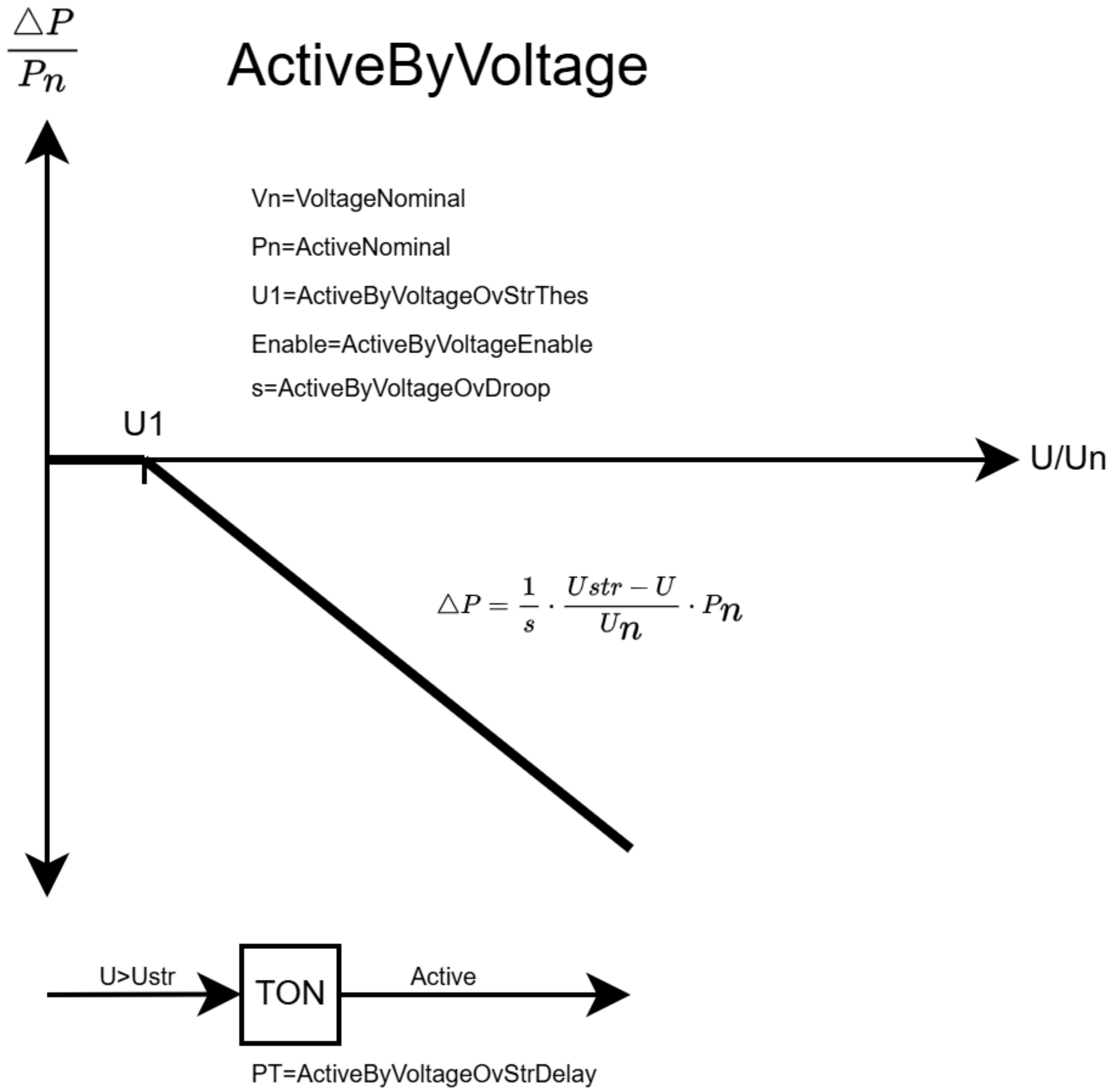


3.1.5.5 Voltage related active power reduction

The voltage-dependent active power reduction reduces the active power of the power generating plant in the event of an overvoltage to prevent the overvoltage protection from responding. This function is required by EN standards.

Implementation is carried out via the `ActiveByVoltage` parameter group (see ActiveByVoltage [▸ 52]). The characteristic curve is enabled via the `Enable` parameter. The switch-on threshold for triggering the reduction is defined by `OvStrThres`, the associated delay time via `OvStrDelay`.

As soon as the measured voltage exceeds the threshold and the delay has expired, the reduction curve is determined by the `OvDroop` factor in the active area of the characteristic curve. This determines the extent to which the active power is reduced depending on the overvoltage.


ΔP/Pn
ActiveByVoltage
Vn=VoltageNominal
Pn=ActiveNominal
U1=ActiveByVoltageOvStrThes
Enable=ActiveByVoltageEnable
s=ActiveByVoltageOvDroop
U1
U/Un
ΔP = 1/s · (Ustr − U)/Un · Pn
U>Ustr
TON
Active
PT=ActiveByVoltageOvStrDelay

3.1.6 Reactive power controller

The reactive power control is configured via the parameters of the `ReactivePower` group (see ReactivePower [▸ 52]). The control is based on the requirements of the VDE and EN standards and takes into account the typical behavior of decentralized power generating plants in grid operation.

Initialization

The reactive power controller is enabled by setting `bEnable = TRUE` in the `Control` input process data (see DataAreas [▸ 56]).

When enabled, all integrators and filters are set or reset to the current input values to ensure a stable control start.

Limiting the reactive power

The reactive power available during operation of the connected power generating plant is specified via the following parameters:

- `ReactiveMaxUdExt`: Maximum capacitive reactive power (lower range)
- `ReactiveMaxOvExt`: Maximum inductive reactive power (upper range)

The values are to be interpreted with signs according to the generator reference arrow system.

Optionally, an active load-dependent reactive power curve of the power generating plant can be activated in order to take into account the Q(P) behavior of the plant (see chapter Reactive power control with active power characteristic curve Q(P) [▸ 35]).

Signal filtering

The following parameters are used to filter the measured reactive power:

- `ActualFilterTime` (Default: 10 ms)
- `ActualFilterType` (Default: PT1)

As well as the following parameters for filtering the measured voltage:

- `VoltageFilterTime` (Default: 10 ms)
- `VoltageFilterType` (Default: PT1)

Controller structure

The reactive power controller is designed as a classic PI controller:

- `ControlGain`: Controller gain
- `ControlIntegration`: Integration time constant

Additional filtering via the following parameters is used both for smoothing and for limiting the rise of the setpoint in the direction of the controller, so that the dynamics of the controller correspond to the required behavior of a first-order filter.

- `ReactiveTargetFilterTime` (Default: 2 s)
- `ReactiveTargetFilterType` (Default: PT1)

A first-order low-pass filter (PT1) is used for additional smoothing and limiting of the setpoint increase. As a result, the set filter time corresponds to a first-order time element with the time constant τ.

- `ReactiveTargetFilterTime` (default: 2000 ms = 2 s = 1 τ)
- `ReactiveTargetFilterType` (default: PT1)

With the default filter time of 2 seconds (1 τ), the target value is raised to approx. 63 % of the end value. This complies with the VDE requirements to maintain a transient response over 3 τ ≈ 6 seconds.

Predictive control (optional)

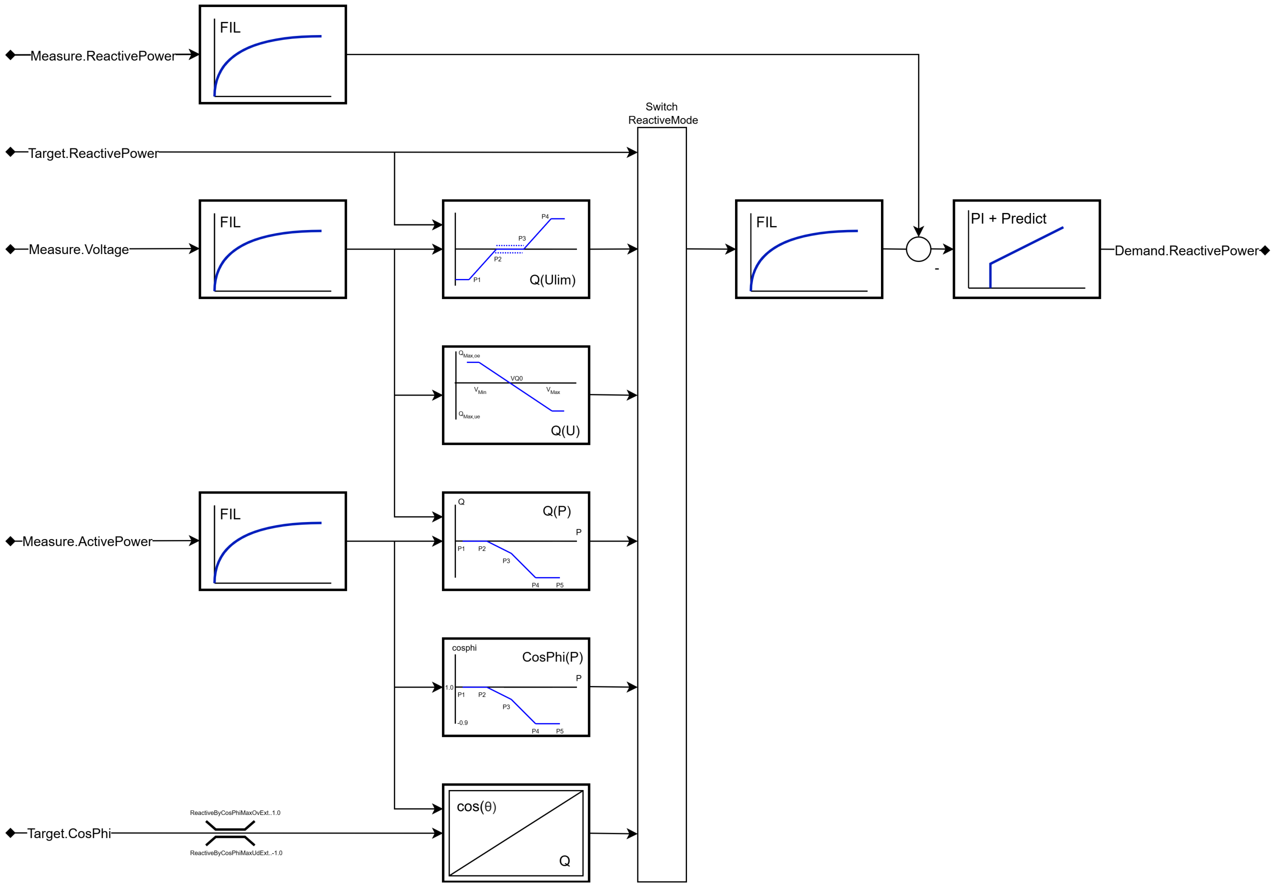
If the plant characteristics are known, the delay can be taken into account based on the model. These parameters improve the transient response, particularly in plants with a dominant dead time in relation to the delay.

- PredictDeadtime: Mapping of the dead time

- PredictFilterTime: Mapping of the PT1 delay

Block diagram

The following figure shows the basic structure of the reactive power controller:



3.1.6.1 Operation modes of the reactive power controller

The `eReactiveMode` process data input under the *Targets* controls the selection of operation mode for the reactive power controller (see DataAreas [▸ 56]). The following modes are available:

- `Default`:
  The setpoint is specified by the static parameter `ReactiveTargetDefault`.
- `Normal`:
  The setpoint comes dynamically from `fReactivePowerSet` and is processed by the controller.
- `Slave`:
  In `Slave` mode, the reactive power controller operates as a subordinate controller. The `fReactivePowerSet` setpoint is passed directly to the PI controller and bypasses the rise limitation so that the specification is implemented without delay.
- `Bypass`:
  In `Bypass` mode, the reactive power controller including rise limitation is bypassed.

The following extended control modes are also available:

- `ByCosPhi`:
  Reactive power control with *CosPhi* displacement factor (see ReactiveByCosPhi [▸ 53])

- `ByVoltage`:
  Voltage characteristic curve *Q(U)* (see ReactiveByVoltage [▸ 53])
- `ByVoltageLim`:
  Voltage-dependent reactive power limitation *Q(Ulim)* (see ReactiveByVoltageLim [▸ 54])
- `ByActive:`
  Active power characteristic curve *Q(P)* (see ReactiveByActive [▸ 54])
- `ByActiveCosPhi`:
  CosPhi(P) characteristic curve according to EN standard (see ReactiveByActive [▸ 54])

These operation modes can be switched dynamically, e.g. via a telecontrol interface of the grid operator (see Setpoint specifications [▸ 18]). Switching takes place in compliance with the transition behavior and filter parameters required by the standard (e.g. `ReactiveTargetFilterTime`, `ReactiveTargetFilterType`, see ReactivePower [▸ 52]).

3.1.6.2 Switching operation modes during operation

The reactive power control mode can be switched during operation via the `eReactiveMode` process data input, for example via a telecontrol interface (see Setpoint specifications [▸ 18]).

The switching behavior is determined by the setpoint filter upstream of the controller. This can be configured via the parameters `ReactiveTargetFilterTime` and `ReactiveTargetFilterType`. In accordance with the requirements of the VDE and EN standards, a PT1 filter behavior is pre-set as standard to ensure smooth and grid-compatible switching.

3.1.6.3 Reactive power control with constant setpoint

The `fReactivePowerSet` process data input under *Targets* (see DataAreas [▸ 56]) defines the reactive power setpoint in `Normal` operation mode. This setpoint is typically specified by the grid operator (`Operator`) via a telecontrol interface (see Setpoint specifications [▸ 18]).

In `Default` operation mode, the controller instead uses the statically configured value `ReactiveTargetDefault` as the fixed reactive power setpoint.

3.1.6.4 Reactive power control with CosPhi displacement factor

The `fCosPhiSet` process data input specifies the setpoint for the displacement factor in `ByCosPhi` operation mode. This control is configured via the `ReactiveByCosPhi` parameter group (see ReactiveByCosPhi [▸ 53]).

The sign of the CosPhi setpoint must be specified according to the generator reference arrow system (see Reference arrow system [▸ 16]):

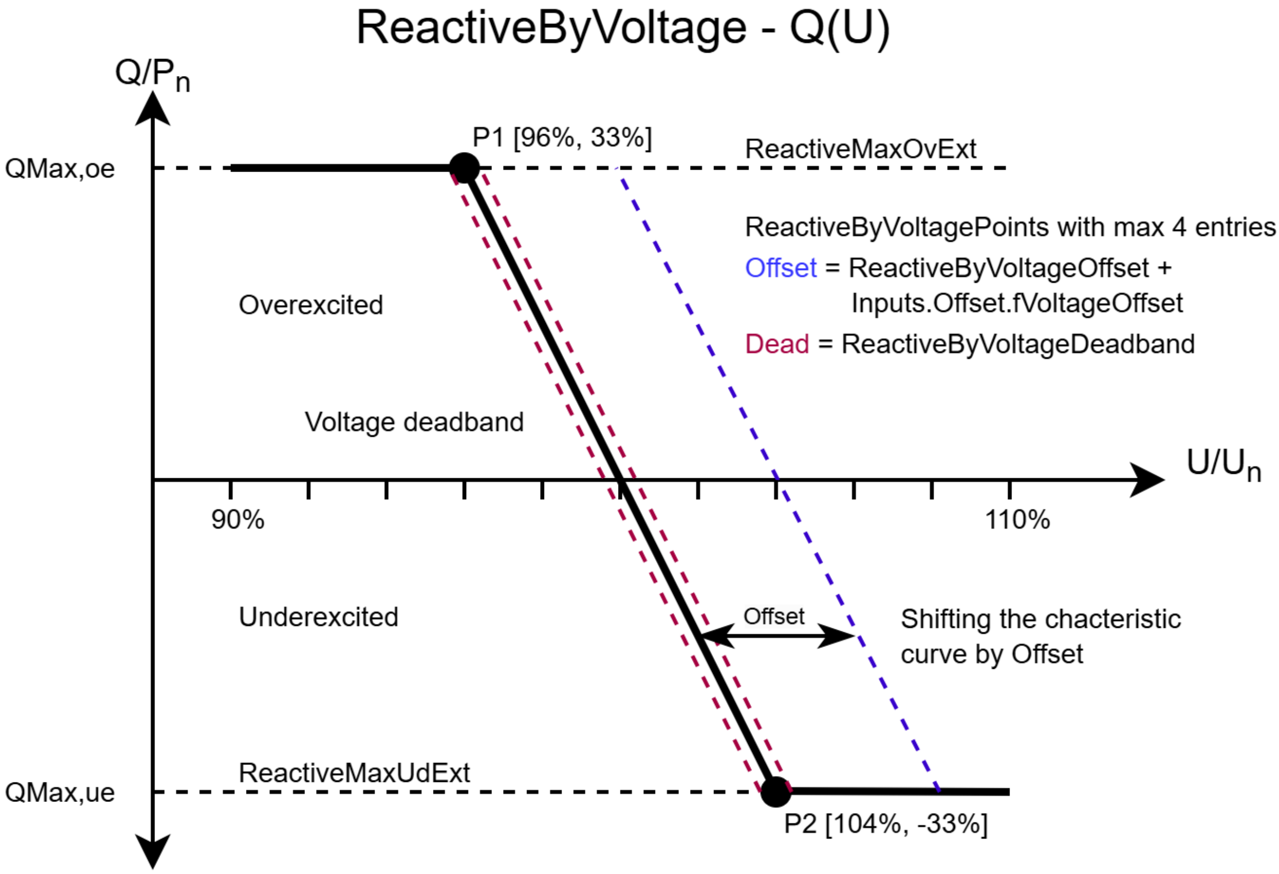
- CosPhi < 0: underexcited operation (reactive power from the grid to the plant), limitation takes place between -1.0 and the `MaxUdExt` parameter.
- CosPhi > 0: overexcited operation (reactive power from the plant to the grid), limitation takes place between +1.0 and `MaxOvExt`.

The `ReactiveTargetDefault` parameter defines the default value for *CosPhi* (see ReactivePower [▸ 52]). This is also used if no valid setpoint is available via the communication interface when the controller is started or if the connection to the grid operator is interrupted.

3.1.6.5 Reactive power control with voltage characteristic curve Q(U)

Setting `eReactiveMode = ByVoltage` activates the voltage characteristic curve Q(U) for reactive power control. The parameters of the `ReactiveByVoltage` group are used to configure the voltage-dependent characteristic curve *Q(U)* (see ReactiveByVoltage [▶ 53]).

A lookup characteristic curve `ReactiveByVoltagePoints` is prepared as a parameter with 4 operating points. The operating points are preset according to VDE-AR-N 4110. A vertical offset of the characteristic curve can be specified with the `ReactiveByVoltageOffset` parameter and shifts the voltage for `Q=0`. A voltage deadband can be set with `ReactiveByVoltageDeadband` parameter.
As soon as the voltage exceeds the limits of the deadband, a new reactive power setpoint is calculated and approached. This results from the intersection of the measured voltage and the exceeded deadband limit. The implemented characteristic curve with the parameters used is shown in the following figure. The EN standards require a blocking and unblocking power as well as a minimum CosPhi to limit the reactive power at low active power levels.
These requirements are provided by the controller via the additional parameters `ReactiveByVoltageStrPower`, `ReactiveByVoltageStpPower` and `ReactiveByVoltageCosPhiMin` and must be disabled for VDE standards.

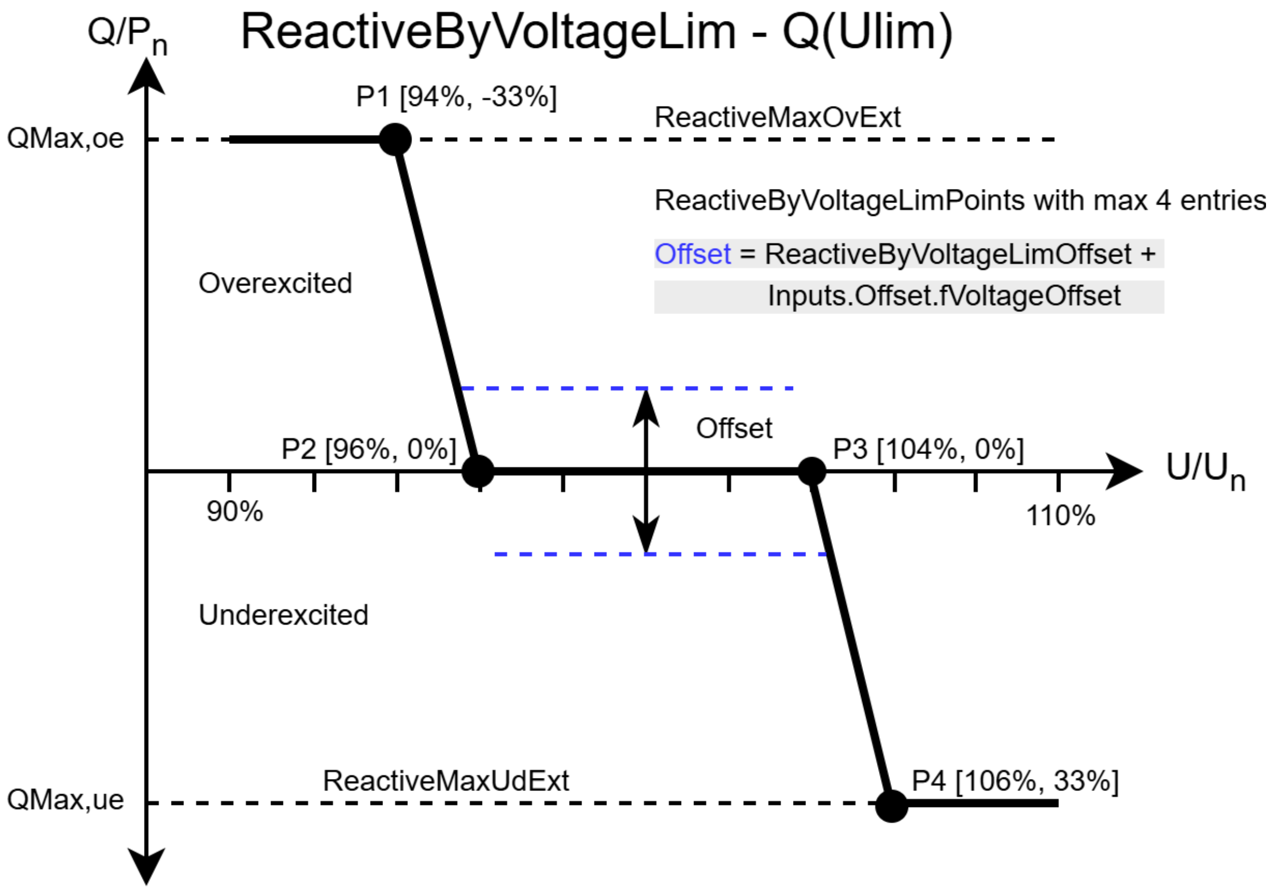


3.1.6.6 Reactive power control with voltage limiting function Q(Ulim)

In `ByVoltageLim` operation mode, the voltage-dependent limiting characteristic curve $Q(U_{lim})$ is active for reactive power control. Configuration is carried out via the `ReactiveByVoltageLim` parameter group (see ReactiveByVoltageLim [▶ 54]).

The characteristic curve is based on a fixed lookup table with four operating points and is implemented in accordance with the specifications of the VDE standards. The operating points are preset by default in accordance with VDE-AR-N 4110. A horizontal offset of the characteristic curve is possible via the `ReactiveByVoltageLimOffset` parameter.

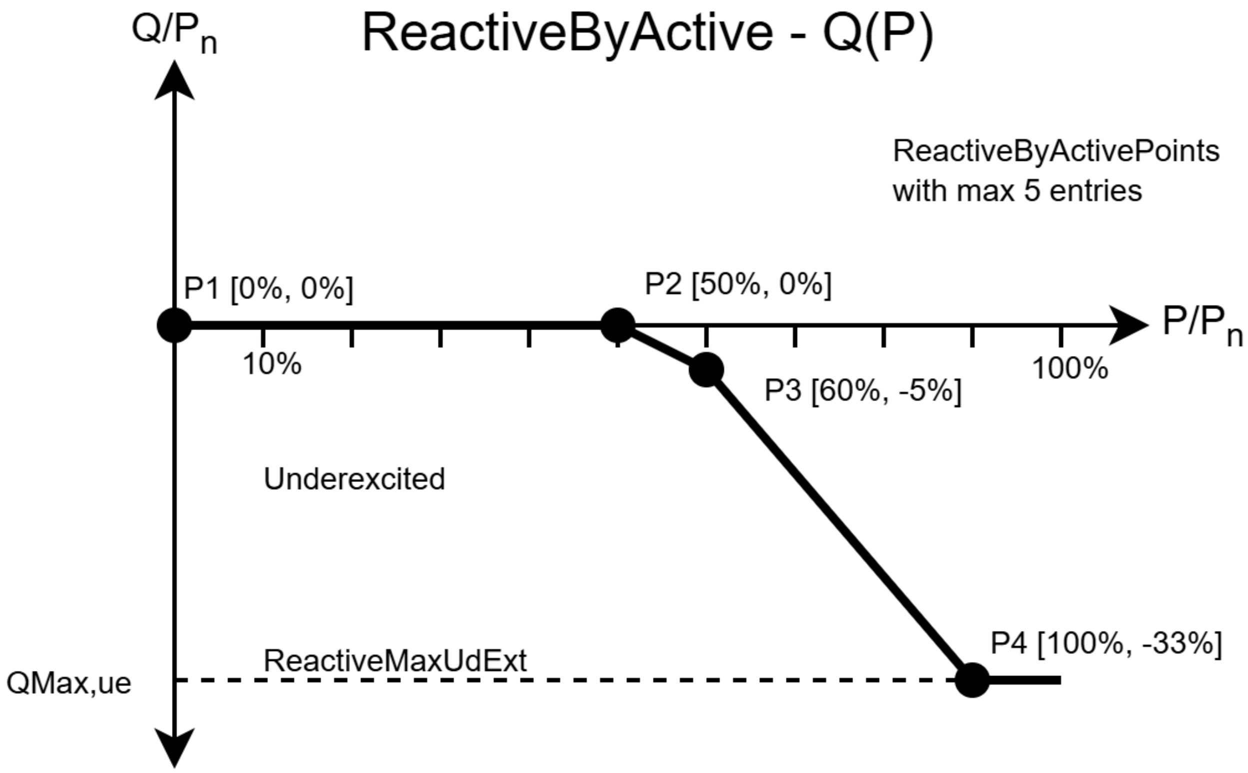
The resulting characteristic curve with the associated parameters is shown in the following figure.



3.1.6.7 Reactive power control with active power characteristic curve Q(P)

Setting `eReactiveMode = ByActive` activates the active power characteristic curve Q(P) for reactive power control. The parameters of the `ReactiveByActive` group are used to configure the active power-dependent characteristic curve *Q(P)* (see ReactiveByActive [▶ 54]).

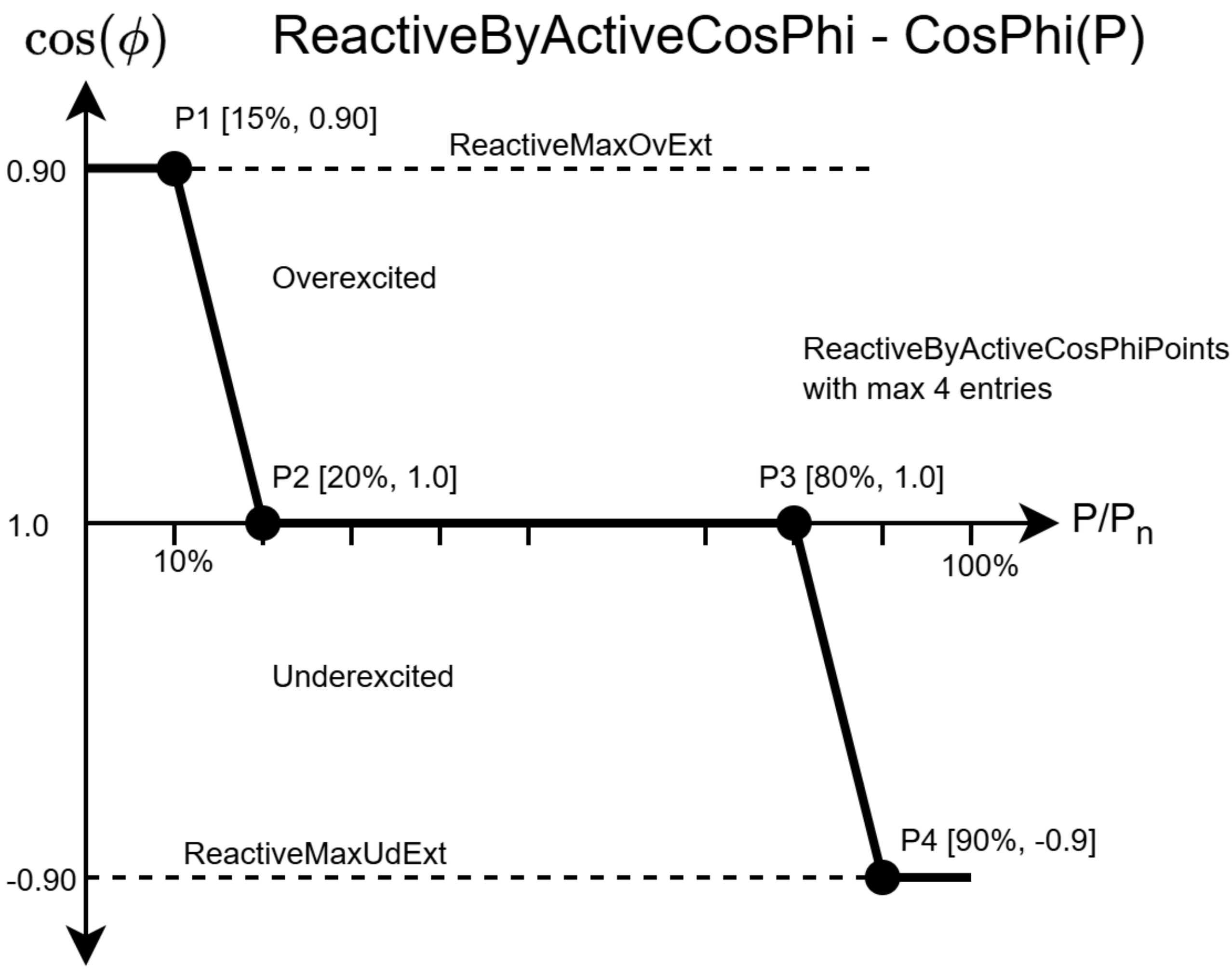
A lookup characteristic curve *Points* is stored as a parameter with 5 operating points. The operating points are preset according to VDE-AR-N 4110. An optional hysteresis for activating the function can be set via the parameters `StrVoltage`, `StpVoltage` and is deactivated by default (`=0.0`). The implemented characteristic curve with the parameters used is shown in the following figure.



3.1.6.8 Reactive power control with CosPhi(P) characteristic curve

A *CosPhi(P)* characteristic curve has been implemented as an extension to the *Q(P)* characteristic curve of the VDE and EN standards. The parameters of the `ReactiveByActive` group apply. (see ReactiveByActive [▸ 54]).

Setting `eReactiveMode = ByActiveCosPhi` activates the CosPhi(P) characteristic curve for reactive power control. This is configured in the same way as Q(P) via the lookup table `ReactiveByActiveCosPhiPoints`. Hysteresis is implemented via the parameters `ReactiveByActiveStrVoltage`, ReactiveByActiveStpVoltage. The resulting characteristic curve with the parameters used is shown in the following figure.



3.1.6.9 Active power-dependent reactive power capacity

It is possible to specify the reactive power capacity of a power generating plant separately for inductive and capacitive power as a function of the active power via the two characteristic curves `UdExt` and `OvExt`. The characteristic curves are stored in the `ReactiveCapability` parameter group (see ReactiveCapability [▶ 53]).

The active power-dependent reactive power capability is optional and not required by VDE or EN standards and is enabled via the `Enable` parameter if required. The outputs of the characteristic curves are limited by the maximum values `ReactiveMaxUdExt` and `ReactiveMaxOvExt` of the power generating plant.

3.1.7 Power supply

An external 24 V DC power supply is required for the embedded PC and the EtherCAT Terminals for grid data acquisition (24 V DC, -15 % / +20 %).

To ensure operation of the PGP controller even in the event of a power failure, an uninterruptible power supply (UPS) must be provided. Typically, a holding time of at least 30 minutes is required. The UPS is dimensioned on the basis of the determined energy requirement.

When designing the power supply, fuses and UPS, the maximum power consumption of the respective embedded PC must be taken into account (see Components [▶ 13]).

The typ. power consumption of the embedded PCs without peripherals:

- CX8290: 4 W
- CX9240: 7 W
- CX5330: 16 W
- CX5340: 18 W

In the event of a power failure, a corresponding message from the UPS must be transferred to `TcPowerPlantControl` via the `bSupplyError` flag in the `Control` area of the input process data (see Behavior in the event of a power supply failure [▶ 22]).

Suitable UPS modules

Product	Description	Reference
CU8130-0120	UPS module, battery-backed Energy of max. 15 Wh with max. output power of 110 W.	WWW
CU8130-0240	UPS module, battery-backed Energy of max. 30 Wh with max. output power of 220 W.	WWW

3.1.8 Model

A model of a PGP controller is provided in order to validate the standard-compliant control of power generating plants in accordance with the applicable requirements (e.g. from VDE-AR-N 4110, VDE-AR-N 4120 or EN 50549).

A *Functional Mock-up Unit* (FMU) according to the FMI standard in version 2 is available for this purpose. This FMU contains the controller kernel of the *TwinCAT Power Plant Control* and faithfully reproduces its functional behavior. All functions, interfaces and parameters correspond completely to the TwinCAT module *TcPowerPlantControl* and are therefore not described again in this chapter.

The use of the FMI standard enables flexible integration of the model into all FMI-compatible simulation environments. These include MATLAB®/Simulink® (MathWorks) and PowerFactory (DIgSILENT). The exemplary integration into these tools is explained in the following sections.

3.1.8.1 PowerFactory

As of PowerFactory version 2025 SP1, the Functional Mock-Up Interface (FMI) 2.0 is supported. This interface can be used to integrate the TwinCAT Power Plant Control controller kernel into simulation models and to validate the PGP controller.

3.1.8.1.1 Application

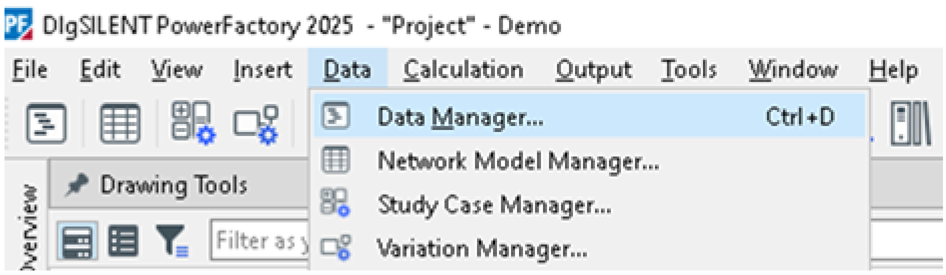
The PowerFactory manual describes the integration in chapter **29.12**.

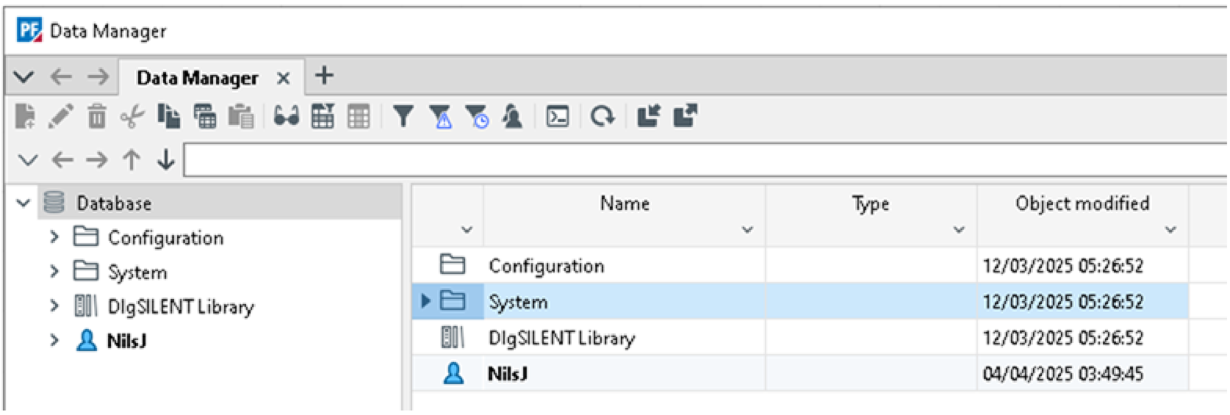
Co-Simulation with external application

- You are given an overview of co-simulation with external application in section **29.12.1**.
- The configuration of the co-simulation tool is described in section **29.12.2**.
- The execution and presentation of the co-simulation results are described in detail in subsection **29.12.3**.

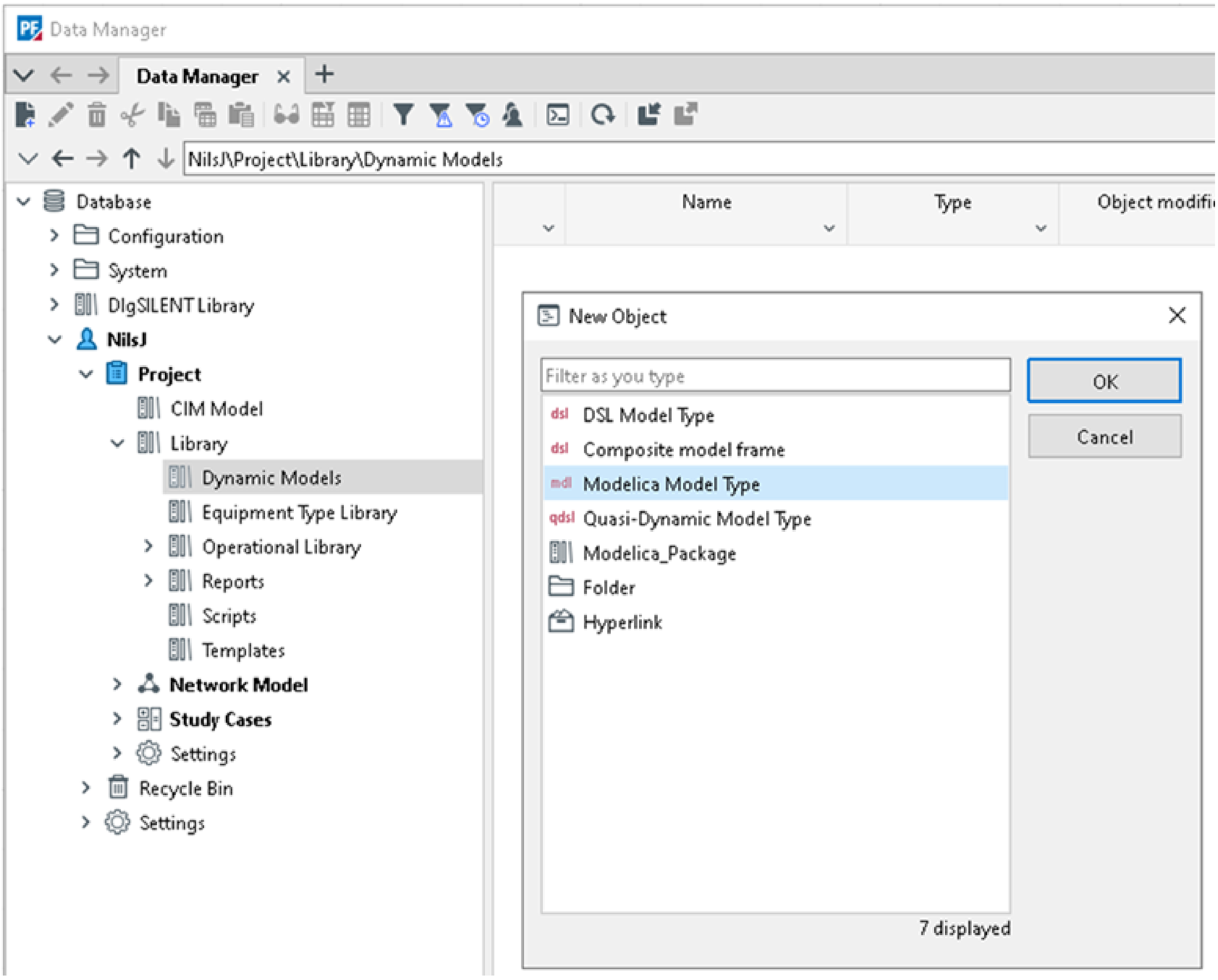
✓ The model of the controller core is integrated into PowerFactory 2025 SP1 as an FMU in the following example.

1. Open **PowerFactory**.
2. Open **Data > Data Manager.**

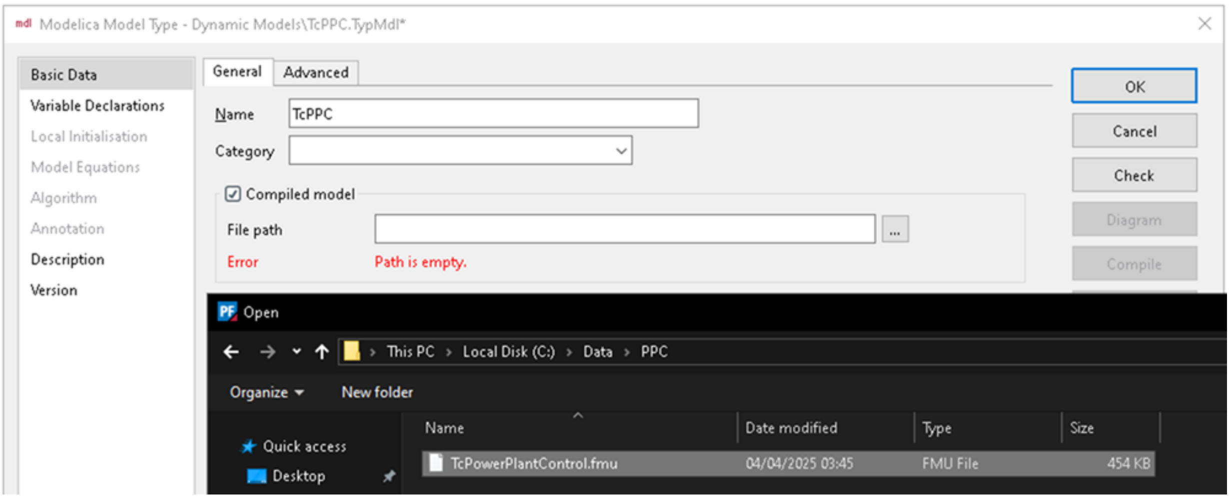




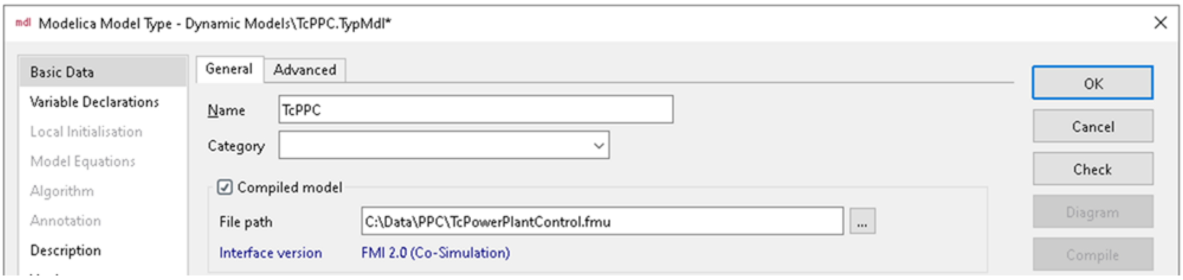
3. Create a "Modelica Model Type" in the Data Manager under **Library > Dynamic Models** using "New Object".

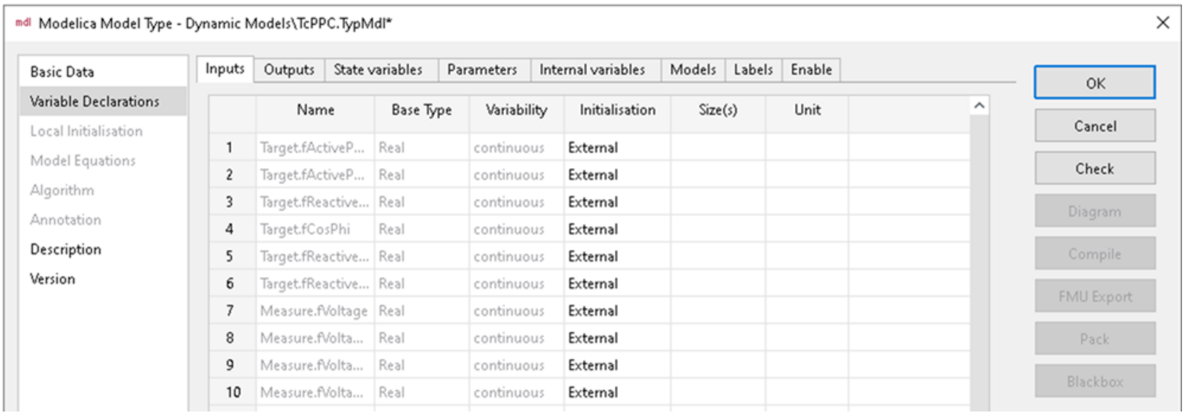


4. Define the name in the new "Modelica Model Type".
5. Activate "Compiled model".
6. Select the FMU under "File path".

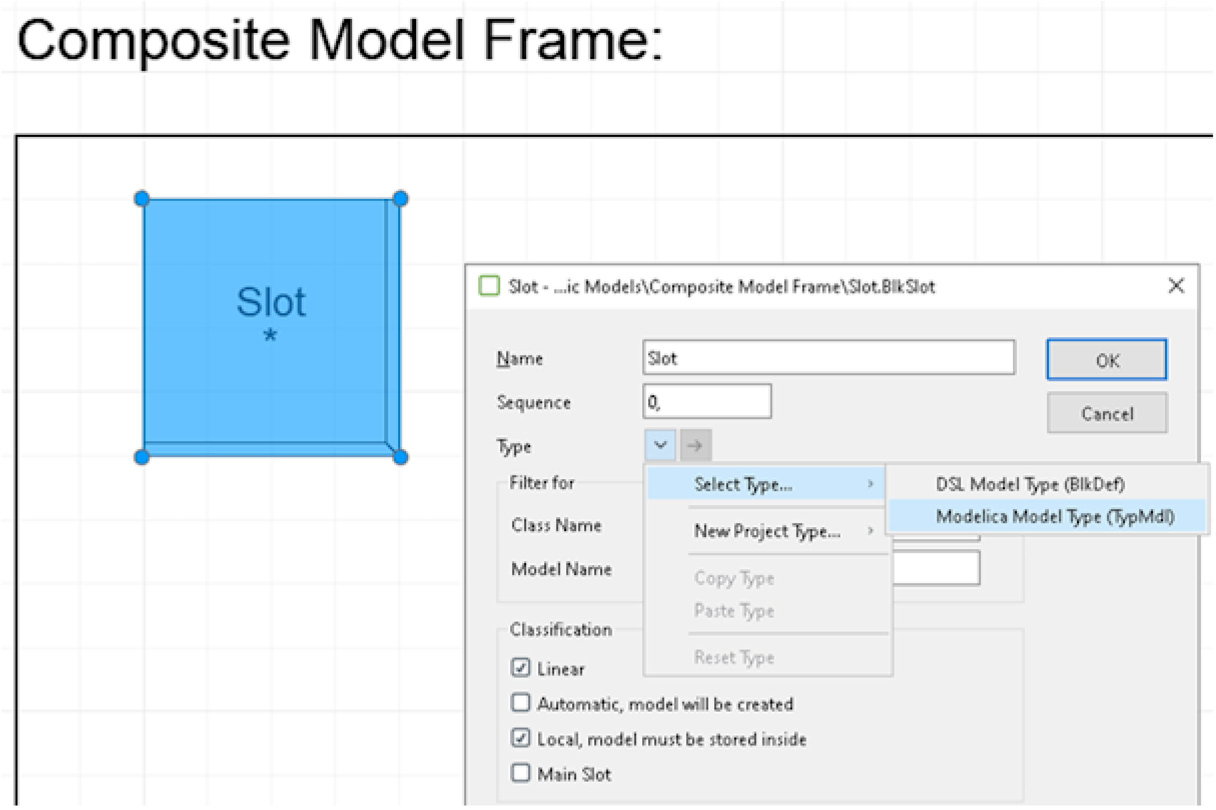


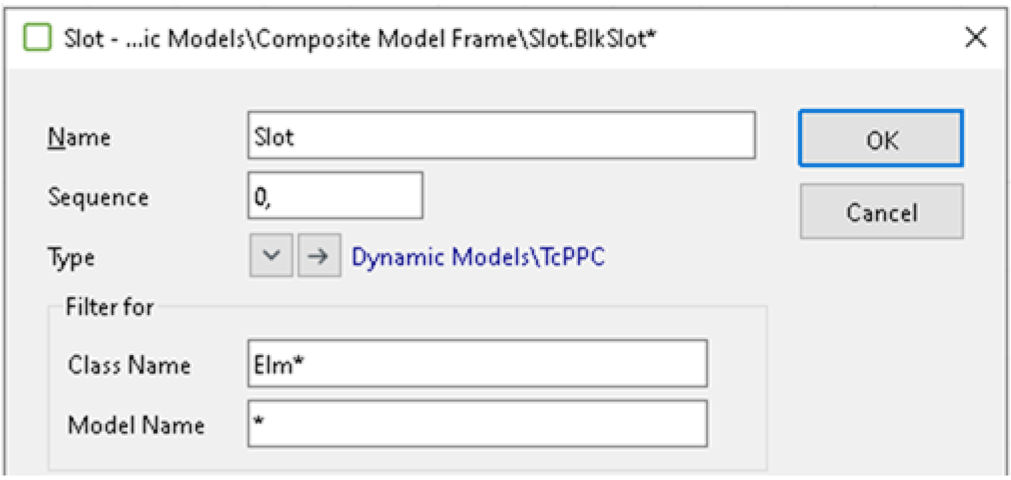
⇨ The inputs and outputs can then be viewed under "Variable Declarations".



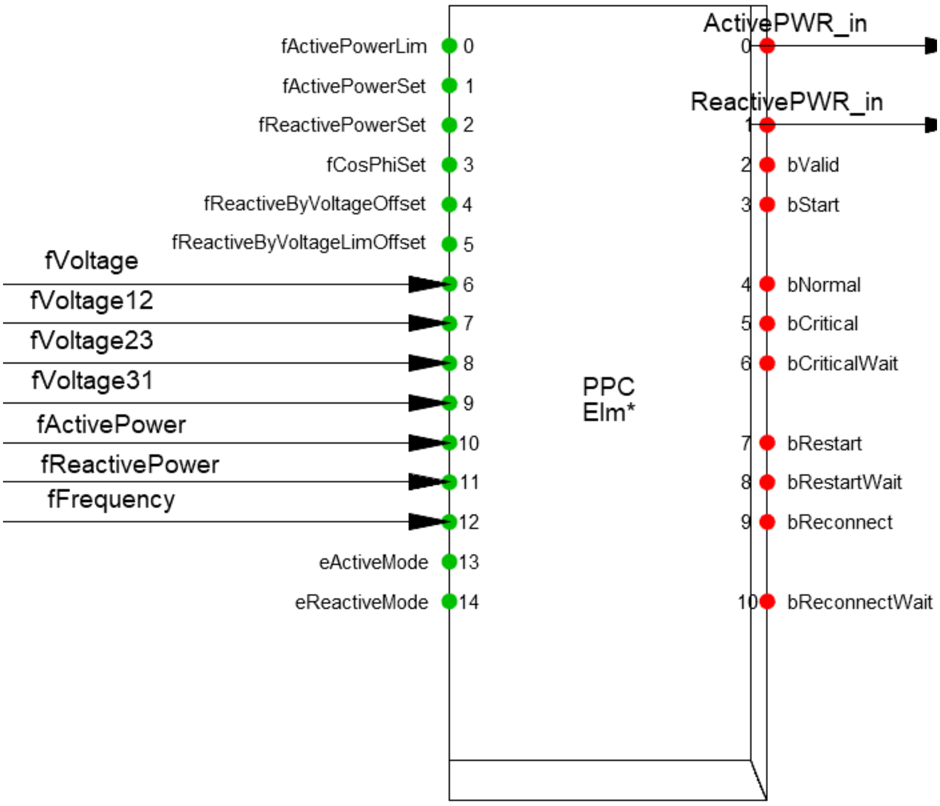


7. Select this new model in the "Composite Model Frame" using "Slot" as the "Modelica Model Type"".



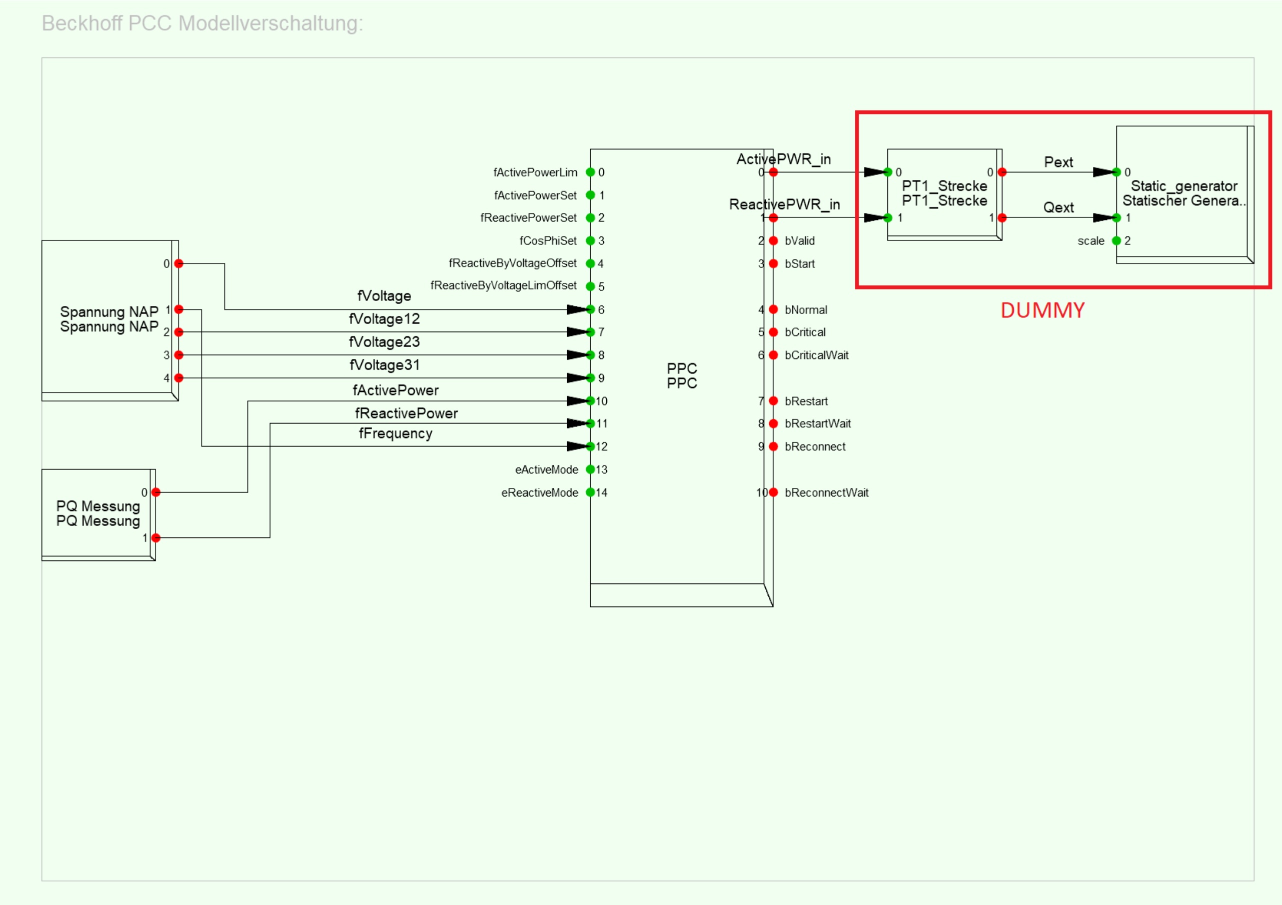


⇨ The inputs and outputs of the model are then displayed.


fActivePowerLim
fActivePowerSet
fReactivePowerSet
fCosPhiSet
fReactiveByVoltageOffset
fReactiveByVoltageLimOffset
fVoltage
fVoltage12
fVoltage23
fVoltage31
fActivePower
fReactivePower
fFrequency
eActiveMode
eReactiveMode
PPC
Elm*
ActivePWR_in
ReactivePWR_in
bValid
bStart
bNormal
bCritical
bCriticalWait
bRestart
bRestartWait
bReconnect
bReconnectWait

3.1.8.1.2 Template

A template of a generation plant can be provided as an example for the integration of the controller kernel in *PowerFactory*. This demonstrates the simulation in combination with an exemplary generation unit (shown in red as *DUMMY* in the screenshot), which must be replaced by the specific unit of the system to be simulated in practical use.



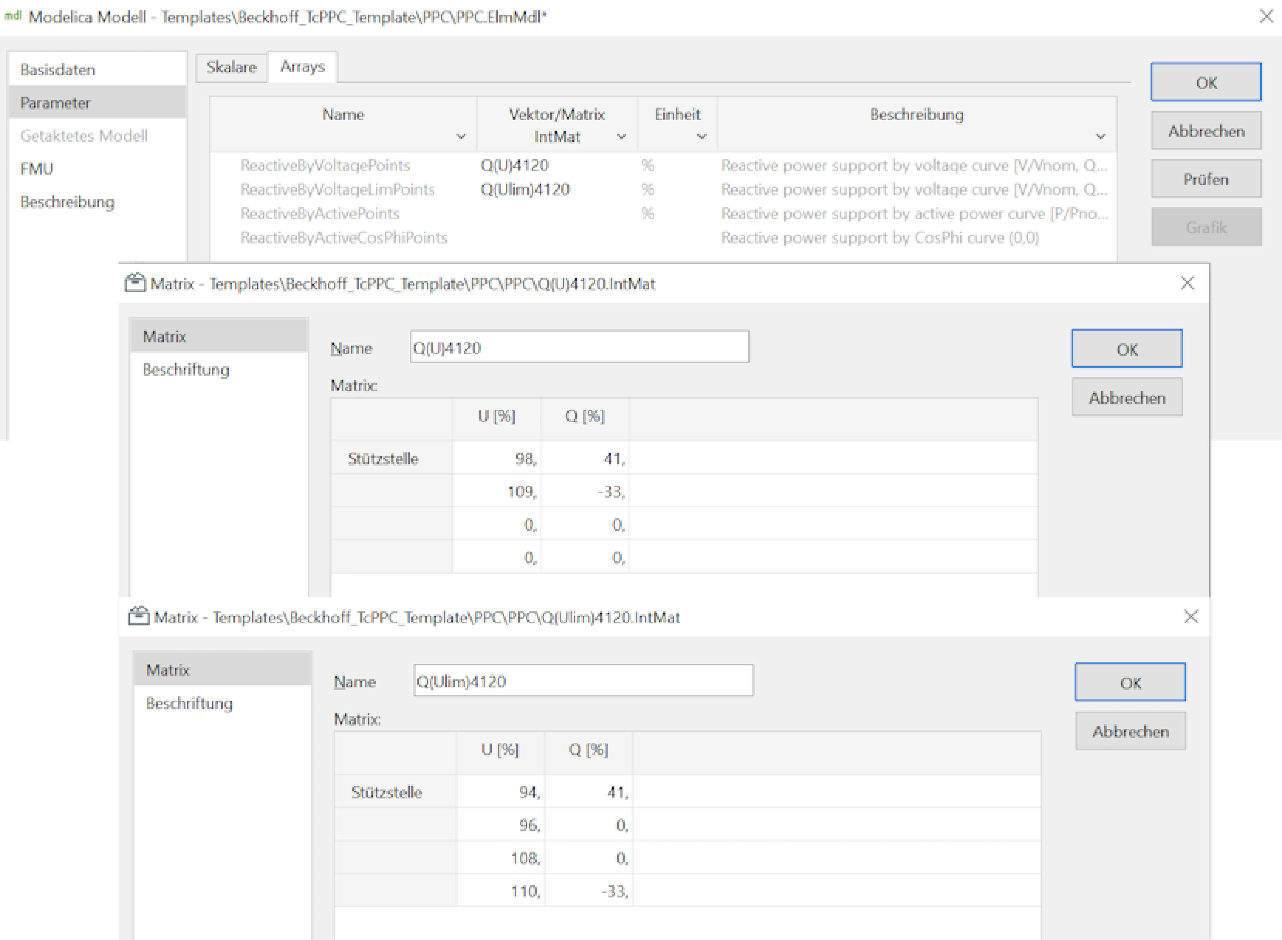
3.1.8.1.3 Parameters

As described in detail, the same parameters are provided in the FMU as by the `TcPowerPlantControl module` (see Parameters [▶ 48]).

For simplified use in *PowerFactory*, the scalings (see Scalings [▶ 19]) are already predefined in Per-Unit (pu). The corresponding default values have been adapted for the following parameters.

Name	Default	Min	Max	Unit	Data type
ActiveNominal	1.0	1.0		W/pu	REAL
ActiveScale	1.0	1.0			REAL
ReactiveScale	1.0	1.0			REAL
VoltageNominal	1.0	1.0		V/pu	REAL

`Vendor annotations` are used for arrays in the FMU to map tables (see Tables [▶ 49]). In *PowerFactory*, these can be displayed as two-dimensional matrices and integrated as follows.



4 Installation

4.1 System Requirements

Engineering (XAE)

Technical data	Requirements
Operating system	Windows 10, Windows 11
Target platform	x64
TwinCAT version	Build 4026
Required TwinCAT license	

Runtime (XAR)

Technical Data	Requirements
Operating system	Windows, Beckhoff RT Linux®, TwinCAT/BSD
Target platform	x64
TwinCAT version	Build 4026
Required TwinCAT license	TF8360

4.2 Installation

TwinCAT Package Manager: Installation (TwinCAT 3.1 Build 4026)

Detailed instructions on installing products can be found in the chapter Installing workloads in the TwinCAT 3.1 Build 4026 installation instructions.

Install the following workload to be able to use the product:

TwinCAT Package Manager UI:

- TF8360 | TwinCAT 3 Power Control

TwinCAT Package Manager CLI:

- `TcPkg install TF8360.PowerControl.XAE`

4.3 Licensing

The TwinCAT 3 function can be activated as a full version or as a 7-day test version. Both license types can be activated via the TwinCAT 3 development environment (XAE).

Licensing the full version of a TwinCAT 3 Function

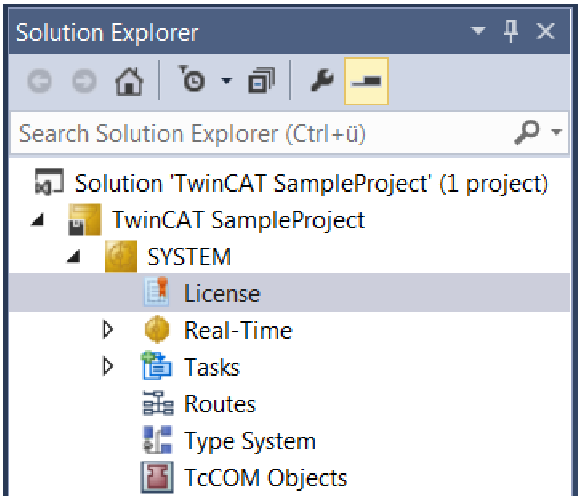
A description of the procedure to license a full version can be found in the Beckhoff Information System in the documentation "TwinCAT 3 Licensing".

Licensing the 7-day test version of a TwinCAT 3 Function

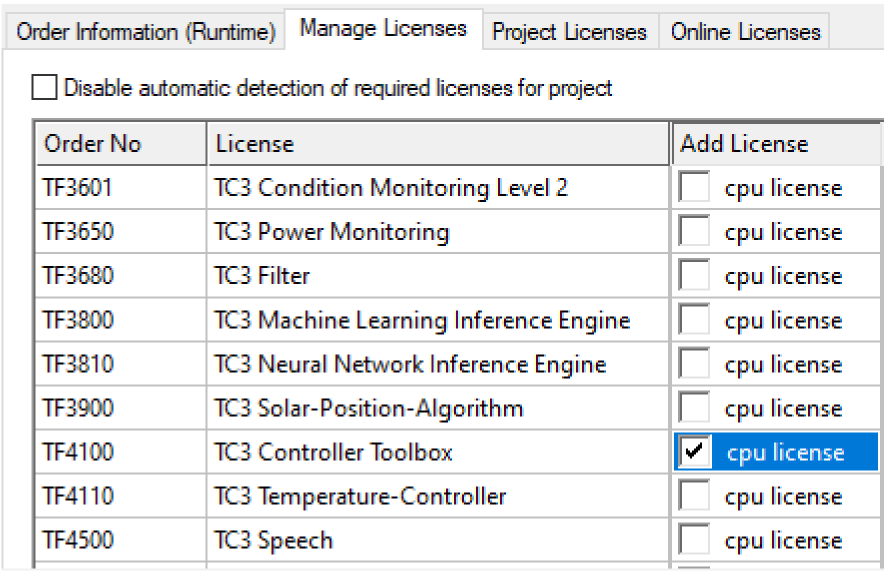
A 7-day test version cannot be enabled for a TwinCAT 3 license dongle.

1. Start the TwinCAT 3 development environment (XAE).
2. Open an existing TwinCAT 3 project or create a new project.

3. If you want to activate the license for a remote device, set the desired target system. To do this, select the target system from the **Choose Target System** drop-down list in the toolbar.
   ⇨ The licensing settings always refer to the selected target system. When the project is activated on the target system, the corresponding TwinCAT 3 licenses are automatically copied to this system.
4. In the **Solution Explorer**, double-click **License** in the **SYSTEM** subtree.

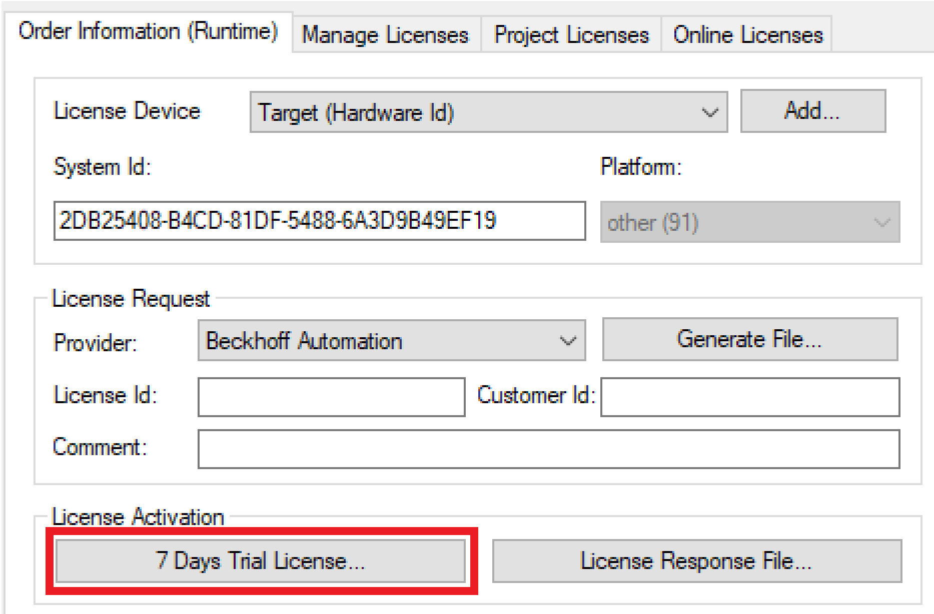


   ⇨ The TwinCAT 3 license manager opens.
5. Open the **Manage Licenses** tab. In the **Add License** column, check the check box for the license you want to add to your project (e.g. "TF4100 TC3 Controller Toolbox").

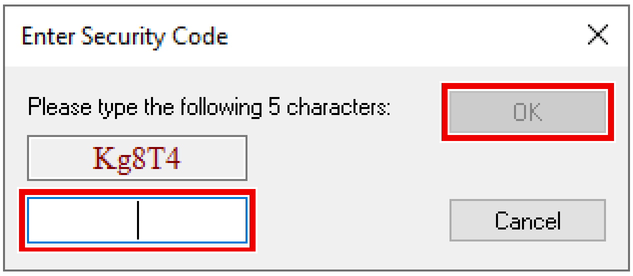


6. Open the **Order Information (Runtime)** tab.
   ⇨ In the tabular overview of licenses, the previously selected license is displayed with the status “missing”**.**

7. Click **7-Day Trial License...** to activate the 7-day trial license.



⇨ A dialog box opens, prompting you to enter the security code displayed in the dialog.



8. Enter the code exactly as it is displayed and confirm the entry.
9. Confirm the subsequent dialog, which indicates the successful activation.
   ⇨ In the tabular overview of licenses, the license status now indicates the expiry date of the license.
10. Restart the TwinCAT system.

⇨ The 7-day trial version is enabled.

4.4 Revision control

Version	Changes
< 0.1.0	First prototypes for certification at FGH.
0.1.0	First release certified according to VDE-AR-N 4110, 4120 and 4130.

4.5 Restrictions

Due to the necessary certification, this software product can only be used on specifically approved embedded PCs and in combination with selected devices for grid data acquisition. Licensing of the TF8360 module is therefore currently only available for TwinCAT platform levels 20, 30, 40 and 50 (see Components [▶ 13]).

The TwinCAT modules themselves are not subject to these restrictions and the software can be executed on all TwinCAT Runtime systems as well as within the TwinCAT Usermode Runtime (see System Requirements [▶ 45]).

5 Modules

5.1 TcPowerPlantControl

TwinCAT Power Plant Control is used to control power generating plants (PGP controller) in the form of the TwinCAT module `TcPowerPlantControl`. A detailed description of the use and functions as a PGP controller can be found in the chapter , while the configuration of the TwinCAT module is described below.

5.1.1 Module

The `TcPowerPlantControl` is integrated into the system as a TcCOM object and executed cyclically via a task. It provides its process data in the form of inputs and outputs and can be connected to a `TcPowerMeasure` module for grid data acquisition via an interface (see Grid data acquisition [▶ 17]).

License

A valid *TF8360 | TwinCAT Power Control license* is required for permanent operation of the module. Alternatively, a 7-day trial license can be used for testing or evaluation (see Licensing [▶ 45]).

5.1.2 Context

The task under which the module is executed is selected at `Context`.

For `TcPowerPlantControl`, the use of a task with a cycle time between 1 ms and 10 ms is recommended.

5.1.3 Parameter

The parameters of `TcPowerPlantControl` are categorized into the following groups and listed accordingly in the following sections.

Group	Description
`Plant`	Erzeugungsanlage (EZA)
`Restart`	Enable signal for the start of power generation
`Reconnect`	Automatic reconnection after shutdown
`ActivePower`	Active power controller
`ActiveByPrimary`	Frequency-dependent primary control of the active power
`ActiveByFrequency`	Frequency support through active power
`ActiveByVoltage`	Active power emission due to overvoltage
`ReactivePower`	Reactive power controller
`ReactiveCapability`	Reactive power capacity as a function of the active power
`ReactiveByCosPhi`	Reactive power control with CosPhi displacement factor
`ReactiveByVoltage`	Reactive power-voltage characteristic curve Q(U)
`ReactiveByVoltageLim`	Reactive power with voltage limiting characteristic curve Q(Ulim)
`ReactiveByActive`	Reactive power-active power characteristic curves Q(P)
`Voltage`	Grid voltage monitoring
`Frequency`	Grid frequency monitoring
`Misc`	Other settings

Details on the adjustable step size of the parameters are described at Step sizes [▶ 19].

5.1.3.1 Tables

Some parameters are specified as tables in the form of multidimensional arrays. Typically, these are so-called *lookup* tables in which two dimensions are used:

- X values (array index 0)
- Y-values (array index 1)

Example: `[[X1, Y1], [X2, Y2], [X3, Y3], ...]`

The X values must be specified in strictly ascending or strictly descending order. If this order is violated for consecutive X values, this is considered to be the end of the table.

The corresponding Y values are determined using the X values. If the query value lies between two table points, linear interpolation is performed. Values outside the X value range are extrapolated linearly if required.

5.1.3.2 Plant

The parameters of the `Plant` group are used for the basic setting of the plant, as well as the reactions in the event of an interface failure (see Behavior in the event of communication errors [▶ 21]).

Name	Default	Min	Max	Unit	Data type
`PlantType`	None				ETcPowerPlantType [▶ 60]
	Type of power generating plant(s)				
`ControllerMode`	EN_VDE4110_2023				ETcPowerPlantControllerMode [▶ 60]
	Standard for defining the behavior of the controller				
`MeasureFallbackMode`	Load				ETcPowerPlantFallbackMode [▶ 61]
	Fallback mode in the event of a measuring system failure				
`MeasureResetDelay`	60000	0		ms	TIME
	Restart delay after elimination of the measuring error				
`PlantFallbackMode`	Load				ETcPowerPlantFallbackMode [▶ 61]
	Fallback mode in the event of communication failure to the plant				
`PlantResetDelay`	60000	0		ms	TIME
	Restart delay after communication failure to the plant				
`OperatorFallbackMode`	Load				ETcPowerPlantFallbackMode [▶ 61]
	Fallback mode in the event of communication failure with the energy provider				
`OperatorFallbackDelay`	60000	0		ms	TIME
	Restart delay after communication failure with the energy provider				
`MarketerFallbackMode`	Load				ETcPowerPlantFallbackMode [▶ 61]
	Fallback mode in the event of communication failure with the direct marketing company				
`MarketerFallbackDelay`	60000	0		ms	TIME
	Restart delay after communication failure to the direct marketing company				

5.1.3.3 Restart

The parameters of the `Restart` group are used to set the behavior after restarting the system (see Enabling power generation [▶ 21]).

Name	Default	Min	Max	Unit	Data type
`RestartAutomatic`	FALSE				BOOL
	Activate automatic restart for power generation				
`RestartDelay`	600000	0		ms	TIME
	Restart delay for enabling after restart				

Name	Default	Min	Max	Unit	Data type
RestartVoltageMin	90.0	50.0	100.0	%	REAL
	Minimum permissible voltage for enabling after restart				
RestartVoltageMax	110.0	100.0	120.0	%	REAL
	Maximum permissible voltage for enabling after restart				
RestartFrequencyMin	49.5	40.0	60.0	Hz	REAL
	Minimum permissible frequency for enabling after restart				
RestartFrequencyMax	50.5	50.0	70.0	Hz	REAL
	Maximum permissible frequency for enabling after restart				

5.1.3.4 Reconnect

The parameters of the `Reconnect` group are used to set the behavior for reconnection after grid faults (see Automatic reconnection after protective tripping [▶ 22]).

Name	Default	Min	Max	Unit	Data type
ReconnectAutomatic	FALSE				BOOL
	Activate automatic enabling of power generation				
ReconnectDelay	600000	0		ms	TIME
	Restart delay for enabling after a grid fault				
ReconnectVoltageMin	95.0	0.0	100.0	%	REAL
	Minimum permissible voltage for enabling after grid fault				
ReconnectVoltageMax	110.0	100.0	120.0	%	REAL
	Maximum permissible voltage for enabling after grid fault				
ReconnectFrequencyMin	49.9	40.0	60.0	Hz	REAL
	Minimum permissible frequency for enabling after grid fault				
ReconnectFrequencyMax	50.1	50.0	70.0	Hz	REAL
	Maximum permissible frequency for enabling after grid fault				

5.1.3.5 ActivePower

The parameters of the `ActivePower` group are used to set the active power control (see Active power controller [▶ 23]).

Name	Default	Min	Max	Unit	Data type
ActiveNominal	10000000	1.0		W/pu	REAL
	Nominal power of the power generating plant (P_{nom})				
ActiveScale	100.0	1.0			REAL
	Active power scaling for process data (1.0 = per unit, 100.0 = percent)				
ActiveMinimum	0.0	-200.0	200.0	%	REAL
	Minimum possible active power of the plant				
ActiveMaximum	100.0	-200.0	+200.0	%	REAL
	Maximum possible active power of the plant				
ActiveModeDefault	Normal				ETcPowerPlantActiveMode [▶ 60]
	Mode of the active power controller on default, failure or restart				
ActiveActualFilterTime	10	0		ms	TIME
	Filter time of active power measurement				
ActiveActualFilterType	PT1				ETcPowerFilterType [▶ 61]
	Filter type of active power measurement				
ActiveTargetDefault	100.0	0.0	100.0	%	REAL
	Active power setpoint in the event of communication failure				

Name	Default	Min	Max	Unit	Data type
ActiveTargetSlopeNormal	0.5	0.1	0.66	%/s	REAL
	Gradient from the active power setpoint in normal operation				
ActiveTargetSlopeCritical	0.167	0.01	0.17	%/s	REAL
	Gradient from the active power setpoint in grid-critical operation (overfrequency or underfrequency)				
ActiveTargetSlopeRestart	0.5	0.1	50.0	%/s	REAL
	Gradient of the active power setpoint at restart				
ActiveTargetSlopeReconnect	0.5	0.1	50.0	%/s	REAL
	Gradient of the active power setpoint when reconnected				
ActivePredictDeadTime	0	0		ms	TIME
	Dead time of plant for compensation in the active power controller (0 = disabled)				
ActivePredictFilterTime	0	0		ms	TIME
	First order (PT1) filter time constant of plant for compensation in the active power controller (0 = disabled)				
ActiveControlGain	100.0	0.1	200.0	%	REAL
	Proportional gain in the active power controller				
ActiveControlIntegration	500	0		ms	TIME
	Integration time constant in the active power controller				

5.1.3.6 ActiveByPrimary

The parameters of the ActiveByPrimary group are used to set the primary control (see Frequency-dependent primary control of the active power [▸ 26]).

Name	Default	Min	Max	Unit	Data type
ActiveByPrimaryEnable	FALSE				BOOL
	Enabling the primary control				
ActiveByPrimaryDroop	2.0	0.4	12.0	%	REAL
	Control deviation factor of primary control				
ActiveByPrimaryDeadband	0.01	0.0	2.0	Hz	REAL
	Deadband around nominal frequency for switching on the primary control				
ActiveByPrimaryMax	100.0	0.0	100.0	%	REAL
	Maximum active power with active primary control				

5.1.3.7 ActiveByFrequency

The parameters of the ActiveByFrequency group are used to set the active power control depending on the frequency (see Frequency-dependent active power adjustment [▸ 27]).

Name	Default	Min	Max	Unit	Data type
ActiveByFrequencyOvEnable	TRUE				BOOL
	Activate active power support in the event of overfrequency				
ActiveByFrequencyOvDroop	5.0	2.0	12.0	%	REAL
	Control deviation factor with active power support				
ActiveByFrequencyOvStrThres	50.2	50.0	70.0	Hz	REAL
	Overfrequency threshold for the start of active power support				
ActiveByFrequencyOvStrDelay	0	0		ms	TIME
	Delay of the overfrequency to the start of active power support				

Name	Default	Min	Max	Unit	Data type
ActiveByFrequencyOvStpThres	50.2	50.0	70.0	Hz	REAL
	Overfrequency threshold for terminating active power support				
ActiveByFrequencyOvStpDelay	600000	0		ms	TIME
	Delay of the overfrequency for terminating the active power support				
ActiveByFrequencyUdEnable	TRUE				BOOL
	Activating the active power support for underfrequency				
ActiveByFrequencyUdDroop	5.0	2.0	12.0	%	REAL
	Control deviation factor with active power support				
ActiveByFrequencyUdStrThres	49.8	40.0	60.0	Hz	REAL
	Underfrequency threshold for the start of active power support				
ActiveByFrequencyUdStrDelay	0	0		ms	TIME
	Delay of the underfrequency for the start of active power support				
ActiveByFrequencyUdStpThres	49.8	40.0	70.0	Hz	REAL
	Underfrequency threshold for terminating active power support				
ActiveByFrequencyUdStpDelay	600000	0		ms	TIME
	Underfrequency delay for terminating active power support				

5.1.3.8 ActiveByVoltage

The parameters of the `ActiveByVoltage` group are used to set the active power control depending on the voltage (see Voltage related active power reduction [▶ 28]).

Name	Default	Min	Max	Unit	Data type
ActiveByVoltageOvEnable	FALSE				BOOL
	Activation of active power support in the event of overvoltage				
ActiveByVoltageOvDroop	0.0	0.0	100.0		REAL
	Control deviation factor with active power support				
ActiveByVoltageOvStrThres	108.0	100.0	120.0	%	REAL
	Overvoltage threshold for the start of active power support				
ActiveByVoltageOvStrDelay	0	0		ms	TIME
	Delay of the overvoltage for the start of active power support				

5.1.3.9 ReactivePower

The parameters of the `ReactivePower` group are used to set the reactive power control (see Reactive power controller [▶ 30]).

Name	Default	Min	Max	Unit	Data type
ReactiveScale	100.0	1.0			REAL
	Active power scaling for process data (1.0 = per unit, 100.0 = percent)				
ReactiveMaxUdExt	-33.0	-100.0	0.0	%	REAL
	Maximum possible reactive power of the underexcited plant				
ReactiveMaxOvExt	+33.0	+100.0	0.0	%	REAL
	Maximum possible reactive power of the overexcited plant				
ReactiveModeDefault					ETcPowerPlantReactiveMode [▶ 60]
	Mode of the reactive power controller on default, failure or restart				
ReactiveActualFilterTime	10	0		ms	TIME
	Filter time of reactive power measurement				
ReactiveActualFilterType	PT1				ETcPowerFilterType [▶ 61]

Name	Default	Min	Max	Unit	Data type
	Filter type of reactive power measurement				
ReactiveTargetDefault	0.0	-100.0	+100.0	%	REAL
	Reactive power setpoint in the event of communication failure				
ReactiveTargetFilterTime	2000	0		ms	TIME
	Filter time of control value of reactive power				
ReactiveTargetFilterType	PT1				ETcPowerFilterType [▸ 61]
	Filter type of control value of reactive power				
ReactivePredictDeadTime	0	0		ms	TIME
	Dead time of plant for compensation in the reactive power controller (0 = disabled)				
ReactivePredictFilterTime	0	0		ms	TIME
	First order (PT1) filter time constant of plant for compensation for compensation in the reactive power controller (0 = disabled)				
ReactiveControlGain	75.0	0.1	200.0	%	REAL
	Proportional gain in the reactive power controller				
ReactiveControlIntegration	200	0		ms	TIME
	Integration time constant in the reactive power controller				

5.1.3.10 ReactiveCapability

The parameters of the `ReactiveCapability` group are used to set the reactive power capacity (see Active power-dependent reactive power capacity [▸ 37]).

Name	Default	Min	Max	Unit	Data type
ReactiveCapabilityEnable	FALSE				BOOL
	Activating the reactive power				
ReactiveCapabilityUdExt				%	ARRAY[1..3, 1..2] OF REAL
	Characteristic curve of the underexcited reactive power capability (P/P_{nom}, Q/P_{nom})				
ReactiveCapabilityOvExt				%	ARRAY[1..3, 1..2] OF REAL
	Characteristic curve of the overexcited reactive power capability (P/P_{nom}, Q/P_{nom})				

5.1.3.11 ReactiveByCosPhi

The parameters of the `ReactiveByCosPhi` group are used to set the reactive power control via a displacement factor (see Reactive power control with CosPhi displacement factor [▸ 32]).

Name	Default	Min	Max	Unit	Data type
ReactiveByCosPhiMaxUdExt	-0.9	-1.0	-0.8		REAL
	Maximum possible displacement factor underexcited				
ReactiveByCosPhiMaxOvExt	0.9	0.8	1.0		REAL
	Maximum possible displacement factor overexcited				
ReactiveByCosPhiDefault	1.0	-1.0	+1.0		REAL
	Displacement factor in the event of communication failure				

5.1.3.12 ReactiveByVoltage

The parameters of the `ReactiveByVoltage` group are used to set the reactive power control depending on the voltage (see Reactive power control with voltage characteristic curve Q(U) [▸ 33]).

Name	Default	Min	Max	Unit	Data type
`ReactiveByVoltagePoints`	[[96.0, 33.0],[104.0, -33.0]]			%	ARRAY[1..4, 1..2] OF REAL
	Reactive power voltage characteristic curve (V/V_{nom}, Q/P_{nom})				
`ReactiveByVoltageDeadband`	0.0	0.0	5.0	%	REAL
	Sliding deadband around characteristic curve.				
`ReactiveByVoltageOffset`	0.0	-20.0	+20.0	%	REAL
	Offset of the voltage characteristic curve (V_{Q0}/V_{nom})				
`ReactiveByVoltageStrPower`	0.0	0.0	100.0	%	REAL
	Active power threshold for the start of reactive power support (0 = disabled)				
`ReactiveByVoltageStpPower`	0.0	0.0	100.0	%	REAL
	Active power threshold for terminating reactive power support (0 = disabled)				
`ReactiveByVoltageCosPhiMin`	0.0	0.0	1.0		REAL
	Minimum permitted displacement factor for reactive power support				

5.1.3.13 ReactiveByVoltageLim

The parameters of the ReactiveByVoltageLim group are used to set the reactive power control with voltage limitation (see Reactive power control with voltage limiting function Q(Ulim) [▶ 34]).

Name	Default	Min	Max	Unit	Data type
`ReactiveByVoltage LimPoints`	[[94.0, 33.0], [96.0, 0.0], [104.0, 0.0], [106.0, -33.0]]			%	ARRAY[1..4, 1..2] OF REAL
	Reactive power voltage limitation characteristic curve (V/V_{nom}, Q/P_{nom})				
`ReactiveByVoltage LimOffset`	0.0	-50.0	+50.0	%	REAL
	Offset of the voltage limitation characteristic curve (Q_{Offset}/P_{nom})				

5.1.3.14 ReactiveByActive

The parameters of the ReactiveByActive group are used to set the reactive power control depending on the active power (see Reactive power control with active power characteristic curve Q(P) [▶ 35]).

Name	Default	Min	Max	Unit	Data type
`ReactiveByActive Points`	[[0.0, 0.0], [50.0, 0.0], [60.0, -5.0], [90.0, -33.0], [100.0, -33.0]]			%	ARRAY[1..5, 1..2] OF REAL
	Reactive power-active power characteristic curve (P/P_{nom}, Q/P_{nom})				
`ReactiveByActive CosPhiPoints`	[[15.0, 0.9], [20.0, 1.0], [80.0, 1.0], [90.0, -0.9]]				ARRAY[1..4, 1..2] OF REAL
	Displacement factor active power characteristic curve (CosPhi, Q/P_{nom})				
`ReactiveByActive StrVoltage`	0.0	0.0	120.0	%	REAL
	Voltage threshold for the start of reactive power support (0 = disabled)				
`ReactiveByActive StpVoltage`	0.0	0.0	120.0	%	REAL
	Voltage threshold for terminating reactive power support (0 = disabled)				

5.1.3.15 Voltage

The parameters of the `Voltage` group are used to set the voltage (see Use for Enabling power generation [▶ 21] and Behavior in the event of a power supply failure [▶ 22]).

Name	Default	Min	Max	Unit	Data type
`VoltageNominal`	20000.0	1.0		V/pu	REAL

Name	Default	Min	Max	Unit	Data type
	Nominal voltage (V_{nom})				
VoltageMinimum	85.0	0.0	100.0	%	REAL
	Minimum permissible voltage				
VoltageMaximum	125.0	100.0	200.0	%	REAL
	Maximum permissible voltage				
VoltageFilterTime	10	0		ms	TIME
	Filter time of voltage measurement				
VoltageFilterType	PT1				ETcPowerFilterType [▶ 61]
	Filter type of voltage measurement				

5.1.3.16 Frequency

The parameters of the `Frequency` group are used to set the frequency (see Use for Enabling power generation [▶ 21] or Automatic reconnection after protective tripping [▶ 22]).

Name	Default	Min	Max	Unit	Data type
FrequencyNominal	50.0	40.0	70.0	Hz	REAL
	Nominal frequency (F_{nom})				
FrequencyMinimum	47.0	40.0	60.0	Hz	REAL
	Minimum permissible frequency				
FrequencyMaximum	53.0	50.0	70.0	Hz	REAL
	Maximum permissible frequency				
FrequencyFilterTime	10	0		ms	TIME
	Filter time of frequency measurement				
FrequencyFilterType	PT1				ETcPowerFilterType [▶ 61]
	Filter type of frequency measurement				

5.1.3.17 Misc

The parameters of the `Misc` group are used to set the module.

Name	Default	Min	Max	Unit	Data type
TimeType	Hard				ETcPowerTimeType [▶ 61]
	Type of time source				
PersistMode	None				ETcPowerPersistMode [▶ 61]
	Mode for persistent storage of parameters (see Behavior in the event of a power supply failure [▶ 22])				

5.1.4 DataAreas

The process data provided by the module as inputs and outputs is defined at Data Area.

Inputs

The following structures are provided as input process data.

Name	Data type	Description
Control	STcPowerPlantControlControl [▶ 56]	Transfer state signals to the module
Target	STcPowerPlantControlTarget [▶ 57]	Transfer setpoints to the module

Outputs

The following structures are provided as output process data.

Name	Data type	Description
Status	STcPowerPlantControlStatus [▶ 57]	State signals from the module
Demand	STcPowerPlantControlDemand [▶ 57]	Control values from the module

Diagnostics

Optionally, the following structures can be provided as output process data for the diagnostics of internal processes.

Name	Data type	Description
Diag	STcPowerPlantControlDiagnostic [▶ 57]	Diagnostic information from the module

Measures

Optionally, external grid data acquisition can be integrated as input process data using the following structures. Using a reference to a TcPowerMeasure module for grid data acquisition, this process data is automatically described.

Name	Data type	Description
Diag	STcPowerMeasureDiag	Diagnostics of grid data acquisition
Voltage	STcPowerMeasureVoltageArea	Voltages from grid data acquisition
Frequency	STcPowerMeasureFrequencyArea	Frequency from grid data acquisition
Fundamentals	STcPowerMeasureFundamentalsArea	Services from grid data acquisition

5.1.4.1 STcPowerPlantControlControl

The STcPowerPlantControlControl structure defines state information for the TcPowerPlantControl as input process data.

Name	Data type	Unit	Description
bEnable	BOOL		Enable controller
bSupplyError	BOOL		Power supply failed (UPS activated)
bMeasureError	BOOL		Grid data acquisition failed
bPlantError	BOOL		Communication to the plant failed
bOperatorError	BOOL		Communication to the grid operator failed
bMarketerError	BOOL		Communication with the direct marketing company failed
bVoltageProtection	BOOL		Voltage protection has triggered
bFrequencyProtection	BOOL		Frequency protection has triggered

5.1.4.2 STcPowerPlantControlTarget

The `STcPowerPlantControlTarget` structure defines setpoints for the `TcPowerPlantControl` as input process data. The units can be set according to the scaling, see Scaling [▸ 19].

Name	Data type	Unit	Description
eActiveMode	ETcPowerPlantActiveMode [▸ 60]		Mode of the active power controller
fActivePowerLim	REAL	%	Limitation of active power (from the grid operator)
fActivePowerSet	REAL	%	Setpoint active power (from direct marketing company)
eReactiveMode	ETcPowerPlantReactiveMode [▸ 60]		Mode of the reactive power controller
fReactivePowerSet	REAL	%	Reactive power setpoint (from grid operator)
fCosPhiSet	REAL	-	Setpoint power factor (from grid operator)

5.1.4.3 STcPowerPlantControlStatus

The `STcPowerPlantControlStatus` structure defines states of the `TcPowerPlantControl` as output process data.

Name	Data type	Unit	Description
bValid	BOOL		Control values are valid.
bStart	BOOL		Start and release of the plant.
bNormal	BOOL		Controller in normal operation.
bCritical	BOOL		Controller in critical operation. (LFSM-O or LFSM-U)
bCriticalWait	BOOL		Controller in critical operation, waiting for normal operation.
bRestart	BOOL		Controller in start-up after restart.
bRestartWait	BOOL		Controller waiting for return to normal operation.
bReconnect	BOOL		Controller in start-up after grid fault.
bReconnectWait	BOOL		Controller waiting for return to normal operation.

5.1.4.4 STcPowerPlantControlDemand

The `STcPowerPlantControlDemand` structure defines control values of the `TcPowerPlantControl` as output process data. The units can be set according to the scaling, see Scaling [▸ 19].

Name	Data type	Unit	Description
fActivePower	REAL	%	Control value of the active power (to the power generating plant)
fReactivePower	REAL	%	Control value of the reactive power (to the power generating plant)

5.1.4.5 STcPowerPlantControlDiagnostic

The `STcPowerPlantControlDiagnostic` structure offers internal signals of the `TcPowerPlantControl` as optional output process data. The underlying structures are listed below.

Name	Data type	Description
Critical	STcPowerPlantControlDiagStatus	Diagnostic status in a grid-critical situation (LFSM)
Restart	STcPowerPlantControlDiagStatus	Diagnostic values for restart sequence
Reconnect	STcPowerPlantControlDiagStatus	Diagnostic values for reconnect process

Name	Data type	Description
Active	STcPowerPlantControlDiagActive	Diagnostic data of the active power control
Reactive	STcPowerPlantControlDiagReactive	Diagnostic data of the reactive power control
Measure	STcPowerPlantControlDiagMeasure	Diagnostic data of the grid measurement

STcPowerPlantControlDiagStatus

Name	Data type	Unit	Description
bVoltageLow	BOOL		Undervoltage detected
bVoltageHigh	BOOL		Overvoltage detected
bFrequencyLow	BOOL		Underfrequency detected
bFrequencyHigh	BOOL		Overfrequency detected

STcPowerPlantControlDiagActive

Name	Data type	Unit	Description
eMode	ETcPowerPlantActiveMode		Active operation mode of the active power controller
fActual	REAL	%/pu	Measured active power
fTarget	REAL	%/pu	Active power setpoint
fPredict	REAL	%/pu	Predicted power based on section model
fControl	REAL	%/pu	Output signal of the PI controller
fDemandByPrimary	REAL	%/pu	Part via primary control
fDemandByFrequency	REAL	%/pu	Part via frequency-dependent control P(f)
fDemandByVoltage	REAL	%/pu	Part due to voltage-dependent active power reduction

STcPowerPlantControlDiagReactive

Name	Data type	Unit	Description
eMode	ETcPowerPlantReactiveMode		Active mode of the reactive power controller
fActual	REAL	%/pu	Measured reactive power
fTarget	REAL	%/pu	Reactive power setpoint
fPredict	REAL	%/pu	Prediction based on model
fControl	REAL	%/pu	PI controller output
fDemandByCosPhi	REAL	%/pu	Setpoint via CosPhi control (ByCosPhi)
fDemandByVoltage	REAL	%/pu	Setpoint via voltage characteristic curve Q(U)
fDemandByVoltageLim	REAL	%/pu	Setpoint via Q(Ulim) limitation
fDemandByActive	REAL	%/pu	Setpoint via active power characteristic curve Q(P)
fDemandByActive CosPhi	REAL	%/pu	Setpoint via CosPhi(P) characteristic curve

STcPowerPlantControlDiagMeasure

Name	Data type	Unit	Description
fVoltage	REAL	V	RMS value of the voltage (3-phase symmetrical)
fVoltage12	REAL	V	Voltage phase L1–L2
fVoltage23	REAL	V	Voltage phase L2–L3
fVoltage31	REAL	V	Voltage phase L3–L1
fActivePower	REAL	W	Measured active power at the PCC
fReactivePower	REAL	var	Measured reactive power at the PCC
fFrequency	REAL	Hz	Grid frequency

5.1.5 Interfaces

Interface Pointers are used to set interfaces and references to other modules. Below this, the reference to the task is automatically defined by `Context`. In addition, a reference to a `TcPowerMeasure` module can be set via `Measure` to integrate the grid data acquisition.

6 Appendix

6.1 Data types

6.1.1 ETcPowerPlantType

The `ETcPowerPlantType` enumeration is used to define a plant type.

Name	Value	Description
`None`	0	No specific plant type
`Generator`	1	Synchronous generator
`Converter`	2	Power converter
`Storage`	3	Energy storage

6.1.2 ETcPowerPlantControllerMode

The `ETcPowerPlantControllerMode` enumeration type defines the behavior of the controller according to different standards.

Name	Value	Description
`EU_EN50549_2019`	1	EN50549-2:2019
`DE_VDE4110_2023`	2	VDE-AR-N 4110:2023-09
`DE_VDE4120_2018`	3	VDE-AR-N 4120:2018-11
`DE_VDE4130_2018`	4	VDE-AR-N 4130:2018-11

6.1.3 ETcPowerPlantActiveMode

The operation mode of the active power controller is defined using the `ETcPowerPlantActiveMode` enumeration type (see Operation modes of the active power controller [▸ 24]).

Name	Value	Description
`Normal`	0	Normal operation
`Default`	1	Apply default from parameters for active power
`Slave`	101	Apply the active power as a lower-level system
`Bypass`	102	Bypass the controller as a lower-level system

6.1.4 ETcPowerPlantReactiveMode

The operation mode of the reactive power controller is defined using the enumeration type ETcPowerPlantReactiveMode (see Operation modes of the reactive power controller [▸ 31]).

Name	Value	Description
`Normal`	0	Normal operation
`Default`	1	Reactive power control with constant setpoint [▸ 32]
`ByCosPhi`	11	Reactive power control with CosPhi displacement factor [▸ 32]
`ByVoltage`	12	Reactive power control with voltage characteristic curve Q(U) [▸ 33]
`ByVoltageLim`	13	Reactive power control with voltage limiting function Q(Ulim) [▸ 34]
`ByActive`	14	Reactive power control with active power characteristic curve Q(P) [▸ 35]
`ByActiveCosPhi`	15	Reactive power control with CosPhi(P) characteristic curve [▸ 36]

Name	Value	Description
Slave	101	Apply the active power as a lower-level system
Bypass	102	Bypass the controller as a lower-level system

6.1.5 ETcPowerPlantFallbackMode

The `ETcPowerPlantFallbackMode` enumeration defines the fallback in the event of a communication failure, for example (see Behavior in the event of communication errors [▶ 21]).

Name	Value	Description
None	0	No fallback defined
Default	1	Fallback to default from parameters
Last	2	Fallback to the last valid value

6.1.6 ETcPowerFilterType

The `ETcPowerFilterType` enumeration defines the behavior of a filter.

Name	Value	Description
None	0	No filter defined
PT1	1	First-order delay element
PT2	2	Second-order delay element
Slope	3	Slope limitation
Average	4	Moving average

6.1.7 ETcPowerTimeType

The `ETcPowerTimeType` enumeration defines the type of time synchronization of the TwinCAT system time.

None	Value	Local system time without time synchronization
Hard	1	System time with DC time synchronization (ns)
Medium	2	System time with PTP time synchronization (us)
Soft	3	System time with NTP time synchronization (ms)

6.1.8 ETcPowerPersistMode

The `ETcPowerPersistMode` enumeration defines the type of persistent storage of the module parameters (see Parameter [▶ 48]) and the input process data (see STcPowerPlantControlTarget [▶ 57] and STcPowerPlantControlControl [▶ 56])

Name	Value	Description
None	0	No storage
Enable	1	Loading and saving enabled
LoadOnly	101	Loading only
SaveOnly	102	Saving only

6.2 References

Name	Description
VDE TR3	Technical guideline for power generating units and plants, Part 3: Determination of the electrical properties of power generating units and plants, storage systems and their components on the medium, high and extra-high voltage grid, Rev. 26, 2022-04-05
VDE-AR-N 4110	Technical requirements for the connection and operation of customer installations to the medium voltage network (TAR medium voltage), Berlin, November 2023.
VDE AR-N 4120	Technical requirements for the connection and operation of customer installations to the high voltage network (TAR high voltage), Berlin, November 2018.
VDE AR-N 4130	Technical requirements for the connection and operation of customer installations to the extra high voltage network (TAR extra high voltage), Berlin, November 2018.
EN 50549-2:2019	Technical requirements for generating plants with a medium voltage connection
EN 50549-10:2022	Measurement protocol
PPPiREE, V1.3: 2024	Technical implementation of (EU) 2016-631 in Poland

6.3 Technical terms

DE	EN	Description
Abtastrate	Sampling rate	Frequency that measured values are recorded at
Akkreditiertes Prüflabor	Accredited test lab	Notified body with formal certification
Anlagenzertifikat	System certificate	Confirmation that a point of connection for a PGP conforms by a certificate authority
Anschlussnehmer	Connection owner	Operator/operators of the electrical system at the point of connection
Automatische Wiedereinschaltung	Automatic reconnection	Function for switching back on after a grid fault
Bemessungs scheinleistung	Nominal apparent power	Nominal value for the maximum apparent power
Bilanzkreis verantwortlicher (BKV)	Balancing responsible party (BRP)	Responsible for balancing (infeed vs. output)
Blindleistung (Q)	Reactive power (Q)	Share of energy that oscillates between source and load
Blindleistungsregler (Q-Regler)	Reactive power controller (Q controller)	Controls the reactive power (Q) for voltage support or grid service
Blockheizkraftwerk (BHKW)	Cogeneration plant (CHP)	Combined heat and power generation
Direktvermarkter (DVM)	Direct marketing company (DMC)	Market participants for electricity marketing
Echtzeit	Real time	Data processing with defined time behavior
Erzeugungsanlage (EZA)	Power generating plant (PGP)	Total of all power generating units at a point of connection
Erzeugungseinheit (EZE)	Power generating unit (PGU)	Individual system for electricity generation within a power generating plant
EZA-Regler	PGP controller	Controls feed-in according to grid specifications
Frequenz	Frequency	Grid frequency, generally 50 Hz in Europe
Gleichstromanteil	DC component	Direct current component in an alternating current measurement
Harmonische	Harmonics	Harmonics in the grid (multiples of the base frequency)

DE	EN	Description
Messdatenerfassung	Measurement data acquisition	Measuring electrical variables
Messmittelwert	Measured mean value	Mean value over time window
Mittelspannung	Medium voltage (MV)	Typically 1–36 kV grid level
Momentanwert	Instantaneous value	Directly measured variable without averaging
Nennspannung	Nominal voltage	Reference value for voltage in a grid system
Netzanschlusspunkt (NAP)	Point of connection (POC)	Physical transfer point to the grid
Netzbetreiber	Grid operator	Responsible for the operation and expansion of a grid
Netzfrequenz	Grid frequency	Number of voltage changes per second
Netzqualität	Power quality	Evaluation of electrical parameters in the grid
Netzschutz	Grid protection	Assurance of grid-compatible operation
Netzverknüpfungspunkt (NVP)	Point of common coupling (PCC)	Evaluation location for grid perturbation
Oberschwingungen	Harmonics	Voltage and current components above the base frequency
Phasenwinkel	Phase angle	Angle between voltage and current
Photovoltaikanlage (PV)	Photovoltaic system (PV)	Power generation using solar cells with inverter
Regeldifferenz	Control error	Deviation between setpoint and actual value
Schaltanlage	Switchgear	System for the control and fuse protection of electrical energy
Schutzgerät	Protective device	Responds to error states in the grid
Schutzrelais	Protective relay	Component for fault detection and tripping
Schutzsystem	Protective system	Combination of relays, logic, measurement, and actuators
Spannungseinbruch	Voltage sag	Short-term reduction of the grid voltage
Speicher	Storage unit	Energy unit with charging and discharging capability
Synchronisierung	Synchronization	Synchronization of time or frequency between systems
Transformatorstation	Transformer station	Station for transforming voltage between grid levels
Transient recorder	Transient recorder	Records faults in high temporal resolution
Verteilnetzbetreiber (VNB)	Distribution system operator (DSO)	Responsible for medium/low-voltage grid
Virtuelles Kraftwerk	Virtual power plant (VPP)	Network of controllable decentralized generation systems
Wirkleistung (P)	Active power (P)	Power that actually performs work
Wirkleistungsregler (P-Regler)	Active power controller (P controller)	Controls the active power
Zeitstempel	Timestamp	Marks a data value with a time
Zwischenharmonische	Interharmonics	Frequencies between integer multiples of the base frequency
Übertragungsnetz-betreiber (ÜNB)	Transmission system operator (TSO)	Responsible for the high-voltage grid

6.4 Abbreviations

Abbreviation	Full form (DE)	Full form (EN)
CHP	Blockheizkraftwerk	Cogeneration plant (or combined heat and power plant)
DSO	Verteilnetzbetreiber (VNB)	Distribution system operator
EN	Europäische Norm	European standard
PGP	Erzeugungsanlage (EZA)	Power generating plant (PGP)
PGU	Erzeugungseinheit (EZE)	Power generating unit (PGU)
FRT	Fehlerüberbrückungsfähigkeit	Fault ride-through capability
FSM	Frequenzabhängige Wirkleistung	Frequency sensitive mode
GCR	Netzanschlussregeln (NAR)	Grid connection regulations
HV	Hochspannung	High voltage
LFSM	Frequenzabhängige Wirkleistungsanpassung	Limited frequency sensitive mode
LV	Niederspannung	Low voltage
MPP	Maximaler Leistungspunkt	Maximum power point
MV	Mittelspannung (MS)	Medium voltage (MV)
POC	Netzanschlusspunkt (NAP)	Point of connection (POC)
PCC	Netzverknüpfungspunkt (NCP)	Point of common coupling (PCC)
P controller	Wirkleistungsregler	Active power controller
PCC	Netzverknüpfungspunkt (NVP)	Point of common coupling
PGU	Erzeugungseinheit (EZE)	Power generating unit
PGP	Erzeugungsanlage (EZA)	Power generating plant
PSC	Energieversorgungsunternehmen (EVU)	Power supply company
POC	Netzanschlusspunkt (NAP)	Point of connection
Q controller	Blindleistungsregler	Reactive power controller
RfG	Netzanschlussanforderungen für Stromerzeugungsanlagen	Requirements for generators
RMS	Effektivwert	Root mean square
SVC	Statischer Var-Kompensator	Static var compensator
TSO	Übertragungsnetzbetreiber (ÜNB)	Transmission system operator
THD	Oberschwingungsverzerrung	Total harmonic distortion
TG	Technische Richtlinie	Technical guideline
VDE	Verband der Elektrotechnik	German Association for Electrical, Electronic, and Information Technologies
DSO	Distribution system operator (VNB)	Distribution system operator (DSO)
TSO	Übertragungsnetzbetreiber (ÜNB)	Transmission system operator (TSO)

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Beckhoff Headquarters

Beckhoff Automation GmbH & Co. KG

Huelshorstweg 20
33415 Verl
Germany

Phone:	+49 5246 963-0
e-mail:	info@beckhoff.com
web:	www.beckhoff.com

More Information:
www.beckhoff.com/tf8360

Beckhoff Automation GmbH & Co. KG
Hülshorstweg 20
33415 Verl
Germany
Phone: +49 5246 9630
info@beckhoff.com
www.beckhoff.com