FAQ • 05.2014

Process control using the technology controller of the SINAMICS G120 and G120P

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1 Introduction

Description of the automation task

SINAMICS G120 inverters have a technology controller with which the speed of the connected motor can be varied as a function of the setpoint and actual value.

Based on this technology controller, control loops can be implemented for process variables, e.g.: for controlling level, temperature, pressure, flow, air quality and many more variables.

This document provides recommendations for configuring, parameterizing and optimizing control loops with the PID controller.

Delimitation

This application does not include any instructions regarding

- Parameterizing
- Commissioning
- Optimizing

of the drive controls as positioning control, speed control and current control.

The technology controller of the SINAMICS G120 is a continuous working linear PID controller. Non-linear control loops with fuzzy logic, adaptive control, extremal value control, and non-continuous control with two or three-step controller are not covered by this application.

Examples for implementing control functions based on the technology controller are provided in the applications:

- Fans for closed-loop control of feed air, entry ID: 43296889
- Fans for closed-loop control of exhaust air, entry ID: 77490904
- Closed-loop control of a tunnel/car park fan, entry ID: 77491575
- Closed-loop control of a staircase fan, entry ID: 77491576
- Closed-loop control cooling tower fans, entry ID: 43297078
- Pumps for the closed-loop control of a cooling circuit, entry ID: 43297284
- Pressure-controlled pumps, entry ID: 43297279
- Closed-loop level controlled pumps, entry ID: 43297280
- Pressure-controlled compressor, entry ID: 77491582
- Pressure-controlled vacuum pumps, entry ID: 77491905

These applications also include scripts that can be executed for the STARTER commissioning tool to completely parameterize control loops in prompted dialog.

Know-how that is required

It is assumed that readers have basic knowledge about parameterizing and commissioning drives using the STARTER tool and have a basic understanding of control technology.

2 Basics of closed-loop control systems

In all types of process industries, HVAC systems as well as the water industry, there are processes where physical variables, such as temperature, pressure, flow etc. must be maintained at a constant value. To achieve this, the measured actual value is compared with the desired setpoint and the difference is corrected to become zero using a controller and actuator. It is called a control loop as it involves a closed system.

2.1 Components of a control loop

In a control loop, a physical variable (controlled variable x) is continually adjusted to obtain a required value (reference variable, setpoint w). To do this, setpoint changes and disturbances (disturbance variable z) must be corrected. The value of the controlled variable x (actual value) is determined using appropriate measuring equipment. The controller compares the difference between the setpoint and actual value (setpoint deviation, system deviation e) and generates a manipulated variable y, which influences the control loop so that the control difference remains at a minimum value.

The simplified block diagram in Fig. 2-1 provides an overview of the control loop components.

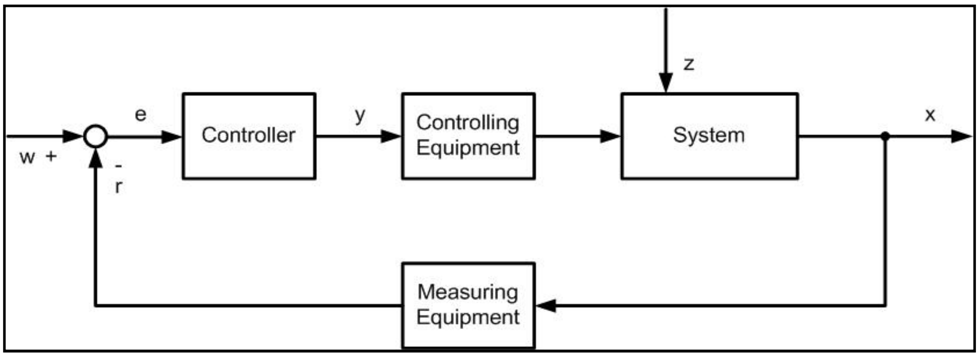


Fig. 2-1: Components of a control loop

w	Reference variable
r	Feedback variable
e	Control difference
y	Manipulated variable
z	Disturbance variable
x	Controlled variable

Note Due to historical reasons other terms are used, partly based on DIN19226. DIN 19226 was withdrawn in 2006 and 2008 replaced by the DIN EN 60027-6 and DIN EN 60050-351.The terms and symbols used in this document are based on the current standards. Different symbols used in technical documentation are listed in the Glossaryy Chapter 6.

2.2 Controlled system

2.2.1 Time response of the controlled system

The controlled system is part of the technological process that is influenced by the technology controller. The controlled system starts where the actuator (pump, fan, compressor) has a direct influence, and ends at the measuring equipment or device.

Controlled systems are evaluated as a result of their time response. To determine the characteristic variables of a controlled system (gain, time constants), a defined input signal (a step in the manipulated variable y) is applied to the system in a quiescent state, and the output signal (controlled variable x) is determined as a function of time. This signal is known as the step response.

Corresponding to the system step response, controlled systems are classified according to the following table. The table does not include all possible combinations of transfer elements, e.g. IT_1 element, PDT_1 element etc.

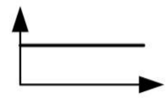
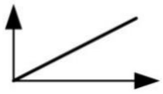
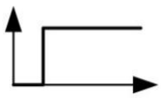
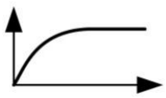
Transfer response of the controlled system	Brief designation	Step response
Proportional action system without delay Example: Pressure as controlled variable.	P element	
Integrating action system (controlled system has no compensation) Example: Level as controlled variable.	I element	
Derivative action system Example: The ideal D element with step response has an infinitely high and infinitely short amplitude (pulse) and does not exist in reality; combinations with delay elements can be implemented in reality.	D element	
Proportional action system with dead time Example: Flow rate as controlled variable after a transport conveyor belt – or after long gas pipes with compressible gas.	Dead-time element PT_t element	
Proportional action system with delay (compensation), 1st order Example: Controlled system with (time-determining) energy storage function, e.g. temperature as controlled variable.	PT_1 element	
Proportional action system with delay (compensation), 2nd order Example: Controlled system with two energy storage functions connected in series.	PT_2 element	
Controlled system with delay (compensation), higher order (general)	e.g. PT_1T_t element	

Table 1: Transfer responses of controlled systems

2.2.2 Compensated systems

If the step response of the controlled system with higher order compensation corresponds to the following Fig. 2-2, then the behavior of the controlled system can be defined using the following model:

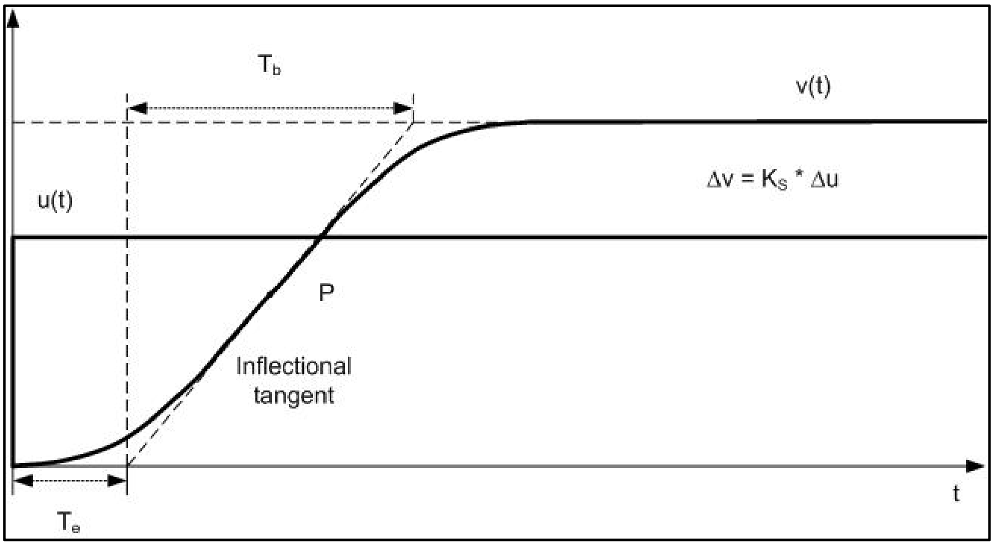


Fig. 2-2: Inflection tangent method for compensated systems

P	Inflectional point
u(t)	Input variable
v(t)	Output variable
K_S	System gain factor
T_e	Equivalent dead time
T_b	Equivalent time constant

These parameters can be simply and graphically defined by drawing the inflection tangent.

System gain K_S

If a constant input variable Δu acts on a controlled system with compensation, then a steady-state final value of output variable Δv is obtained as follows:

$$\Delta v = K_S \times \Delta u$$

K_S is therefore given by:

$$K_S = \frac{Output\ value\ change}{Input\ value\ change} = \frac{\Delta v}{\Delta u}$$

Equivalent time constant T_b

In this model, the equivalent time constant defines the time that the actual value requires for the transition from the initial value to the new steady-state final value, assuming it moves along the inflection tangent.

Equivalent dead-time T_e

The equivalent dead-time T_e is the time that the actual value requires to respond to a step in the manipulated variable, assuming that the step response moves along the inflection tangent. The equivalent dead-time is defined by the dead-time and delay elements of the controlled system. In practice, it is difficult to separately evaluate dead time T_t and delay-time T_u. As a consequence, the dead time is assigned to the equivalent dead-time T_e. T_e is also known as the equivalent dead time.

Controllability of the control system, degree of difficulty

Time constants T_G and T_e are parameters that define the slowness of the controlled system until the steady-state final value is reached after injecting a step at the input to the controlled system. They define the dynamic response of the system and the controllability of the controlled system. The term "degree of difficulty" is used for the controllability of the controlled system. It is calculated from the ratio between delay time T_e and the equivalent dead-time T_G, also see Chapter 5.1.1.

2.2.3 Uncompensated systems

Controlled systems without compensation are systems with an integrating response. Instead of the inflection tangent, an asymptote is drawn along the step response.

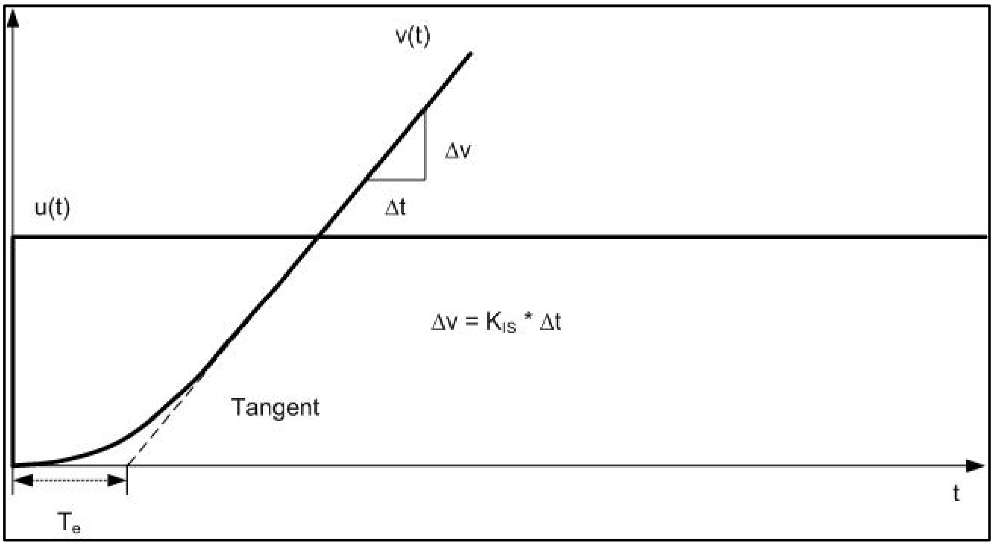


Fig. 2-3: Inflection tangent method for uncompensated systems

u(t)	Input variable
v(t)	Output variable
K_{IS}	Integral action coefficient
T_e	Equivalent dead-time

Integral action coefficient K_{IS}

The gradient of the tangent represents the integral action coefficient of the controlled system K_{IS}.
K_{IS} is also known as transfer coefficient of the controlled system without

compensation. The gradient can be graphically determined by measuring the intersections with the coordinates.

K_{IS} is obtained from:

$$K_{IS} = \frac{Output\ value\ change}{Time\ duration} = \frac{\Delta v}{\Delta t}$$

Equivalent dead-time T_e

The equivalent dead-time T_e is obtained from where the tangent (asymptote) intersects with the time axis. The equivalent dead-time also includes dead-time T_t.

2.2.4 Practically determining the controlled system variables

To determine the system gain and the system time constants, the inverter is operated without technology controller in the open-loop controlled mode. From a stable operating point, a setpoint step is injected into the system, e.g. via the fixed setpoints and the system response traced.

2.3 Actuator, actuating device, actuator drive

Generally, the controller does not directly control the controlled system, but an actuating device. The actuating device is an (electro) mechanical device, which generates the manipulated variable from the controller output signal. This manipulated variable then acts on the controlled system.

If the auxiliary power required by the actuating device is fed in from the outside, then this is also known as an actuator drive. The actuating device can be subdivided into the actuator drive and actuating element. Frequently, the complete actuating device is only called actuating element or actuator.

2.4 Measuring device, measuring element

The measuring device comprises sensors, which provide the feedback variable for the controller as a scaled value from the controlled variable (actual value).

2.5 Controller

2.5.1 Overview

The controller determines the control difference (deviation from the setpoint) from the difference between the setpoint and actual value – and generates the manipulated variable so that setpoint changes and disturbances, which act on the controlled system, are compensated in the appropriate way.

The dynamic behavior of the controller corresponds to the transfer response of transfer elements in the controlled system and their combinations.

Controller types that are frequently used include

- P controller – proportional action
- PI controller – proportional-integrating action
- PIT controller – proportional-integrating-derivative action

Note The technology control of the SINAMICS G120 is a continuous, linear PID controller. This document does not go into any more detail about non-linear controls with fuzzy controllers, adaptive controllers, extreme value controllers and discontinuous controls with two and three-step controllers.

2.5.2 Controller types

P controllers (proportional controllers)

Manipulated variable y is always proportional to the control difference that is sensed. This results in a fast control response. A manipulated variable is only generated if a control difference exists; this means that the operating point is not adjusted. Disturbance variables that continuously act on the system can never be completely compensated, and this results in a remaining control difference. A high K_P results in a lower control difference, but also an increasing tendency of the system to oscillate.

I controller (integral controller)

Control differences are completely corrected at every operating point. The manipulated variable is corrected until the control difference goes to zero. In the fully corrected state (control difference = 0), the manipulated variable of the I controller remains at its value, which is comparable with an automatic operating point adjustment.

D controller (derivative action controller)

Manipulated variable y is generated from the rate of change of the control difference. As a consequence, the controller response is faster than a P controller – even low control differences result in high manipulated variables. A D controller does not respond to a constant control difference. As a consequence, in practice it is only used in a combination of different controllers.

PD controller

This combination has a higher control dynamic response than a P controller. The tendency of the control loop to oscillate is reduced as a result the stabilizing effect of the D component. As a consequence, K_P can be selected to be higher; which means that the remaining control difference is reduced.

PI controller

This controller compensates the disadvantages of P and I controllers. It is a stable and fast controller – without any remaining control difference.

PID controller

The PID controller allows a higher control dynamic response to be achieved than with a PI controller. It is the preferred controller for controlled systems involving large delays and with high demands placed on the dynamic response of the control.

2.5.3 Control parameters to achieve a dynamic response

A PID controller generates the manipulated variable by superimposing the proportional, integrating and differentiating components. The dynamic response of the controller for a step in the reference value w or control difference e, is shown in Fig. 2-4.

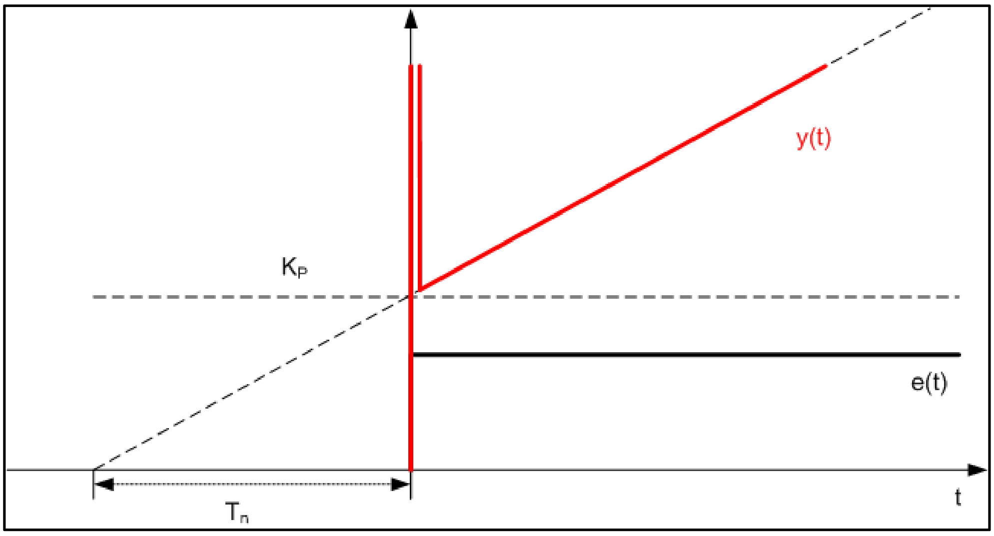


Fig. 2-4: Dynamic response of a PID controller

e(t)	Control difference
y(t)	Manipulated variable
K_P	Proportional gain
T_i	Reset time
T_d	Rate time

Proportional gain K_P

Proportional gain K_P designates the proportional action component of the controller. Manipulated variable y is always proportional to the control difference e (reference variable e minus feedback variable r).

The following relationship applies

$$y(t) = K_P \times e(t)$$

Changes to K_P have the following effect on the control loop:

- Reducing K_P (p2280) results in a more stable but slower response.

Reset time T_i

Reset time T_i designates the integrating component of the controller. Manipulated variable y is generated by integrating control difference e over time with a weighting as a result of the reset time T_i.

The following relationship applies

$$y(t) = \frac{1}{T_i} \times \int_{t_0}^{t} e(t) \times dt$$

Changes to T_i have the following effect on the control loop:

- Increasing T_i means that the I component is reduced. This results in a more stable but slower response.

Rate time T_d

The rate time T_d designates the derivative action component of the controller. Manipulated variable y is generated as a result of the rate of change of the control difference e with a weighting as a result of the rate time T_i.

The following relationship applies

$$y(t) = T_d \times \frac{d}{dt} e(t)$$

As a step response, a D element theoretically supplies a pulse of infinite size; in reality, a delay in the form of a PT_1 element is added. As a consequence, the step response has a finite maximum value and decays to zero according to an exponential function. A linear increase in the control difference results in a constant manipulated variable.

Changes to T_d have the following effect on the control loop:

- Increasing T_d means increasing the D component. In a control operation, a D component identifies the increasing difference between the reference variable and actual value, and directly outputs a manipulated variable, which is added to the P component. The magnitude of this additional manipulated variable depends on the rate of change of the control difference. As a consequence, the dynamic response of the control loop is increased.
- For the SINAMICS G120 technology controller, the D component can either be switched using p2263 in the channel of the control difference or the actual value. This means that the control loop response can be optimized to either achieve a good response to command variables or a good response to disturbance variables.

3 The SINAMICS G120 technology controller

3.1 Individual blocks

The technology controller is depicted in detail in function block diagram 7958 of the parameter list. The individual elements are separately described in order to make the functions more understandable.

To control process variables, the technology controller is used as main setpoint for the inverter. To do this, parameter p2251 should be set to 0 "Technology controller as main speed setpoint". Further, the technology controller must be enabled using parameter p2200.

3.1.1 Setpoint input

Practically all possible setpoint input versions can be used as command variables

- Analog setpoints via the analog inputs
- Serial setpoints via the process interface
- Fixed setpoints, binary and decimal coded
- Motorized potentiometer

Analog setpoints

To enter setpoints using analog values 0 … 10V or 0/4 ... 20mA, depending on the inverter and CU module involved, up to three analog inputs can be used. The corresponding outputs of the analog inputs are entered in setpoints 1 and 2 of the technology controller.

Serial setpoint input via the process interface

Depending on the telegram length and pre-assignment of the protocol used, data of PZD2 up to PZD8 can be used as setpoint for the PID controller.

Fixed setpoints binary selection

Up to 15 different technology setpoints p2201 to 2215 in the range +/- 200% can be selected by selecting the four parameters p2220, p2221, p2222, and p2223. The fixed setpoints can only be individually selected and cannot be combined.

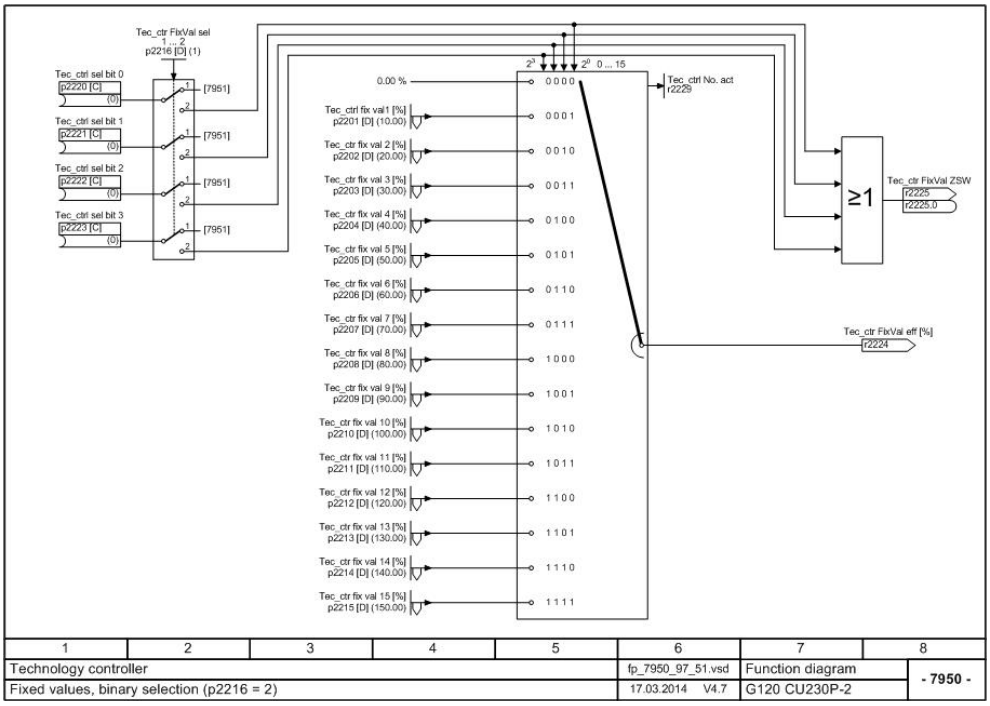


Fig. 3-1: Function block diagram fixed setpoints technology controller binary selection

Fixed setpoints direct selection

Up to 4 different technology setpoints p2201 to 2204 in the range +/- 200% can be selected by selecting the four parameters p2220, p2221, p2222, and p2223. The fixed setpoints can be combined with one another as required.

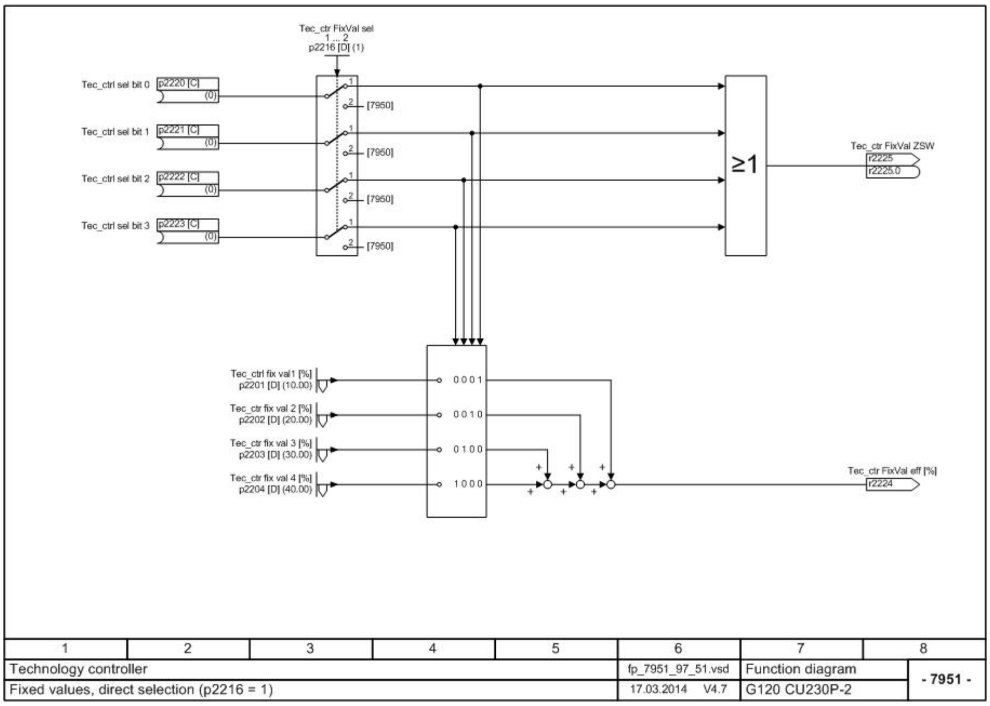


Fig. 3-2: Function block diagram fixed setpoints technology controller direct selection

Motorized potentiometer

The technology controller has its own motorized potentiometer; it can be controlled using the raise and lower keys.

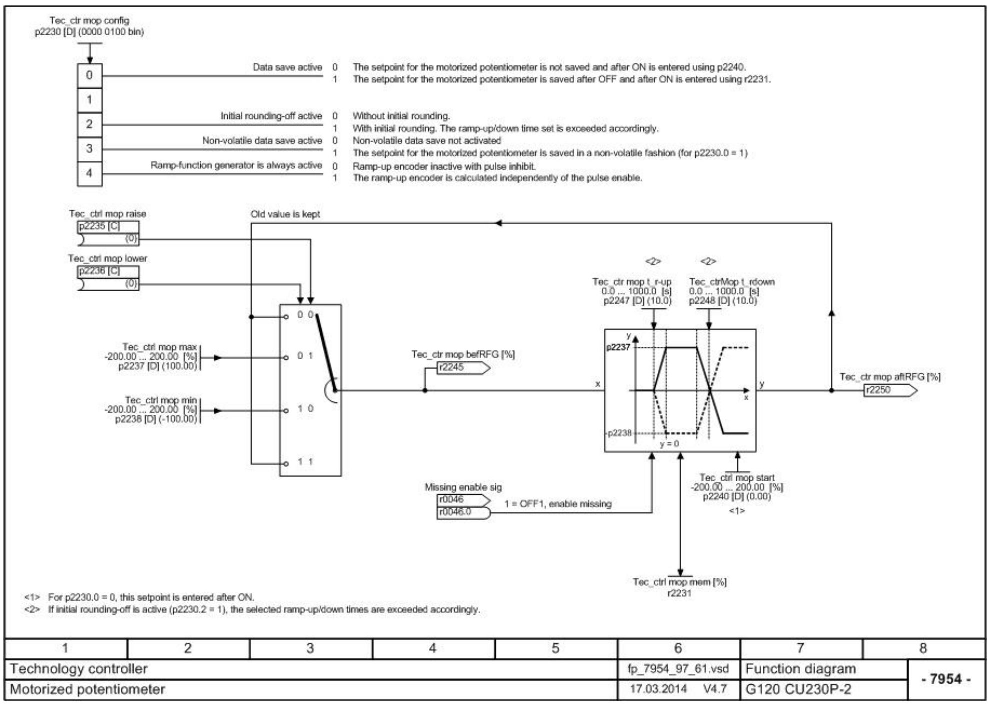


Fig. 3-3: Function block diagram technology controller motorized potentiometer

3.1.2 Setpoint channel

The setpoint channel of the technology controller comprises a summation point for technology setpoints 1 and 2, a ramp-function generator and a filter for the setpoint signal. Both technology setpoints can be scaled in the range 0 … 100%. The ramp-function generator has separately adjustable ramps for the ramp-up and ramp-down times in the range from 0.00 … 650.00sec. The filter can be set in the range 0.00 … 60.00sec. The total filtered setpoint signal can be viewed using display parameter r2262.

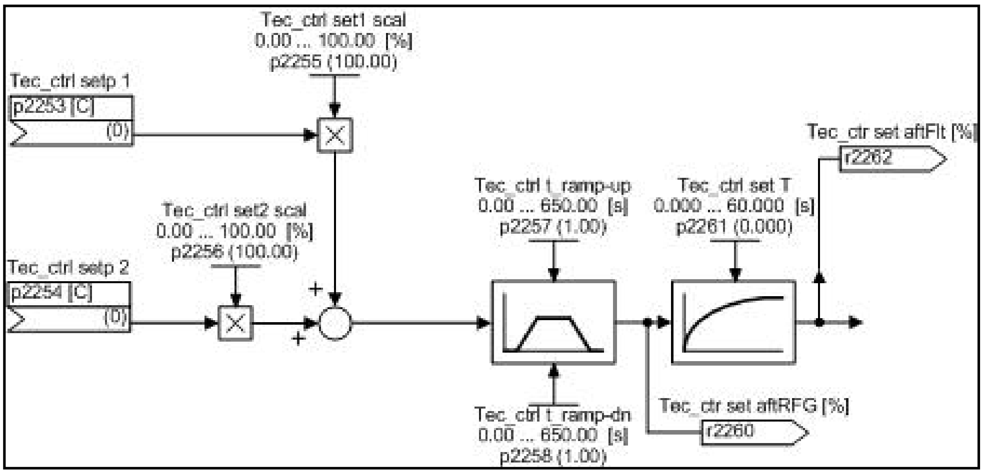


Fig. 3-4: Setpoint channel of the technology controller

3.1.3 Actual value channel

Typically, actual values for the technology controller are read in through analog inputs. Depending on the inverter and CU module being used, up to 4 analog inputs can be used.

SINAMICS G120C:

- 1 analog input AI0

SINAMICS G120 modular:

- Control Unit CU240B-2 – 1 analog input AI0
- Control Unit CU240E-2 – 2 analog inputs AI0 and AI1
- Control Unit CU250E-2 – 2 analog inputs AI0 and AI1

SINAMICS G120P:

- Control Unit CU230P-2 – 4 analog inputs AI0 … AI3, whereby AI3 can only be used to directly connect NI1000/Pt1000 temperature sensors.

The outputs of the analog input block are entered into p2264, and therefore connected to the actual value channel. In the downstream actual value filter, the actual value signal can be smoothed with a time constant p2265 in the range from 0.000 up to 60.000sec. As standard, the limiting block limits the actual value signal to -100 … +100%; when exceeded, a fault message is output using the technology controller status word.

Actual value signals, which do not reach the full amplitude, can be adapted using parameter p2269.

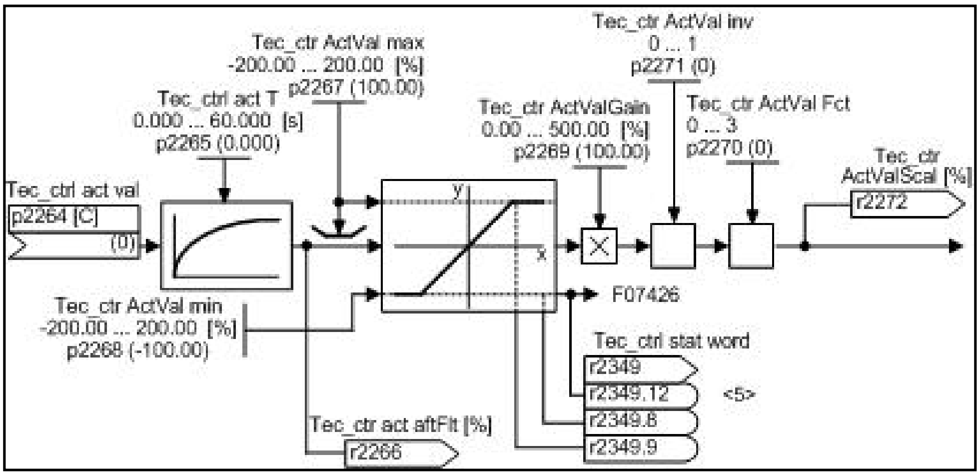


Fig. 3-5: Actual value channel of the technology controller

Modification of the actual value

The actual value can be modified using parameter p2270 "Technology controller actual value function".

Parameter	Value	Comment
p2270	0 1 2 3	No function No effect on the actual value Square root function $\sqrt{x}$ Square function x^2 Cube function x^3

For instance, the square root function can be used if a pressure transmitter is used to measure flow (pitot tube, back pressure sensor).

$$Flow\ rate = k \times \sqrt{pressure}$$

When measuring flow in the ventilation duct, constant k is determined based on the duct cross-section and the air density.

The square and cube functions are intended for comparable special cases, and are used to linearize the actual value.

3.1.4 Technology controller

The final setpoint used for the technology controller can be read in parameter r2262 – and the corresponding actual value, in parameter r2272. After the summation point of the setpoint and actual value, parameter p2306 is used to select whether the process control sense is normal or inverted.

Normal/inverse control sense

Pumps, fans and compressors can only pump/move the medium being processed in one direction. This is the reason that the controller response is adapted to the particular technological application and where the equipment is located.

A normal or direct control sense is involved if, with increasing positive setpoint deviation (control difference e = reference variable w – feedback variable r), the flow rate of the mechanical unit must be increased.

An inverse control sense is involved if, for an actual value that exceeds the setpoint, the flow rate is to be increased.

The control sense is simply inverted by inverting the sign of the control difference (control difference e = feedback variable r - reference variable w). As a result of the inversion, the setpoint is subtracted from the actual value.

For the G120, the control difference is known as "Technology controller error" (r2273). Parameter p2306 "Technology controller fault signal inversion" is used to invert the system deviation.

The following examples clearly illustrate the control sense.

Normal control sense

Example: A pump fills a tank, e.g. a drinking water storage tank, and the level is controlled so that it remains constant. The pump operates as long as the level is less than the setpoint; if the setpoint is reached or exceeded, then the control difference is negative, and the drive remains stationary.

The drive operates as long as the reference variable w is greater than the feedback variable r, i.e. reference variable w – feedback variable r = pump/fan speed. If the feedback variable r is equal to or also higher than the reference variable w, the drive operates at the minimum speed and may be switched-off as a result of the sleep mode.

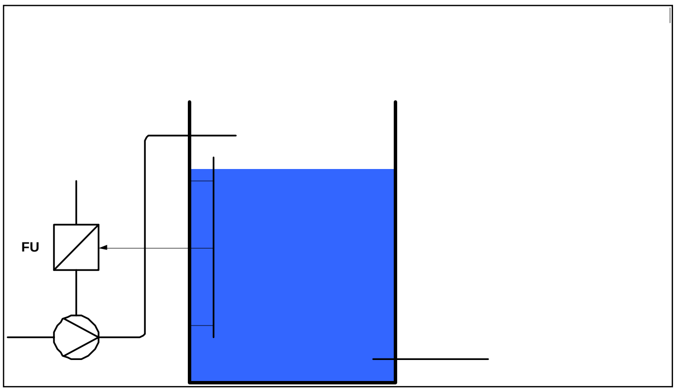


Fig. 3-6: Normal control sense with a pump at the intake

Inverse control sense

Example: A pump is used to empty a tank, e.g. a tank that is used to capture rainwater. As long as the tank is empty, or a certain level has still not been reached, the control difference is positive per definition (control difference = setpoint minus actual value), but the pump must remain stationary. If the level exceeds the permissible setpoint, the control difference becomes negative; however, the pump must start to run and empty the tank. The sign of the control difference is negated in order to achieve this control behavior.

The drive operates as long as the feedback variable r is higher than the reference variable w, i.e. feedback variable r - reference variable w = pump/fan speed. If the feedback variable r is equal to or also less than the reference variable w, the drive operates at the minimum speed and may be switched-off as a result of the sleep mode.

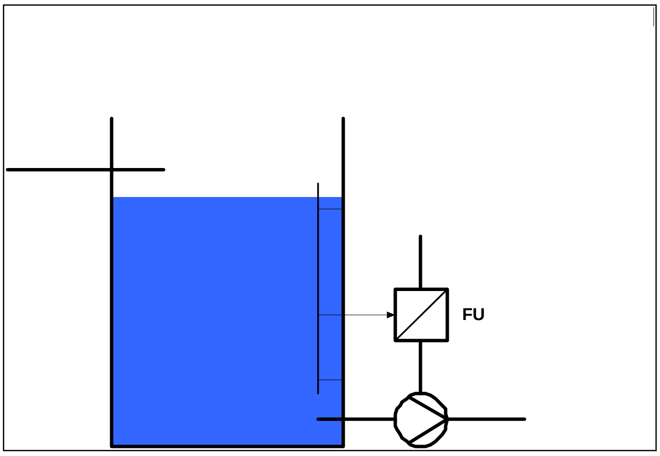


Fig. 3-7: Example of inverse control sense with a pump at the outlet

Controller parameters

Parameter p2263 can be used to define as to whether a possibly active D component acts on the total control difference – or only on the feedback variable. If the D component only acts on the feedback variable, then larger setpoint changes are not influenced. Controller parameters Td, Kp, and Ti are entered via p2274, p2280 and p2285.

Inhibiting the I component

The signal source for the technology controller to inhibit the integrator is set using parameter p2286 "Hold technology controller integrator".

The I component of the controller is inhibited in order to prevent what is known as the wind-up effect. Even if the controller output is at its limit, the I component of the controller continues to integrate a positive control difference; internally, the output value of the integrator is increased further. If the feedback variable then exceeds the reference variable, the control difference becomes negative and the manipulated variable should be reduced. The integrator now reduces its manipulated variable; however, initially it remains above the manipulated variable limiting. This results in significant overshoot of the actual value. This effect can be avoided by inhibiting the I component. As a consequence, the I controller only operates in the operating range of the manipulated variable. By connecting signal r2349.1 "Technology controller limited" in addition to signal r0056.13 "Current/torque limiting" in parameter p2286 "Hold technology controller integrator", it can be avoided that the integrator continues to integrate further when it reaches the current/torque limit and the maximum speed.

Parameter	Value	Comment
p20046[0]	0056.13	OR 0 input 0
p20046[1]	2349.1	OR 0 input 1
p20048	1	Runtime group 1
p20049	60	Run sequence
p2286	20047	Input, TechReg integrator stop

Note

For SINAMICS G120, interconnecting several functions to the integrator stop is only possible using freely assignable function blocks; this is not possible for SINAMICS G120C.

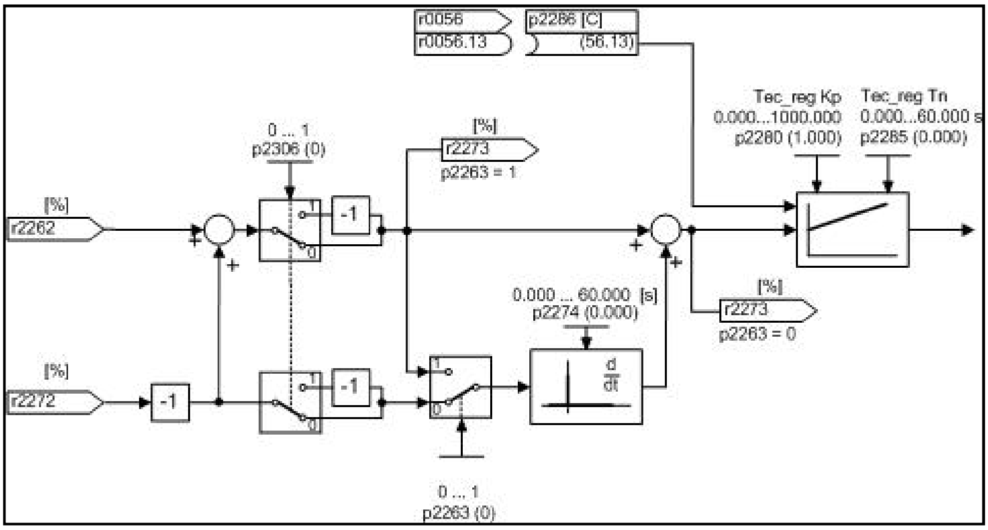


Fig. 3-8: Function block diagram of the technology controller

3.1.5 Limiting, enable and output interconnection

The PID controller output is limited to an upper and a lower value. These limit values can be entered as speed values; alternatively, they can also be entered as percentage values. When switching on the inverter or when enabling the technology controller, these limits are at zero. Using the ramp-function generator with selectable ramp, the limits can then be ramped up to the specified maximum and minimum values.

Parameter	Value	Comment
p2293	0.00 … 100.00s	Up and down ramp limits
p2297	r1084 p2291	Upper limit based on the maximum speed Upper limit based on a fixed value as a %
p2298	r1087 p2292	Lower limit based on the minimum speed Lower limit based on a fixed value as a %

Technology controller error response

An error response for the technology controller can be activated if the actual value reaches a limit. It is possible to either switchover to closed-loop speed controlled operation without PID controller, or to a freely selectable setpoint.

Parameter	Value	Comment
p2345	0 1 2	Function inhibited For an error: Switchover to r2344 (or p2302) For an error: Switchover to fixed setpoint p2215

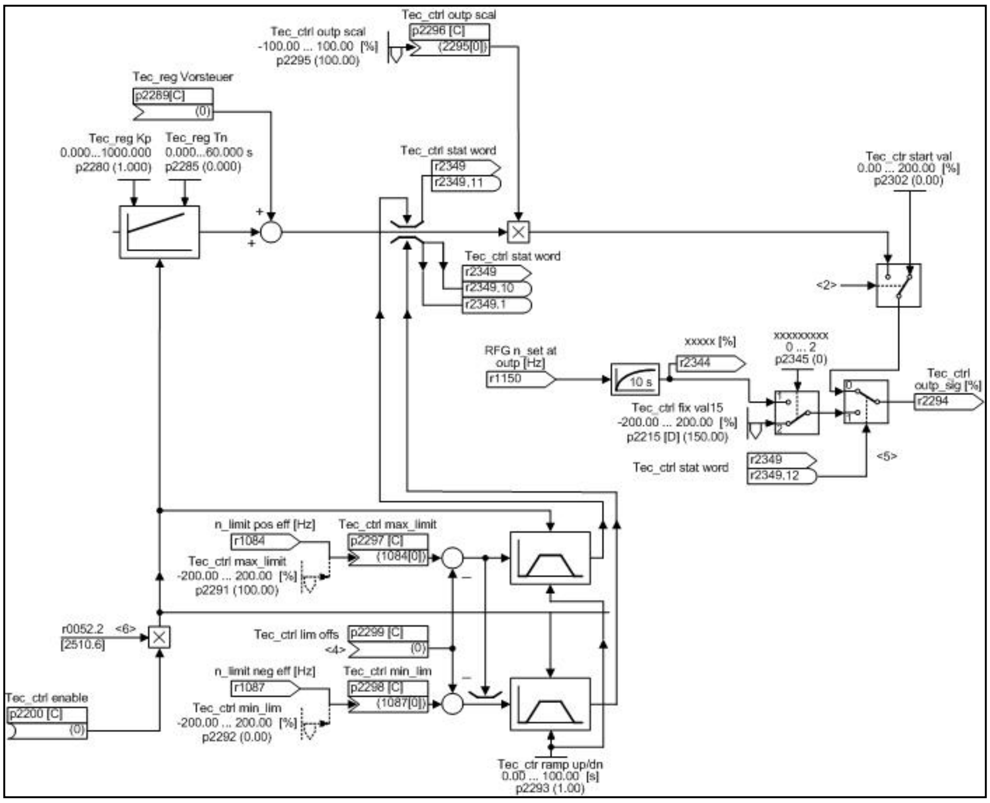


Fig. 3-9: Function block diagram, limiting functions of the technology controller

And finally, the output signal of the PID controller is entered into the setpoint channel of the inverter at r2294.

4 Special functions of the CU230P-2 Control Unit

4.1 Sleep mode

The sleep mode means that the inverter is shut down if, from the perspective of the technology controller, it is not required. This is always the case if the control difference r2277 is negative. For a normal control sense, the actual value is higher than the setpoint (in a tank, the level is higher than specified, in a pressure vessel, the pressure is higher than necessary). For an inverse control sense, the actual value is less than the setpoint (the level in a rainwater capture basin is below the minimum height). As a result of the negative control difference, the technology controller output integrates to zero and the drive operates at a minimum speed. The inverter can be shut down after a selectable time. The technology controller remains active and the inverter is switched-on again as soon as the control difference reaches a positive value again.

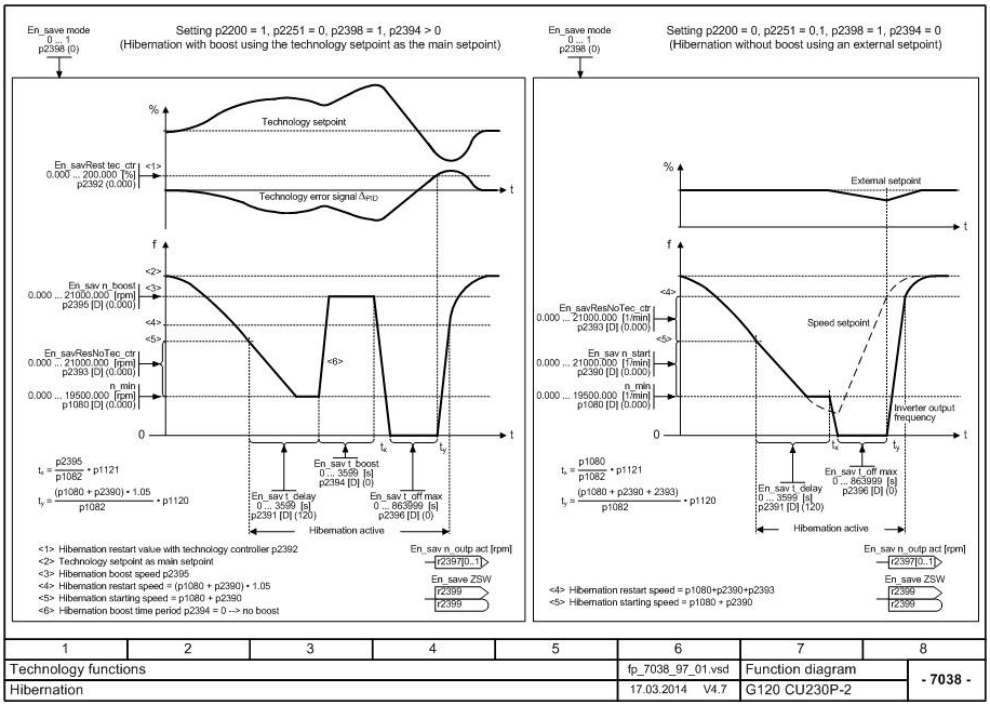


Fig. 4-1: Sleep mode

4.2 Multi-zone control

Multi-zone control is involved if the technology controller is to control several setpoints and actual values to achieve a common optimum.

For this closed-loop control mode, in total, a maximum of two setpoints and actual values are taken into account. This limit arises from the number of analog inputs (r0755[0...2], AI0 to AI3) of the CU320P-2.

Three control versions can be selected for the multi-zone control:

- One setpoint, and one, two or three actual values with actual value preprocessing as average value, maximum value or minimum value
- Two setpoint/actual value pairs as maximum value control (cooling)
- Two setpoint/actual value pairs as minimum value control (heating)

In addition, day and night switchover can be selected.

Other setpoints can be entered for specific times using the day/night switchover function. For instance, an external signal or free blocks and real-time clock can be used to control the day/night switchover function.

Three parameters are used to configure the multi-zone control

- p31020 multi-zone control interconnection (i.e. activation/deactivation)
- p31021 multi-zone control configuration (selecting the control mode)
- p31022 multi-zone control, actual value preprocessing

By setting this parameter, subsequent parameterization is realized so that the processed values of analog inputs 0 to 3 are connected to the setpoint and actual value input of the technology controller, see Fig. 4-2.

More detailed information on multi-zone control is provided in the operating instructions SINAMICS G120 inverter with the CU230P-2 HVAC, CU230P-2 DP, CU230P-2 CAN, 01/2011 Control Units. An example for parameterizing a temperature control in a large office with three measuring locations is provided there.

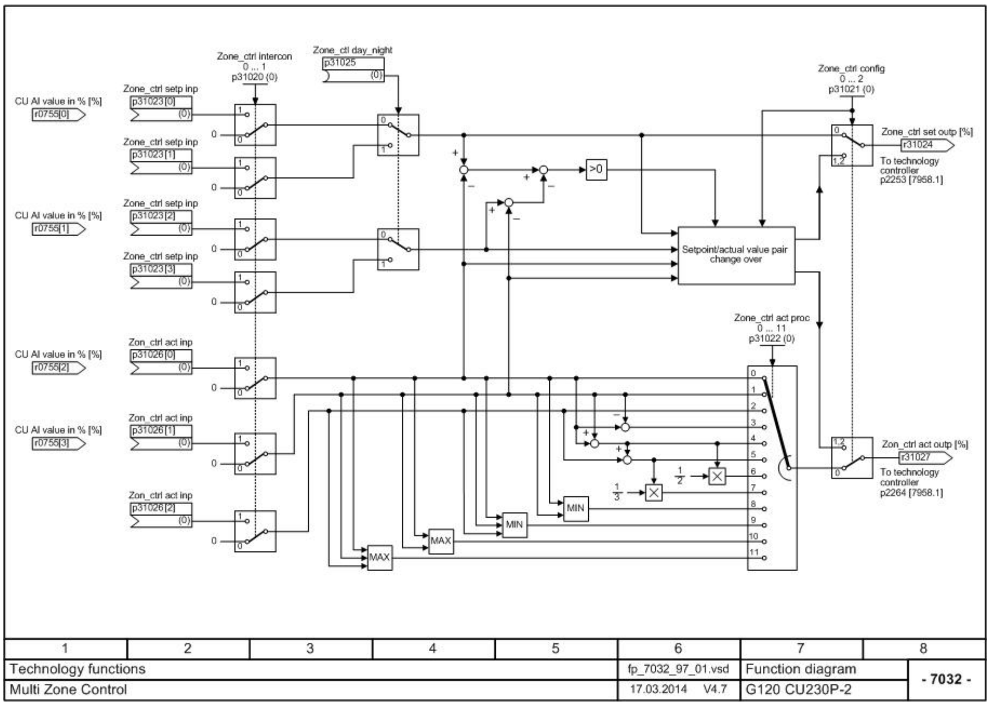


Fig. 4-2: Multi-zone control

4.3 Cascade control

Cascade control is used in applications where between one and four motors may have to be operated simultaneously depending on the load. For instance, this allows significantly varying pressures or flow rates to be handled.

Cascade control comprises the main variable speed drive and up to three additional drives. Using contactors or motor starters, these three additional drives are switched in or switched out according to a fixed assignment or depending on the operating hours.

You can find more information on cascade control in the operating instructions SINAMICS G120 inverter with CU230P-2 control units, 11/2013.

You can find a macro for the STARTER commissioning tool in the "Pressure controlled pumps SINAMICS G120P_CU230P-2“ application, entry ID 43297279. Based on this macro, in prompted dialog, you can parameterize cascade control for up to four pumps.

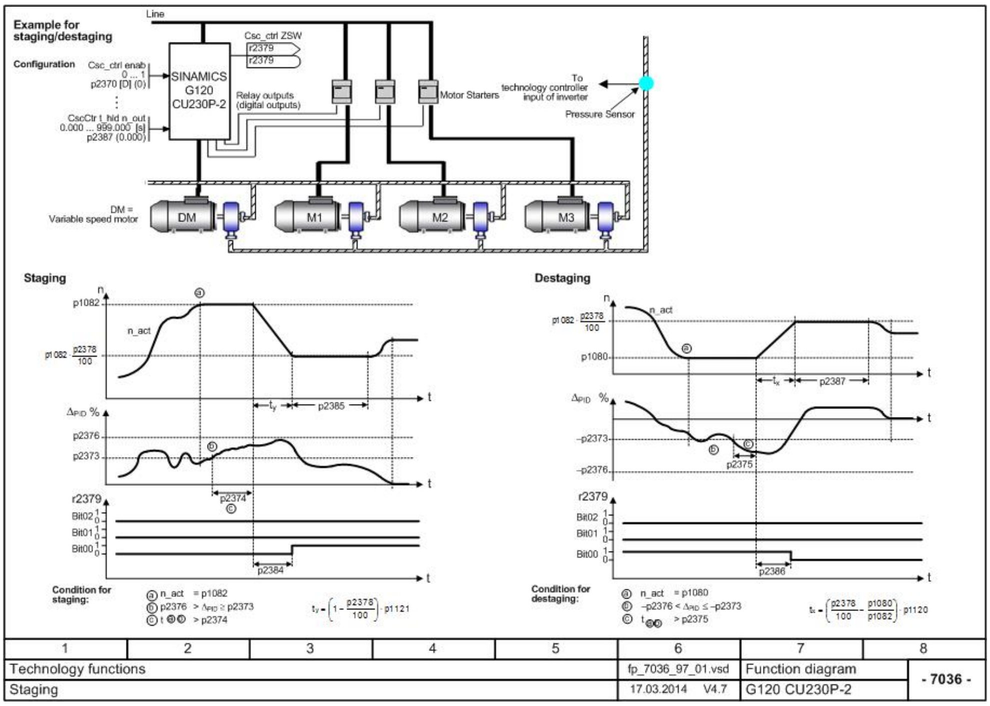


Fig. 4-3: Function diagram of motor staging

4.4 Free technology controller

In addition to the technology controller for speed control, the control module CU230P-2 includes three additional technology controllers that can be freely interconnected. Essentially, these free technology controllers correspond to the main controller; however, they have a somewhat more basic structure. These free technology controllers can be used to control additional process variables. For example, a climate control system with heating and cooling valves to process the air. In this case, the main controller controls the fan drive speed. The additional technology controllers control the cooling or heating via the two analog outputs available. In this way, several process variables can be controlled via one interface connection (that of the inverter). Override or mutually limiting controllers can be configured as they can be freely connected up.

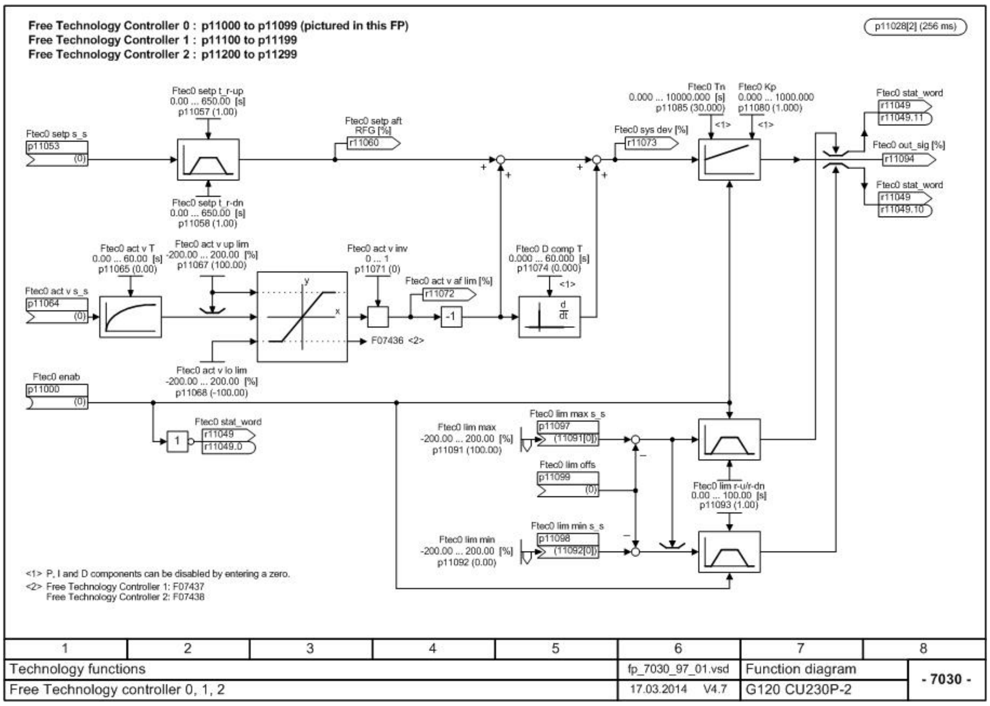


Fig. 4-4: Function block diagram of the free technology controller

5 Tuning rules for the technology controller

5.1 Practical rules

5.1.1 Selecting a suitable controller

For a controlled system with higher order compensation, to select a suitable controller type, the ratio between equivalent time constant T_G and delay time T_e can be considered:

Controllability of the controlled system	T_G/T_e	Selecting the controller
Good controllability	> 10	P controller
Controllable	10 ... 3	PI controller
Poor controllability	< 3	PID controller

Table 5-1: Selecting a suitable controller

5.1.2 Optimizing the control response

Several tuning rules have been developed to adapt the controller to a controlled system and to optimize the control response.

To optimize controllers using the Ziegler – Nichols technique, there is the oscillation technique for fast controlled systems, and for other control systems with higher orders with compensation, optimization using the inflection tangent technique.

Tuning rules according to Chien, Hrones and Reswick represent a further development of the optimization methods utilizing the inflection tangent technique from Ziegler – Nichols.

5.2 Optimization using the Ziegler – Nichols technique

5.2.1 Oscillation technique

The technique can be used for relatively fast controlled systems, e.g. speed controlled systems. However, it assumes that the control loop can be deliberately made unstable.

The parameters are practically determined at a point where the control loop is about to become instable. The control loop is only operated with the proportional component of the controller. With the setpoint constant, the proportional gain of the controller is increased until the control loop continuously oscillates with cycle T_{crit} for controller gain $K_{P\ crit}$.

Sequence

- Set the controller as P controller, $T_d = 0$ and $T_i = \infty$. Parameters p2274 (T_d) and p2285 (T_i) should be set to zero
- Increase K_P (p2280) up to the stability limit → $K_{P\ crit}$. Controlled variable x starts to oscillate at $K_{P\ crit}$. with cycle duration T_{crit}

- With values $K_{P\ crit}$. and T_{crit}, controller parameters K_P, T_n, T_V are defined corresponding to the following table

	Proportional gain K_P	**Reset time T_i**	**Rate time T_d**
P	0.50 × $K_{P\ crit}$		
PI	0.45 × $K_{P\ crit}$	0.83 × T_{crit}	
PID	0.60 × $K_{P\ crit}$	0.50 × T_{crit}	0.125 × T_{crit}

Table 5-2: Controller setting using the oscillation technique

Comment: Table values from /1/.

5.2.2 Inflectional tangent method

In the second Ziegler-Nichols tuning technique, it is assumed that a higher order controlled system can be approximately defined as first order transfer element with dead time (PT_1T_t element). To do this, K_S, equivalent dead-time T_e and equivalent time constant T_G, determined using the inflection tangent technique, must be known. This tuning technique should achieve the shortest control settling time for a permissible overshoot of the controlled variable of approx. 20%. The setting values can be taken from Table 5-3.

Controller	**Proportional gain K_P**	**Reset time T_i**	**Rate time T_d**
P controller	$1/K_S \cdot T_b/T_e$		
PI controller	$0.9/K_S \cdot T_b/T_e$	$3.33 \cdot T_e$	
PID controller	$1.2/K_S \cdot T_b/T_e$	$2 \cdot T_e$	$0.5 \cdot T_e$

Table 5-3: Controller setting using the inflection tangent technique

Comment: Table values from /1/.

5.3 Tuning using the Chien, Hrones Reswick technique

Tuning using the Chien, Hrones and Reswick technique has the advantage that the control parameters can be defined for a good response to a command variable or good response to a disturbance variable. Further, the transient recovery (settling) type can be defined to be aperiodic (without any overshoot) or with an overshoot of 20%. Also for this optimization technique, the system gain K_S, equivalent dead-time T_e and equivalent time constant T_G, must be known – or determined using the inflection tangent technique.

5.3.1 Controlled systems with compensation

The setting values for the controller parameters are listed in the following tables.

Controller	Proportional gain K_P	Reset time T_i	Rate time T_d
P controller	$0.3/K_S \bullet T_b/T_e$		
PI controller	$0.35/K_S \bullet T_b/T_e$	$1.2 \bullet T_b$	
PID controller	$0.6/K_S \bullet T_b/T_e$	T_G	$0.5 \bullet T_e$

Table 5-4: Controller setting – aperiodic – favorable response to command variables

Controller	Proportional gain K_P	Reset time T_i	Rate time T_d
P controller	$0.3/K_S \bullet T_b/T_e$		
PI controller	$0.6/K_S \bullet T_b/T_e$	$4 \bullet T_e$	
PID controller	$0.95/K_S \bullet T_b/T_e$	$2.4 \bullet T_e$	$0.42 \bullet T_e$

Table 5-5: Controller setting – aperiodic – favorable response to disturbance variables

Controller	Proportional gain K_P	Reset time T_i	Rate time T_d
P controller	$0.7/K_S \bullet T_b/T_e$		
PI controller	$0.6/K_S \bullet T_b/T_e$	$1 \bullet T_b$	
PID controller	$0.95/K_S \bullet T_b/T_e$	$1.35 \bullet T_b$	$0.47 \bullet T_e$

Table 5-6: Controller setting – 20% overshoot – favorable response to command variables

Controller	Proportional gain K_P	Reset time T_i	Rate time T_d
P controller	$0.7/K_S \bullet T_b/T_e$		
PI controller	$0.7/K_S \bullet T_b/T_e$	$2.3 \bullet T_e$	
PID controller	$1.2/K_S \bullet T_b/T_e$	$2 \bullet T_e$	$0.42 \bullet T_e$

Table 5-7: Controller setting – 20% overshoot – favorable response to disturbance variables

Comment: Table values from /2/.

5.3.2 Controlled systems without compensation

Essentially, tuning using the Chien, Hrones and Reswick technique can also be used in controlled systems without compensation, if T_b is set = 1 and K_S is set = K_{IS}.

Note According to Orlowsky /3/, PI and PID controllers are unsuitable for achieving a favorable control response.

Controller	Proportional gain K_P	Reset time T_i	Rate time T_d
P controller	$0.3/K_{IS} \cdot 1/T_e$		

Table 5-8: Controller setting – aperiodic – favorable response to command variables

Controller	Proportional gain K_P	Reset time T_i	Rate time T_d
P controller	$0.3/K_{IS} \cdot 1/T_e$		
PI controller	$0.6/K_{IS} \cdot 1/T_e$	$4 \cdot T_e$	
PID controller	$0.95/K_{IS} \cdot 1/T_e$	$2.4 \cdot T_e$	$0.42 \cdot T_e$

Table 5-9: Controller setting – aperiodic – favorable response to disturbance variables

Controller	Proportional gain K_P	Reset time T_i	Rate time T_d
P controller	$0.7/K_{IS} \cdot 1/T_e$		

Table 5-10: Controller setting – 20% overshoot – favorable response to command variables

Controller	Proportional gain K_P	Reset time T_i	Rate time T_d
P controller	$0.7/K_{IS} \cdot 1/T_e$		
PI controller	$0.7/K_{IS} \cdot 1/T_e$	$2.3 \cdot T_e$	
PID controller	$1.2/K_{IS} \cdot 1/T_e$	$2 \cdot T_e$	$0.42 \cdot T_e$

Table 5-11: Controller setting – 20% overshoot – favorable response to disturbance variables

Comment: Table values from /2/.

6 Glossary

Parameters and symbols of a control loop

The following table provides an overview of the parameters and symbols of a control loop used in this document. For comparison purposes, additional symbols that are used in technical literature are listed. The differences essentially result from the definitions in the DIN 19226 (until 2006) and DIN EN 60027-6 / DIN EN 60050-351 standards (from 2008 onwards).

Designation	DIN 19226	DIN EN 60027-6 DIN EN 60050-351
Input variable		u
Output variable		v
Manipulated variable	y	y
Controlled variable	x	x
Feedback variable	r	r
Reference variable	w	w
Disturbance variable	z	z
Control difference, setpoint deviation	e	e
Dead-time	T_t	T_L
Equivalent dead-time	T_U	T_e
Equivalent time constant	T_G	Tb
Integral time	T_n	T_i
Derivative action time	T_V	T_d

Table 6-1: Glossary

7 References

7.1 References

This list is in no way complete and only reflects a selection of suitable literature.

	Subject area	Title
/1/	Controller tuning using the Ziegler - Nichols technique	Taschenbuch der Regelungstechnik: Mit MATLAB und Simulink Authors: Professor Dr.-Ing. Holger Lutz, Professor Dr.-Ing. Wolfgang Wendt Publishing house: Deutsch Harri Gmbh; Edition: 9 (2012) ISBN: 978-3-8171-1895-3 Chapter 10.3.2, Page 478
/2/	Controller tuning according to Chien, Hrones, Reswick	Taschenbuch der Regelungstechnik: Mit MATLAB und Simulink Authors: Professor Dr.-Ing. Holger Lutz, Professor Dr.-Ing. Wolfgang Wendt Publishing house: Deutsch Harri Gmbh; Edition: 9 (2012) ISBN: 978-3-8171-1895-3 Chapter 10.3.3, Page 479
/3/	Controller tuning according to Chien, Hrones, Reswick (controlled system without compensation)	Praktische Regeltechnik: Anwendungsorientierte Einführung für Maschinenbauer Author: Professor Dipl.-Ing. Peter F. Orlowski Publishing house: Springer; Edition: 9 (2011) ISBN: 978-3-642-19216-6 Chapter 4.1.2, Page 148

Table 7-1: References

7.2 Internet links – data

This list in no way complete and only reflects a selection of suitable information.

	Subject area	Title
\1\	Reference to the article	http://support.automation.siemens.com/WW/view/de/BeitragsID
\2\	Siemens Industry Online Support	http://support.automation.siemens.com
\3\	General rule of thumb technique	http://de.wikipedia.org/wiki/Faustformelverfahren_(Automatisierungstechnik)
\4\	Closed-loop control technology	http://en.wikipedia.org/wiki/Control_theory

Table 7-2: Internet links

8 History

Version	Date	Change
V1.0	05/2014	First Edition

Table 8-1: History