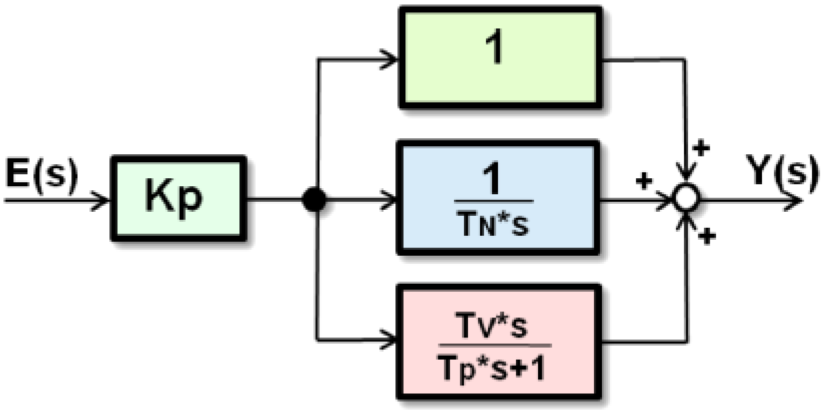
DC Power Supplies Series TopCon



Manual for

Standard Controller Parameterization

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1. Principles of Closed Control Loops

Continuous automatic control is a self-correcting system which maintains a given parameter on or close to a predetermined level. The following application note highlights how TC.GSS systems achieve this across a variety of applications.

Control systems always have a loop structure, because the actual value of the controlled quantity is sensed and fed back to an error detector. The error detector unit compares either continuously (analogue controller) or at regular time intervals (digital controller) the following two values:

a) **set value W:** given set condition, i.e. voltage, speed, temperature
b) **actual value X:** actual measured value

The deviation is then determined. A signal passes a PID amplifier stage and acts as **controller output Y** directly on the power stage.

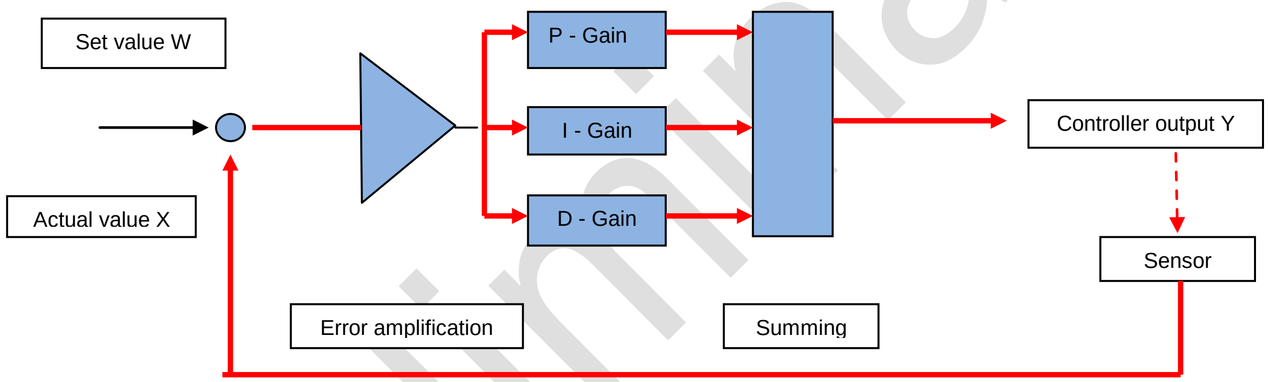


Figure 1: Closed control loop scheme

Figure 1 illustrates the loop structure. The blue circle on the left represents the error detector feeding the time dependent PID network and summing. Functionality of the PID stage will be explained later within this document.

Please note, the controller loop function described above is the same with analogue or digital controllers. While analogue controllers use concrete signal amplitudes (e.g. voltage), digital controllers work with digital numbers representing the quantities.

Topcon Controllers are fully digital. 12 bits are allocated for each value ensuring a resolution of 0.025%. The small stepping value provides a granular but even control along the full scale value. Instead of electronic elements, digital controllers use specialised calculation algorithms in order to determine the PID portion of the loop signal. The advantages of digital controllers are: perfect reproducibility, lack of any ageing or drift and the possibility to implement a variety of special functions into the controller.

2. Controller Parameters

2.1 General Information

A control system has four basic attributes:

a) Stability
b) Accuracy
c) Speed
d) Minimal overshoot (damping)

These are partially contradictory and therefore need to be optimised for best results. A control loop cannot be set to optimise all of the above mentioned attributes. Take the attributes ‘stability’ and ‘speed’ as an example. A very fast setting of the controller will offer quick responses, but will always lead to instabilities or significant overshoots if applying step changes.

A satisfactory setting of PID parameters takes all 4 attributes into account.

These attributes require a certain amount of ‘computing’ with respect to the error signal to ensure a good compromise for the overall system. An important parameter of a system is the timely behaviour of the load, e.g. the time lag between the application of power and the response of the system.

Take a room heating system as an example:

At the time of switching the system on, the room may have a significant undertemperature. The controller will force the heater to send the maximum amount of heat energy possible into the room. As the temperature rises, the error detector still detects an undertemperature room so the power will remain on full. At a certain moment, the set point of temperature is met. The error becomes zero and the power is switched off. Due to the energy still present in the heater, the temperature will overshoot significantly. As the temperature falls again below the set point, the heater is again powered up. However, due to thermal inertia, a timelag will be experienced while the energy is transmitted and re-heats the room. So the room temperature will ‘underswing’ the set point. As a result, this heating system will produce a steady oscillating room temperature instead of a continuous and stable one.

The **PID section of a control system** introduces a time-defined response to the control path. The signals produced aim to to keep the controlled quantity stable within close limits, even at the occurrence of a perturbation.

The main controller parameters are:

- **P = proportional part**
- **I = integral part**
- **D = differential part**
- **(Adaptive part)** for special cases used in TC.GSS power supplies

The goal of adapting the PID parameters of a control loop is to provide a stable, accurate, fast and well damped system. This process is called **'controller parameterisation'**, the corresponding PID parameter values is called the **'parameter set'**.

Each TC.GSS unit is shipped with a default set of PID parameters which give satisfactory results for a wide variety of electrical loads. The system's fast response times mean that no further tuning is required for the majority of applications.

Nevertheless, highly complex loads with lengthy time constants (either inductive or capacitive) may need adaption of the PID controllers for satisfactory operation. The same applies to special operational conditions such as pulsed loads or oscillatory electrical networks. In such cases parameter optimisation provides stable outputs even in extreme conditions.

How to detect non-optimum PID parameterisation

The symptoms of an inadequate parameterisation of the control system are:

- Instability: The control process does not settle, the actual value periodically or aperiodically oscillates or fluctuates.
- Damping: The control process results in a slow and too much damped controller reaction.
- Speed: The control process takes too much time, particularly the voltage drops/rises significantly at a load step.
- Accuracy: The residual control loop error is significant.
- Dynamics: The controller reaction to load steps or set value steps is insufficient.

Controller parameterisation can be optimised by means of exact computed models. However this method assumes an extensive knowledge of the time response of all elements of the complete controller chain and the load itself.

Parameter optimisation "by hand" is the most usual method which needs some basic knowledge of the controller system and a tool for characterising the controller operation. TC.GSS systems provide an easy- to-use SCOPE function via the TopControl software. This monitors all controller signals such as voltages, current and further quantities without the need for external measurement equipment.

In the following section, the basic functions of the three controller parameters P, I & D are discussed more in detail.

2.2 The Proportional Parameter P

Parameter name:

- P – gain , or
- P – part, or
- P – amplification, or
- Occasionally Xp

Effect:

The P–gain generates a controller output Yp. This is proportional to the actual control loop error (deviation between set and actual value). Therefore the P–gain determines the magnitude of the controller output Yp caused by a given control loop error. The larger the P–gain parameter is, the larger the controller output Yp will be with respect to a given control loop error.

Note:

The P-part of the controller appears immediately after a (W – X) loop error.
In case of zero control loop error, no controller output Yp is produced at all.

A pure P-controller is very fast acting, but not able to adjust the loop to zero error. This is because at zero error, the controller output Y will also be zero, therefore no energy will be transferred towards the load.

Properties of the P-gain Parameter:

- The P–controller part reacts very quickly to any changes in load or set values.
- A control system which consists only of the P–controller part is unable to control a loop without a residual error, because no error results in no controller output Yp.
- The larger the P–gain parameter, the smaller the residual error will become.
- The larger the P–gain parameter, the more instable and time-critical the control loop will become.

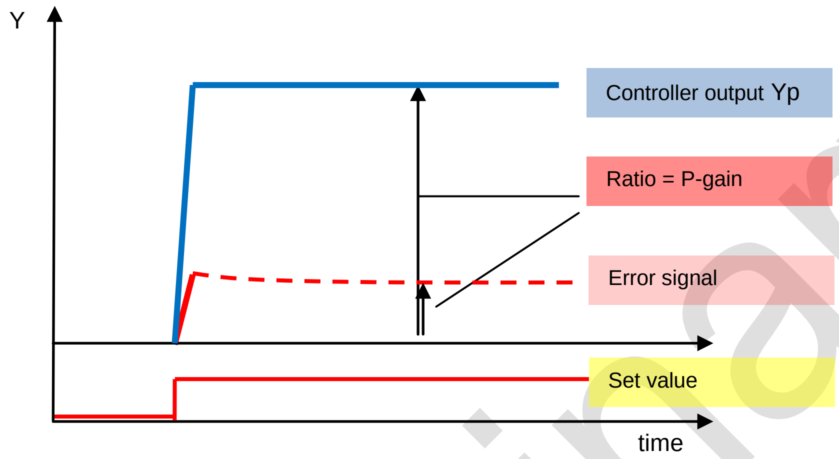


Figure 2: P-gain

Figure 2 shows the function of P-gain: At zero error, the output (blue) is zero also.
If an error (red) exists, the output equals: ERROR * P-gain

Functional description: At the timepoint of a set value step, the error signal steps immediately to the actual difference value between the set value and the actual value. This in turn creates a controller output signal of the amplitude:

Yp = (Set value – actual value)*P-gain (Observe the red and blue traces in Fig. 2)

The P-gain parameter allows for the adaptation of the basic controller sensitivity and plays an important role for the optimisation of the controller.

2.3 The Integral Parameter I

Parameter name:

- I – gain parameter, or
- Ti – integral time, or
- Tn– integral reset time

(Ti and Tn: time constants)

Effect:

The controller output Yi is generated by an integration of the control loop error over time. Depending on the actual control loop error, which can be positive or negative, a "pool" is filled up or emptied. A small error means only a small rate of filling the pool and vice versa. The level of the pool represents the integral controller output Yi. This controller output, as shown in figure 1, is summed together with the P-gain. This has an impact on the power electronic stage of the above mentioned proportional output.

The larger the control loop error is, the quicker the "pool" fills itself up. Therefore the quicker the controller output Yi starts to have an effect on the control process.

The same applies for the integral parameter: the higher 'I' is, the quicker the "pool" fills itself up at a given control loop error.

Note: A high 'I' – gain parameter value stands for a fast response time of the I-part

Example

In some circumstances the P-gain of a control loop is not able to remove the residual error completely. Introducing an additional I-gain path adds to a 'pool' which is initially empty. Due to the residual error, the pool is filled steadily, increasing the controller output respectively. This in turn reduces the error further and further until the error approaches zero. At this point, the P-part also approaches zero (see the formula above for Yp on the previous page). The process is now balanced and kept up only by the 'pool filling level'. The controller output Y now represents the I-part exclusively. These conditions last upon the changing of test conditions, e.g. a load change or a disturbance appearing externally. In this case an error signal is created which restarts the controlling function.

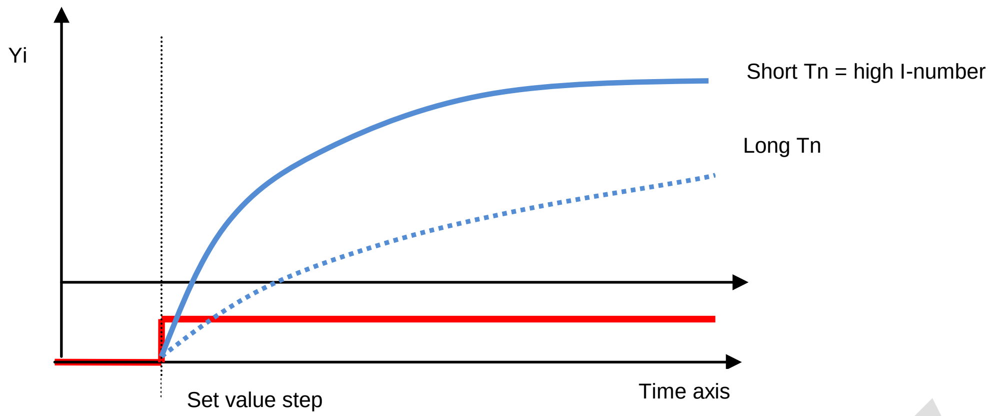


Figure 3: Time response of the I–controller part

Properties of the I–gain parameter:

- The I-controller works more slowly than the P-controller.
- Given an adequate controller parameterisation, by means of the I-gain parameter, the residual error will be adjusted to zero.
- *In the case of a negative error, the positively filled pool has to be emptied accordingly – this requires some amount of time. Therefore, an I-controller tends to slow down the control process.*
- Given an inadequate controller parameterisation, the “integral pool” may overflow or reach a limit.
- As with P-controllers, inadequate I-parameters may destabilise the control loop until it results in permanent oscillations.
- A combination of P-path with I-control path is called a ‘P/I-controller’ and allows for sufficient fast and accurate controlling processes in most cases.

2.4 The Differential Parameter D

Parameter name:

- D–gain, or
- Td (differentiation time constant)

Effect:

The D–controller part is distinctly dynamic and refers to the **rate of change** of the control loop error.

The faster the loop error changes, the higher the value of the D-part of the controller. On the other hand, a constant control loop error does not cause any D–part controller output (rate of change = zero).

Often the D–part is described as a derivative. The D–signal immediately goes against the controller error and re-establishs stationary conditions after a step.

Comment:

As the D–part parameter is highly dynamic, the influence on the loop response may be very high. An adjustment by hand has to be made with caution as the control loop can become unstable very quickly. The D-part is helpful in certain high dynamic applications, in order to make the loop quicker in the event of a step of either the set value or the actual value.

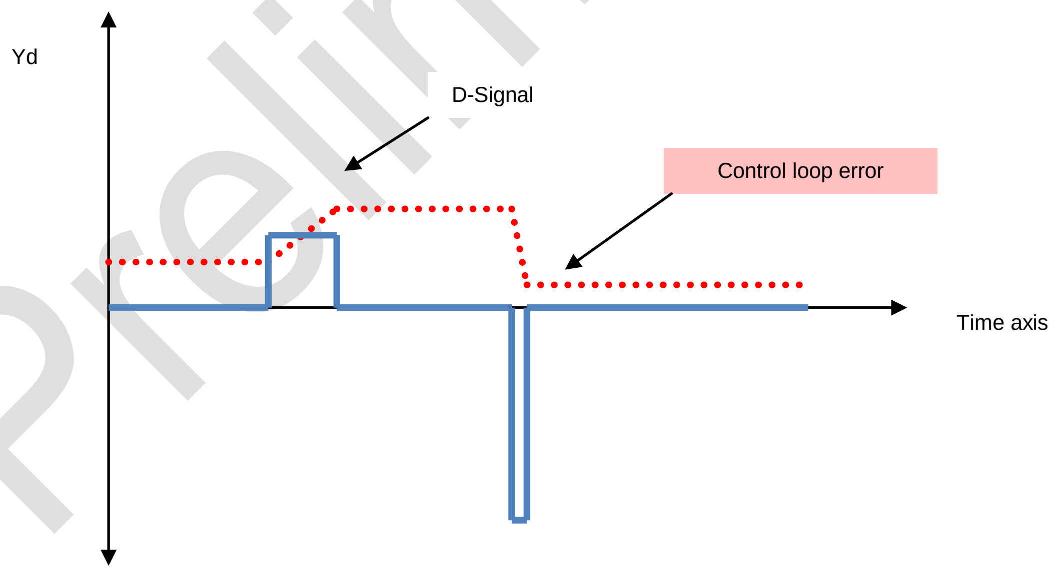


Figure 4: Time response of the D–controller part

It can be seen from figure 4 that the magnitude of the D–signal depends on the velocity of change and the direction of change of the control loop error.

2.5 PID Combined Controller Output

In practice, all PID channels are summed to form a PI or a PID controller structure. This summed signal is the controller output Yc, which is working directly on the power stage. In order to highlight the control loop states, these conditions are to be distinguished:

a) The balanced state (zero error, stable loop condition)
- The P-channel gives zero output (no error)
- The I-channel gives the output necessary to fulfil the condition for ‘zero error’
- The D-channel gives zero output

b) The system response to a step change
- The P-channel gives a value Yp= (W-X)*P-gain
- The I-channel fills the ‘pool’ according to the error signal and the I-settings
- The D-channel gives a signal derived from the ‘rate of rise/fall’ of the error signal
  and helps the controller to reach the ‘zero error state’.

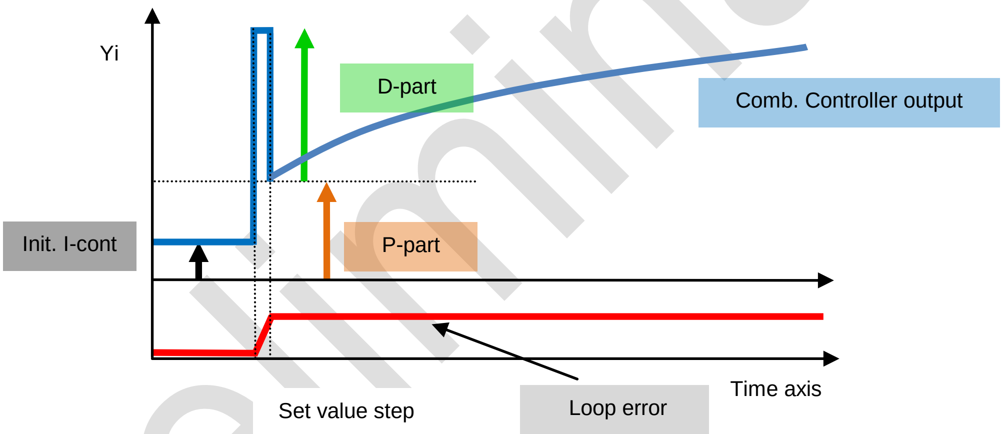


Figure 5: Combined controller output at a set value step

Figure 5 shows the response of the controller to a step change of the set value. At the step time, the P-part immediately rises to the value given by the formula in section 2.2. If the D-part is programmed, this value is summed with the P-value, giving a ‘spike’ during the rise time. From then on, the I-part fills up with a rate determined by the I-parameter and by the momentary loop error value. As the actual value X is approaching the set value W, the error becomes smaller and smaller. Therefore the P-value is reduced more and more, while the I-value is filled up until the error is corrected.

3. Controller Parameterisation

3.1 Controller Structure

3.1.1 CP-CC-CV-Ri Structure

Figure 6 depicts the basic controller structure of TC.GSS power supplies. The two controllers for current and voltage work in parallel (see figure 1). The power controller is superposed onto the current controller and assumes control if the upper power limit is reached.

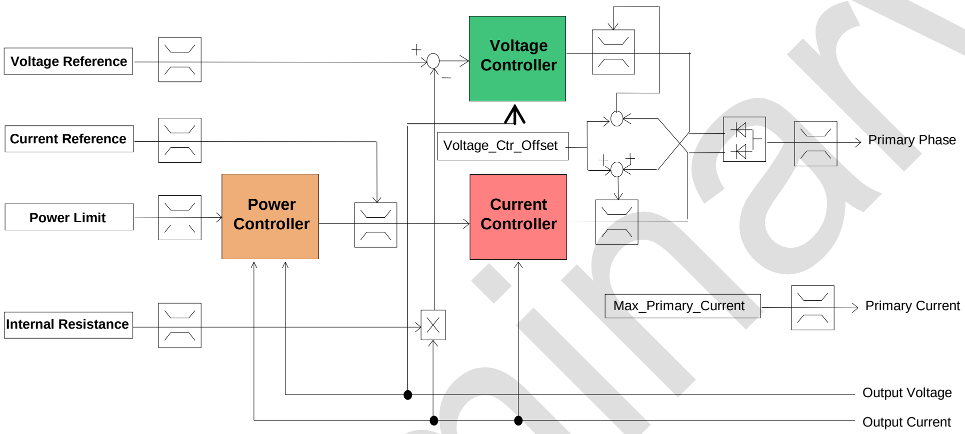


Figure 6: Basic controller scheme of TC.GSS

3.1.2 Operation of the Controller Scheme

As long as the given power limit is not exceeded, then both the voltage controller and current controller operate in parallel. A signal is given by both the voltage and current controllers to a 'lower than' electronic circuitry. The controller feeding the smaller voltage is selected to drive the output signal 'Primary Phase'.

Assuming that the voltage controller is working to maintain the voltage constant (CV mode of operation) and the current is below the current set value, then the current controller will have no influence on the control process. If the current rises due to lower load impedance and reaches the set current level, then the current controller will take over from the voltage controller. This results in the voltage no longer being controlled, in favour of the current which is now held constant. The parallel structure allows for a fast change from one controller to the other within a fraction of a msec.

If the power limit is reached, the power controller will reduce the actual current limit to a level within the preset power level.

3.1.3 Setting of the Parameters

Power, current and voltage controllers have default parameter settings which are adequate for a wide variety of load impedances.

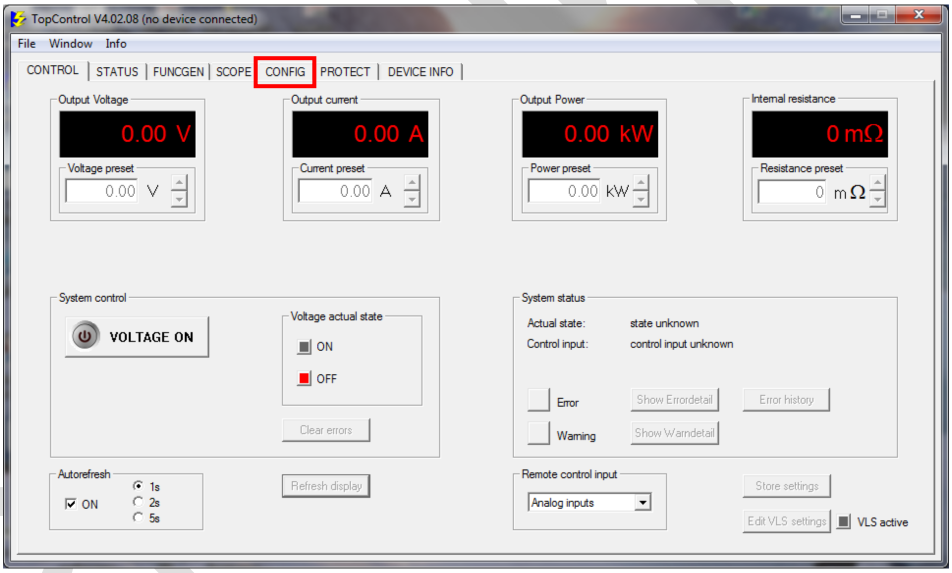
Complex loads such as high capacitance or pulsed short circuit conditions may require an adjustment of the controller parameters to achieve optimum performance.

Optimum controller parameterisation can either be calculated or evaluated by trial and measurement under real load conditions.

The controller parameterisation when performed by hand during operation of the power supply is discussed below. For the following procedure it is highly recommended to use an external oscilloscope or the TopControl SCOPE function to monitor the load voltage and/or current. See the main TC.GSS operating manual for further details of the integrated scope function.

In operation mode, the “inner controller” is optimised in the first step, while the superposed controller follows in the second step.

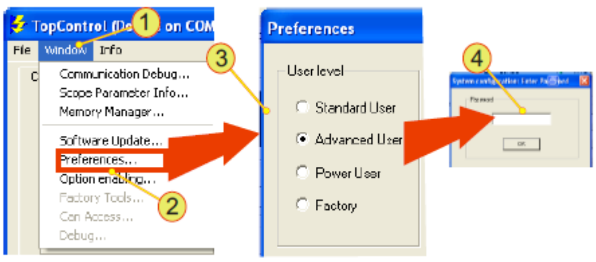
Opening the CONFIG tab



The CONFIG tab within the TopControl software provides access to the parameter set. If the CONFIG and PROTECT tabs are not shown when your PC is connected to the TC.GSS the you need to enter ‘Advanced User’ mode.

To reveal the Config Tab

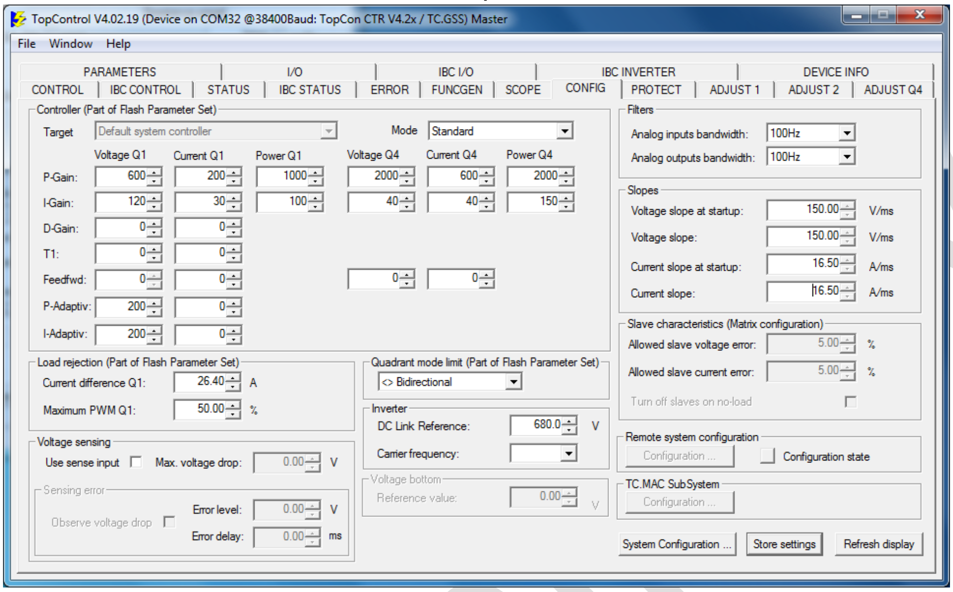
1 -> Select Window
2 -> Select Preferences
3 -> Check Advanced User
4 -> Enter password: *kilowatt*
5 -> Restart TopControl



3.2 Typical Controller Settings in Practice

3.2.1 Factory settings at delivery

Table 1 lists the factory default parameters. This parameter set will work well with a variety of loads. An adaption of parameters is only advised, if the static or dynamic behaviour of the TC.GSS is not acceptable.



Controller Parameter Settings:

Parameter	Voltage Q1	Current Q1	Power Q1	Voltage Q4	Current Q4	Power Q4	Remarks
P-Gain	600	200	1000	2000	600	2000	
I-Gain	120	30	100	40	40	150	
D-Gain	0	0					
T1	0	0					
Feedfwd	0	0		0	0		Not used yet
P-Adaptiv	200	0					
I-Adaptiv	200	0					

Table 1

3.2.2 Working into a capacitive mode, voltage control (CV-Mode)

Rule of thumb : P-gain: Voltage controller : 600 + #µF (number of µF's)
I-gain: 15 / #mF (number of mF's)

Controller Parameter Settings:

Parameter	Voltage Q1	Current Q1	Power Q1	Voltage Q4	Current Q4	Power Q4	Remarks
P-Gain	#	200	1000	#	600	2000	
I-Gain	#	30	100	#	40	150	
D-Gain	0	0					
T1	0	0					
Feedfwd	0	0		0	0		Not used yet
P-Adaptiv	200	0					
I-Adaptiv	200	0					

Table 2

Working into an inductive load, current control (CC-Mode)
Rule of thumb : With increasing inductance increase the P-gain of the current controller while decreasing the I-gain of Current Controller

Controller Parameter Settings:

Parameter	Voltage Q1	Current Q1	Power Q1	Voltage Q4	Current Q4	Power Q4	Remarks
P-Gain	600	#	1000	2000	#	2000	
I-Gain	120	#	100	40	#	150	
D-Gain	0	0					
T1	0	0					
Feedfwd	0	0		0	0		Not used yet
P-Adaptiv	200	0					
I-Adaptiv	200	0					

Table 3

3.2.3 Using the TC.GSS in a Multi-Unit environment

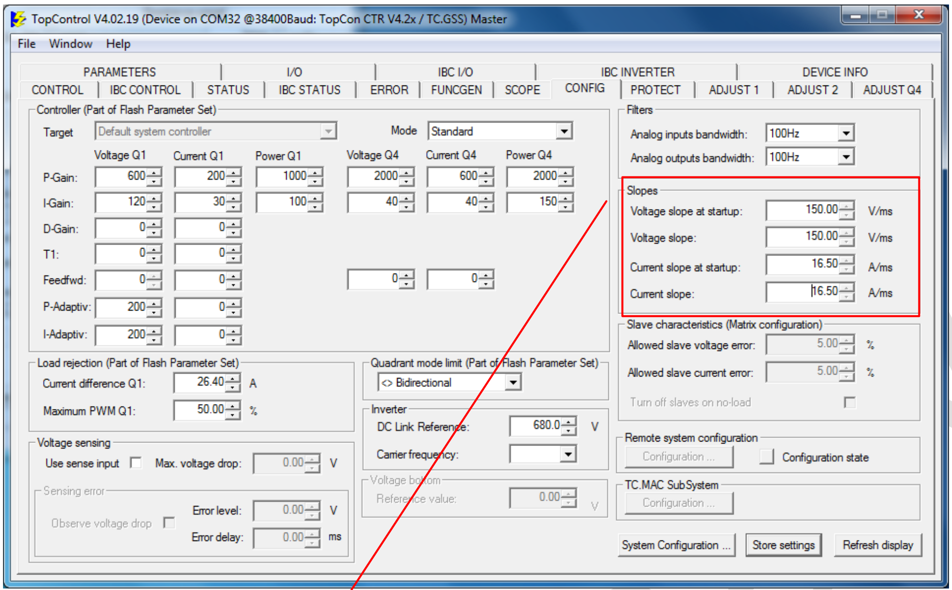
Table shows a typical set up for a system comprising of 2 * TC.GSS modules connected in parallel to form a 64 kW / 500V system.

Controller Parameter Settings:

Parameter	Voltage Q1	Current Q1	Power Q1	Voltage Q4	Current Q4	Power Q4	Remarks
P-Gain	600	600	1000	300	500	2000	
I-Gain	30	30	100	40	40	150	
D-Gain	0	0					
T1	0	0					
Feedfwd	0	0		0	0		Not used yet
P-Adaptiv	200	200					
I-Adaptiv	200	400					

Table 4

3.3 Voltage and Current Slopes



Voltage slope & slope at startup

This parameter may be used to give the voltage set value a ‘ramp’ functionality. A change in the voltage set value will occur according to the rate of rise according to this setting.

- Slope at startup: ramp function activates only at the ‘VOLTAGE ON’ command
- Voltage slope: The preset ramp value is active all the time

Current slope & slope at startup

This parameter enables the user to adjust the ramp time of the output current. The rate of rise is therefore controlled according to this setting.

- Slope at startup: The current ramp activates only at the ‘VOLTAGE ON’ command
- Current slope: The preset ramp value is active all the time

Note, that the ‘Slope at startup’ function may eventually be terminated automatically. If the current rise is too fast then the current controller will take over the process.

3.4 Constant Voltage Mode Optimisation

Connect your load to the unit and monitor the system voltage and current either by Topcontrol 'SCOPE' or by an external oscilloscope. Refer to the TC.GSS manual for details of SCOPE functionality. If you encounter unsatisfactory results or want to optimise the dynamic response then proceed as follows:

Load:	• Rather high impedance, e.g. $R_{Load} > R_{nom} > (V_{nom} / I_{nom})$
Set values for test:	• $V_{ref} = 0.1$ to $1 * V_{nom}$ (or your load device voltage) • $I_{ref} > V_{ref} / R_{Load}$: **This ensures that the voltage controller and not the current controller is active.**
Step 1:	• Voltage-D-Gain = 0 (default setting) • Voltage-I-Gain = 0 • Voltage-P-Gain: to be increased from small values (100) to > 1000, until the output voltage is tending to oscillate. Then reduce the voltage-P-Gain sufficiently to reach stable conditions.
Step 2:	• Voltage-I-Gain: to be incresed from zero (to ca. 20 to150), until the output voltage shows no residual error any more.
Step 3:	• Run some set value steps either by hand control or automated by TFE function generator and check for correct settling of voltage/current. If necessary, repeat steps 1 and 2

Table 5

Note:

If the set value of the Integral-part is low (Voltage-I-Gain in this case), then the robustness is increased. However, low integral values also cause the controller speed to decrease.

3.5 Constant Current Mode Optimisation

Note that the current controller can only be set in CC mode, if the voltage controller is not operative. This can be achieved by running low impedance loads well below the nominal load. Thus R_{test}<(Rnom = Unom/Inom).

Load:	• Rather low impedance, e.g. RLoad = 0.1 to 0.5 * Rnom
Set values:	• Iref = according to the choosen R_{test} • Vref ≥ Iref * RLoad: **This ensures that the current controller and not the voltage controller is active.**
Step 1:	• Current-I-Gain = 0; Current D-gain = 0 • Current-P-Gain: to be increased from small values (50) to some 1000, until the output current begins to oscillate. Then reduce the current-P-Gain sufficiently to have stable output
Step 2:	• Current-I-Gain: to be increased from small values to max. ca. 1000, until the output current shows no residual error any more and response is satisfactory.
Step 3:	• Run some set value steps either by hand control or automated by TFE function generator and check for fast rise and settling of voltage/current. If necessary, repeat steps 1 and 2

Table 6

Note:

- The Integral-part should be as low as possible (Current-I-Gain) as this increases the robustness.
- The smaller the load impedance, the smaller the values (especially for the Integral-part).

3.6 Constant Power Mode

Step 1:	• Power-I-Gain = 0 • Power-P-Gain: to be increased from small values (100) to some 1000, until the output current begins to oscillate. Then reduce the power-P-Gain to half or quarter of the value.
Step 2:	• Power-I-Gain: to be increased from zero (to max. ca. 1000), until the output current shows no residual error any more.

Table 7

Note:

- The Integral-part should be set as low as possible (Power-I-Gain) because this increases the robustness.
- The smaller the load impedance, the smaller the values (especially for the Integral-part).

3.7 Load Steps and Their Parameterisation

In order to adjust the parameters with regard to optimum load step regulation, load steps should be generated by switching on and off load impedances (e.g. with external IGBT-switches). By doing so, the controller parameters can be fine tuned in order to increase the dynamics or minimize the overshoot.

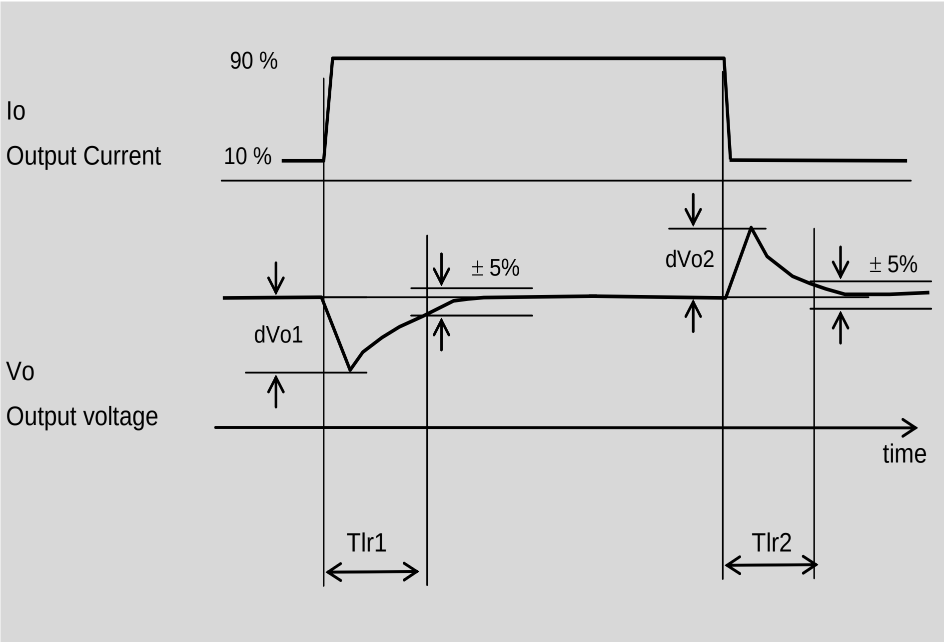


Figure 7: Load step characteristics

An important requirement is a robust and stable basic setting of the controllers. By applying load or set value steps, the dynamic behaviour can be optimised step by step. This can be achieved by using the capability of the TC.GSS to accept parameter changes during full operation.The SCOPE function found within the TopControl software provides a convenient method for observing the response after adjustment of the controller settings. This allows optimisations to be done quickly and effectively.

Note: that during value steps the CC/CV modes may swap according to load conditions. This in turn affects the optimisation process:

Unnecessary control mode (CC/CV) swaps should be avoided by appropriate adjustment of the individual controllers.

Tlr1 and Tlr2 : In the order of 2-4 msec with Standard Controller
dVo1 and dVo2: In the order of 10% of nominal voltage*

* When working within the ‘continous current region’ above some 10% of the nominal current.

3.8 Load Step Application Specific Examples

A variety of application specific examples are demonstrated below. The screenshots show the Topcontrol SCOPE tool being used. The SCOPE function is provided within the standard software that is provided with the unit. TopControl can also be downloaded from the software section of the website here

In addition to voltage and current traces, the controller Y-output (PWM_ref) and the Constant Voltage signal (Const_Volt_module) are shown.

3.8.1 Optimisation of the Current Controller in Stationary Conditions

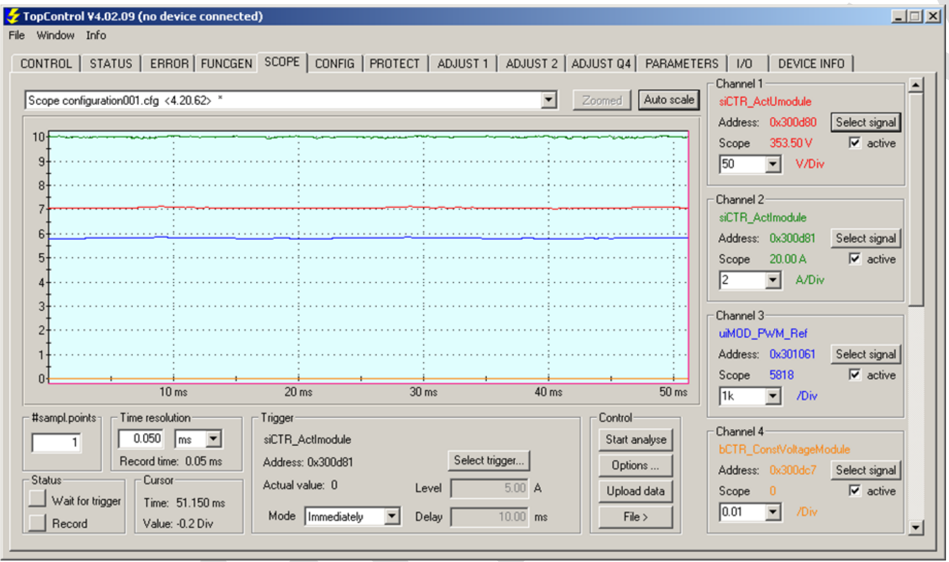


Figure 8: Stable output Actual values: 363V / 20A

Scope signals: red = voltage; green = current; blue = controller output; amber: controller state

3.8.2 Current step into a Resistive Load

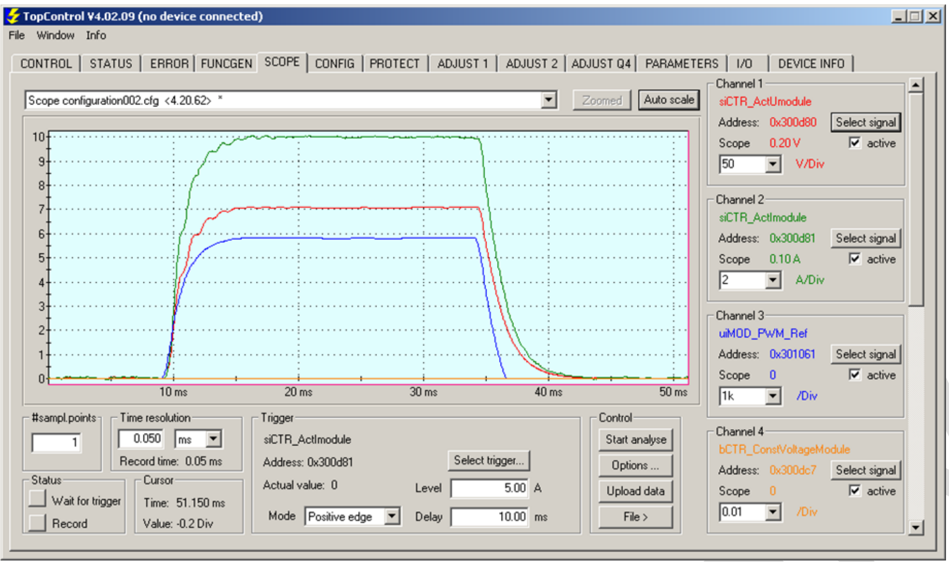


Figure 9:

Controller Parameter Settings:

Parameter	Voltage Q1	Current Q1	Power Q1	Voltage Q4	Current Q4	Power Q4	Remarks
P-Gain	600	700	1000				
I-Gain	120	280	100				
D-Gain	0	0					
T1	0	0					
Feedfwd	0	0					Not used yet
P-Adaptiv	200	0					
I-Adaptiv	200	0					

Figure 9 shows a stable setting of the current controller, amplitude 20ADC. The controller always runs in the CC mode as displayed by the amber trace. The pulse rise time 10% to 90% Iset is about 2msec, a typical value for TC.GSS family.

By using the **‘NT controller’ facility**, these rise times may be reduced significantly. See section 4 for details.

3.8.3 Current step into a Resistive Load: Current-I-Gain too slow

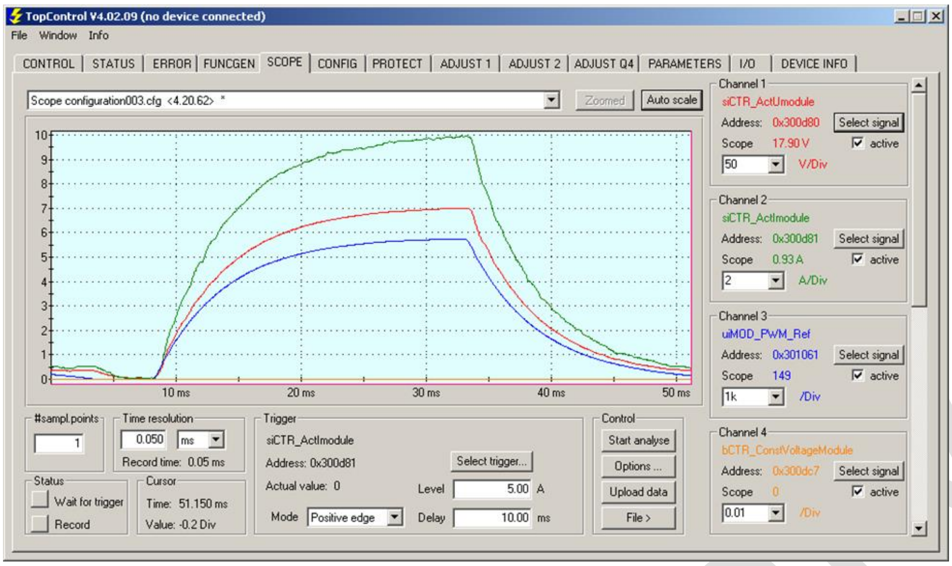


Figure 10:

Controller Parameter Settings:

Parameter	Voltage Q1	Current Q1	Power Q1	Voltage Q4	Current Q4	Power Q4	Remarks
P-Gain	600	700	1000				
I-Gain	120	70	100				
D-Gain	0	0					
T1	0	0					
Feedfwd	0	0					Not used yet
P-Adaptiv	200	0					
I-Adaptiv	200	0					

In this example, the controller I-gain is set too low according to a slow integration time. The rising and falling edges are stable, but quite slow. This is because the Current-I-Gain controller has been set to 70 rather than 280 as shown in Fig. 9.

3.8.4 Current step into a Resistive Load: Current-P-Gain too high

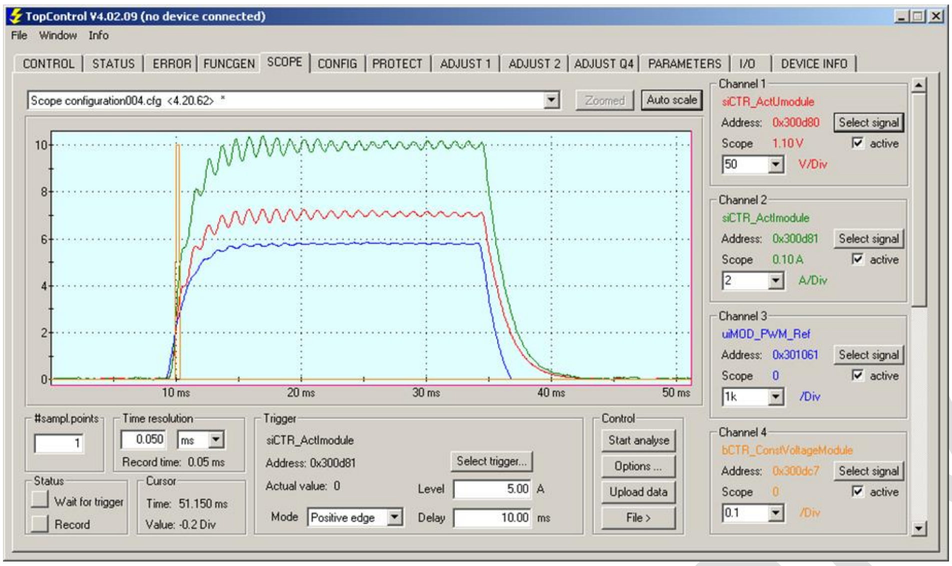


Figure 11:

Controller Parameter Settings:

Parameter	Voltage Q1	Current Q1	Power Q1	Voltage Q4	Current Q4	Power Q4	Remarks
P-Gain	600	3000	1000				
I-Gain	120	280	100				
D-Gain	0	0					
T1	0	0					
Feedfwd	0	0					Not used yet
P-Adaptiv	200	0					
I-Adaptiv	200	0					

The Current Controller P-gain in figure 11 is set too high resulting in an almost permanent oscillation of both current and voltage. This is caused by the Current -P-Gain controller being set to 3000 which is over 4 times the stable value of 700 shown in Fig 9)

Note:

- Current rise and fall times are faster than in figure 9.
- Oscillation of the DC output current of several Amps is not ideal and should be avoided.

3.8.5 Current step into a Capacitive Load

Highly capacitive loads present special conditions to the controller, as a step in voltage is no longer possible. Therefore, a current flow is necessary to alter the voltage of the capacitive load.

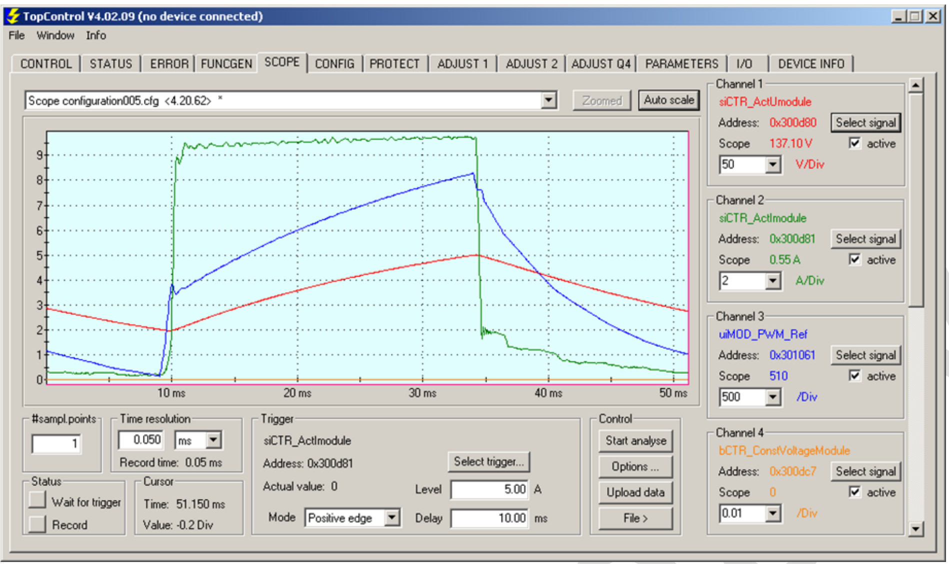


Figure 12:

Controller Parameter Settings:

Parameter	Voltage Q1	Current Q1	Power Q1	Voltage Q4	Current Q4	Power Q4	Remarks
P-Gain	600	2000	1000				
I-Gain	120	150	100				
D-Gain	0	0					
T1	0	0					
Feedfwd	0	0					Not used yet
P-Adaptiv	200	0					
I-Adaptiv	200	0					

The green trace shows the programmed current step into a capacitive load. While the current settles within a very short time of <1msec, the voltage (red trace) increases during the current pulse time. Blue trace = controller output Y.
The Current Controller settings (P-gain=2000; I-gain=150),are typical for capacitive loads.

3.8.6 Current step into a Capacitive Load: Current-P-Gain too high

If the P-gain is set too high the result is often damped oscillations at the leading edge of a pulse. If the P-gain is increased further, a steady oscillation will occur.

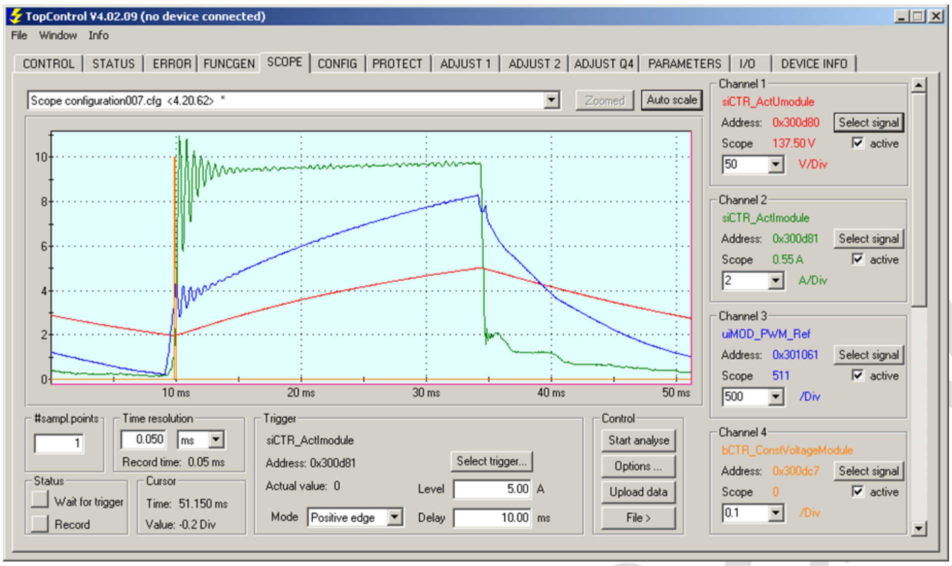


Figure 13:

Controller Parameter Settings:

Parameter	Voltage Q1	Current Q1	Power Q1	Voltage Q4	Current Q4	Power Q4	Remarks
P-Gain	600	3000	1000				
I-Gain	120	150	100				
D-Gain	0	0					
T1	0	0					
Feedfwd	0	0					Not used yet
P-Adaptiv	200	0					
I-Adaptiv	200	0					

The only setting difference is the increase in the Current-P-Gain. Reducing it back to 2000 will achieve satisfactory results as shown in figure 12.

3.8.7 Current step into an Inductive Load

In this example, the controller is well parameterised, giving a stable output.

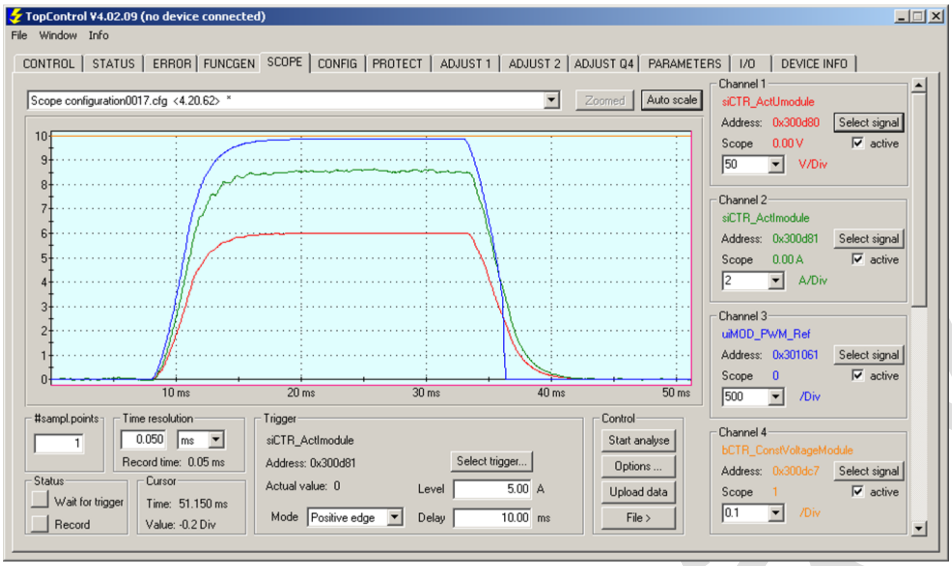


Figure 14:

Controller Parameter Settings:

Parameter	Voltage Q1	Current Q1	Power Q1	Voltage Q4	Current Q4	Power Q4	Remarks
P-Gain	500	2000	1000				
I-Gain	50	150	100				
D-Gain	0	0					
T1	0	0					
Feedfwd	0	0					Not used yet
P-Adaptiv	200	0					
I-Adaptiv	200	0					

3.8.8 Current step into an Inductive Load: Voltage-I-Gain too low

In this example, the controller output raises too slowly due to a low setting of the Voltage controller I-gain (30) instead of (50).

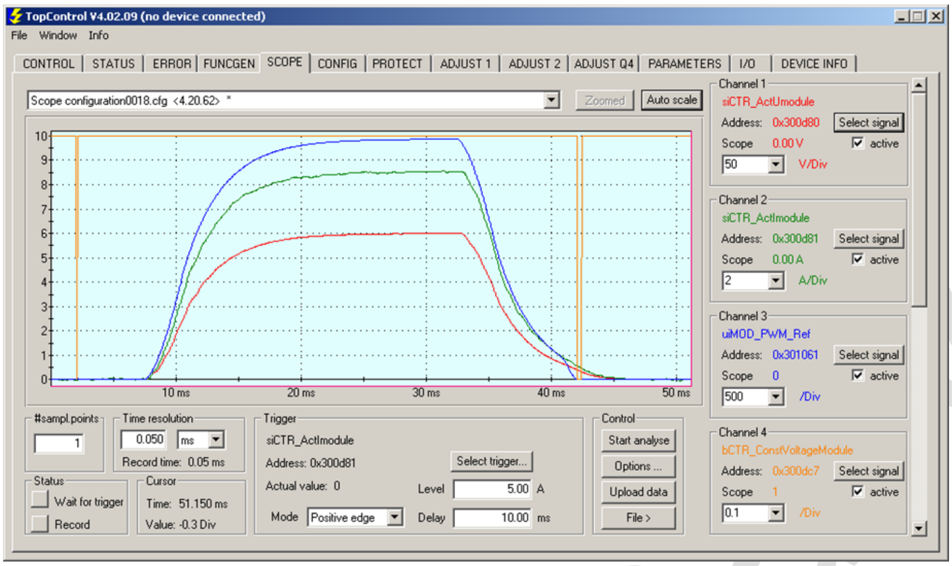


Figure 15:

Controller Parameter Settings:

Parameter	Voltage Q1	Current Q1	Power Q1	Voltage Q4	Current Q4	Power Q4	Remarks
P-Gain	500	2000	1000				
I-Gain	30	150	100				
D-Gain	0	0					
T1	0	0					
Feedfwd	0	0					Not used yet
P-Adaptiv	200	0					
I-Adaptiv	200	0					

3.8.9 Complex Load Example: Periodic Cycling of a Battery

A battery forms a rather complex load as from zero volts up to V_{batt} no current will flow. As soon as the power supply voltage reaches $V_{batt,}$ the current will rise rapidly due to the low impedance of batteries.

Cycling batteries means that this process will appear also in discharge mode. Therefore the TC.GSS has to switch between Q4 (sink) mode and Q1 (source) mode periodically. Optimising the unit for this case may not only need adjustment of the PID controllers, but may also require the 'Adaptive parameters' to be altered. The P-Adaptiv and I-Adaptiv controllers work mainly in the low current range to speed-up the current rise and fall times. The adaptive controllers also affect the quadrant changeover time. See the example below:

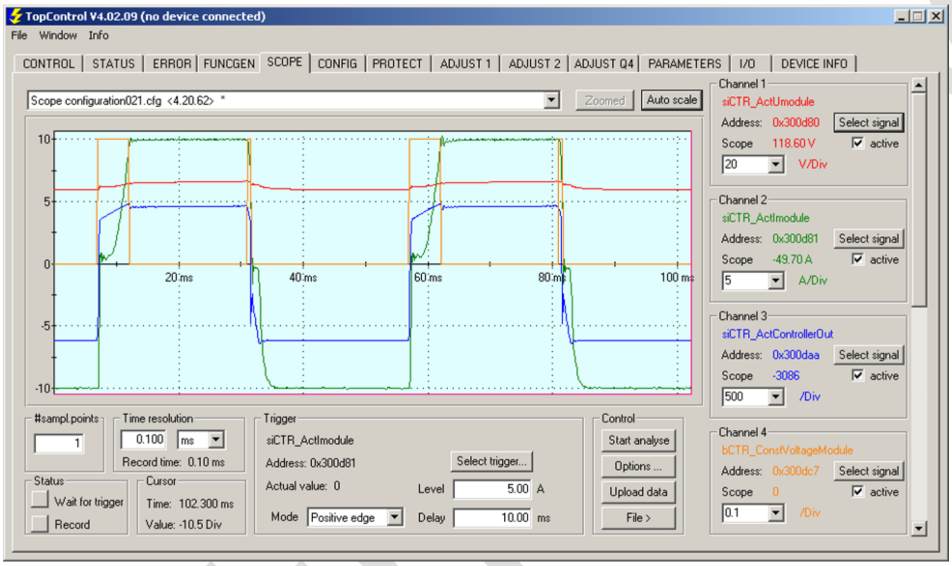


Figure 16: Cycling of a battery pack

Controller Parameter Settings:

Parameter	Voltage Q1	Current Q1	Power Q1	Voltage Q4	Current Q4	Power Q4	Remarks
P-Gain	1600	2400	1000	300	1100	2000	
I-Gain	30	35	100	6000	45	150	
D-Gain	0	0					
T1	0	0					
Feedfwd	0	0		0	0		Not used yet
P-Adaptiv	200	500					
I-Adaptiv	1000	500					

Figure 16 shows the behaviour of a TC.GSS in cycling mode. The green trace depicts the current, which is either charging or discharging the battery pack. An entire swing from full charge to full discharge and vice versa takes some 3-4 msec. The crossover of quadrants was optimised by the 'adaptive parameters', see parameter value table below the picture.

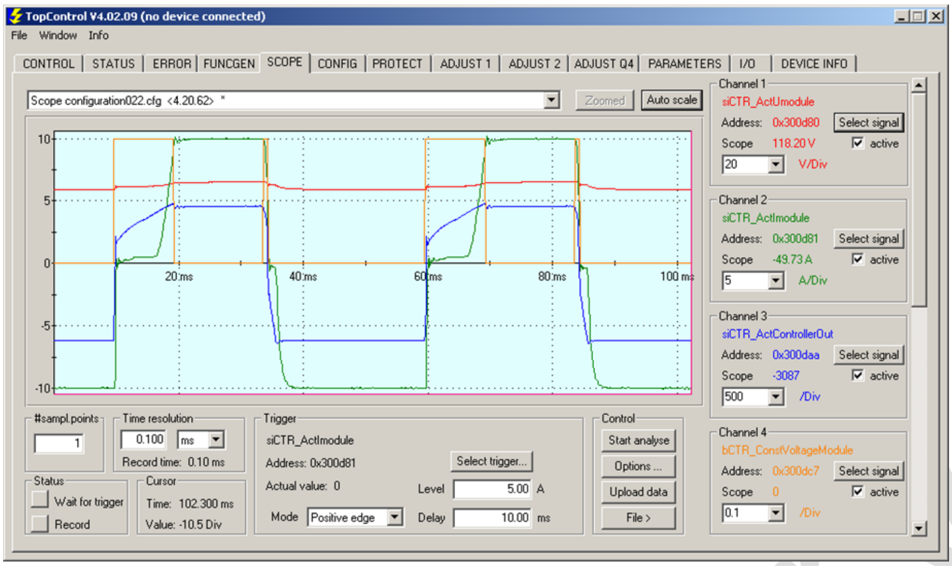


Figure 17: Cycling of a battery pack with a sub-optimal TC.GSS parameter set.

Controller Parameter Settings:

Parameter	Voltage Q1	Current Q1	Power Q1	Voltage Q4	Current Q4	Power Q4	Remarks
P-Gain	1600	2400	1000	300	1100	2000	
I-Gain	30	35	100	6000	45	150	
D-Gain	0	0					
T1	0	0					
Feedfwd	0	0		0	0		Not used yet
P-Adaptiv	200	500					
I-Adaptiv	200	500					

In the example shown in figure 17, the adaptive parameters are not optimised for the application. The leading edge of the green current slope shows that at low current, the rate of rise is very small. This unnecessarily extends the current rise and total cycling time.

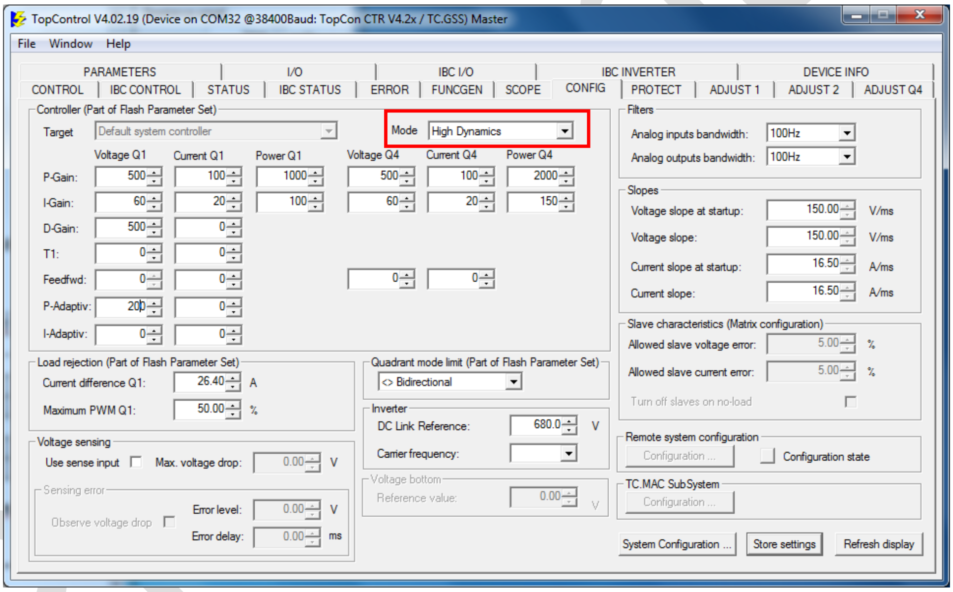
4. The novel NT-Controller

4.1 Principle of Operation

This section is under construction

4.1.1 Typical Parameter Settings in High Dynamics-mode

This section is under construction



Controller Parameter Settings:

Parameter	Voltage Q1	Current Q1	Power Q1	Voltage Q4	Current Q4	Power Q4	Remarks
P-Gain	500	100	1000	500	100	2000	
I-Gain	60	20	100	60	20	150	
D-Gain	500	0					
T1	0	0					
Feedfwd	0	0		0	0		Not used yet
P-Adaptiv	200	0					
I-Adaptiv	0	0					