Power Capacitors Limited

Power Quality Solutions

A2-HPQ Application Notes

2 Introduction

HPQ-application includes traditional detuned capacitor banks which are controlled with Merus A2-active harmonic filter. HPQ-Application combines two existing technologies in to the one compact and well performing solution.

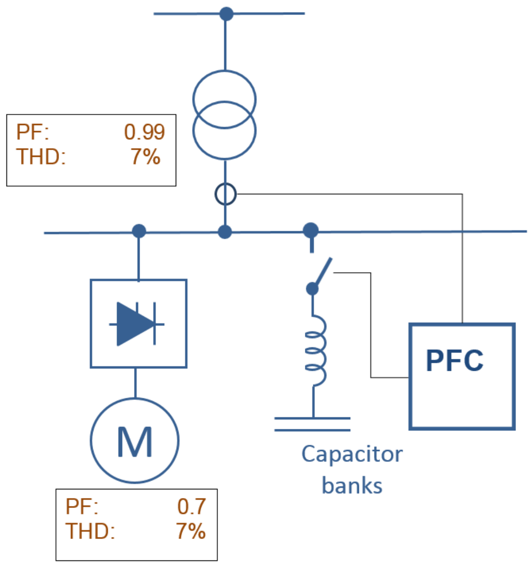

Figure 1: Traditional PFC application

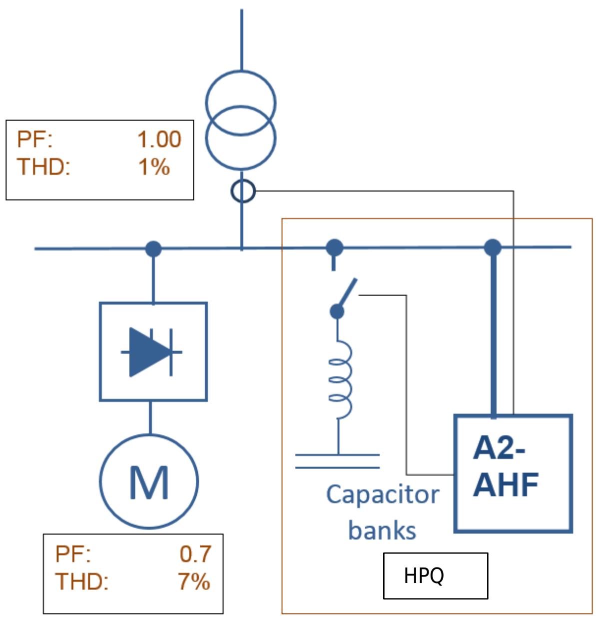

Figure 2: PFC application with A2-HPQ-mode

3 Operation principle and advantages

OPERATION PRINCIPLES

The HPQ-application is aiming to be the overall Hybrid Power Quality (HPQ) solution. HPQ-application is basically A2-active filter with connected detuned capacitor steps. Capacitor step switches are controlled with A2-module Digital Output (**DO**) relays with HPQ-mode.

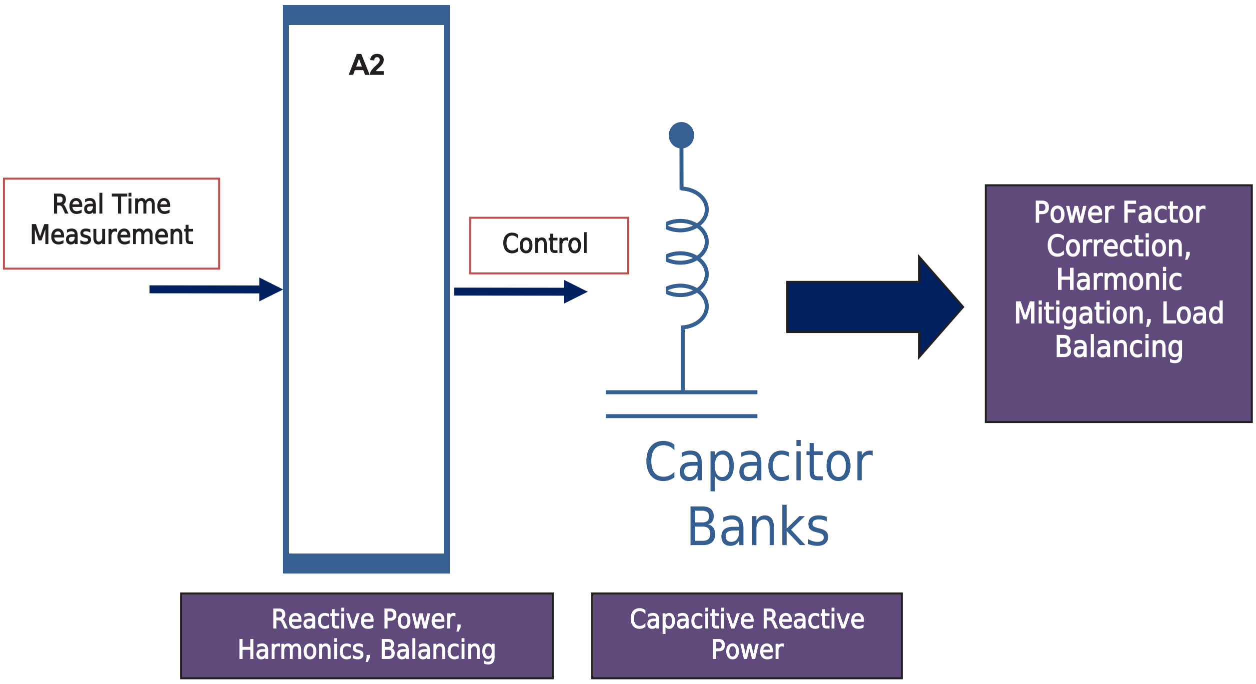

Figure 3: Overall presentation of the HPQ-Application

HPQ-application utilizes the capacitor steps to fulfill the most of the capacitive reactive power needs while the active filter part will take the midsteps. At the same time the A2 will be able to filter out the harmonics and balance the unbalanced loads of the system. Because the A2 will take care of the midsteps there is no need to use different size capacitor steps at all. with HPQ-application the user can control up to 5 capacitors steps*.

A2-module can itself perform all of these functionalities, but in some cases combined solution might be more cost effective and attractive solution.

**Up to 12 pcs in the future.*

Example for HPQ-application usage rate between A2 and steps is presented below:

- **Step size:** 50 kVAr
- **Step count:** 3
- **Hysteresis limit:** 10 %

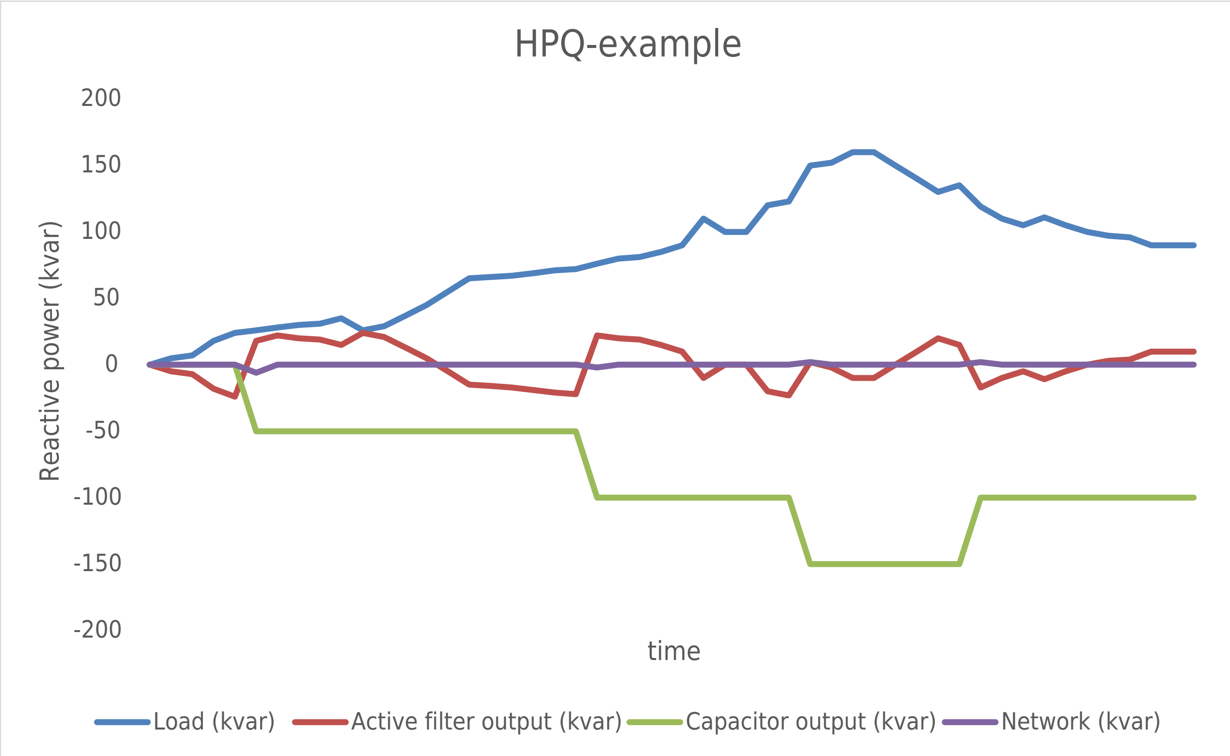

Figure 4: HPQ-Operation example

As you can see from the Figure 4 the active filter load rate is always kept in the minimum and the main part of the reactive power is produced with capacitor banks. Note that this is only an illustrative picture and the actual operation might differ little.

ADVANTAGES FOR HPQ-MDOE USAGE

- **Linearly good output**
  - No visible “steps” in the reactive power
  - better performance than only capacitor steps
  - Load balancing
  - Harmonic mitigation

- **Only one CT-signal required**
  - No need for 2pcs CT-circuits

- **No external PFC-controller required**
  - Extra cost can be neglected

- **No need for different step ratios. 1:1:1:1:1 will do as the AHF will take care of the rest.**
  - Higher power density
  - Only one type of capacitor in stock
  - Simplified design

- **Active filter is not disturbing the PFC-controller**
  - More stable control and majority of the needed reactive current is produced with the capacitors

- **2 Operation modes**
  - ULTRA FAST -mode for changing loads in Open-Loop.
  - PFC-mode for traditional Closed-Loop control.

- **Inductive side compensation**
  - Active filter is capable producing also inductive reactive power
  - No overshooting from steps or loads.

- **Easy to use**
  - Easy commissioning and use with A2-HMI
  - Changeable step sizes, modes etc.

4 Operation modes

There are two operation modes in the HPQ-application. First one is **ULTRA FAST** for the fast Open-Loop reactive power compensation. The second one is **PFC** Which is designed for longer period averaging in Closed-Loop which is the traditional PFC control type. In both modes the user can program the A2-module(s) to mitigate harmonics and unbalances loads at the same time.

ULTRA FAST -MODE

In this mode the A2-module is measuring the **LOAD** current in **Open-Loop.** The A2 in calculating required fundamental current based on the target power factor and load current measurement. In this mode there is instantaneous connection and disconnection of the steps. Thus, there cannot be used magnetic switch (**MC**) as the capacitors can be controlled ON-OFF-ON within milliseconds. In this mode the capacitors need to be controlled via thyristor switch (**TC**). Then we avoid connecting charged capacitor in to the network which might damage capacitors and network (discharge problems).

- In startup, none of the capacitor banks are connected
- When device is running the control will start using the capacitor steps
- The next capacitor will be connected when ½ from the step size is needed. Thus, the active filter capacity is not fully used for fundamental current at any time.
- Active filter will take care of the remaining reactive power.
- Target PF: Power factor what device is trying to reach
- Steps are connected and disconnected with **FILO**-principle
- No discharge or connection delays →**TC** as switches
- Step will be taken off-state when the load has decreased below the "Hysteresis" - amount from last connection.
- When A2 is stopped or tripped the capacitor banks are instantaneously disconnected.

FC-MODE

In this mode the A2-module is measuring the **NETWORK** current in **Closed-Loop**. The A2 is equipped with internal PFC-controller. Capacitor bank can be triggered also with magnetic switches such as contactors in this mode because this mode is not instantaneous, and the user can parametrize the minimum OFF-time (discharge time) for the control logic.

- In startup, none of the capacitor banks are connected
- When device is running the control will start using the capacitor steps
- The next capacitor will be connected when ½ from the step side is needed. Thus, the active filter capacity is not fully used for fundamental current at any time.
- Active filter will take care of the remaining reactive power.
- Steps are connected with **CYCLIC**-principle. The least used bank will be connected next and the most used will be disconnected next. ON-times are saved in EEPROM-memory so the actual usage between the steps is kept as small as possible
- 1 second connection delay: Only one connection/disconnection per 1 s is accepted. Except if there is trip in the system
- Discharge time (minimum OFF-time): how long capacitor must remain OFF-state before ON-time
- Target PF: Power factor what device is trying to reach
- Capacitive PF limit: if the PF is between **target PF** and **Capacitive PF limit** the HPQ-application fill not produce reactive power
- Step will be taken off-state when the load has decreased below the “Hysteresis” -amount from last connection.
- When A2 is stopped or tripped the capacitor banks are instantaneously disconnected.

5 Electrical installation

Capacitors must be detuned with reactors and no plain capacitor banks can be used! The inductance need to be >6%.

The capacitor bank must be installed in the **upstream** of the active filter. Thus, no harmonic current can disturb the capacitor banks. In some cases, the banks can also be installed **downstream** of the active filter, however in that case there is a possibility that capacitors withdraw harmonics from the load.

Note also that some capacitors have limits for U_{thd} limits for the operation. Be careful when choosing capacitors!

The A2-module digital outputs are potential free, so the user can bring desired voltage level up to 277VAC in to the control outputs. The outputs are not designed to draw high currents, so the user should not wire any other than control signals in these terminals. The actual controlling of the capacitor bank can usually be done with the manufacturer switches. However, in **ULTRA FAST MODE** The control must be done with the **TC**'s.

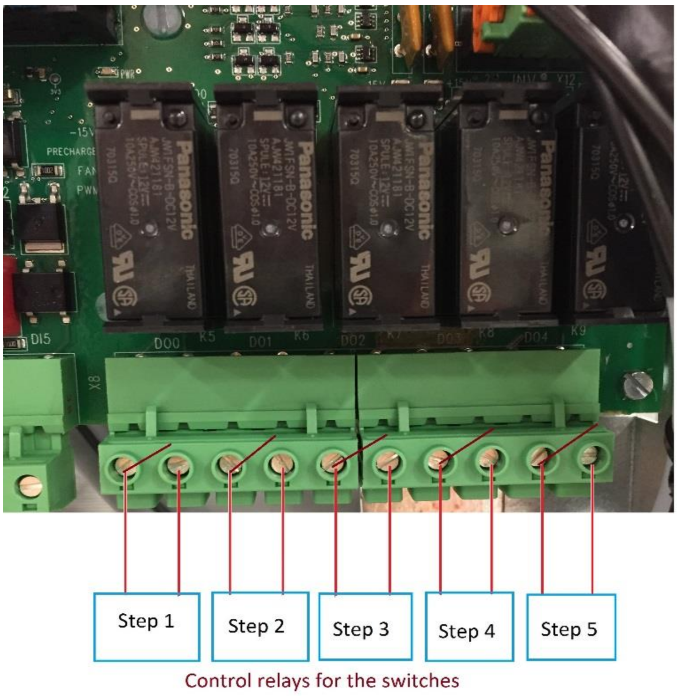

Figure 5: HPQ-control relay outputs

6 HMI and settings

The HMI main screen is little bit different than the standard version. the illustrative picture below:

Figure 6: HPQ-Application main screen

In the beginning the screen is normal, but when the HPQ-Enable is activated in the setting the above screen will be in the home screen. **Capacitor steps are showing RED when active and GREEN when inactive**. The load rate equals only active filter output and does not include HPQ-applications steps. **CB output** is the kvar-reading how much capacity is in use from the capacitors. **Power factor** shows the network power factor.

The settings for HPQ-Application are found in the own **HPQ PARAMETERS** -tab, which is password protected.

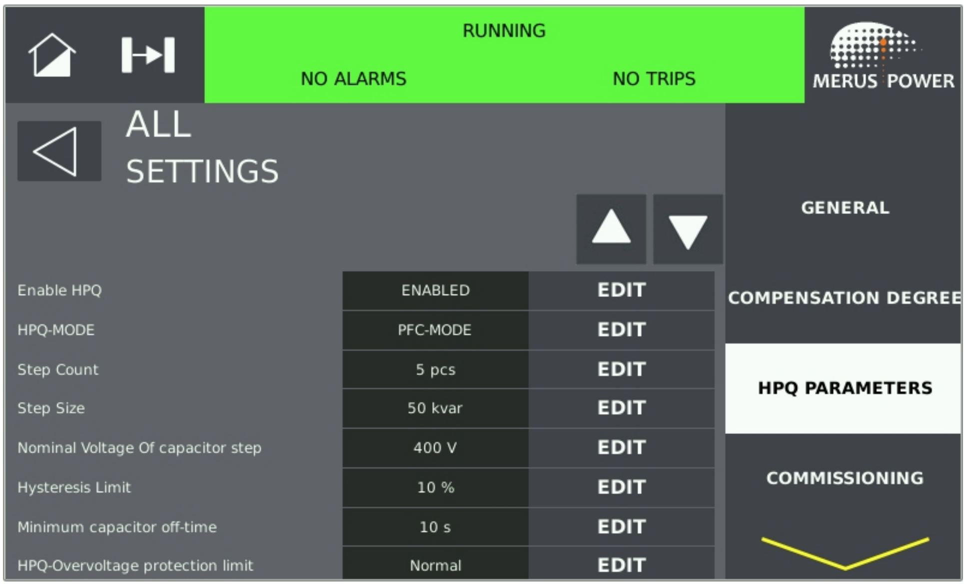

Figure 7: HPQ-settings part 1/2

The settings are following:

- Enable HPQ
  - Disables normal DO-settings and enables HPQ-mode.
  - Enabling this will change the main screen as shown in Figure 6
- HPQ-MODE
  - Select which type of operation is wanted: **PFC-MODE** of **ULTRA FAST MODE**
- Step count
  - How many capacitor steps are connected and wanted to be controlled
- Step size
  - One capacitor step size in kVAr
- Nominal voltage of the capacitor step
  - Nominal voltage for the capacitor step. Normally read on the side of the capacitor. e.g. using 500VAC steps insert 500 even that the device is @ 400V
- Hysteresis limit
  - Hysteresis range when no connection is done in the critical point. Value in %from the one capacitor step size
- Minimum capacitor off-time
  - Used only in **PFC-MODE.** Minimum time that one step is kept disconnected before connecting again (discharge time)
- HPQ-Overvoltage protection limit
  - Overvoltage protection settings when device will trip. Change between: normal (15%), 10% or 20%

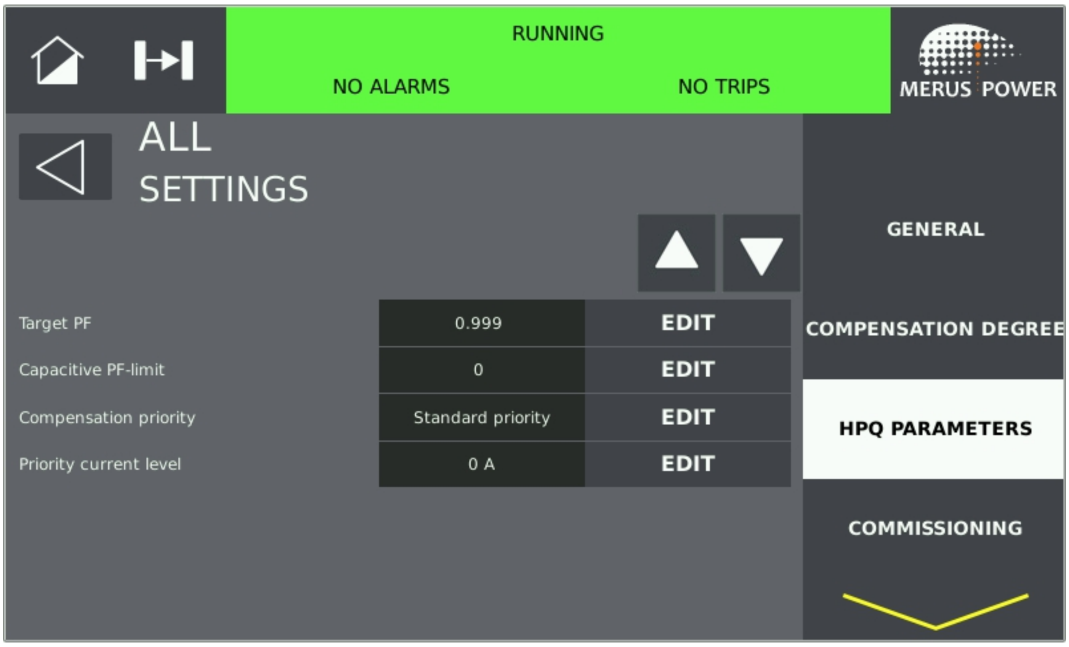

Figure 8: HPQ-settings part 2/2

- **Target PF**
  - Desired power factor that the device is compensating. Value is selected in range:
    -0.7...0.7 e.g. 0.980 equals PF value: 0.980_{Ind}
- **Capacitive PF limit**
  - This limit is used in **PFC-mode.** Set upper limit for the power factor. if the network PF is between **target PF** and **Capacitive PF limit** the HPQ-application fill not produce reactive power and allows the **Stand By** -mode operation and energy savings.
- **Compensation priority**
  - Compensation priority: **Standard/PFC/Harmonics.** Select what happens if the needed compensation is bigger than capacity of the device
    - **Standard**: Both harmonics and fundamental are cut down linearly
    - **PFC:** Fundamental compensation is in priority
      - Maximum PFC current is the **PRIORITY CURRENT LEVEL.** Any extra capacity can be used in harmonics
    - **Harmonics:** Harmonic compensations as priority
      - Maximum harmonic current is the **PRIORITY CURRENT LEVEL.** Any extra capacity can be used in PFC
      -
- **Priority current level**
  - The maximum ampere level for the priority current.

7 EXAMPLES

HPQ-EXAMPLE 1

Needed capacity:

- 120A of harmonics mitigation
- 200 kVAr (cap) of reactive power compensation (PF 0.95). No instantaneous filtering required
- Voltage 400VAC.
- Closed-Loop and Open-Loop available

Solving:

- One A2-200A can produce up 140 kVAr @ 400 V so we would need 2 modules to fulfill this with only active filter, furthermore there is still 120A needed for harmonic mitigation.
- Could be fulfilled with traditional PFC + capacitor steps, but the active filter would be also needed due the harmonics.
- 1 pcs of A2-200 HPQ-application with **PFC-mode** in Closed-Loop as there is no need for instantaneous filtering.
  - 4 pcs of capacitors 50 kVAr with nominal voltage of 400 V
  - With 50 kVAr steps the active filter is needed to compensate only 50 kVAr between steps.
  - 50 kVAr @400 V equals roughly 72 A_{RMS}.
  - So, the remaining current can be calculated following
  - $I_{Nominal}{}^2 = I_{Harmonics}{}^2 + I_{Fundamental}{}^2$
  - $I_{Harmonics} = \sqrt{I_{nominal}{}^2 - I_{Fundamental}{}^2} = \sqrt{200^2 - 72^2} = 186$ A*

- The Actual output for this solution:
  - Fundamental: 4*50kVAr (steps) + 50 kVAr (filter) = 250 kVAr
  - Harmonics: 186A

*__NOTE__: This is the capacity left for harmonics is an assumption that only 50 kVAr are produced with A2-module. With the load changing the momentary capacity for harmonics might be smaller.

Priority example 2

- **All the priority is wanted to be in fundamental (PFC).**
  - Select compensation priority as PFC and priority current level as the nominal of the device.
    - If the needed compensation for PFC is bigger than nominal all the capacity is used for that.

    - If the needed capacity is 80% from the nominal all the rest capacity is still usable for harmonics with following equation.
      - $I_{Nominal}{}^{2} = \overline{I_{Harmonics}{}^{2} + I_{Fundamental}{}^{2}}$
      - $I_{Harmonics} = \sqrt{I_{nominal}{}^{2} - I_{Fundamental}{}^{2}}$

    - So, if the nominal is 200 A and needed capacity for PFC is 160 A harmonics capacity is still **120 A** not 40 A.

PRIORITY EXAMPLE 2

- **Needs to compensate maximum 170 A of the harmonics to match U_{thd} limits. The rest is wanted to use with PFC.**
  - Selecting compensation priority **to harmonics** and the **priority current** to 170 A in A2-200A-module.

  - The harmonics are compensated up to 170 A and the rest >100 A is used for fundamental compensation.

  - Even in the worst case the current available for PFC is enough for 50 kvar step HPQ-application @400 V. And in the same time there is always capacity to fulfill 170A harmonic compensation without putting the PFC in the priority or using that linear "load cutting".

  - **Setting priority current level below the nominal current level is a good way to limit the harmonics mitigation so that certain level is still compensated.**

8 Restrictions and differences between general and HPQ-application A2-operation

At this point there are some restriction or properties in the software that are disturbed with HPQ-Application.

- **Digital outputs** are no longer programmable if HPQ-Operation is enabled even though the user is not using all the outputs for controlling the capacitor banks.

- **Ih1 compensation settings** as one of the harmonics is not available in HPQ-application. Use Target PF instead.

- **PFC-mode:**
  - Load side measurement (Harmonics/Reactive power and waveforms) are not showing correct values

- **ULTRA FAST -mode:**
  - Network side measurement (Harmonics/Reactive power and waveforms) are not showing correct values

- **Only one parallel unit with HPQ-application at a time for now!**
  - One unit is good for most of the cases
  - Putting more modules parallel with HPQ-Application is not allowed. Normal A2-modules can be inserted parallel with A2-HPQ.

- During the TRIP-state of the device also the capacitor control will be off. Thus saving the capacitors to be in too high harmonics level and ensuring the operation.

9 Technical data

Table 1: Technical data for HPQ-application

Configuration	Power factor correction mode	Ultra-fast compensation mode
Max step number (pcs)	5*	5*
Acceptable module ratings	ALL	ALL
3W/4W configuration	3W/4W	3W/4W
CT-signals	Closed-Loop (System side)	Open-Loop (Load side)
Load balancing	Yes	Yes
Harmonic compensation	Yes	Yes
Compensation mode	Selectable	Selectable
Voltage range	208..480 VAC	208..480 VAC
Frequency	50 Hz / 60 Hz	50 Hz / 60 Hz
HPQ-control type	Relay up to 277 VAC, Max 5A	Relay up to 277 VAC, Max 5A
Minimum step change time	1s	<200us
Programmable turn off time	30…999s	N/A
Capacitor selection	Cyclic with RTC counter	FILO
Hysteresis limit	0..50%	0..50%
Power factor range	-0.7…0.7	-0.7…0.7
Overvoltage protection	Selectable 10%,15%,20%	Selectable 10%,15%,20%
Programmable priority between harmonics and fundamental compensation in the A2-module	Yes	Yes
HMI Showing capacitor states	Yes	Yes
HMI showing network PF	Yes	Yes, but only theoretical
HMI showing ON-times for capacitors	Yes	Yes, but not with RTC

* Up to 12 steps coming soon. The extra steps come from another unit DO-channel.

Table 2: Technical data for capacitor steps

Configuration	Power Factor Correction Mode	Ultra-Fast Compensation Mode
Capacitor size per step (kvar)	10...200kVar*	10...200kVar*
Possible step-ratios	1:1:1:1:1	1:1:1:1:1
Series reactor (%)	>6	>6
Switch type	Thyristor Switch or magnetic switch	**Thyristor Switch (TC) only**
Capacitor type	Three-phase	Three-phase

* Maximum step size depending the nominal current level, voltage level and hysteresis.

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