Power Factor Controller

TECHNICAL DATA

MEASURING CIRCUIT		
Voltage range	:	58 V to 690 V, stepless
Current range	:	25 mA to 5 A
Frequency	:	50 Hz (60 Hz upon request)
Input filter	:	each measuring circuit is provided with a band-pass filter
Voltage connection	:	phase to phase or phase to neutral
Current power input	:	1 VA maximum
Galvanic separation	:	potential-free connection with both measuring circuits
Current continuous overloading	:	20 % maximum
Current transformer	:	x/5A or x/1A, category 1
Precision U-I	:	1 %
Precision harmonic current	:	the accuracy of harmonic current measurement is better than 90 %

CONTROL CIRCUIT		
Number of steps	:	6 or 12 steps
Switching delay time	:	a function of reactive load (2 to 500 seconds) or, settable to 10, 30, 60, 120, 180, 300 or 500 seconds
Re-switching blocking delay time	:	settable to 20, 60, 180 or 300 seconds
Relay contact load-bearing capacity	:	5 A/265 V_{AC}, the contact is bridged with a 47 nF anti-interference capacitor

MONITORING		
Watchdog	:	monitors correct function of the processor
Temperature	:	monitors ambient temperature
Alarm relay	:	can be programmed with various alarm functions
Display	:	shows symbols for the various types of faults
Harmonic current	:	alarm signal
No-voltage release	:	all capacitor steps will be switched out immediately upon interruption of supply voltage. Switching-in can take place only after the re-switching blocking delay has elapsed.

ELECTRICAL CONNECTION		
Operating voltage	:	230 V_{AC} ± 15 %, 50 Hz (60 Hz and/or 120 V_{AC} upon request)
Power input	:	8 W maximum
Instrument fuse	:	100 mA tr. 5 x 20 mm, inside the device
Connection	:	via 20-pole (PFC12: an additional 6-pole) multipoint connectors, 2.5 mm^2, rigid or flexible cable
Interface	:	RS232, 3-pole multipoint connector

MECHANICAL DETAILS		
Panel cut-out	:	138 mm x 138 mm
Depth	:	approximately 70 mm
Weight	:	0.80 kg maximum
Design	:	to EN 50178, protective class II, and EN 61010-1, **CE** - Certification: EN50081-2, EN61000-6-2
Type of protection	:	IP 40 with multipoint connector mounted (IP 55 upon request: but only for the frontside protected by a lockable controller cover, when controller is mounted in the cubicle door)
Ambient operating temperature	:	- 25 °C up to + 60 °C
Position of installation	:	at option

GENERAL

FUNCTIONS AND MODE OF OPERATION

The inductive reactive current required by induction motors for the three-phase magnetic field is an additional load on the power supply network, lines and switching devices. It also increases the expenditure for the energy to be paid to the Electrical Power Supply Utility, although the so-called reactive energy is, de facto, no real energy consumption. This inductive reactive current will be compensated by means of a Power Factor Controller with the related capacitor units.

The ESTAmat PFC Controller can be applied wherever automatic control of the power factor (cosφ) is required. All functions of the ESTAmat PFC are controlled by a microprocessor. A protective device (watchdog) continuously monitors the processor to guarantee its faultless operation. There are no internal time or date functions.

The measurable variable current and voltage are conducted across a 50 Hz or 60 Hz (related to the fundamental frequency) band-pass filter. Thus harmonics existing in the network cannot affect the measurement process. Both measurement entries are potential free. The measuring voltage shall be in the range of 58 V to 690 V and may be optionally connected between phase to neutral or phase to phase. The current measuring range is 0.025 A to 5 A, and there is no need to differentiate between X/1A or X/5A current transformer.

A measuring cycle lasts 0.5 seconds. During this cycle, values are measured, all required parameters (such as power factor, current, and harmonic current) are calculated, and, if necessary, additional actions such as switching the steps and activating alarms are taken.

Using the 6, respectively 12 relay contacts, the currently required capacitor output can be achieved as a sum of equal or different step sizes to obtain **optimized switching performance**.

In case the actual power factor is lower than the target power factor, and the demand on reactive current for compensation exceeds 75 % of the smallest capacitor step (measuring current ≥ 5 mA; 100 % between 25 and 50 mA), the ESTAmat will switch in the next step. Allowing for a possibly still valid **re-switching blocking delay time**, this switching is done after either an automatic and load depending **or fixed preset switching delay time**. When the standard **switching in circular mode** setting is applied, the ESTAmat PFC distributes the total number of switching operations uniformly on all connected capacitor steps. Delay times for switching steps in or out can be either left automatic or preset as a fixed value, as is done for the re-switching blocking delay time.

The ESTAmat PFC Controller is capable of determining, during the start-up procedure, **the location of the current transformer** as well as the **output rating of the connected capacitor steps** (i.e. **the switching program**) by means of test switchings.

When the controller is mounted into a switch cabinet, the cabinet's internal temperature can be monitored via an internal temperature sensor. By setting limit values, an alarm function can be activated.

The setting via menu is done by means of the three keys on the front panel, which can be locked and thus protected against unauthorized modification.

By **turning from automatic to manual operation**, the automatic control may be deactivated during start-up procedure or for test purposes, allowing capacitors to be switched in or out manually.

Moreover in case of circular switching mode, any number of same-sized capacitor steps can be defined as **fixed steps**. One circular step, however, shall remain for the control operation.

The ESTAmat PFC is equipped with an **RS232 serial interface**. A PC can be used to request all relevant measuring values and Power Factor Controller data. Furthermore, all Power Factor Controller's parameters can be modified via PC. The PC software and a PC connector cable for the ESTAmat PFC are available at option.

TYPE ESTAmat PFC/MSP FOR MEDIUM VOLTAGE APPLICATIONS

When using the medium-voltage version of the ESTAmat, the following differences from the low-voltage version should be considered:

• Modes of initialization

Fully automatic and semi-automatic initialization modes are not feasible. Therefore only the manual initialization AU3 is possible and preset. The operator will have to set the current transformer location, the output and number of capacitor steps, the C/k-value, and the switching program.

• Blocking delay time for re-switching

The re-switching blocking delay time can be set to 300 seconds or 600 seconds (preset value).

IDENTIFICATION OF C.T. LOCATION AND OR CAPACITOR STEP OUTPUT (switching program)

During the start-up routine, the ESTAmat PFC Controller is capable of independently determining the location of the current transformer as well as the output rating of the connected capacitor steps by means of test switchings.

Three modes of initialization are possible:

• Fully automatic initialization AU1:

The ESTAmat PFC Controller determines the location of the current transformer, the output and number of capacitor steps, and the switching program.

• Semi-automatic initialization AU2:

The ESTAmat PFC Controller determines, after presetting the location of the current transformer, the output and number of capacitor steps and the switching program.

• Manual initialization AU3:

The location of the current transformer, the output and number of capacitor steps, and the switching program have to be set by the operator.

The ESTAmat PFC Controller is supplied with the fully automatic initialization mode **AU1** as the default setting. The fully automatic initialization may not be successful in case of strong oscillations in the public power lines. In such a case, the semi-automatic **AU2** or the manual initialization **AU3** can be applied.

DISPLAY ON THE FRONT PANEL

Indicated on the large four-digit LED display

• The actual power factor: a minus in front means that the power factor is capacitive

• Actual fundamental frequency current and actuall-root-mean-square current (comprising the mains frequency plus the harmonic components)

• The set target power factor range:
0.85 inductive ...1...0.95 capacitive (- 0.95)

• The switching delay time as a function of the load or as a fixed switching delay time (10, 30, 60, 20, 180, 300, and 500 seconds)

• The current I_c and the number Σ of switching operations of the selected capacitor step

• The percentage current, related to the fundamental frequency current, of the selected 3rd, 5th, 7th, 11th, 13th, or 17th harmonic

Displayed via the “ind” or “cap” LEDs:

• Exceeding of the set C/k value

• Faults during compensation

Displayed via the step LED 1-6 (1-12 respectively):

• The number of activated capacitor steps

PARAMETER SETTING

The following parameters can be set, modified, and stored in two different ways: either by keys on the Controller’s front panel or by a PC via the serial interface of the controller.

• Modes of initialization AU1, AU2, or AU3
• Re-switching blocking delay time
• Switching-in delay time
• Switching-out delay time
• Switching in circular or series mode
• Number of fixed capacitor steps, settable only in case of circular switching mode
• Locking of keyboard operation
• Functioning of the alarm relay
• C.T. transformation ratio k
• Time delay for switching out steps in case of measuring current too low and feeding back of energy

AUTOMATIC - / MANUAL OPERATING MODE

In the automatic operating mode, the capacitors are automatically switched in or out depending on the demand for reactive power. The actual power factor is shown in the display. A minus in front of the power factor means that the power factor is capacitive. For testing purposes, capacitors can be switched in or out manually at any time in the automatic operating mode.

When the manual operating mode is set, the automatic operating mode is deactivated, i.e. no capacitor steps are switched. The manual operating mode can be called upon from any other mode.

SWITCHING IN CIRCULAR MODE

Switching in circular mode means that capacitors which have been switched in first, will also be switched out again first. Switching follows the first in, first out (FIFO) principle. If the switching-in follows the order 1-2-3-4-5, then also the switching-out of the capacitors will follow that same order 1-2-3-4-5.

The circular switching mode distributes the load uniformly on all elements such as contactors and capacitors. A further advantage of this mode is that a capacitor step, when switched out, has enough time for discharging before it is switched in again.

The advantages of the circular switching sequence are also applicable for "hunting" programs. With the switching sequence 1:2:2:2:2:2, for example, the "double-size" steps are likewise switched in a circular switching sequence. The "single-size" step will then be used only for fine tuning.

With the switching programs of equivalent hunting steps, e.g. 1:1:2:2:4, the hunting steps of same size (1:1 or 2:2) will also be switched alternately.

NO-VOLTAGE RELAY

In case of an interruption of the mains voltage, the ESTAmat PFC Controller switches out all the capacitor steps.
When the supply voltage is restored, the capacitors will be switched in again after the blocking delay for re-switching has elapsed.

This ensures enough time for the capacitors to discharge and thus avoids any harmful switching-in in phase opposition to the mains voltage.

C/k VALUE

The C/k-value is the pick-up value of the ESTAmat PFC Controller. The value represents the reactive current response threshold of the controller in Ar ("ampere reactive"). In case the reactive current portion of the load exceeds the set C/k value, either the "ind" or "cap" LED will indicate this trend.

The C/k value can be calculated as follows

$$C/k = \frac{Q}{\sqrt{3} \cdot U \cdot k_{ct}}$$

Q = output of the smallest capacitor step [var]
U = phase-to-phase voltage [V]
k_{ct}= C.T. transformation ratio

Example: Q = 25 kvar, U = 400 V, k_{ct} = 1000 : 5 = 200
C/k = 25000 var/ (1.732 • 400V • 200) = 0.18 A

The setting range of the C/k value is 0.025 A up to a maximum 1.5 A. The maximum value is a function of the selected switching program. The C/k value has only to be set with the initialization mode **AU3**. Assuming a minimum **C/k_{min}-value** of 0.025 A and a specified C.T. transformation ratio, the smallest possible capacitor step **Q_{min}** can be calculated as follows:

$$Q_{min} = \sqrt{3} \cdot U \cdot kct \cdot C/k_{min}$$

U = phase-to-phase voltage [V]
kct = C.T. transformation ratio
C/k_{min} = smallest possible C/k - value (= 0.025)

Example: U = 400 V, k_{ct} = 1000 : 5 A
Q_{min} = 1.732 • 400 V • 200 • 0.025 A = 3.46 kvar

GENERATOR OPERATION (4-quadrant operation)

Renewable energy sources such as wind and thermal regeneration, as well as emergency power supply systems, require trouble-free operation from state-of-the-art power factor controllers to handle any feedback of active power into the general supply mains (generator operation).

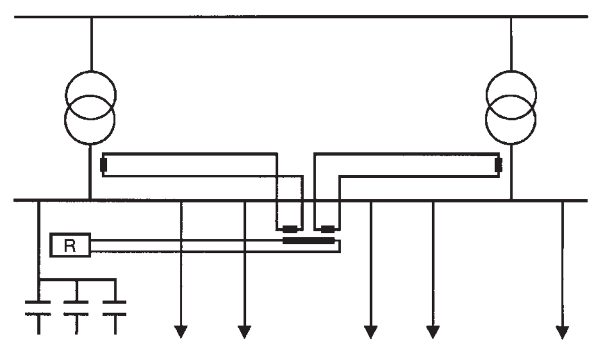
Whether energy supply or energy feedback is the issue, the ESTAmat PFC Controller can identify correctly the inductive reactive power and compensate for it.

CONNECTION FOR CURRENT TRANSFORMER

In case of an unbalanced load of the phases, the current transformer should be connected to the phase which is most highly loaded.
The current transformer should be installed at a position which ensures that all the subsequent consumer current, including the capacitor current, will flow through it. Normally, this position is next to the feed-in transformer and on the load side of the tariff meter reading.

Parallel operation:
In case two network sections, each with independent power factor control equipment, are interconnected, the two power factor controllers influence each other, because the currents distribute across the two transformers. In such a case, to avoid hunting of the two power factor controllers, the C/k-values should be set to different current levels with the **manual initialization mode AU3**. The result will be a "lead-follow" behavior because both controllers react at a different speed. The power factor controller with the lower C/k value is quicker in switching than the one with the higher C/k value.

Summation current transformer:
When several transformers supply one single L.V. bus bar, the individual currents should be measured by means of current transformers and then added together via a summation current transformer. Special attention should be given to the correct polarity, since otherwise, the current intensities of the individual transformers will subtract.



OPTIMIZED SWITCHING PERFORMANCE

The ESTAmat PFC Controller continuously measures the demand for reactive power and changes in this demand, and thanks to its optimized switching performance, switches in or out the largest possible capacitor step. In case of, for example, a power factor correction equipment of 25 : 25 : 50 : 50 : 50 kvar, the ESTAmat PFC Controller will immediately switch in a step of 50 kvar instead of gradually switching in steps of 25 kvar. This way, the number of switching operations is reduced, which results in an increased life expectancy of both the capacitors and the contactors.

SWITCHING DELAY TIME

The period between the illumination of the "ind" or "cap" LEDs and the switching in or out of capacitor steps is defined as the switching delay time. The switching delay time can either be determined by the ESTAmat PFC Controller as a function of load (yielding delay times from 2 seconds to a maximum of about 8 minutes), or preset to 10, 30, 60, 120, 180, 300, or 500 seconds by the operator.

BLOCKING DELAY TIME FOR RE-SWITCHING

The period between switching out a certain capacitor step and the earliest possible re-switching in of the same step is defined as re-switching blocking delay. With the ESTAmat PFC Controller, this blocking delay for re-switching can be either 20, 60, 180, or 300 seconds. This period is necessary in order to allow the voltage existing at the capacitor after the switching-out to reduce to an acceptable level. The blocking delay for re-switching should be selected in accordance with the existing discharging device. Switching-in should be effected only when the residual voltage is less than 10% of the operating voltage.

SWITCHING PROGRAMS

1. 1:1:1:1:1...
2. 1:1:2:2:2...
3. 1:1:2:2:4...
4. 1:1:2:3:3...
5. 1:1:2:4:4...
6. 1:1:2:4:8...
7. 1:2:2:2:2...
8. 1:2:3:3:3...
9. 1:2:3:4:4...
10. 1:2:3:6:6...
11. 1:2:4:4:4...
12. 1:2:4:8:8...

The step LEDs indicate permanently the number of activated steps, and these must correspond with the activated terminals.

TEMPERATURE MONITORING

Using an internal temperature sensor located in the lower part of the casing, the ESTAmat PFC Controller can continually measure the ambient temperature. Although the sensor is installed within the device, venting slots allow sufficient air circulation to enable accurate measurements.

When the controller is mounted into a switch cabinet, the cabinet´s internal temperature can also be monitored.
By setting limit values, an alarm function can be activated.

RMS CURRENT / HARMONIC CURRENT

The root-mean-square (“rms”) current I_{eff} comprises the fundamental frequency current plus the harmonic components. Using Fast Fourier Transformation (FFT) analysis, the ESTAmat PFC Controller can determine harmonic currents of the 3rd, 5th, 7th, 11th, 13th, 17th, and 19th harmonic. These are displayed as a percentage value relative to the current of the fundamental frequency.

The controller displays the percentage values up to the 17th harmonic. If harmonic generators exist and if the resonance frequency between the compensation equipment and the line transformer is on a typical harmonic frequency, the percentage part of this harmonic increases excessively. This may activate alarms and switch-out operations by means of various limit-value profiles.

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FUNCTIONING OF THE ALARM RELAY

During normal operation, the alarm relay is operative and the auxiliary contact is open. In case of faults or breakdown of the supply voltage, this contact closes.

The fault alarm relay is an additional means of monitoring correct operation. Users can select which of these fault conditions will activate the alarm relay:

- Undercompensation, i.e. when the plant is not sufficiently compensated for more than 15 minutes continuously with a power factor below 0.9. The condition of compensation having become insufficient or other faults will be perceived in time and can thus be eliminated.
- Measuring current too low, if secondary current of the C.T. is less than 25 mA
- Measuring current too high, if secondary current of the C.T. is higher than 5.3 A
- No measuring voltage, connection to the supply may have broken
- Over-temperature, i.e. the preset maximum ambient temperature has been exceeded.
- The root-mean-square current is too high, i.e. the relation I_{eff}/I_{fund} between the root-mean-square value and the fundamental frequency value of the current exceeded its specified limit.
- The harmonic current is too high, i.e. a specified percentage amount of a harmonic has been exceeded.

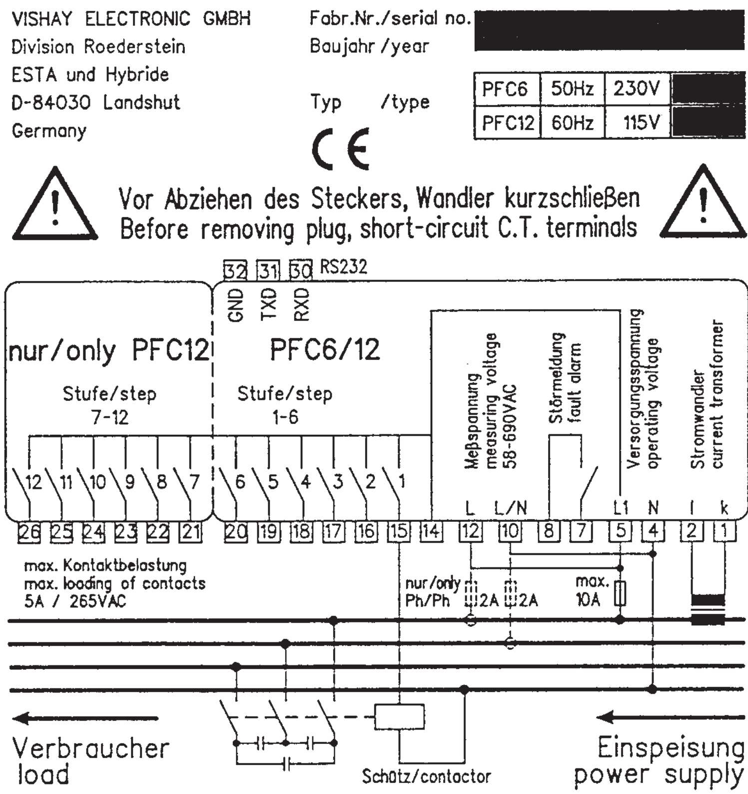
Sometimes it is appropriate to switch out capacitor steps when certain alarm signals are given. The user can select which fault alarms will cause a switch-out. The specific kind of fault alarm determines the switch-out behavior and indicates the priorities:

1. The capacitor steps will be switched out immediately without any time delay.
2. The capacitor steps will be switched out after a time delay which can be modified.
3. Steps will continue being switched out until the fault alarm has disappeared.

INTERFACE

The ESTAmat PFC is equipped with an RS232 serial interface. All relevant measuring values and Power Factor Controller data can be requested using a PC. Furthermore, all Power Factor Controller's parameters can be modified via a PC. The PC software and a PC connector cable for the ESTAmat PFC are both available from Vishay.

CONNECTION DIAGRAM



CONCISE OPERATING INSTRUCTIONS

SETTINGS

The **ESTAmat PFC** Controller will be supplied with the following standard setting:

Supply voltage	:	230 V_{AC} or 120 V_{AC}
Measuring voltage connection	:	phase to neutral
Frequency	:	50 Hz or 60 Hz
Initialization mode AU1	:	fully automatic identification of - measuring voltage connection - C.T. location and - output of the connected capacitor steps

MOUNTING AND CONNECTION OF THE ESTAMAT PFC CONTROLLER

A cut-out measuring 138 mm by 138 mm is required for mounting the Controller. The added springs for attachment should be pushed into the slots at the back of the device until they have reached the switchboard and have locked in place.

TERMINALS	CONNECTION
1	C.T. connection **k (S1)**, X/5 A or X/1 A
2	C.T. connection **l (S2)**, X/5 A or X/1 A
4	Mains connection **N**, 230 V_{AC}
5	Mains connection **L1**, 230 V_{AC}
7, 8	Potential-free alarm contact, normally open
10	Measuring voltage L or N
12	Measuring voltage L
15-20	Control terminals for contactors 1-6
21-26	Control terminals for contactors 7-12 (only PFC12)

When standard settings are used, the measuring voltage can be connected to the mains supply, i.e. terminal 4 should be bridged to terminal 10, and terminal 5 should be bridged to terminal 12.

START-UP PROCEDURE

After the supply voltage has been applied to it, the **ESTAmat PFC Controller** starts a **self-test**.

The following data will be displayed for about 2 seconds:

- The type of program e.g.: 1.0.1.
- The mode of initialization e.g.: AU1 *)
- The set target cosφ e.g.: 1.00
- The switching delay time e.g.: LoAd
- The measuring voltage connection e.g.: U-0

***) with AU3 the additional display of:**

- the switching program and number of engaged relay steps e.g.: and with LED ••••••
- the C/k-value e.g.: 0.025

Owing to the basic setting made at the factory, the **ESTAmat PFC Controller** changes into the fully automatic initializat AU1

This means that no further settings need to be made by the operator.

PREREQUISITE FOR STARTING THE FULLY AUTOMATIC INITIALIZATION:

- The C.T. secondary current must be at least 25 mA (reactive current)
- The current of the smallest capacitor connected must be at the C.T. secondary side in the range of 0.05 A to 1.00 A

SEQUENCE OF THE FULLY AUTOMATIC INITIALIZATION	
DISPLAY	**FUNCTION**
AU1 -1- to -5- no	The controller starts with step 1 and continues switching in steps until the location of the current transformer has been determined due to the changes in current. The trial runs are counted and evaluated. The C.T. location is determined only after 5 consecutive trial runs producing all the same result. The controller starts at the meter reading -1- and stops, in the normal case, at -5- after 5 trial runs. In cases of unfavorable conditions of the mains supply, the value of the meter reading may reduce again. If the value -3- is not reached, either the setting AU2 or AU3 should be selected. Continous changes of display between AU1 and no indicates that the controller has already stored a connection value for the C.T. location. The controller will start at AU2 after the re-switching blocking delay time has elapsed. An activated blocking delay time for re-switching for one step is indicated by a flashing decimal point.

Having identified the location of the current transformer, the current or output ratings of the capacitor steps will be determined.

DISPLAY	FUNCTION
AU2 2.1 to 2.3	Starting with step 1, the controller switches in each **individual** step briefly, and switches it out again immediately. (PFC6 :6 steps, PFC 12: 12 steps). The procedure is repeated three times.

Normally, the **ESTAmat PFC Controller** terminates successfully the initialization, after approximately 5 minutes, determines correctly the configuration of the plant, and indicates the actual power factor.

If one of the following symbols is on display, the following conditions may be the case:

DISPLAY	DISPLAY	REMEDY
≡I	The measuring current is less than 25 mA	Check C.T. electric circuit
≡0	The measuring current is in excess of 5.3 A	C.T. transformation ratio is too small
≡U	The measuring voltage is missing.	Check connection of controller
≡AU1	AU1 could not be carried out correctly. Possible causes: quick reversals of load, insufficient compensation output, load too low.	Set AU2
≡AU2	AU2 could not be carried out correctly. Possible causes: quick reversals of load, no switching of capacitor steps.	Set AU3
SLE	The faults ≡AU1 or ≡AU2 have appeared five times in succession. This condition can be modified only upon fundamental change of load.	Set AU3

Default pre-set is for a desired power factor of 1.00.

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