VISHAY INTERTECHNOLOGY, INC.

ESTAmat® PFC

Microprocessor-Controlled Power Factor Controller for Connection to PC via Data Bus

POWER CAPACITORS

PRODUCT OVERVIEW

E 04-08 E/04

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TECHNICAL DATA

MEASURING CIRCUIT		
Voltage range	:	58V to 690V, stepless
Current range	:	25mA to 5A
Frequency	:	50Hz (60Hz 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	:	1VA 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, 500 seconds
Re-switching blocking delay time	:	settable to 20, 60, 180, 300 seconds
Relay contact load-bearing capacity	:	5A/265VAC, the contact is bridged with a 47nF anti-interference capacitor

MONITORING		
Watchdog	:	monitoring correct function of the processor
Temperature	:	monitoring ambient temperature
Alarm relay	:	can be programmed with various alarm functions
Display	:	showing 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	:	230VAC ± 15%, 50Hz (60Hz and/or 120VAC upon request)
Power input	:	8W maximum
Instrument fuse	:	100mA tr. 5 x 20mm, inside the device
Connection	:	via 20-poles (PFC12: an additional 6-poles) multipoint connectors, 2.5mm^2, rigid or flexible cable
Interface	:	RS232, 3-poles multipoint connector

MECHANICAL DETAILS		
Panel cut-out	:	138 x 138mm
Depth	:	approximately 70mm
Weight	:	0.80kg 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 and also increases the expenditure for the energy to be paid to the Electrical Power Supply Utility although the socalled 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) continously 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 or 60Hz (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 58V-690V and may be connected, at option, between phase to neutral or phase to phase. The current measuring range is 0.025 to 5A, and there is no need to differentiate between X/1A or X/5A current transformer.

A measuring cycle lasts 0.5 seconds and comprises the measurement of values, the calculation of all required parameters, such as power factor, current, harmonic current, etc., and if necessary, the initialization of certain actions, e.g. switching the steps and activating alarms.

By means of the 6 or the 12 relay contacts, as much capacitor steps as requested, of same or different size, can be controlled according to an **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 ≥ 5mA; 100% between 25 and 50mA), the ESTAmat PFC is going to switch in the next step. Considering 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 **switching in circular mode**, as the standard setting, is applied, the ESTAmat PFC is anxious to distribute 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 it 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.

Via an internal **temperature sensor**, when the Controller is mounted into a switch cabinet, there is the possibility of monitoring the cabinet's internal temperature. 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 plate, which can be locked and thus protected against unauthorized modification.

By **turning from automatic to manual operation**, the automatic control is not effective during start-up procedure or for test purposes, i.e. capacitors may 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 a **serial interface RS232**. By means of the computer , all relevant measuring values and Power Factor Controller data can be requested. Furthermore, all Power Factor Controller's parameters can be modified via a computer. The computer software and the connection cable ESTAmat PFC to the computer are available at option.

TYPE ESTAmat PFC/MSP FOR MEDIUM VOLTAGE APPLICATIONS

The following differences to the standard Low Voltage version have to 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)

The ESTAmat PFC Controller is capable of determining by itself, during the start-up procedure, 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 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 P.F. Controller is supplied with the fully automatic initialization mode **AU1** set, which is the normal application. 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 PLATE

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 actual 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 Ic and the number ∑ 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 LEDs “ind” and “cap”:

- 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 memorized in two different ways:

Either by means of the keys at the Controller’s front plate 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 the purpose of testing, 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 ineffective, 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 FIFO principle: First-IN-First-OUT. 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 the so-called hunting programs. With the switching sequence 1:2:2:2:2:2 for example, the “double-size” steps are like wise switched in 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 switches out all the capacitor steps.

Upon return of the supply voltage, 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 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 reactif). In case the reactive current portion of the load exceeds the set C/k value, one of the two LEDs "ind" or "cap" will indicate the 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 = 400V, k_{ct} = 1000 : 5 = 200
C/k = 25000var/ (1.732 • 400V • 200) = 0.18A

The setting range of the C/k value is 0.025A up to a maximum 1.5A. The maximum value is a function of the selected switching program. The C/k value has to be set only with the initialization mode **AU3**. Conditional on the minimum **C/k_{min}-value** of 0.025A 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]
k_{ct} = C.T. transformation ratio
C/k_{min} = smallest possible C/k - value (= 0.025)

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

GENERATOR OPERATION (4-quadrant operation)

The increasing use of renewable energy sources e.g. wind and thermal regeneration, as also the application of emergency power supply systems, require that state-of-the-art power factor controllers operate trouble-free in case of a feed-back of active power into the general supply mains (generator operation). In both cases of energy supply and of energy feed-back, the ESTAmat PFC Controller can identify correctly the inductive reactive power and compensate 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 shall 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 differently with the **manual initialization mode AU3**. The result will be a so-called "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 shall be measured by means of current transformers and then added together via a summation current transformer. Special attention shall be given to the correct polarity because, otherwise, the current intensities of the individual transformers will subtract.

OPTIMIZED SWITCHING PERFORMANCE

The ESTAmat PFC Controller measures continuously the demand for reactive power and the variations of it and, due to the 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 : 50kvar, the ESTAmat PFC Controller will immediately switch in a step of 50kvar instead of gradually switching in steps of 25kvar. 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 lighting-up of one of the light-emitting diodes (LED) ("ind", "cap") and the switching in or out of capacitor steps is defined as switching delay time. The switching delay time can either be determined by the ESTAmat PFC Controller as a function of load (in the range between 2 seconds and max. app. 8 minutes), or preset to 10, 30, 60, 120, 180, 300 or 500 seconds by the operator himself.

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 shall be selected in accordance with the existing discharging device. Switching-in shall 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

Via an internal temperature sensor located in the lower part of the casing, the ESTAmat PFC Controller can permanently measure the ambient temperature. Although the sensor is installed within the device, the measuring can be carried out with sufficient precision because of the existing venting slots which allow sufficient air circulation. When the Controller is mounted into a switch cabinet, there is the possibility of monitoring the cabinet's internal temperature. 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. By means of the FFT-analysis (Fast-Fourier-Transformation), the ESTAmat PFC Controller can determine harmonic currents of the 3rd, 5th, 7th, 11th, 13th, 17th and 19th harmonic. The presentation is in percentage with regard 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.

FUNCTIONING OF THE ALARM RELAY

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

The fault alarm relay is an additional means of monitoring correct operation. The fault situation to which the alarm relay shall react can be selected:

- 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 25mA
- Measuring current too high, if secondary current of the C.T. is higher than 5.3A
- 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.

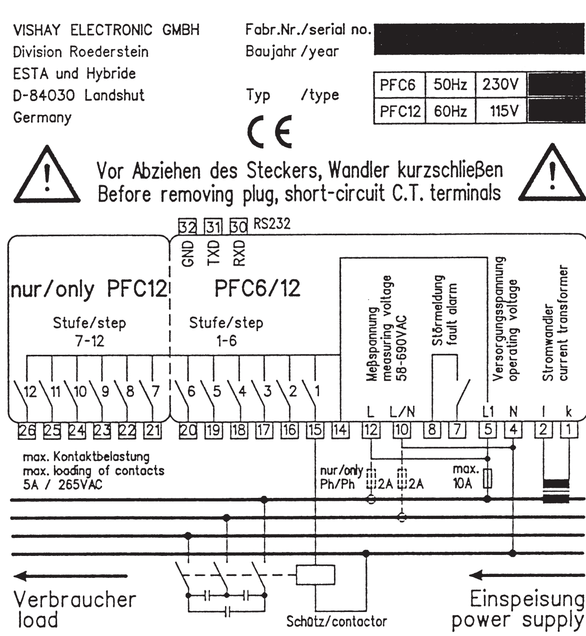
Sometimes it is already sufficient to switch out capacitor steps when certain alarm signals are given. The fault alarm which shall cause a switch-out can be selected by a parameter. The specific kind of fault alarm determines the switch-out behavior and indicates the priorities:

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 a serial interface RS232. By means of a computer, all relevant measuring values and Power Factor Controller data can be requested. Furthermore, all power Factor Controller's parameters can be modified via a computer. The computer software and the connection cable ESTAmat PFC to the computer are available at option.

CONNECTION DIAGRAM



CONCISE OPERATING INSTRUCTIONS

SETTINGS

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

Supply voltage	:	230VAC or 120VAC	
Measuring voltage connection	:	phase to neutral	
Frequency	:	50Hz or 60Hz	
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 of 138 by 138mm is required for mounting the Controller. The added springs for attachment shall be pushed into the slots at the device's rear 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**, 230VAC
5	Mains connection **L1**, 230VAC
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)

In case of standard setting the measuring voltage can be connected to the mains supply, i.e. terminal 4 shall be bridged to terminal 10, and terminal 5 is to 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.: L1-0

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

- the switching program and number of engaged relay steps e.g.: 1111 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 initialization 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 25mA (reactive current)
- The current of the smallest capacitor connected must be at the C.T. secondary side in the range of 0.05 to 1.00A

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 unfavourable 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, and 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	CONDITION	REMEDY
≡I	The measuring current is less than 25mA	Check C.T. electric circuit
≡O	The measuring current is in excess of 5.3A	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

The standard is that a desired power factor of 1.00 is preset.

SEMICONDUCTORS:
Rectifiers • Small-Signal Diodes • Zener and Suppressor Diodes • MOSFETs • RF Transistors • Optoelectronics • ICs

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