DUCATI energia

HISTORY DRIVES THE FUTURE

Since 1926

Low voltage power factor correction: capacitors, components, fixed & automatic equipment and active harmonic filters

EQUIPMENT

SELECTION CRITERIA

PFC: why?

There are many objectives to be pursued in the planning of an electrical system. Among the measures that enable electricity use to be optimized, improving the power factor of electrical systems is undoubtedly one of the most important. If we quantify this aspect from the utility company's point of view, raising the average operating power factor of the network from 0.7 to 0.95 means:

- Cutting costs due to ohmic losses in the network by 45%
- Increasing the potential of production and distribution plants by 35%

The user which corrects the power factor in his plants gets these advantages:

- To avoid the fees by the supplier
- It reduces the absorbed current and it optimizes the electrical system
- It reduces the voltage drops and the losses due to Joule effect

How to correct

The most appropriate technical solution is to put on each load its own power factor correction capacitor to be included with the drive switch (distributed PFC).
The most effective power factor correction, however, is the one that involves the installation of an automatic battery on the bars of the distribution panel (Centralized PFC) and, if necessary, the installation of fixed capacitor banks for the correction of transformers, asynchronous motors and any loads that absorb significate amount of reactive power.
For electrical machines such as induction motors and transformers it is often used a fixed power factor correction, most of the time sized on values obtained from tables.

How to compute

The calculation of the capacitor bank to be installed in an installation is simple: given the cosφ of the system without any correction (often obtainable from electric bills) and the cosφ that has to be reached, the reactive power necessary to achieve the wanted Power factor is obtained by few calculations:

$Qc = P \cdot (\tan\varphi_0 - \tan\varphi_1) = P \cdot K$
P = active power of the system
$\cos\varphi_0 = \cos\varphi$ of the system without PFC
$\cos\varphi_1 = \cos\varphi$ target
Qc = reactive power of PFC system to be installed
K = given $\cos\varphi_0$ and $\cos\varphi_1$ K is derived from the table below

If the system's coφs value should be unknown, the calculation of the reactive power necessary for the compensation can be done starting from the data found on the energy utility's bills or read directly from the utility's energy meter.

Knowing the active power [kW] P and the reactive power [kVAr] Q of the system, or the active energy [kWh] and the reactive energy [kVArh], the following formula can be used:

$Q / P = \tan\varphi$

The tanφ value thus calculated can be used with the table to calculate the reactive power of the PFC equipment necessary to correct the PF to the desired value.
For the monitoring of the system's electrical parameters we suggest the installation of one or more Network Analysers, providing measurements of all parameters characterising the system and the loads. DUCATI Energia offers a comprehensive range of Energy Analysers and Monitoring Systems.

Reference notes

The capacitors and the automatic power factor correction equipment must be installed in well-ventilated areas.
The air should be able to circulate freely through the air vents. The ambient temperature must comply with EN 60831-1/2 standards.
When the system subject to power factor correction has AC/DC static conversion systems (e.g. for the operation of DC motors, uninterrupted power systems, etc.), harmonic currents are generated and may cause either current or voltage overloads which the capacitors are unable to withstand.
DUCATI energia can provide properly protected equipment suitable for use in such systems as well as filter systems designed to eliminate harmonic components.
When the capacitors are used in automatic equipment, be sure to check that the regulator response time is greater than the capacitor discharge time. If this is not the case, suitable discharge resistors should be installed.
The use of rigid connections should be avoided with cylindrical capacitors in order to avoid blocking the intervention of the overpressure device.
For this reason at least 3 cm should be left between the terminals and any surface above the upper capacitor.
In the automatic equipment the integrity of the pre-charging resistors should be checked every 10.000 operations or at least once a year.
Plan to replace the contactors every 100.000 operations.
The guarantee does not cover problems arising from operation:

- In the presence of excessive harmonic overloads (> 1.3 In, > 1.1 Un.)
- Contactors with worn-out electrical contacts or interrupted precharging resistors

Installation notes

As required by the standards, it is necessary to ensure an appropriate protection against short-circuit and overload (via magnetic/thermic circuit breaker or fuses) for the line supplying the PFC units. The protection must be dimensioned for capacitive currents (approx. 1,45 times the equipment's nominal current) and taking into account the short-time short-circuit current values expected in the point of installation and sustainable by the PFC equipment.

K FACTOR

See the full table at page 64.

Existing values		Target cosφ										
tgφ	**cosφ**	**0.90**	**0.91**	**0.92**	**0.93**	**0.94**	**0.95**	**0.96**	**0.97**	**0.98**	**0.99**	**1.00**
0.72	0.81	0.240	0.268	0.298	0.329	0.361	0.395	0.432	0.473	0.521	0.581	0.724
0.70	0.82	0.214	0.242	0.272	0.303	0.335	0.369	0.406	0.447	0.495	0.556	0.698
0.67	0.83	0.188	0.216	0.246	0.277	0.309	0.343	0.380	0.421	0.469	0.530	0.672
0.65	0.84	0.162	0.190	0.220	0.251	0.283	0.317	0.354	0.395	0.443	0.503	0.646

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Criteria for choosing equipment according to network conditions

Once the maximum necessary power has been determined as directed in the previous sections, the choice of which type of equipment to adopt must be based on the conditions of the electrical network and the types of loads present.The selection table below, drawn up on the basis of general plant characteristics (and thus not usable for planning purposes), aims to provide an indication of the power factor correction system generally suited to the most frequently encountered conditions; electrical systems with mains voltage of 400V-50Hz, characterized by the presence of distorting loads with a spectrum composed of 5th, 7th, 11th and 13th harmonics.

SERIES	THDi < 12% (THDic <50%)	THDi < 20% (THDic < 70%)	THDi < 27% (THDic < 85%)	THDi < 80% (THDic < 95%)	THDi < 80% (THDic <100%)	PV system
Fixed PFC equipment						
DUCATI F120 (5 - 120 kVAr) 	Un = 415 V	Un = 450 V	Un = 525 V	Un = 525 V	Un = 525 V	
Automatic PFC equipment						
DUCATI 50-M (5 - 50 kVAr) 	Un = 415 V	Un = 450 V	Un = 525 V			Un ⩾ 450 V
DUCATI 200-M (60 - 200 kVAr) 	Un = 415 V	Un = 450 V	Un = 525 V			Un ⩾ 450 V
DUCATI 400-M (220 - 400 kVAr) 	Un = 415 V	Un = 450 V	Un = 525 V			Un ⩾ 450 V
DUCATI 1600-R (240-1600 kVAr) 	Un = 415 V	Un = 450 V	Un = 525 V			Un ⩾ 450 V
Automatic PFC equipment with detuning reactors						
DUCATI 170-ML (25,5-170 kVAr) 	✔	✔	✔	✔		✔
DUCATI 1000-RL (150 -1000 kVAr) 	✔	✔	✔	✔		✔
DUCATI 1000-RL/HP (132 - 1056 kVAr) 	✔	✔	✔	✔	✔	✔
Real time automatic PFC equipment						
DUCATI 1000-RL/S (250 - 600 kVAr) 	✔	✔	✔	✔		✔

DUCATI 170-ML

Automatic equipment with detuning reactors

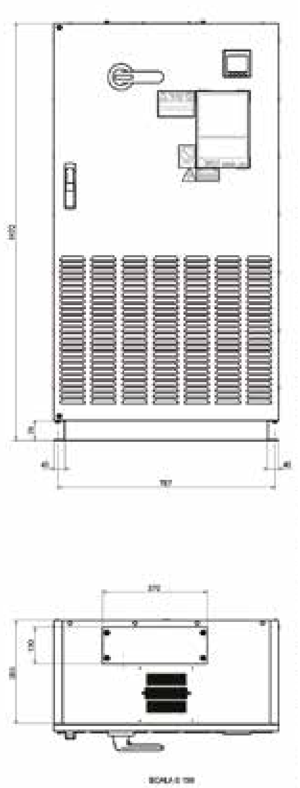
Technical details

- Single-phase capacitors **MONO Long Life 4I_N** series in PPMh, for a continuous duty under highly demanding condition in harmonic rich environments. Rated voltage 480 V
- Power Factor Controller series **rEvolution R5** 485 radio. Auto-sensing of the direction and the position of the TC, to ease the operations of setup. Suitable for cogeneration plants as PV. NFC connection for the exchange of the configurations with **"DUCATI Smart Energy" App**. Optional integration with cloud data sharing system **DUCNET**, through RS485 connection or radio 868 MHz transmission
- Harmonic filter reactors with tuning frequency 189 Hz (p= 7%)
- External steel structure painted with epoxy powder color RAL 7035
- Omni pole disconnecting switch, with door lock, and rated current 1.45 In according to the CEI EN standard
- Contactors designed for controlling capacitive loads, equipped with an inrush current limiting device with 230 V 50 - 60 Hz power supply

General Characteristics

Rated voltage	400 V
Rated frequency	50 Hz
Insulating voltage	690 V
Ventilation	Forced
Usage	Indoor
Protection degree	IP30
Duty	Continuous
Temperature range	-5 +40 °C
Power supply	3PH + PE
Cable entry	Top
Internal connection	FS17
Discharge devices	On each capacitor
Fuse	NH-00 GL
Standards	IEC 61439 where applicable IEC 61921
I_{SH}	50 kA (conditioned by the upstream protective device)

TECHNICAL DRAWING DUCATI 170-ML



DUCATI 170-ML
Un - Cond = 480 V FILTER 189 Hz(*)

THD_I% ≤ 80%(*) THD_V% ≤ 6%(*) Un 400 V - 50 Hz

Part n. 415.04.	Qn (kVAr) (400 V)	Bank Power (kVAr)	Steps	In (A)	In sw. (A)	LxPxH (mm)	Weight (kg)
2110N	25.5	3 x 8.5	3	37	160	800x400x1470	170
2115N	34	2 x 8.5 + 17	4	49	160	800x400x1470	170
2120N	42.5	8.5 + 2 x 17	5	61	160	800x400x1470	175
2125N	59.5	8.5 + 17+34	7	86	160	800x400x1470	185
2130N	68	2 x 17 + 34	4	98	160	800x400x1470	185
2135N	85	17 + 2 x 34	5	123	250	800x400x1470	190
2140N	102	2 x 17 + 2 x 34	6	147	250	800x400x1470	220
2145N	119	17 + 3 x 34	7	172	250	800x400x1470	220
2150N	136	2 x 17 + 3 x 34	8	196	400	800x400x1470	240
2155N	153	17 + 4 x 34	9	221	400	800x400x1470	245
2160N	170	5 x 34	5	245	400	800x400x1470	250

* Other operating voltages and tuning frequencies available upon request.

DUCATI 1000-RL

Automatic equipment with detuning reactors

Technical details

- Single-phase capacitors **MONO Long Life 4$_{IN}$** series in PPMh, for a continuous duty under highly demanding condition in harmonic rich environments. Rated voltage 480 V
- Power Factor Controller series **rEvolution R8** with 868 MHz radio module and RS485 and Bluetooth connection. In addition of the NFC module, there's BT connection to exchange configuration files and status information with **"DUCATI Smart Energy" App**. Auto-sensing of the direction and the position of the TC, to ease the operations of setup. Suitable for cogeneration plants as PV. NFC connection for the exchange of the configurations with **"DUCATI Smart Energy" App**. Optional integration with cloud data sharing system **DUCNET**, through radio 868 MHz transmission
- Harmonic filter reactors with tuning frequency 189 Hz (p= 7%)
- External steel structure painted with epoxy powder color RAL 7035, with modular chassis style internal structure
- Omni pole disconnecting switch, with door lock, and rated current 1.45 In according to the CEI EN standard
- Contactors designed for controlling capacitive loads, equipped with an inrush current limiting device with 230 V 50 - 60 Hz power supply

General Characteristics

Rated voltage	400 V
Rated frequency	50 Hz
Insulating voltage	690 V
Ventilation	Forced
Usage	Indoor
Protection degree	IP30 - IP54
Duty	Continuous
Temperature range	-5 +40 °C
Power supply	3F + PE
Cable entry	Top or bottom
Internal connection	FS17
Discharge devices	On each capacitor
Fuse	NH-00 GL
Standards	IEC 61439 where applicable IEC 61921
I_{SH}	50 kA (0.5 s)

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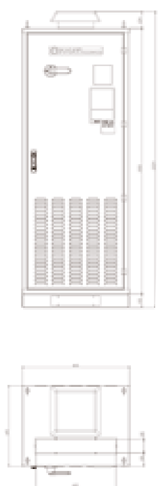
DUCATI 1000-RL Un - Cond = 480 V FILTER 189 Hz(*)

THD_I% ≤ 80%(*) THD_V% ≤ 6%(*) Un 400 V - 50 Hz

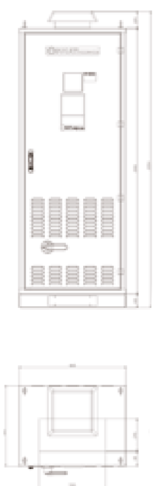
Qn (kVAr) (400 V)	Bank Power (kVAr)	Steps	In (A)	In sw. (A)	Top cable entry			Bottom cable entry		
					Part n. 415.04.	LxPxH (mm)	Weight (kg)	Part n. 415.04.	LxPxH (mm)	Weight (kg)
150	2 x 25 + 2 x 50	6	217	630	**2010**	800x600x2250	360	**2010B**	800x600x2250	360
175	25 + 3 x 50	7	253	630	**2015**	800x600x2250	365	**2015B**	800x600x2250	365
200	4 x 50	4	289	630	**2020**	800x600x2250	370	**2020B**	800x600x2250	370
200	2 x 25 + 3 x 50	8	289	630	**2023**	800x600x2250	400	**2023B**	800x600x2250	460
250	5 x 50	5	361	630	**2025**	800x600x2250	410	**2025B**	800x600x2250	465
300	6 x 50	6	433	630	**2030**	800x600x2250	445	**2030B**	800x600x2250	475
350	7 x 50	7	505	1000	**2035**	800x600x2250	485	**2035B**	800x600x2250	485
400	8 x 50	8	577	1000	**2040**	800x600x2250	520	**2040B**	800x600x2250	520
500	10 x 50	10	722	1000	**2045**	800x600x2250	595	**2045B**	1600x600x2250	885
600	6 x 50 + 3 x 100	12	866	630 + 630	**2050**	1600x600x2250	890	**2050B**	1600x600x2250	890
700	6 x 50 + 4 x 100	14	1010	630 + 1000	**2055**	1600x600x2250	965	**2055B**	1600x600x2250	965
800	4 x 50 + 6 x 100	16	1155	1000 + 1000	**2060**	1600x600x2250	1045	**2060B**	1600x600x2250	1045
900	2 x 50 + 8 x 100	18	1299	1000 + 1000	**2065**	1600x600x2250	1110	**2065B**	2400x600x2250	1350
1000	2 x 50 + 7 x 100 + 200	20	1443	1000 + 1000	**2070**	1600x600x2250	1190	**2070B**	2400x600x2250	1430

* Other operating voltages and tuning frequencies available upon request.
IP54 on demand (same sizes as the previous table).

TECHNICAL DRAWING DUCATI 1000-RL



1 Door top cable entry



1 Door bottom cable entry

2 Doors top cable entry

2 Doors bottom cable entry

DUCATI 1000-RL/HP

Automatic equipment with detuning reactors

Technical details

- Single-phase capacitors GP84 series in PPMh for high performance, built exclusively with dual-element series to work in systems characterized by high harmonic currents. Rated voltage 550 V
- Power Factor Controller series **rEvolution R8** with 868 MHz radio module and RS485 and Bluetooth connection. In addition of the NFC module, there's BT connection to exchange configuration files and status information with **"DUCATI Smart Energy" App**. Auto-sensing of the direction and the position of the TC, to ease the operations of setup. Suitable for cogeneration plants as PV. NFC connection for the exchange of the configurations with **"DUCATI Smart Energy" App**. Optional integration with cloud data sharing system DUCNET, through radio 868 MHz transmission
- Harmonic filter reactors with tuning frequency 189 Hz (p= 7%)
- External steel structure painted with epoxy powder color RAL 7035, with modular chassis style internal structure
- Omni pole disconnecting switch, with door lock, and rated current 1.45 In according to the CEI EN standard
- Contactors designed for controlling capacitive loads, equipped with an inrush current limiting device with 230 V 50 - 60 Hz power supply

General Characteristics

Rated voltage	400 V
Rated frequency	50 Hz
Insulating voltage	690 V
Ventilation	Forced
Usage	Indoor
Protection degree	IP30 - IP54
Duty	Continuous
Temperature range	-5 +40 °C
Power supply	3F + PE
Cable entry	Top or bottom
Internal connection	FS17
Discharge devices	On each capacitor
Fuse	NH-00 GL
Standards	IEC 61439 where applicable IEC 61921
I_{SH}	50 kA (0.5 s)

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DUCATI 1000-RL/HP Un - Cond = 550 V FILTER 189 Hz (*)

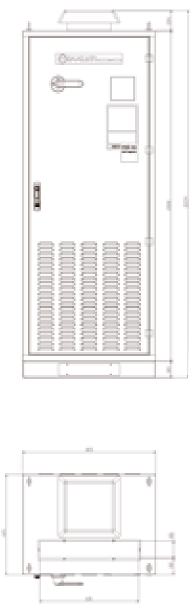
$THD_I\% \leq 100\%$(*) $THD_V\% \leq 7\%$(*) Un 400 V - 50 Hz

Qn (kVAr) (400 V)	Bank Power (kVAr)	Steps	In (A)	In sw. (A)	Top cable entry			Bottom cable entry		
					Part n. 415.04.	LxPxH (mm)	Weight (kg)	Part n. 415.04.	LxPxH (mm)	Weight (kg)
132	2 x 22 + 2 x 44	6	191	630	**2510**	800x600x2250	380	**2510B**	800x600x2250	380
176	4 x 44	4	254	630	**2515**	800x600x2250	400	**2515B**	800x600x2250	400
264	6 x 44	6	381	630	**2520**	800x600x2250	480	**2520B**	800x600x2250	480
352	8 x 44	8	508	1000	**2525**	800x600x2250	600	**2525B**	800x600x2250	600
440	10 x 44	10	635	1000	**2530**	1600x600x2250	850	**2530B**	1600x600x2250	850
528	6 x 44 + 3 x 88	12	762	1250	**2535**	1600x600x2250	930	**2535B**	1600x600x2250	930
616	6 x 44 + 4 x 88	14	889	1600	**2540**	1600x600x2250	1000	**2540B**	1600x600x2250	1000
704	4 x 44 + 6 x 88	16	1016	1600	**2545**	1600x600x2250	1080	**2545B**	1600x600x2250	1080
792	2 x 44 + 8 x 88	18	1143	2500	**2550**	2400x600x2250	1400	**2550B**	2400x600x2250	1400
880	2 x 44 + 7 x 88 + 176	20	1270	2500	**2555**	2400x600x2250	1500	**2555B**	2400x600x2250	1500
968	2 x 44+ 6 x 88 + 2 x 176	22	1397	2500	**2560**	2400x600x2250	1600	**2560B**	2400x600x2250	1600
1056	8 x 88 + 2 x 176	12	1524	2500	**2565**	2400x600x2250	1700	**2565B**	2400x600x2250	1700

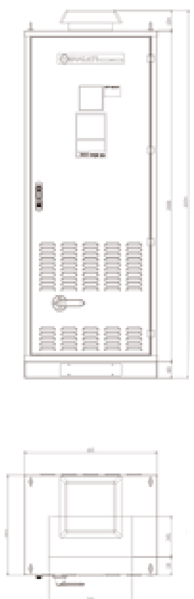
* Other operating voltages and tuning frequencies available upon request.

IP54 on demand (same sizes as the previous table).

TECHNICAL DRAWING DUCATI 1000-RL/HP



1 Door top cable entry



1 Door bottom cable entry

2 Doors top cable entry

2 Doors bottom cable entry

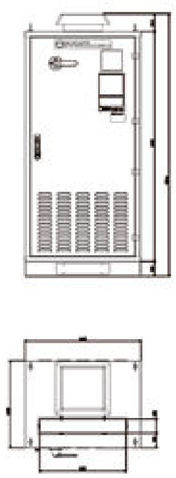
DUCATI 1000-RL/S

Real time automatic PFC equipment

Technical details

- Single-phase capacitors **MONO Long Life 4I_N** series in PPMh, for a continuous duty under highly demanding condition in harmonic rich environments. Rated voltage 480 V
- Power factor **controller FCR** with enhanced VLSI and Digital Signal Processor system for FFT measurement. Realtime analysis with duty cycle around 5 millisecond RS-485
- Communication serial port RS-485 and built-in customization help software
- Harmonic filter reactors with tuning frequency 189 Hz (p= 7%)
- External steel structure painted with epoxy powder color RAL 7035, with modular chassis style internal structure
- Omni pole disconnecting switch, with door lock, and rated current 1.45 In according to the CEI EN standard
- **Static Switching Module SCR**, suitable for controlling capacitive loads, inserted outside the delta connection formed by the single-phase capacitive elements

General Characteristics	
Rated voltage	400 V
Rated frequency	50 Hz
Insulating voltage	690 V
Ventilation	Forced
Usage	Indoor
Protection degree	IP30
Duty	Continuous
Temperature range	-5 +40 °C
Power supply	3F + PE
Cable entry	Top
Internal connection	FS17
Discharge devices	On each capacitor according to EN 60831 standard
Fuse	NH-00 GL
Standards	EN 61000-4-2 EN 50081-2 EN 50082-2 IEC 61921 -1/2



TECHNICAL DRAWING DUCATI 1000-RL/S

DUCATI 1000-RL/S
Un - Cond = 480 V FILTER 189 Hz

THD_I % ≤ 80%(*) THD_V% ≤ 6%(*) Un 400 V - 50 Hz

Part no. 415.14.	Q (400 V) (kVAr)	Bank Power (kVAr)	Steps	In (A)	In sw. (A)	LxPxH (mm)	Weight (kg)
1360	250	2 x 25 + 4 x 50	10	361	630	800x700x2150	465
1365	300	6 x 50	6	433	630	800x700x2150	505
1370	350	7 x 50	7	505	1000	1600x700x2150	780
1372	400	8 x 50	8	577	1000	1600x700x2150	820
1375	450	9 x 50	9	650	1000	1600x700x2150	860
1380	500	10 x 50	10	722	1000	1600x700x2150	900
1385	550	11 x 50	11	794	1250	1600x700x2150	940
1390	600	12 x 50	12	866	1250	1600x700x2150	980

* Other operating voltages and tuning frequencies available upon request.

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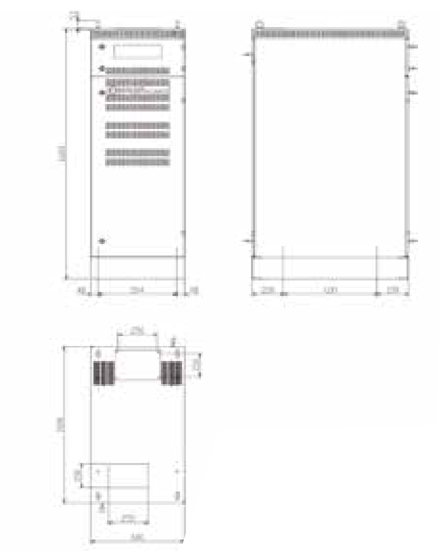
DUCATI Active Filter Un = 400 V

Power Range: 35 – 120 A - Harmonic orders: 2° - 51°

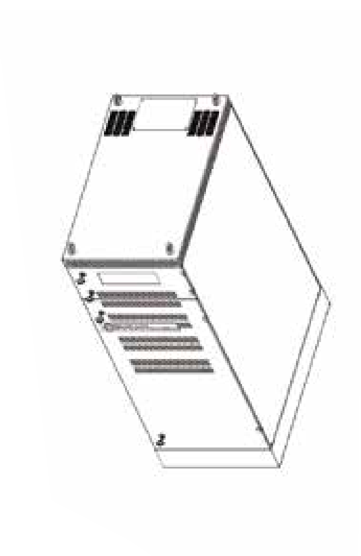
TECHNICAL DRAWING DUCATI ACTISINE



Part n. 415.14	I - L1/L2/L3 (Arms)	I - neutral (Arms)	LxPxH (mm)	Weight (kg)
		3 phases – 3 wires		
2001 K	35	-	600x1000x1600	75
2002 K	60	-	600x1000x1600	120
2003 K	90	-	600x1000x1600	190
2004 K	120	-	600x1000x1600	235
		3 phases – 4 wires		
2005 K	35	105	600x1000x1600	75
2006 K	60	180	600x1000x1600	120
2007 K	90	270	600x1000x1600	190
2008 K	120	360	600x1000x1600	235

DUCATI Active Filter Un = 480 V

Power Range: 30 – 100 A - Harmonic orders: 2° - 51°



Part n. 415.14	I - L1/L2/L3 (Arms)	I - neutral (Arms)	LxPxH (mm)	Weight (kg)
		3 phases – 3 wires		
2011 K	30	-	600x1000x1600	85
2012 K	50	-	600x1000x1600	130
2013 K	75	-	600x1000x1600	200
2014 K	100	-	600x1000x1600	245
		3 phases – 4 wires		
2015 K	30	90	600x1000x1600	85
2016 K	50	150	600x1000x1600	130
2017 K	75	225	600x1000x1600	200
2018 K	100	300	600x1000x1600	245

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APPENDIX

Glossary

Cosφ. In an electrical system the phi (φ) is the phase shift between voltage and current at the fundamental frequency of 50Hz. The cosφ is a dimensionless number between 0 and 1 that represent this shift.

Power Factor. It's a ratio between the active power and the apparent power and as cosφ has value between 0 and 1. In a system without harmonics, cosφi and Power Factor are the same; in a system with harmonic, the power factor is always less than the cosφ.

Nominal Voltage of the capacitor (Un) it's the rated voltage or the capacitor, at which its output rated power is given. This is the maximum effective value of the alternating sinusoidal voltage for which the capacitor was designed.

Nominal Power of the Capacitor (Qn) it's the reactive power delivered by the capacitor at the rated voltage and frequency applied.

Rated capacitance (Cn) This is the value of the capacitance which permits the delivery of the rated power when the rated voltage and frequency are applied to the terminals.

Rated current (In) this is the effective value of the alternating current that circulates through the capacitor when the rated voltage and frequency are applied at the rated capacitance.

Insulation voltage. For a PFC system that complies with IEC 60429-1/2, the insulation voltage is indicative of the maximum voltage that the entire system can withstand.

Short circuit current I_{SH}. As indicated in the IEC 61429-1 it the prospective short circuit current that the cabinet can endure for a specified time. It's a value stated by the manufacturer based on laboratory tests. It can be increased by installing fuses in this case the data must indicate the presence of the fuses.

Steps of an automatic PFC unit. They are the physical units of the bank, each of them controlled by a dedicated switching device.

Combinations it's the number of the different configurations that the PFC unit can made with the combinations of the physical steps For example, a 160 kvar unit with steps 20-20-40-40-40 can use 8 different combinations: 20-40-60-80-100-120-140-160. The more combinations can be used, the better flexibility to use the PFC unit.

THD (Total Harmonic Distorsion). For a periodic non-sinusoidal wave, the THD is the ratio between the rms value of all harmonic components and the rms value of the fundamental 50 Hz.

THD_{IC} it's the maximum THD that a capacitor can bear in terms of current passing through it.

THD_{IR} it' the maximum THD present in the plant without any PFC unit on. It's useful to define the type of the capacitor to install.

THD_{V} it's the voltage THD that a PFC bank with harmonic blocking reactors can bear.

Operating conditions

Unlike most electrical equipment, power factor correction capacitors, each time they are energized, continuously operate at full load or at loads which differ from this value only as a consequence of variations in voltage and frequency. Overstressing and overheating shorten the lifespan of the capacitor. For this reason the operating conditions (temperature, voltage and current) must be carefully controlled in order to obtain optimum results as regards the lifespan of the capacitor.

Voltage

The capacitors are produced in accordance with standards EN 60831-1/2, which regulate their manufacture, testing, installation and application of capacitors, indicating the following maximum overvoltages:

- +10% for 8 hours every 24 hours
- +15% for 30 minutes every 24 hours
- +20% for 5 minutes
- +30% for 1 minute

Overvoltages in excess of 15% should not occur more than 200 times during the life of a capacitor.
When overload conditions may be assumed to occur during service – in the presence of a moderate harmonic load for example – it is common to use capacitors that are oversized in terms of voltage.
In such cases the output power at the operating voltage will be reduced in comparison with the rated load. It is advisable to evaluate the reduction occurring in the output power on the basis of the ratio between the operating voltage and the rated voltage.

$Q_{resa} = Qn \times (Ue/Un)^2$

Where:
Ue= Operating voltage Q_{resa} = Output power at Ue
The table below shows the power output by a 100 kvar capacitor used on a 400 V network having a rated voltage respectively of 415, 450 and 525 V.

U_n [V]	415	450	525
Q_{resa} [kVAr]	93	79	58

Temperature

The temperature of the capacitor during operation is the parameter that, along with the voltage, has the greatest influence on the lifespan of a capacitor.
It is important that the capacitor always be placed in a position where cooling air can freely circulate and away from the radiant heat of hot surfaces of other components.
When capacitors are placed in closed cabinets it is necessary to have air vents which allow for an easy exchange of air between the interior and exterior of the cabinet. Where the degree of protection of the cabinet does not permit such an exchange to take place, the positioning of the capacitors must be carefully planned so as to provide the necessary channels for the circulation of cooling air. In this case, suitable fans will have to be installed to force cooling air through the cabinet. As a rule, the temperature of the cooling air inside the cabinet should not differ from the outside air temperature by more than 5 °C.

Cooling air temperature
This is the temperature of the cooling air measured at the hottest point of the capacitor bank, under working conditions, halfway between two capacitors or on the surface of one of them.

Ambient temperature class
This represents the range of cooling air temperatures in which the capacitor is designed to operate. There are 4 standard categories represented by a number and a letter or by two numbers as shown in the table.

Category		Category Ambient air temperature		
		Max	Highest mean over any period of:	
			24 h	1 Year
-25/A	-25 +40 °C	40	30	20
-25/B	-25 +45 °C	45	35	25
-25/C	-25 +50 °C	50	40	30
-25/D	-25 +55 °C	55	45	35

The first number represents the minimum cooling air temperature at which the capacitor can be energized (- 25°C; on request -40°C). The letter or second number represents the upper limit of the temperature range and precisely. the max. value indicated in the table.

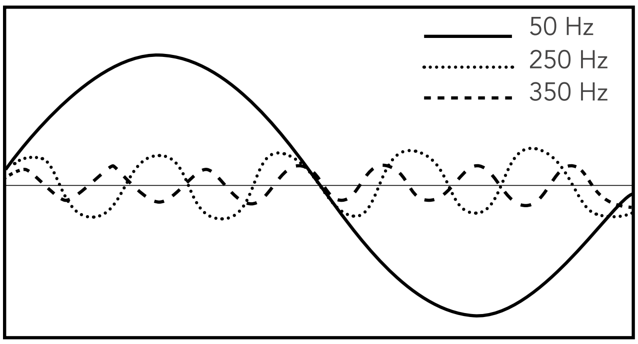
Residual voltage
This is the voltage that remains after the capacitor is disconnected from the network. This voltage must be eliminated in order to avoid exposing the operator to dangerous conditions. All three-phase capacitors are equipped with discharge devices that reduce residual voltage to less than 75 V in 3 minutes.
It is important to bear in mind that the capacitors cannot be energized if there is a residual voltage of more than 10% across them. Particular care must thus be taken to harmonise the capacitor discharge times with the response times of the control devices (Power control relays). In cases where the lag time of the controllers is shorter than the capacitor discharge time, additional discharge devices must be provided so that the connection will occur with a residual voltage not exceeding 10%.

Max current
In accordance with standard EN 60831-1/2, the capacitors are designed to function continuously at an effective current that is 1.3 times the current at the rated voltage and frequency. Bearing in mind the capacitance tolerance, the maximum current may reach 1.5 In, value to which it is necessary to refer in the sizing of the lines of control and protection devices. This overcurrent factor can be determined by the combined effect of harmonics, overvoltages and capacitance tolerance.

Max inrush current
Transient overcurrents having elevated amplitudes and high frequencies occur when the capacitors are switched in to the circuit. This is especially true when a capacitor bank is put in a parallel connection with other already energized banks.
It may therefore be necessary to reduce these transient overcurrents to values acceptable both for the capacitor and the contactor used by connecting the capacitor using suitable devices (resistors or reactors) in the power circuit of the bank.
The crest value of overcurrents caused during switching operations must be limited to a maximum of 100 In (crest value of the 1st cycle).

Protection and safety
To ensure protection, the capacitor elements making up the unit are individually fitted with an overpressure safety device.
The function of this device is to interrupt a short circuit when the capacitor reaches the end of its useful life and is no longer able to regenerate itself. This device breaks the connections of the terminal by exploiting the internal pressure that builds during the film's decomposition, which results from the overheating caused by the short circuit.
It should be noted that an external fuse is not as reliable since the short circuit current, being strongly limited by the metallized surface, may vary widely.
All the capacitors are built with environmentally friendly materials conforming to standards EN 60831-1/2.

The effect of harmonics in electrical systems
A harmonic is defined as one of the components obtained from the breakdown of a periodic wave in the Fourier series. The order of a harmonic is further defined as the ratio between the frequency of the harmonic and the fundamental frequency of the periodic wave considered.
In the case of a perfectly sinusoidal waveform (as should characterize the voltage supplied by the utility) only the fundamental harmonic of the first order will be present, which in Europe has a frequency of 50 Hz.
If a sinusoidal voltage is applied to a load, the circulating current will also have a sinusoidal waveform only in the presence of loads with "linear characteristics".
In the presence of a "non-linear" load the current waveform will deviate from the ideal pattern and breaking down the wave according to the Fourier theorem will show evidence of harmonics whose number and amplitude will increase with the degree of distortion in the current waveform.
The increasingly frequent use of non-linear loads in industrial facilities (inverters, fluorescent lamps, welders, etc.) creates elevated distorsions in the waveform of circulating current.
This is true in the case of ac/dc converters, for which the input current theoretically displays only harmonics of the order:
$h = mp \pm 1$
where m is an integer other than 0 (thus 1, 2, 3, 4, ...) and p is the number of solid-state switches of the bridge. Therefore, a converter with six-phase reaction (p= 6) generates characteristic harmonics of the 5th and 7th order (m= 1), 11th and 13th order (m= 2), 17th and 19th order (m= 3) etc., whereas a converter with twelve-phase reaction (p= 12) generates characteristic harmonics of the 11th and 13th order (m= 1), 23rd and 25th order (m= 2).



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The parameter used to determine the level of harmonic distortion presents in an electrical network is THDI% (Total Harmonic Distortion), defined as:

$$TDH_i\% = \frac{\sqrt{\sum_{k=2}^{\infty} I_k^2}}{I_1}$$

Where I_1 is the effective value of the fundamental and Ik represents the effective values of harmonics of order k.

The presence of current harmonics in the system is therefore an indication of a distortion (deviation from a sinusoidal pattern) in the waveform of the current itself.
This results in increased losses due to the Joule effect and the skin effect in the cables and increased losses due to hysteresis and parasite currents in the iron of transformers and motors. In addition, because of the equivalent cable impedances, the mains voltage may also be distorted.

Installing power factor correction capacitors in the network serves to create a condition of parallel resonance between the equivalent capacitance of the capacitors and the equivalent inductance of the system (which may usually be approximated by calculating the equivalent inductance of the transformer) in correspondence to a frequency fr.

$$\int_r = \int_1 \cdot \sqrt{\frac{Scc}{\Omega}}$$

Where S_{cc} indicates the short circuit power of the system (expressed in MVA) at the point where the capacitors are connected and Ω is the installed reactive power (expressed in Mvar), the parallel resonance frequency fr is thus determined:

$$S_{cc} = \frac{A}{V_{cc}\%} \cdot 100$$

Where A is the rated power of the transformer (expressed in MVA) and Vcc% is the percentage short circuit voltage of the transformer.
The voltage harmonics present in the system - having a frequency close to the parallel resonance frequency fr - are amplified. For this reason, an extremely high voltage comes to be created at the capacitor terminals, which causes the dielectric to age rapidly and hence significantly shortens the lifespan of the capacitor.

Risk of Explosion and Fire
All capacitors consists mainly of polypropylene. They can rupture and ignite cause of internal faults (malfunction of safety system, if present) or external overload (Overvoltage, overcurrent, high temperature, etc.).
It must be ensured, by appropriate measures, to avoid any risk of explosion, fire and hazard to their environment in the event of malfunction.

Correcting the power factor of MV/LV transformers
It is always a good idea to ensure a power factor correction for MV/LV transformers, since even when they are operating loadless (e.g. during the night) they absorb reactive power, which must be compensated.
The exact capacitor power necessary may be calculated using the formula below:
Q = Io% · Pn/100
Io = loadless current (specified by the transformer manufacturer)
Pn= rated power of the transformer.
Alternatively, if the required data is not available, you can refer to the table below, which differentiates among types of transformers with NORMAL losse

Power transformer	Oil transformer	Resin transformer kVAr
10	1	1.5
20	2	1.7
50	4	2
75	5	2.5
100	5	2.5
160	7	4
200	7.5	5
250	8	7.5
315	10	7.5
400	12.5	8
500	15	10
630	17.5	12.5
800	20	15
1000	25	17.5
1250	30	20
1600	35	22
2000	40	25
2500	50	35
3150	60	50

Power factor correction of three-phase asynchronous motors

One of the most commonly occurring loads is the three-phase asynchronous motor. The table below shows the power factor correction in the case of squirrel-cage motors. An additional 5% is recommended for motors with wound armatures.

The table shows the approximate powers of the capacitor banks to be installed according to motor power.

Reactive power to be installed - Three-phase motor: 230/400 V					
Rated power		**Rotation speed (rpm)**			
(kW)	**(Cv)**	**3000**	**15000**	**1000**	**750**
22	30	6	8	9	10
30	40	7.5	10	11	12.5
37	50	9	11	12.5	16
45	60	11	13	14	17
55	75	13	17	18	21
75	100	17	22	25	28
90	125	20	25	27	30
110	150	24	29	33	37
132	180	31	36	38	43
160	218	35	41	44	52
200	274	43	47	53	61
250	340	52	57	63	71
280	385	57	63	70	79
355	482	67	76	86	98
400	544	78	82	97	106
450	610	87	93	107	117

Minimum cable cross section for equipment power supply

Main voltage 400 V – 50 Hz – 3F		
Qn kVAr	**In A**	**Minimum cablecross-section suggested for phase[1] (mm²)**
5	7	2.5
10	14	4
15	22	6
20	29	10
30	43	16
40	58	16
50	72	35
100	144	70
200	288	185 opp./or2x70
300	433	2x150
400	576	2x240
500	722	3x185
600	864	3x240
700	1010	4x240
800	1154	4x240
900	1300	6x185
1000	1443	6x240

(1) = Values reported for single-core PVC cables in free air laid not separated on horizontal shelves. For other types of cables and/or installation refer to IEC 60364-5, CEI 64-8 and table UNEL 35024/1.

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K FACTOR

Existing values		Target cosφ															
tgφ	**cosφ**	**0.85**	**0.86**	**0.87**	**0.88**	**0.89**	**0.90**	**0.91**	**0.92**	**0.93**	**0.94**	**0.95**	**0.96**	**0.97**	**0.98**	**0.99**	**1.00**
3.18	**0.30**	2.560	2.586	2.613	2.640	2.667	2.695	2.724	2.754	2.785	2.817	2.851	2.888	2.929	2.977	3.037	3.180
3.07	**0.31**	2.447	2.474	2.500	2.527	2.555	2.583	2.611	2.641	2.672	2.704	2.738	2.775	2.816	2.864	2.924	3.067
2.96	**0.32**	2.341	2.367	2.394	2.421	2.448	2.476	2.505	2.535	2.565	2.598	2.632	2.669	2.710	2.758	2.818	2.961
2.86	**0.33**	2.241	2.267	2.294	2.321	2.348	2.376	2.405	2.435	2.465	2.498	2.532	2.569	2.610	2.657	2.718	2.861
2.77	**0.34**	2.146	2.173	2.199	2.226	2.254	2.282	2.310	2.340	2.371	2.403	2.437	2.474	2.515	2.563	2.623	2.766
2.68	**0.35**	2.057	2.083	2.110	2.137	2.164	2.192	2.221	2.250	2.281	2.313	2.348	2.385	2.426	2.473	2.534	2.676
2.59	**0.36**	1.972	1.998	2.025	2.052	2.079	2.107	2.136	2.166	2.196	2.229	2.263	2.300	2.341	2.388	2.449	2.592
2.51	**0.37**	1.891	1.918	1.944	1.971	1.999	2.027	2.055	2.085	2.116	2.148	2.182	2.219	2.260	2.308	2.368	2.511
2.43	**0.38**	1.814	1.841	1.867	1.894	1.922	1.950	1.979	2.008	2.039	2.071	2.105	2.143	2.184	2.231	2.292	2.434
2.36	**0.39**	1.741	1.768	1.794	1.821	1.849	1.877	1.905	1.935	1.966	1.998	2.032	2.069	2.110	2.158	2.219	2.361
2.29	**0.40**	1.672	1.698	1.725	1.752	1.779	1.807	1.836	1.865	1.896	1.928	1.963	2.000	2.041	2.088	2.149	2.291
2.22	**0.41**	1.605	1.631	1.658	1.685	1.712	1.740	1.769	1.799	1.829	1.862	1.896	1.933	1.974	2.022	2.082	2.225
2.16	**0.42**	1.541	1.567	1.594	1.621	1.648	1.676	1.705	1.735	1.766	1.798	1.832	1.869	1.910	1.958	2.018	2.161
2.10	**0.43**	1.480	1.506	1.533	1.560	1.587	1.615	1.644	1.674	1.704	1.737	1.771	1.808	1.849	1.897	1.957	2.100
2.04	**0.44**	1.421	1.448	1.474	1.501	1.529	1.557	1.585	1.615	1.646	1.678	1.712	1.749	1.790	1.838	1.898	2.041
1.98	**0.45**	1.365	1.391	1.418	1.445	1.472	1.500	1.529	1.559	1.589	1.622	1.656	1.693	1.734	1.781	1.842	1.985
1.93	**0.46**	1.311	1.337	1.364	1.391	1.418	1.446	1.475	1.504	1.535	1.567	1.602	1.639	1.680	1.727	1.788	1.930
1.88	**0.47**	1.258	1.285	1.311	1.338	1.366	1.394	1.422	1.452	1.483	1.515	1.549	1.586	1.627	1.675	1.736	1.878
1.83	**0.48**	1.208	1.234	1.261	1.288	1.315	1.343	1.372	1.402	1.432	1.465	1.499	1.536	1.577	1.625	1.685	1.828
1.78	**0.49**	1.159	1.186	1.212	1.239	1.267	1.295	1.323	1.353	1.384	1.416	1.450	1.487	1.528	1.576	1.637	1.779
1.73	**0.50**	1.112	1.139	1.165	1.192	1.220	1.248	1.276	1.306	1.337	1.369	1.403	1.440	1.481	1.529	1.590	1.732
1.69	**0.51**	1.067	1.093	1.120	1.147	1.174	1.202	1.231	1.261	1.291	1.324	1.358	1.395	1.436	1.484	1.544	1.687
1.64	**0.52**	1.023	1.049	1.076	1.103	1.130	1.158	1.187	1.217	1.247	1.280	1.314	1.351	1.392	1.440	1.500	1.643
1.60	**0.53**	0.980	1.007	1.033	1.060	1.088	1.116	1.144	1.174	1.205	1.237	1.271	1.308	1.349	1.397	1.458	1.600
1.56	**0.54**	0.939	0.965	0.992	1.019	1.046	1.074	1.103	1.133	1.163	1.196	1.230	1.267	1.308	1.356	1.416	1.559
1.52	**0.55**	0.899	0.925	0.952	0.979	1.006	1.034	1.063	1.092	1.123	1.156	1.190	1.227	1.268	1.315	1.376	1.518
1.48	**0.56**	0.860	0.886	0.913	0.940	0.967	0.995	1.024	1.053	1.084	1.116	1.151	1.188	1.229	1.276	1.337	1.479
1.44	**0.57**	0.822	0.848	0.875	0.902	0.929	0.957	0.986	1.015	1.046	1.079	1.113	1.150	1.191	1.238	1.299	1.441
1.40	**0.58**	0.785	0.811	0.838	0.865	0.892	0.920	0.949	0.979	1.009	1.042	1.076	1.113	1.154	1.201	1.262	1.405
1.37	**0.59**	0.749	0.775	0.802	0.829	0.856	0.884	0.913	0.942	0.973	1.006	1.040	1.077	1.118	1.165	1.226	1.368
1.33	**0.60**	0.714	0.740	0.767	0.794	0.821	0.849	0.878	0.907	0.938	0.970	1.005	1.042	1.083	1.130	1.191	1.333
1.30	**0.61**	0.679	0.706	0.732	0.759	0.787	0.815	0.843	0.873	0.904	0.936	0.970	1.007	1.048	1.096	1.157	1.299
1.27	**0.62**	0.646	0.672	0.699	0.726	0.753	0.781	0.810	0.839	0.870	0.903	0.937	0.974	1.015	1.062	1.123	1.265
1.23	**0.63**	0.613	0.639	0.666	0.693	0.720	0.748	0.777	0.807	0.837	0.870	0.904	0.941	0.982	1.030	1.090	1.233
1.20	**0.64**	0.581	0.607	0.634	0.661	0.688	0.716	0.745	0.775	0.805	0.838	0.872	0.909	0.950	0.998	1.058	1.201
1.17	**0.65**	0.549	0.576	0.602	0.629	0.657	0.685	0.714	0.743	0.774	0.806	0.840	0.877	0.919	0.966	1.027	1.169
1.14	**0.66**	0.519	0.545	0.572	0.599	0.626	0.654	0.683	0.712	0.743	0.775	0.810	0.847	0.888	0.935	0.996	1.138
1.11	**0.67**	0.488	0.515	0.541	0.568	0.596	0.624	0.652	0.682	0.713	0.745	0.779	0.816	0.857	0.905	0.966	1.108
1.08	**0.68**	0.459	0.485	0.512	0.539	0.566	0.594	0.623	0.652	0.683	0.715	0.750	0.787	0.828	0.875	0.936	1.078
1.05	**0.69**	0.429	0.456	0.482	0.509	0.537	0.565	0.593	0.623	0.654	0.686	0.720	0.757	0.798	0.846	0.907	1.049
1.02	**0.70**	0.400	0.427	0.453	0.480	0.508	0.536	0.565	0.594	0.625	0.657	0.692	0.729	0.770	0.817	0.878	1.020
0.99	**0.71**	0.372	0.398	0.425	0.452	0.480	0.508	0.536	0.566	0.597	0.629	0.663	0.700	0.741	0.789	0.849	0.992
0.96	**0.72**	0.344	0.370	0.397	0.424	0.452	0.480	0.508	0.538	0.569	0.601	0.635	0.672	0.713	0.761	0.821	0.964
0.94	**0.73**	0.316	0.343	0.370	0.396	0.424	0.452	0.481	0.510	0.541	0.573	0.608	0.645	0.686	0.733	0.794	0.936
0.91	**0.74**	0.289	0.316	0.342	0.369	0.397	0.425	0.453	0.483	0.514	0.546	0.580	0.617	0.658	0.706	0.766	0.909
0.88	**0.75**	0.262	0.289	0.315	0.342	0.370	0.398	0.426	0.456	0.487	0.519	0.553	0.590	0.631	0.679	0.739	0.882
0.86	**0.76**	0.235	0.262	0.288	0.315	0.343	0.371	0.400	0.429	0.460	0.492	0.526	0.563	0.605	0.652	0.713	0.855
0.83	**0.77**	0.209	0.235	0.262	0.289	0.316	0.344	0.373	0.403	0.433	0.466	0.500	0.537	0.578	0.626	0.686	0.829
0.80	**0.78**	0.183	0.209	0.236	0.263	0.290	0.318	0.347	0.376	0.407	0.439	0.474	0.511	0.552	0.599	0.660	0.802
0.78	**0.79**	0.156	0.183	0.209	0.236	0.264	0.292	0.320	0.350	0.381	0.413	0.447	0.484	0.525	0.573	0.634	0.776
0.75	**0.80**	0.130	0.157	0.183	0.210	0.238	0.266	0.294	0.324	0.355	0.387	0.421	0.458	0.499	0.547	0.608	0.750
0.72	**0.81**	0.104	0.131	0.157	0.184	0.212	0.240	0.268	0.298	0.329	0.361	0.395	0.432	0.473	0.521	0.581	0.724
0.70	**0.82**	0.078	0.105	0.131	0.158	0.186	0.214	0.242	0.272	0.303	0.335	0.369	0.406	0.447	0.495	0.556	0.698
0.67	**0.83**	0.052	0.079	0.105	0.132	0.160	0.188	0.216	0.246	0.277	0.309	0.343	0.380	0.421	0.469	0.530	0.672
0.65	**0.84**	0.026	0.053	0.079	0.106	0.134	0.162	0.190	0.220	0.251	0.283	0.317	0.354	0.395	0.443	0.503	0.646
0.62	**0.85**		0.026	0.053	0.080	0.107	0.135	0.164	0.194	0.225	0.257	0.291	0.328	0.369	0.417	0.477	0.620
0.59	**0.86**			0.027	0.054	0.081	0.109	0.138	0.167	0.198	0.230	0.265	0.302	0.343	0.390	0.451	0.593
0.57	**0.87**				0.027	0.054	0.082	0.111	0.141	0.172	0.204	0.238	0.275	0.316	0.364	0.424	0.567
0.54	**0.88**					0.027	0.055	0.084	0.114	0.145	0.177	0.211	0.248	0.289	0.337	0.397	0.540
0.51	**0.89**						0.028	0.057	0.086	0.117	0.149	0.184	0.221	0.262	0.309	0.370	0.512
0.48	**0.90**							0.029	0.058	0.089	0.121	0.156	0.193	0.234	0.281	0.342	0.484
0.46	**0.91**								0.030	0.060	0.093	0.127	0.164	0.205	0.253	0.313	0.456
0.43	**0.92**									0.031	0.063	0.097	0.134	0.175	0.223	0.284	0.426
0.40	**0.93**										0.032	0.067	0.104	0.145	0.192	0.253	0.395
0.36	**0.94**											0.034	0.071	0.112	0.160	0.220	0.363
0.33	**0.95**												0.037	0.078	0.126	0.186	0.329
0.29	**0.96**													0.041	0.089	0.149	0.292
0.25	**0.97**														0.048	0.108	0.251
0.20	**0.98**															0.061	0.203
0.14	**0.99**																0.142

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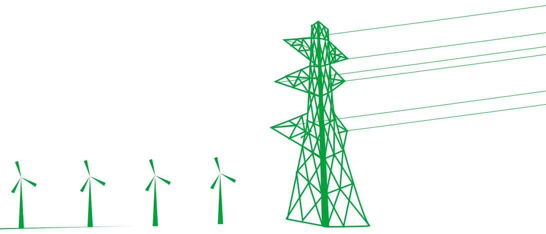
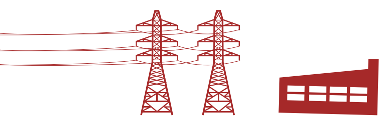
Product range

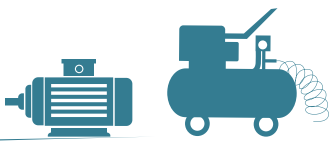
Instruments and systems for electrical measurements



Power electronics capacitors



Capacitors MV and HV power factor correction systems and filters



Motor capacitors

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Low voltage power factor correction: capacitors, components, fixed & automatic equipment and active harmonic filters