VACON® 100 INDUSTRIAL
VACON® 100 FLOW
VACON® 100 HVAC
VACON® 100 X

AC DRIVES

DU/DT FILTER
TECHNICAL GUIDE

VACON®

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1. Introduction

1.1 INTENDED USE

This manual describes the dU/dt filters used with VACON® 100 Family AC drives. The filter range is designed for the wall-mounted drive up to a current rating of 208 A.

1.2 SAFETY

⚠	**WARNING!** Do not touch the components of the filter when the drive system is connected to mains. The components are live when the drive system is connected to mains. A contact with this voltage is very dangerous.
⚠	**WARNING!** Do not touch the input / output terminals of the filter. They can have a dangerous voltage also when the drive system is disconnected from mains.
⚠	**WARNING!** Before you do electrical work on the drive system, disconnect the drive from the mains and make sure that the motor has stopped. Lock out and tag out the power source to the drive system. Make sure that no external source generates unintended voltage during work. Note that also the load side of drive system can generate voltage. Wait 5 minutes before you open the the cover of the filter product. Use a measuring device to make sure that there is no voltage. The terminal connections and the components of the filter can be live 5 minutes after the drive system is disconnected from the mains and the motor has stopped.
⚠	**WARNING!** Only qualified electricians are allowed to do installation and service work.
⚠	**WARNING!** Do not do repair work on a defective product.
⚠	**HOT SURFACE!** Do not touch the surface of the filter. The surface of the filter product becomes hot during operation.

⚠	CAUTION! Use shielded cables to reduce noise, electromagnetic interference noise and to prevent malfunction in the installation.

2. dU/dt filter range

2.1 GENERAL

A pulsed PWM output voltage of an AC drive has typically a high rise time speed (6-8 kV/us) with an unloaded IGBT switch. When the motor cable and the motor are connected, the rise time will drop to 2-3 kV/us. A high switching speed together with the cable transmission line effect cause overvoltage in motor input terminals and high frequency leakage currents in motor coils and chassis. As a result, there might be damage on the motor insulation and bearings.

Usually there is no need for additional protection with motors designed for a 400 V supply. Such motors are typically designed for a voltage level of 1200 V, which exceeds the induced stress of the AC drive.

In a 500 V supply, the motor has to withstand at least 1600 V peak voltages. A dU/dt filter is often required with these motors in order not to exceed the allowed voltage stress. In a 690 V supply, the motor has to withstand 2000 V peak voltages and a dU/dt filter is required.

NOTE! In uncertain cases, confirm the rating of the motor in AC drive application with the motor manufacturer.

NOTE! Set the switching frequency parameter to correspond to the value given in the Application Manual of the AC drive or in the nameplate of the filter. Do not increase the switching frequency above the given value. Decreasing it below the given value is allowed.

The high switching speed with the motor and cable connected creates a travelling wave in the cable. The speed of this wave is set by the wave impedance of the cable, and usually it is approximately 50-100 Ω. This is less than the wave impedance of the motor, which is on the order of 1 kΩ. As the travelling voltage wave hits this discontinuity, it is reflected back, increasing the instantaneous voltage on the motor winding. The wave is reflected back and forth between the motor and the AC drive, and finally the steady state voltage is reached.

Winding voltage stresses

The rapid change in voltage is not distributed equally over all windings. The first windings show higher voltage stresses than the inner ones, due to the capacitive coupling between the windings. Modern motors can withstand a voltage rise times of < 2 kV/us. In case of doubt, use a dU/dt filter or contact the motor manufacturer.
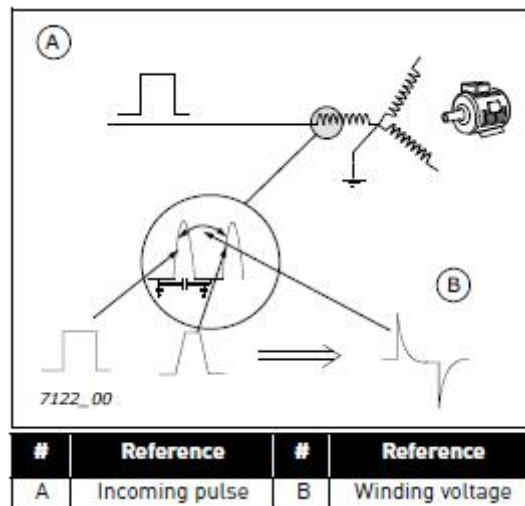
#	Reference	#	Reference
A	Incoming pulse	B	Winding voltage

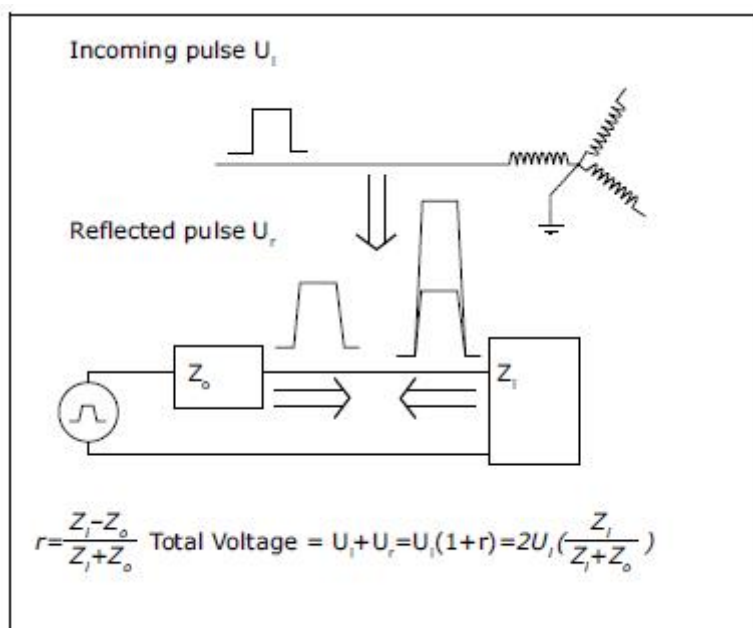*Figure 1. Change of the voltage shape in winding*

Voltage stress

Figure 2. Voltage pulse reflection

The maximum value of the reflected voltage is 2 x DC link voltage, in practice 1.8-1.9 x Udc. The voltage is fully developed at cables that are > 5 m.

Note that the DC link voltage is increased if the supply is higher or if an active front end maintains a high DC link voltage. If this voltage stress is too high, it is recommended to use the dU/dt filter.

A dU/dt filter is an undamped serial LC type filter, with a resonance frequency between 120kHz and 160kHz. This will limit the voltage rise speed to < 1000 V/us.

The filter, the cable and the motor form a complex high frequency circuit, which causes a voltage at the motor with different rise times and peak values depending on the cable length, type etc. Typical voltage peak values as function of cable length are as follows:
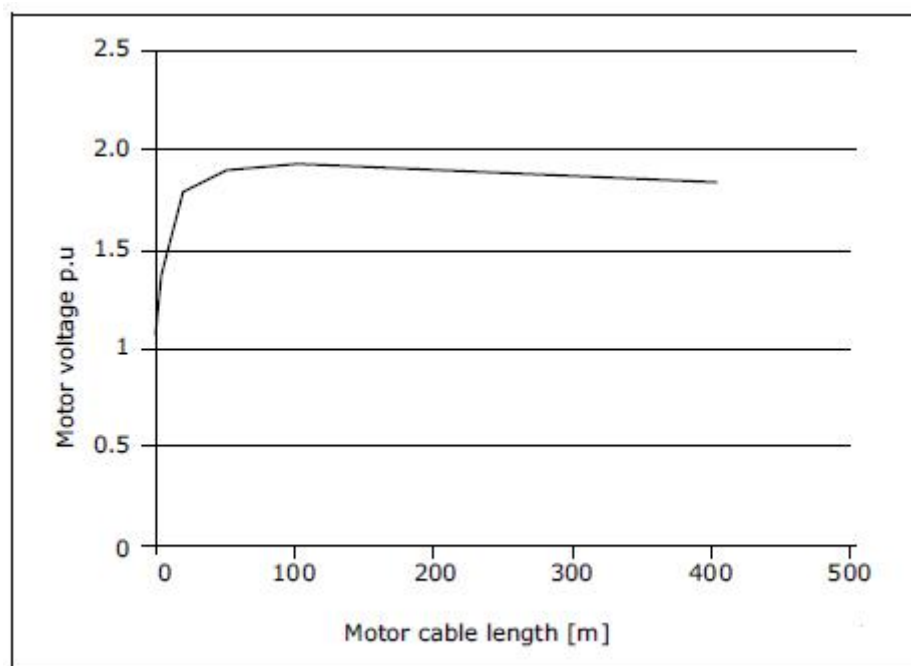

Figure 3. Typical motor voltage p.u. as a function of motor cable length [m]

Due to the inductance in series with the load there is a voltage drop across the dU/dt filter, decreasing the voltage available for the motor. At full rated current this drop is typically < 1% at a 690 V system voltage.

Filters are chosen so that their rated current is bigger than the drive current. They will thermally withstand the same overload specification as the drive.

NOTE! The dU/dt filters are designed for a switching frequency of 2 kHz for a 690 Vac and 3 kHz for a 500 Vac voltage level. For other switching frequency values, see the safe operating curves for a specific filter. Do not exceed the values of the safe operating curves.

NOTE! The dU/dt filters are designed for the maximum output frequency of 50Hz - if this value is exceeded there is a risk of overheating. If higher output frequency is requested, the drive output current must be decreased. Derating of drive output current is shown in table 1.

Motor frequency	Current
50 Hz	Inominal
60 Hz	0.94 x Inominal
100 Hz	0.75 x Inominal

Table 1. dU/dt filter current derating as a function of motor frequency

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Recommendations

Figure 4 shows the motor requirements based on IEC & NEMA motor standards.

- IEC60034-17 – general purpose motors, 500 V
- IEC60034-25 A – motors for converter operation, 500 V
- IEC60034-25 B – motors for converter operation, 690 V

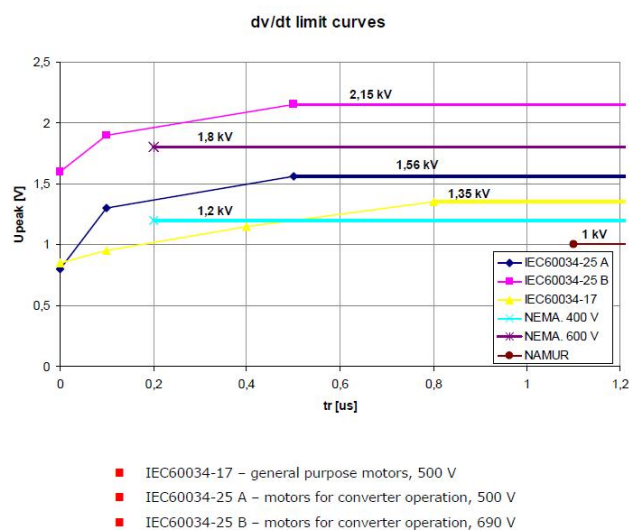*Figure 4. Limiting curves of impulse voltage Upk, measured between two motor phase terminals*

Cable length [m]	Voltage [V]	Filter	Upk [V]	dU/dt [kV/us]
20	500 690	No	< 1550 < 1950	< 2.5 < 4
50	500 690	No	< 1600 < 2000	< 2.2 < 3
20	500 690	Yes	< 1150 < 1650	< 0.45 < 0.65
50	500 690	Yes	< 1190 < 1750	< 0.3 < 0.55
150	500 690	Yes	< 1200 < 1800	< 0.25 < 0.35

Table 2. Typical peak voltage Upk and dU/dt values for VACON® 100 dU/dt filters. Values are based on default cable types given in drive manual.

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2.2 INSTALLATION

The connection of the dU/dt filter is shown in figure 5.

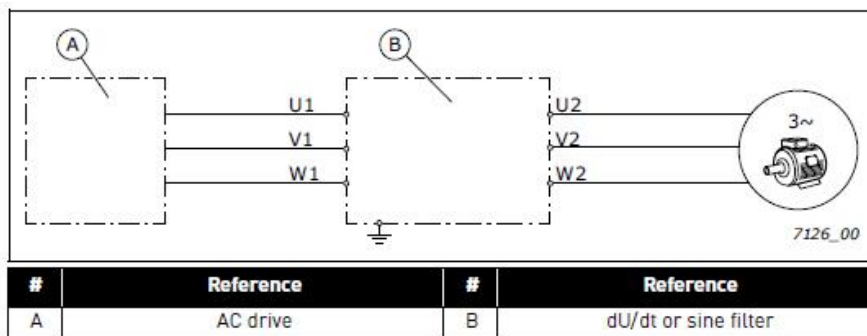| #	Reference	#	Reference
A	AC drive	B	dU/dt or sine filter

Figure 5. Filter connection

In 690 V system the maximum motor cable length for the dU/dt filter is 150 m with default switching frequency and a default cable. The default cable size and capacitance values are given in chapter 3 Safe operating curves. In case of multiple cables, the length is the sum of the cable lengths. The cable capacitance and high frequency current increase as a function of cable length. Therefore, there is a risk of the filter overheating when long cables are used. With cables that are longer than 150 m, it is recommended to use a filter that is bigger by one size or a sine filter. A filter that is bigger by one size can be used to increase cable length up to 200 m. Above that, a sine filter must be used.

NOTE! The safe operating curves will limit the cable length as a function of switching frequency. If a reduced switching frequency is allowed, the cable length will be above 150m.

Cooling of the dU/dt filters is based on natural convection (AN). Proper ventilation and placement inside an enclosure must be ensured during the assembly.

Mounting

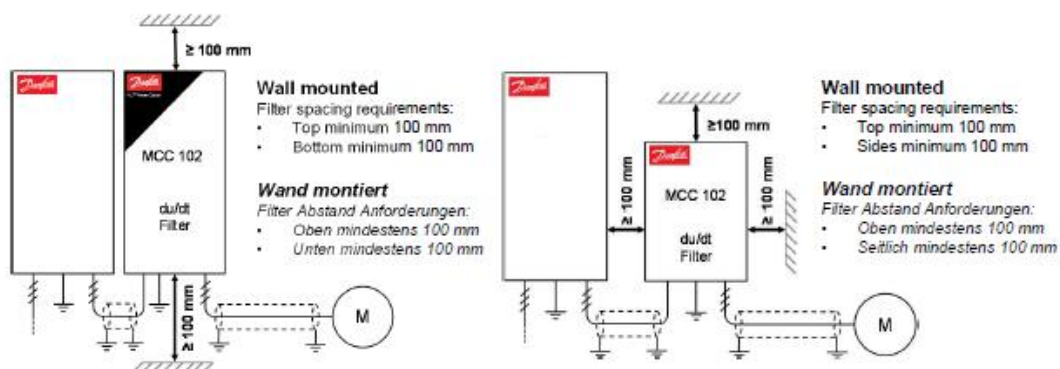Spacing requirements for wall-mounted filters are shown in figure 6.

Figure 6. Installation spacing requirements for IP20 / IP23 enclosed filters

It is recommended to use screened cables to reduce the radiation of electromagnetic noise into the environment and prevent malfunctions in the installation.

- Between the converter output and the unit input (U1, V1, W1), use screened and/or twisted cables.
- Between the unit output (U2, V2, W2) and the motor, use shielded cables.

If you use unscreened cables, make sure that the installation minimises the possibility of cross-coupling with other cables that are carrying sensitive signals. This can be achieved for example by cable segregation and by using grounded cable trays.

2.3 FILTER TYPES

The filter range has been designed to 380-690 Vac voltage systems. The design is based on multiple current ratings, when the current through filter choke can be higher at lower voltage level.

The filters are available as enclosure classes IP00, IP20, IP23 and IP54 with a separate IP21/NEMA 1 KIT option. The filters are UL and CE approved.

Filter code	Filter current rating at 230-690 V mains supply and motor frequency, at 40°C				Power loss [W]	IP class	Default switching frequency
	230-440 V 50/60/100 Hz [A]	500 V 50/60/100 Hz [A]	600 V 50/60/100 Hz [A]	690 V 50/60/100 Hz [A]			
130B2835 130B2836 130B2837	44/41/33	40/37/30	34/32/25	27/25/20	182	IP00 IP20	600-690 V: 2 kHz < 500 V: 3 kHz
					113	IP54	
130B2838 130B2839 130B2840	90/85/67	80/75/60	62/58/46	54/51/40	130	IP00 IP20	
					110	IP54	
130B2841 130B2842 130B2843	106/100/79	105/99/78	100/94/75	86/81/64	145	IP00 IP20	
					130	IP54	
130B2844 130B2845 130B2846	177/167/133	160/151/120	131/123/98	108/102/81	205	IP00 IP20	
					160	IP54	
130B2847 130B2848	315/298/236	303/287/227	242/229/181	192/181/144	315	IP00 IP23	
130B2849 130B2850	480/454/360	443/419/333	344/326/258	290/274/218	398	IP00 IP23	

Table 3. dU/dt filter types for VACON® 100 wall-mounted drives

Dimensional data for IP00 / IP20 / IP23

| Filter code	IP class	Moun-ting	Dimensions [mm]									Weight [kg]	Max. wire cross-section [mm²]	Terminal screw torque [Nm]
			A	a	B	b	C	c	d	e	f			
130B2835	IP00	Wall	295	279	115	85	200	11.50	13	6.2	6	5.8	16	2.0-4.0
130B2836	IP20		370		118		242					7.8		
130B2838	IP00	Wall	395	379	155	125	220	11.50	13	6.2	6	12.7	50	2.0-6.0
130B2839	IP20		475		158		310					16.2		
130B2841	IP00	Wall	395	379	155	125	220	11.50	13	6.2	6	22	50	2.0-6.0
130B2842	IP20		475		158		310					25.5		
130B2844	IP00	Wall	445	429	197	165	240	11.50	13	6.2	6	27	95	6.0-12.0
130B2845	IP20		525		200		355					30		
130B2847	IP00	Floor	300	275	190	100	235	-	-	11	22	33	Bus bar 1 x D10.5	18
130B2848	IP23		425	325	700	660	620			13	17	64.5		
130B2849	IP00	Floor	300	325	250	125	235	-	-	11	22	36	Bus bar 2 x D13	30
130B2850	IP23		425	325	700	660	620			13	17	67.5		

Table 4. dU/dt filter mechanical data
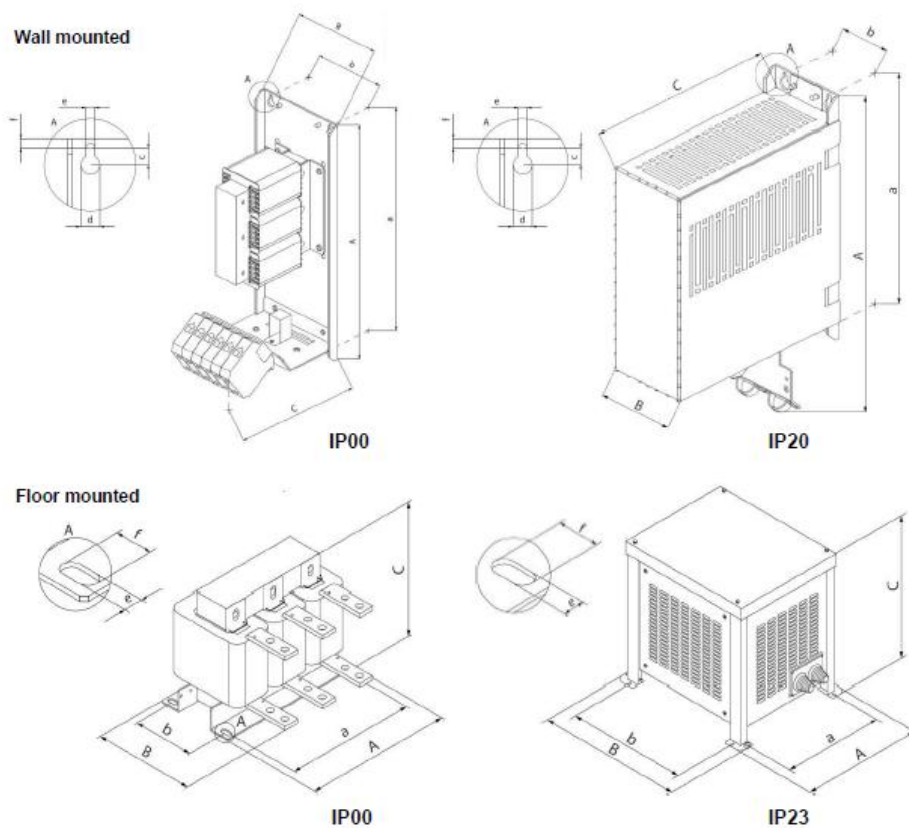
Figure 7. dU/dt filter dimensional drawing

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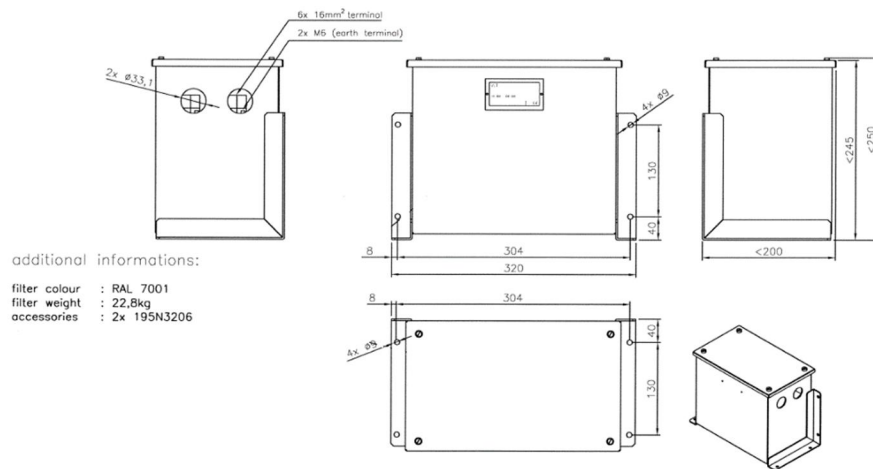### Dimensional data for IP54

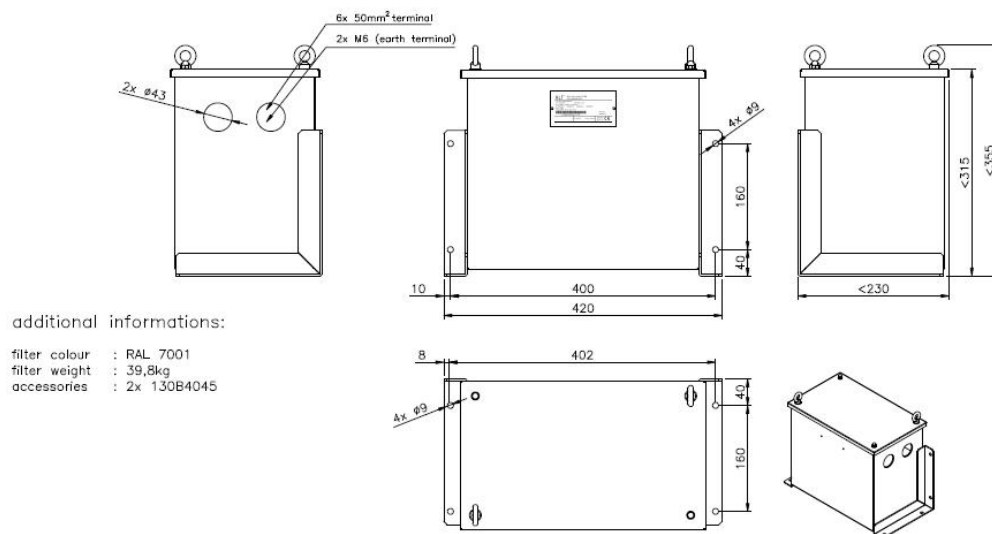*Figure 8. IP54 130B2837 dimensional drawing*

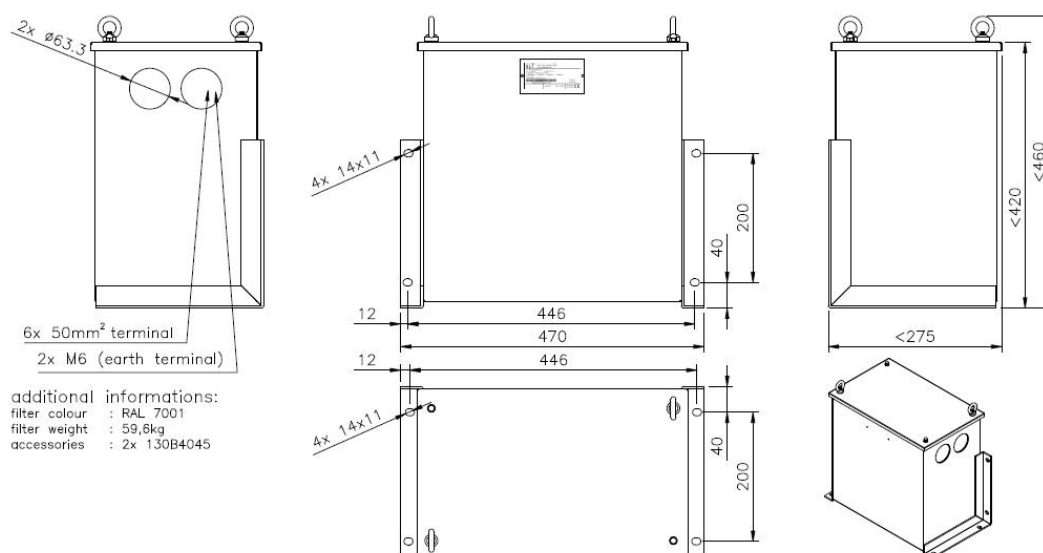*Figure 9. IP54 130B2840 dimensional drawing*
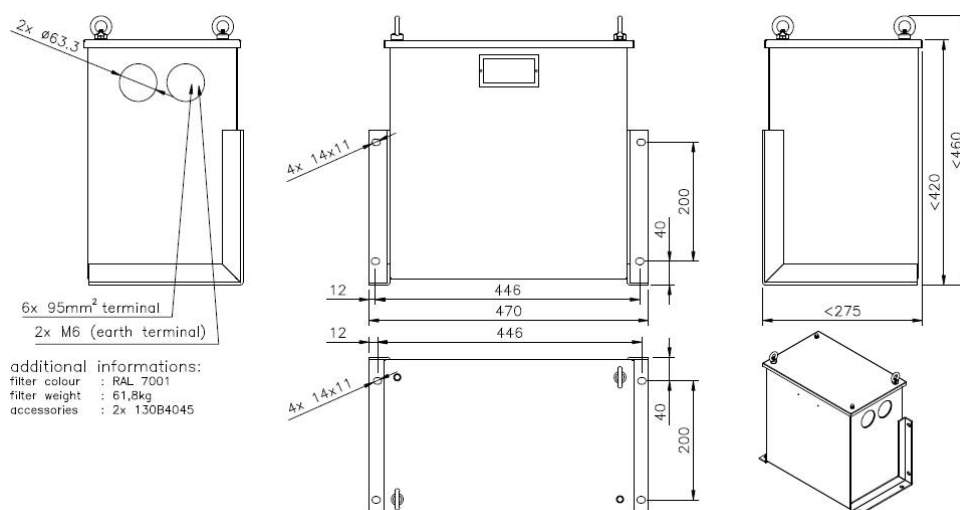
Figure 10. IP54 130B2843 dimensional drawing.

Figure 11. IP54 130B2846 dimensional drawing

3 Safe operating curves

The safe operating curves for dU/dt filters 130B2835 - 37 are shown in figures 12 and 13. It is assumed that the default cable type has a capacitance of 40 nF/100 m. The values should be scaled in accordance with the actual cable capacitance. In case of multiple cables, the capacitance is the sum of the cable capacitances.
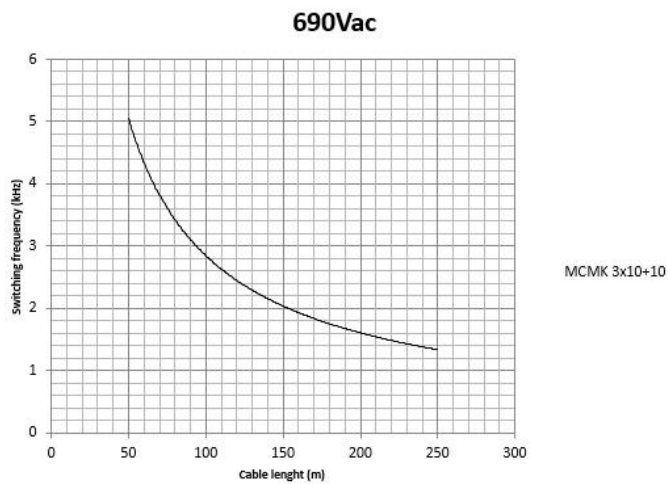
690Vac

Figure 12. Safe operating curve for 130B2835 - 37 at 690 V mains supply
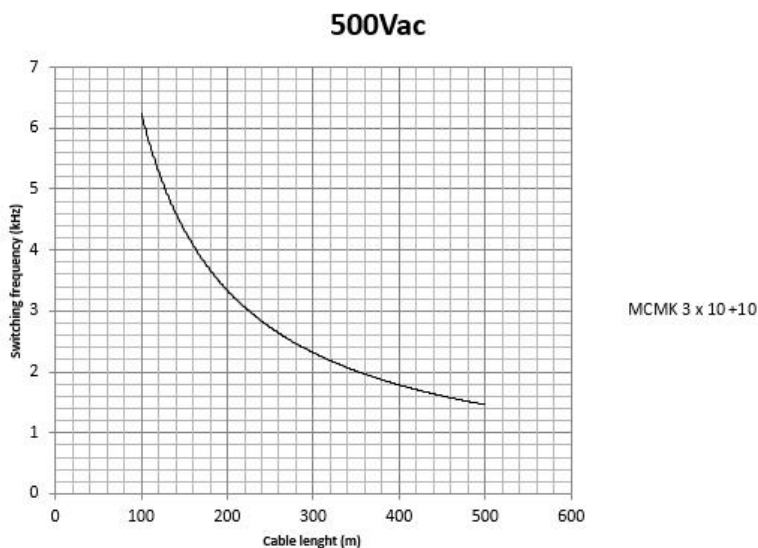
500Vac

Figure 13. Safe operating curve for 130B2835 - 37 at 500 V mains supply

The safe operating curves for dU/dt filters 130B2838 - 40 are shown in figures 14 and 15. It is assumed that the default cable types have a capacitance of 45 - 55 nF/100 m. The values should be scaled in accordance with the actual cable capacitance. In case of multiple cables, the capacitance is the sum of the cable capacitances.
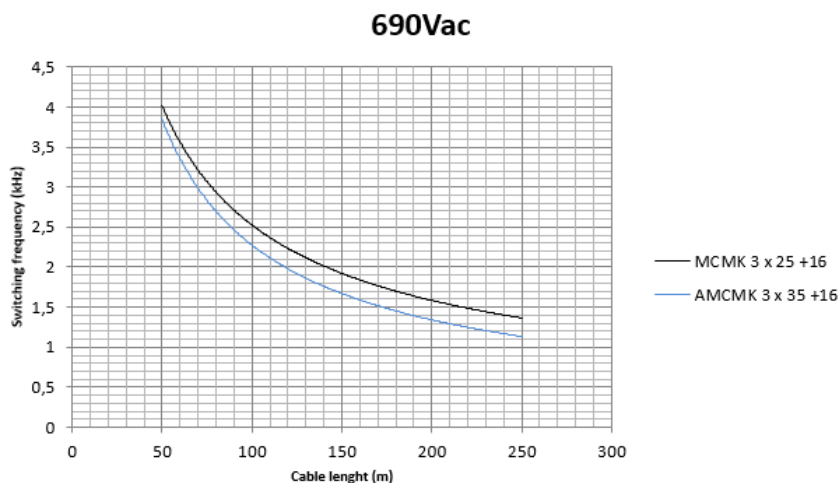
690Vac

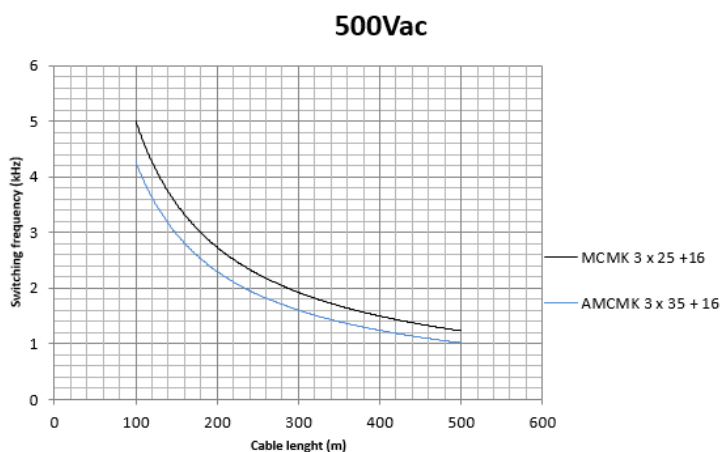Figure 14. Safe operating curve for 130B2838 - 40 at 690 V mains supply.

500Vac

Figure 15. Safe operating curve for 130B2838 - 40 at 500 V mains supply.

The safe operating curves for dU/dt filters 130B2841 - 43 are shown in figures 16 and 17. It is assumed that the default cable types have a capacitance of 55 - 60 nF/100 m. The values should be scaled in accordance with the actual cable capacitance. In case of multiple cables, the capacitance is the sum of the cable capacitances.
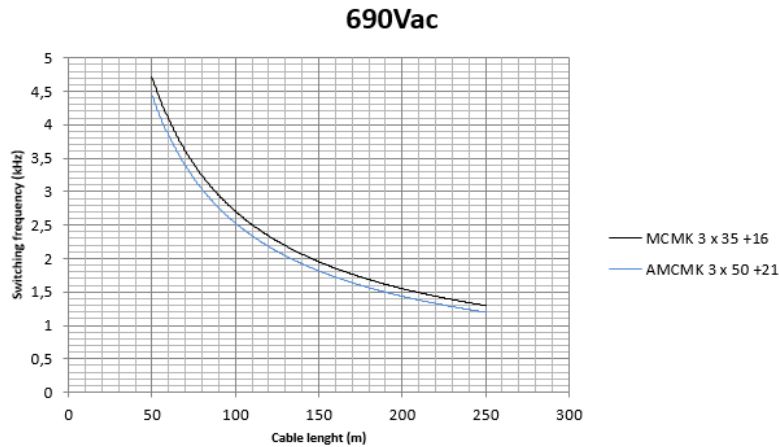

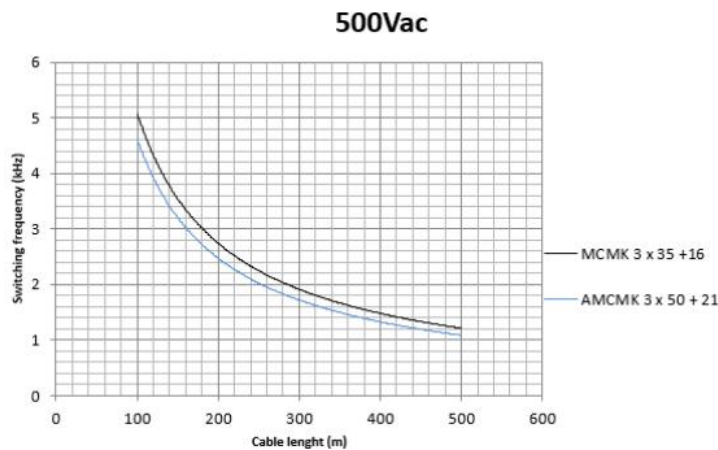Figure 16. Safe operating curve for 130B2841 - 43 at 690 V mains supply.

Figure 17. Safe operating curve for 130B2841 - 43 at 500 V mains supply.

The safe operating curves for dU/dt filters 130B2844 - 46 are shown in figures 18 and 19. It is assumed that the default cable types have a capacitance of 60 - 65 nF/100 m. The values should be scaled in accordance with the actual cable capacitance. In case of multiple cables, the capacitance is the sum of the cable capacitances.
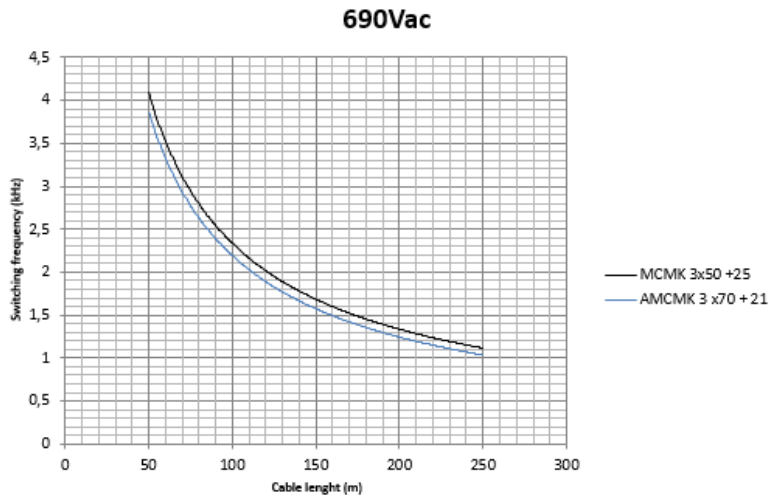

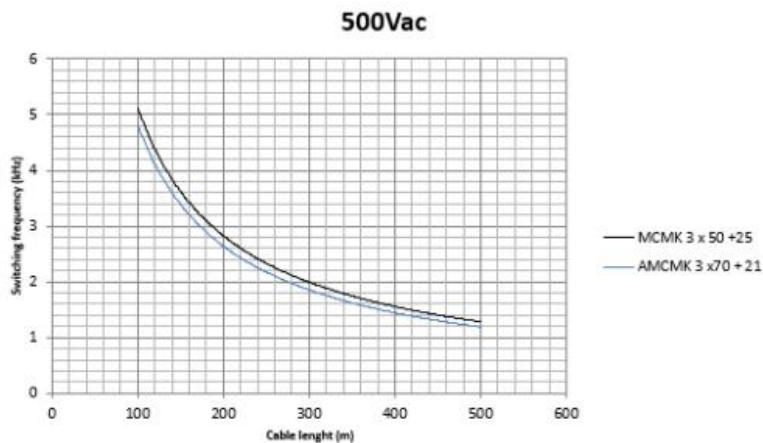Figure 18. Safe operating curve for 130B2844 - 46 at 690 V mains supply

Figure 19. Safe operating curve for 130B2844 - 46 at 500 V mains supply

The safe operating curves for dU/dt filters 130B2847 - 48 are shown in figures 20 and 21. It is assumed that the default cable types have a capacitance of 80 - 85 nF/100 m. The values should be scaled in accordance with the actual cable capacitance. In case of multiple cables, the capacitance is the sum of the cable capacitances.
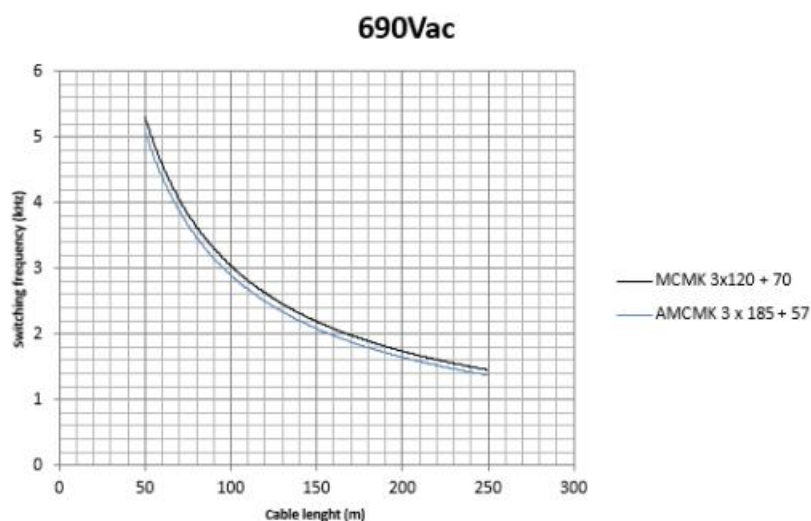

Figure 20. Safe operating curve for 130B2847 - 48 at 690 V mains supply
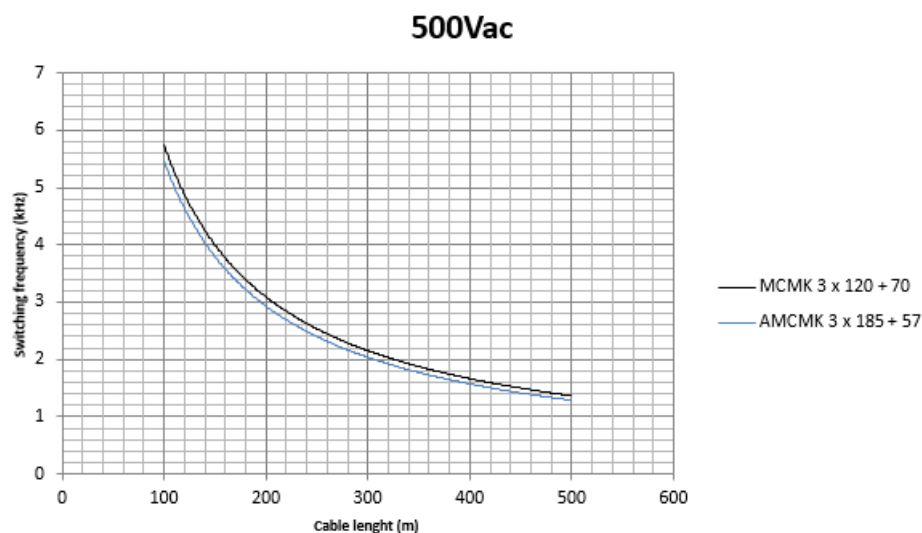

Figure 21. Safe operating curve for 130B2847 - 48 at 500 V mains supply

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4 How to select a filter

The selection of a filter is shown in the tables below. The current rating of the filter must be the same or higher than the matching AC drive current rating.

Table 5. dU/dt filter selection for 208–240 Vac drives

208–240 Vac		dU/dt filter selection			
Enclosure size	AC drive	IP00	IP20	IP23	IP54
MR4	0003-0012	130B2835	130B2836	-	130B2837
MR5	0018-0031	130B2835	130B2836	-	130B2837
MR6	0048-0062	130B2838	130B2839	-	130B2840
MR7	0075-0088	130B2838	130B2839	-	130B2840
	105	130B2841	130B2842	-	130B2843
MR8	0140-0170	130B2844	130B2845	-	130B2846
	205	130B2847	-	130B2848	-
MR9	0261-0310	130B2847	-	130B2848	-

Table 6. dU/dt filter selection for 380–500 Vac drives

380-500 Vac		dU/dt filter selection			
Enclosure size	AC drive	IP00	IP20	IP23	IP54
MR4	0003 - 0012	130B2835	130B2836	-	130B2837
MR5	0016 - 0031	130B2835	130B2836	-	130B2837
MR6	0038 - 0061	130B2838	130B2839	-	130B2840
MR7	72	130B2838	130B2839	-	130B2840
	0087 - 0105	130B2841	130B2842	-	130B2843
MR8	140	130B2844	130B2845	-	130B2846
	0170 - 0205	130B2847	-	130B2848	-
MR9	261	130B2847	-	130B2848	-
	310	130B2849	-	130B2850	-

Table 7. dU/dt filter selection for 525–600 Vac drives

525-600 Vac		dU/dt filter selection			
Enclosure size	AC drive	IP00	IP20	IP23	IP54
MR5	0004 - 0011	130B2835	130B2836	-	130B2837
MR6	0018 - 0034	130B2835	130B2836	-	130B2837
MR7	0041 - 0062	130B2838	130B2839	-	130B2840
MR8	0080 - 0100	130B2841	130B2842	-	130B2843
	125	130B2844	130B2845	-	130B2846
MR9	0144 - 0208	130B2847	-	130B2848	-

Table 8. dU/dt filter selection for 525–690 Vac drives

525-690 Vac		dU/dt filter selection			
Enclosure size	AC drive	IP00	IP20	IP23	IP54
MR6	0007 - 0027	130B2835	130B2836	-	130B2837
	34	130B2838	130B2839		130B2840
MR7	0041 - 0052	130B2838	130B2839	-	130B2840
	62	130B2841	130B2842		130B2843
MR8	80	130B2841	130B2842	-	130B2843
	100	130B2844	130B2845		130B2846
	125	130B2847	-	130B2848	-
MR9	0144 - 0170	130B2847	-	130B2848	-
	208	130B2849	-	130B2850	-

Using the safe operating curves

The safe operating curves provide the maximum allowed cable length at a specific switching frequency. Cable length is read from the curve at a point that corresponds to the actual switching frequency. Vice versa, the maximum switching frequency is given as a function of cable length. Do not exceed these values.

The cable types declared in the curves are default cables for matching AC drives. Both copper and aluminium cables can be used where applicable. Table 9 shows the default cable types for the filter. This data can be used for scaling if other than the default cable is used.

Table 9. dU/dt filter default cable types

Filter code	Filter default cabling at 2 kHz switching frequency		
	Voltage [V]	Default cable length [m]	Cable type
130B2835	690 / 500	150 / 350	MCMK 3 x 10 +10
130B2836			
130B2837			
130B2838	690 / 500	150 / 280	MCMK 3 x 25 + 16
130B2839			
130B2840			
130B2841	690 / 500	150 / 280	MCMK 3 x 35 + 16
130B2842			
130B2843			
130B2844	690 / 500	120 / 300	MCMK 3 x 50 + 25
130B2845			
130B2846			
130B2847	690 / 500	150 / 320	MCMK 3 x 120 + 70
130B2848			
130B2849	690 / 500	150 / 320	MCMK 3 x 185 + 95
130B2850			

Other than default cable

In general, the allowed cable length can be calculated as a ratio between the default cable and actual cable capacitances. As an example, if filter 130B2836 has cable MCMK 3 x 25 + 16 (45 nF/100 m) instead of the default MCMK 3 x 10 +10, the max cable length is calculated as follows:

40 nF / 45 nF x 150 m = 133 m

Parallel cables

In case of parallel connected cables, the actual capacitance is the sum of the cable capacitances. That is, if filter 130B2836 has 2 x MCMK 3 x 10 + 10 cables in parallel, 50 m long each, the total length is considered to be 2 x 50 m = 100 m. In that case, the safe operating curve gives the max switching frequency: Fs = 2.8 kHz.

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