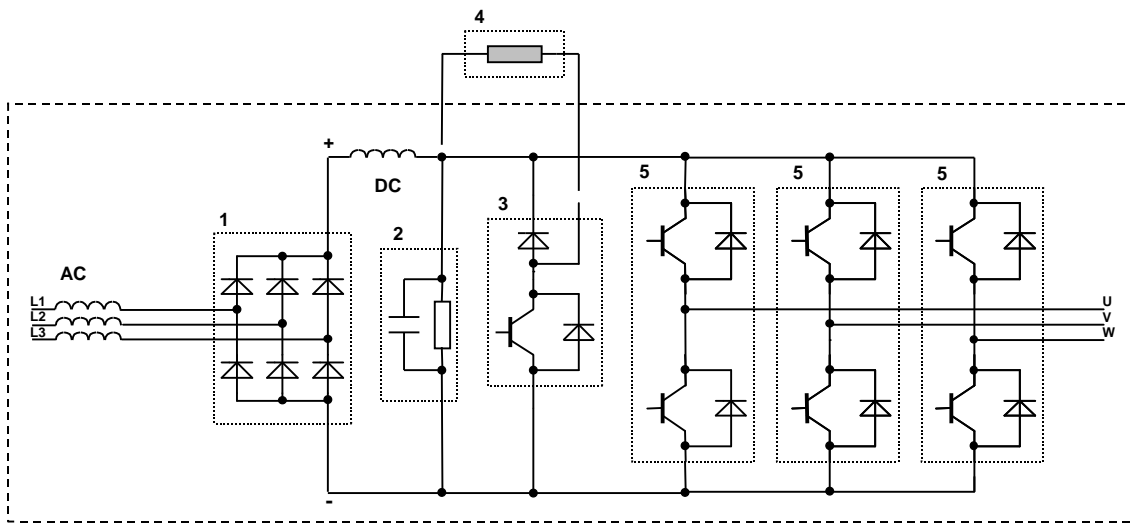


# PROBLEMS AND FUTURE OF INVERTERS IN THE LIGHT OF THE NEW REGULATIONS ON LOW-FREQUENCY HARMONICS.

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## 1) INVERTER OPERATING PRINCIPLE (block diagram) fig.(1)

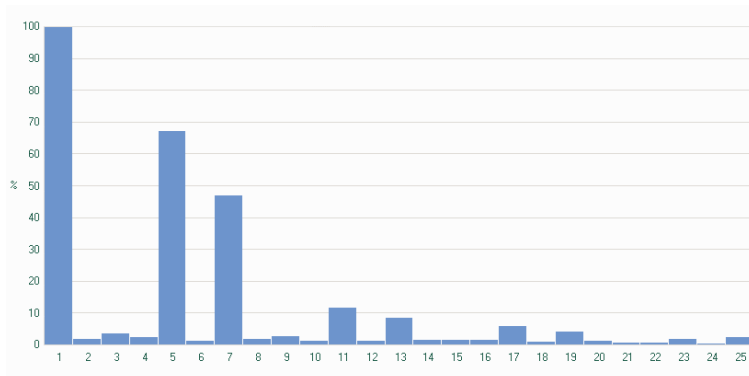
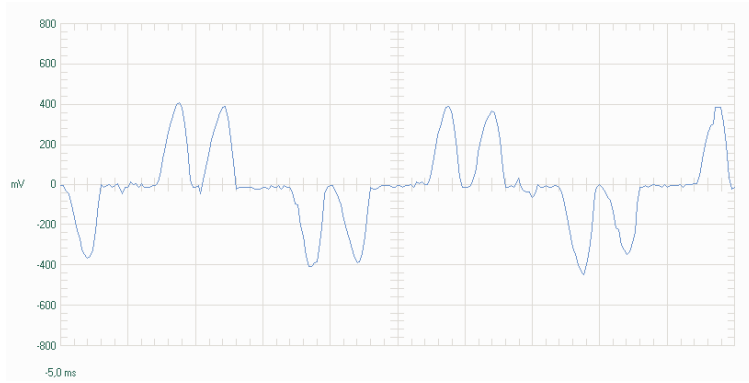
As everyone is aware, the block diagram of a standard inverter is that shown in the diagram; in other words, the three-phase alternating mains current is converted to direct current by means of a three-phase diode bridge (1), levelled by a capacitor (2) and then transformed back into alternating current by an IGBT bridge having frequency and voltage values which can be varied at will within a given range.



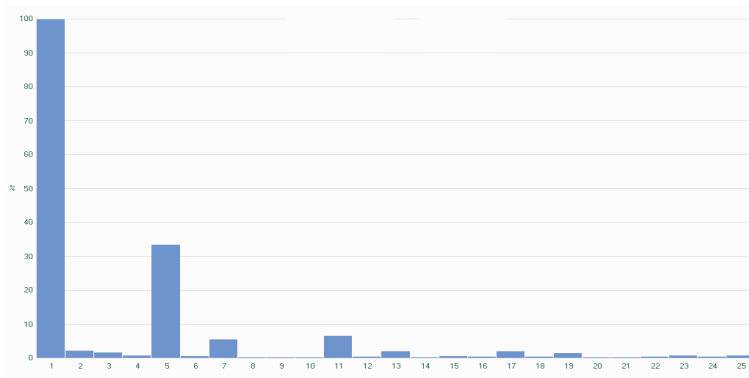
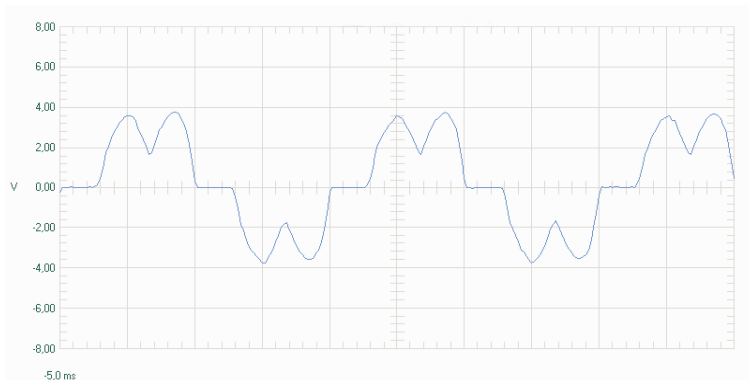
- |  |                                 |
|--|---------------------------------|
| 1 = Three-phase diode bridge (AC/DC converter) | 2 = Capacitor                   |
| 3 = Internal braking unit                      | 4 = Braking resistance          |
| 5 = Voltage and frequency converter (DC/AC)    | AC = AC voltage side inductance |
| DC = DC voltage side inductance                |                                 |

**Fig.1 – Inverter block diagram**

As already explained in a previous article, IGBT switching procedures cause EMI electromagnetic interference problems, while the three-phase input bridge causes stray harmonics in the system; although the input voltage is perfectly sinusoid, the current has the trend shown in fig. (2). The waveform of the input current depends on the line impedance. If an additional impedance of 1.2 mH (drop 2% at 20 A) is connected in series with the power supply network, the input current obtained is significantly different fig. (3).



**Fig.2** – Input current at full load (20 A) without inductance (waveform and harmonic spectrum)



**Fig.3** – Input current at full load (20 A) with inductance of 1.2 mH (waveform and harmonic spectrum)

As figures 2 and 3 show, considering that the tests were performed in the same load conditions, the peak input current value is higher if the inductance is not connected in series, and therefore the 5<sup>th</sup>, 7<sup>th</sup> etc. harmonics are greater in this case.

The harmonic current generated by the three-phase rectifier bridge system, present with harmonics of order  $6xn \pm 1$ , i.e. 5th and 7th, 11th and 13th, 17th and 19th, etc., has no power, but it is still an additional current on the cables which causes the following problems:

- \_ reduction of the power factor;
- \_ overloading and overheating in the conductors;
- \_ distortion of the mains voltage;
- \_ malfunction in measuring systems;
- \_ sometimes serious interference with other equipment synchronised with the network;
- \_ overheating of the power factor correction and levelling capacitors;
- \_ possibility of serious electrical resonances for the entire system;
- \_ inappropriate tripping of differential security breakers;
- \_ increase in energy consumption;
- \_ premature ageing of insulators;
- \_ measuring errors in energy meters.
- \_ etc...

## 2) *POWER FACTOR CORRECTION AND COSPHII*

### 2.1) *COSPHII*

If a motor is supplied with power by connecting it directly to the mains, the voltage and current absorbed by the motor are both sinusoid, with a phase shift between them of a given angle  $F1$ , which depends on the type of motor and the load. Normally, with the motor at full load the phase shift angle  $F1$  of the current in relation to the voltage is 35-40° with a  $\cosPHII$  of about 0.8.

As you will be aware, the active power absorbed by the motor is:

$$P(w) = \sqrt{3} * V * I * \cosPHII$$

So it can be noted that for a given power, the lower the  $\cosPHII$  (large phase shift angle), the higher the current. An ordinary power factor correction capacitor connected into the line when the motor is operating is able to reduce the phase shift angle; consequently the  $\cosPHII$  increases and the current requested from the line is reduced.

### 2.2) *POWER FACTOR*

When a motor is supplied by means of an inverter, things change radically since, as we have seen above, in addition to the fundamental component of the current at 50 Hz, a number of frequency harmonics appear. In this case it is not correct to talk in terms of  $\cosPHII$ , which is the phase shift between voltage and current at 50 Hz; instead, we have a power factor defined as follows:

$$\text{Power factor} = \frac{\text{Active power}}{\text{Apparent power}}$$

Where the active power is the power absorbed at 50Hz, while the apparent power is the total absorbed power, considering all the harmonics present.

The active power calculation is:

$$\text{Active P} = \sqrt{3} * V * I_1 * \cos\text{PHII}$$

While the apparent power is:

$$\text{Apparent P} = \sqrt{3} * V * I_{\text{eff}}$$

Where:

V = power supply mains voltage (50Hz);

I<sub>1</sub> = current of the fundamental harmonic (50Hz);

cosPHII = phase shift between voltage and current at 50Hz;

I<sub>eff</sub> = effective value of the total input current considering all the harmonics.

The power factor will therefore be:

$$\text{Power factor} = \frac{I_1 * \cos\text{PHII}}{I_{\text{eff}}}$$

With I<sub>eff</sub> calculated as follows:

$$I_{\text{eff}} = \sqrt{\sum I_n^2}$$

I<sub>n</sub> = percentage value of the current harmonics in relation to the fundamental at 50Hz.

E.g.: in fig. 2 it can be seen that the 5<sup>th</sup> harmonic is about 70% of the fundamental, so in the formula it will be 0.7, etc.

From the formula shown above, we deduce that the lower the harmonics, the lower the effective current, and thus the higher the power factor, and so the capacitors are not required for power factor correction, but inductances are needed to reduce the harmonic content (see fig.3).

The inductances can be installed both in series with the AC power supply and in series with the intermediate DC branch (see fig. 1).

In a standard inverter without inductance, the total harmonic content ranges from 70 to 100% of the fundamental. The variation depends both on the proper impedance of the power supply line and on the load required from the motor at that moment.

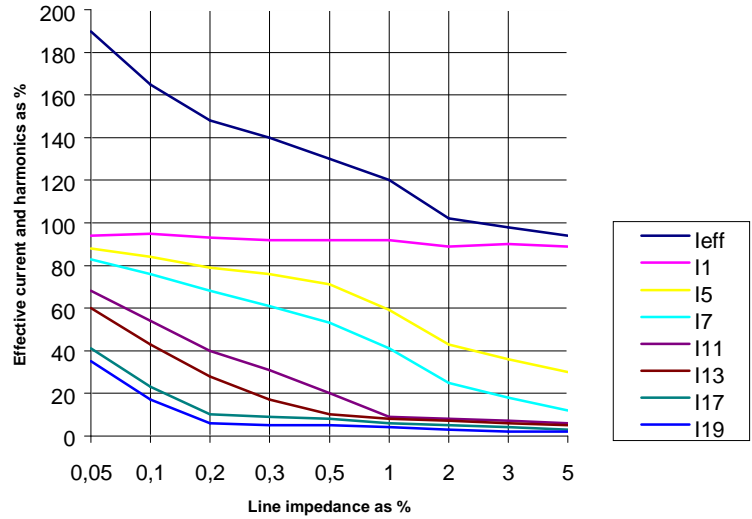
The input inductances therefore perform a number of fundamental functions:

- They increase the power factor.
- They reduce the harmonic content.
- They reduce the line current necessary to supply the inverter.

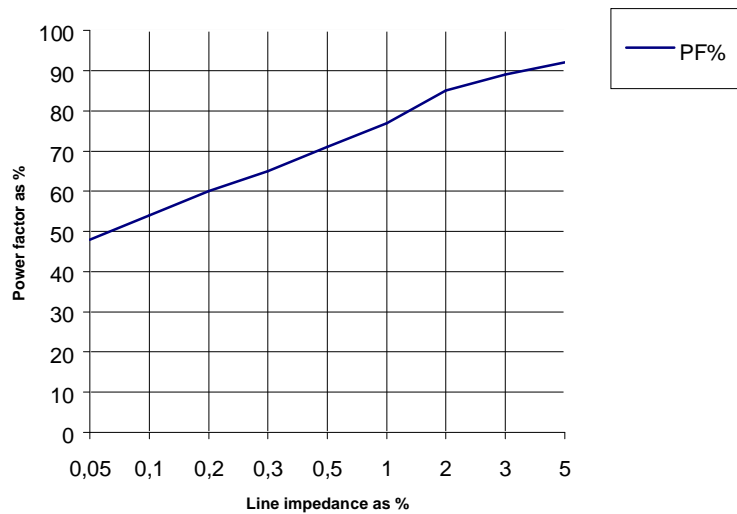
In addition:

- They protect the input diode bridge against mains overvoltages if they are installed on the AC branch
- They prolong the lifetime of the levelling capacitors.
- They simplify protection of the motor.
- They reduce the overload of any power factor correction capacitors.
- They protect the inverter when it is installed close to high-power transformers (10 times greater than the inverter power).

The graphs in figures 4 and 5 show the trend of the harmonics content and the power factor in relation to variation in the input impedance of an inverter supplying a motor at full load.



**Fig.4** – Harmonic currents and inverter effective current in relation to line inductance with motor at full load.



**Fig.5** – Inverter power factor in relation to line impedance with motor at full load.

As the graph shows, an inductance of 3% brings the power factor to the value of about 0.9, which is the minimum value required by the main electricity supply companies; however, considering that the higher the inductance, the greater the line voltage drop, an inductance of 2% is normally used, partly for reasons of cost. An inductance fitted on the DC branch (diode bridge output) produces the same effects, but use of an AC inductance is preferred since it produces the same effects and is less expensive.

### 3) LIMITATIONS OF AN INVERTER AND NEW POSSIBILITIES

#### 3.1) LIMITATIONS OF A CONVENTIONAL INVERTER.

The three-phase converter with diode bridge input is certainly a sturdy, economical solution, but it has a number of problems:

- \_ High harmonic content and consequent lower power factor.
- \_ Unidirectional energy flow (i.e. from the mains to the inverter).
- \_ Limited output voltage (same as or less than the mains voltage)

In most applications there are no special problems (e.g. in regulation of the speed of pumps, compressors, fans, etc.); however, in lifting applications such as cranes and lifts, i.e. when braking operation is also required, since the motor, dragged by the load, returns energy (e.g. lift system with lift cab rising empty), the energy generated by the motor has to be dissipated by a resistor, controlled by a chopper, automatically supplied by the inverter when the DC branch voltage exceeds a given threshold value.

This solution becomes precarious when large powers or very long travel strokes are involved. As an example, for a system having a motor of 22kW 400V, stroke of 70 m and speed 1.6 m/s, a resistance of about  $15\Omega$  with power 6 kW is required to brake the upward travel of the empty cab for the travel time, which is about 45 seconds. Moreover, during deceleration and arrival at the floor there is a power peak of 10-12 kW with consequent intense heat to be dissipated in the machinery room.

#### 3.2) 4-QUADRANT OR REGENERATIVE INVERTER.

A regulator is said to have “four quadrants” when it is capable of generating and receiving energy from and to the motor and towards the mains in both operating directions; this is not possible with a conventional inverter.

With a few modifications, an inverter can be made regenerative; in other words, the energy generated by the motor can be discharged onto the mains rather than onto a resistor. 2 methods are generally used:

- A) Use of a total-controlled double SCR bridge as input converter instead of a diode bridge.
- B) Use of an IGBT active bridge as input converter.

The SCR bridge is a sturdy, economical solution, but there are the following problems:

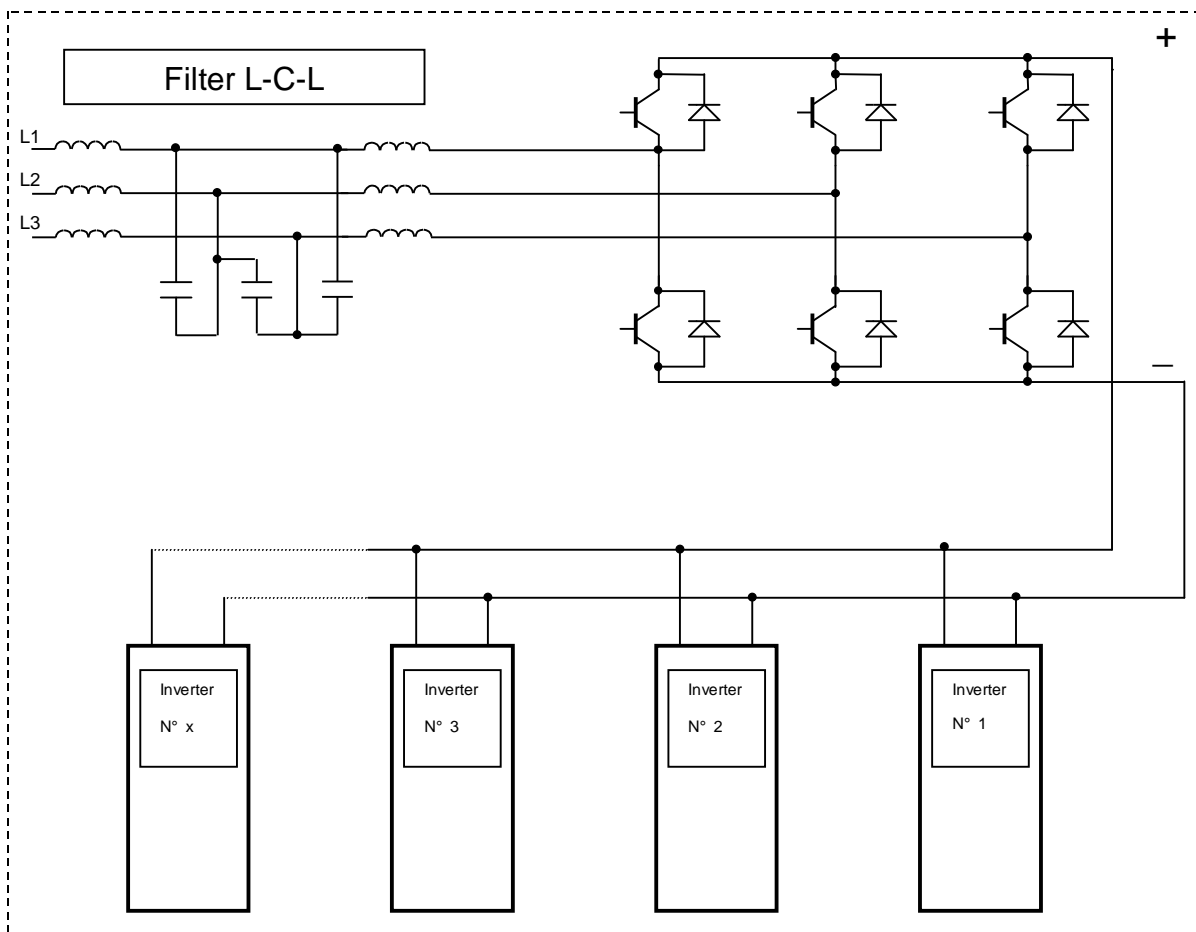
- \_ Worse system harmonics content than with an ordinary diode bridge.
- \_ Regenerative operation requires an autotransformer or a low-voltage motor (max. 300V for a 400V mains system), meaning a motor with special winding.
- \_ In regenerative operation, immunity to disturbances towards the mains is critical, so extrarapid protective fuses must be used.

The IGBT bridge (see fig.6) with vectorial control and PWM modulation overcomes all the problems of the SCR or diode bridge and offers the following advantages:

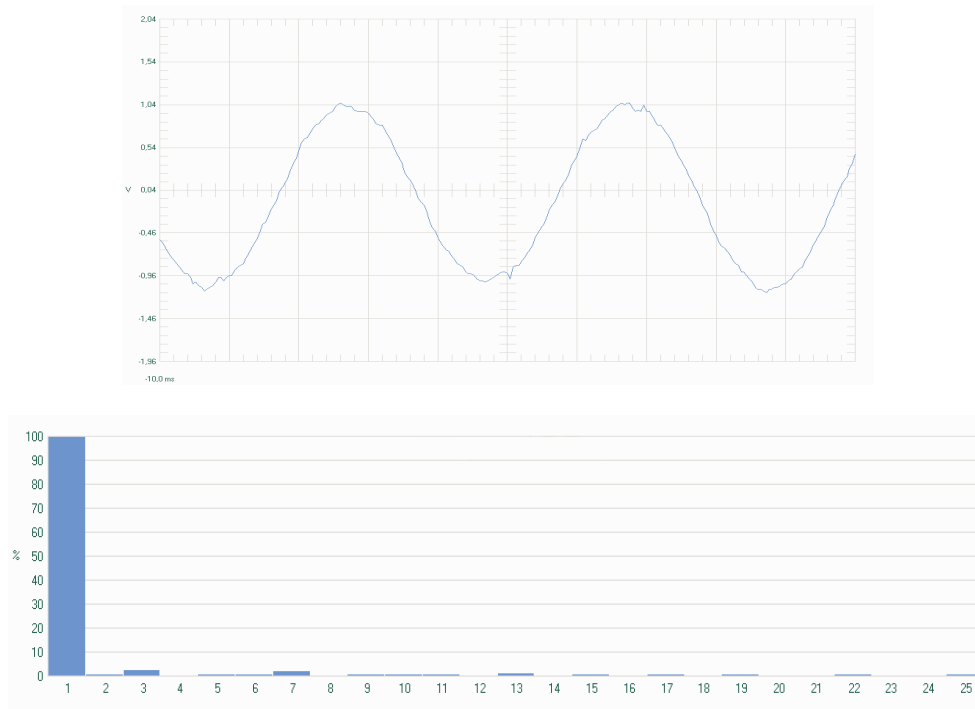
- \_ Regenerative operation and recovery of energy in the mains without autotransformer or special motor.
- \_ Harmonic content of the current exchanged with the mains below 4%, allowing compliance with the most severe norms on harmonic content, and thus the current absorbed and returned to the mains is virtually sinusoid (see fig. 7).
- \_ The high adjustment dynamics and closed-loop control of the voltage on the DC branch allow compensation for both the imbalance and the lowering of the mains voltage.

- \_ The converter operates with power factor 1, so the mains current level is lower for any given power level, but it is also able to operate as capacitive or reactive power factor corrector, allowing the power factor correction of other loads.
- \_ The voltage of the DC branch may be set at values higher than those possible with an ordinary diode bridge; in other words, a motor at 500V can be supplied starting from a mains power supply of 400V, with consequent greater possibility of dynamic corrections of the control and lower currents. In some cases, the motor power can actually be increased.
- \_ Possibility of using the system as active filter, i.e. a filter capable of eliminating the main disturbance harmonics of a low voltage power supply network (3<sup>rd</sup>, 5<sup>th</sup>, 7<sup>th</sup>)
- \_ The low harmonics content guarantees the absolute immunity of complex systems to the dangerous resonances inevitably present in systems with a large number of inverters and with capacitor power factor correction systems.

In the lifts sector, the inverter with IGBT input converter offers many advantages; the higher purchase cost (the only disadvantage) can easily be recovered, especially in systems with high capacities, long travel strokes and in banks with high efficiency gear or gearless, since the energy generated by a motor during braking is used by the other systems or the other users connected to the same energy meter. Moreover, if the solution shown in fig. 6 is adopted (single input bridge for a number of lifts), the initial difference in cost compared to a large number of individual conventional inverters is very small.



**Fig.6** – IGBT active bridge of the regenerative inverter



**Fig.7–** Current absorbed by the line with regenerative inverter (waveform and harmonics spectrum)

Apart from the energy saving, which is the immediate benefit for the user, it must be noted that at the regulatory level measures are being taken to keep down harmonics and their negative effects on the electricity network as a whole. Norm CEI-EN61000-3-2 for currents up to 16A is already in force; norm CEI-EN61000-3-4 for currents over 16 A will soon be introduced. With this norm it will no longer be possible to install conventional inverters without line inductance and the harmonic content will have to be limited to clearly specified values.

The regenerative inverter is therefore the best solution to these problems, since the maximum harmonic content is 4%, far below the level required by the norm.

Even now, various industries are already installing regenerative inverters for energy saving, but only in order to “clean” the absorbed current, with total elimination of any problem of electric resonance with other equipment in the factory.

#### **CONCLUSION:**

Regenerative inverters, already on the market in the lift and industrial field, are proving a new alternative to the use of conventional inverters; an alternative offering energy saving, “cleaning” of the energy consumed, longer equipment lifetime and less harmonic pollution.

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