so-called harmonic waves whose frequencies are a multiple of the supply frequency (in three-phase supplies these are mainly the fifth, seventh and eleventh harmonic waves).

These harmonic waves increase the current of the capacitor for power factor correction, as the reactance of a capacitor decreases with increasing frequency.

The increasing capacitor current can be accommodated by improving the design of the capacitor, but this does not eliminate the risk of resonance phenomena between the power capacitors on the one hand and the inductance of the feeding transformer and the grid on the other.

If the resonance frequency of a resonance circuit consisting of power capacitors and inductance of the feeding transformer is near enough to the frequency of a harmonic wave in the grid, this resonance circuit can amplify the oscillation of the harmonic waves and cause immense overcurrent and overvoltage.

The harmonic wave contamination of an AC voltage supply can have some or all of the following effects:

- early failure of capacitors
- premature triggering of protective switches and other safety devices
- failure or malfunction of computers, drivers, lighting installations and other sensitive consumers
- thermal overload of transformers caused by increased iron losses
- overload of the neutral conductor (particularly by the 3rd harmonic wave)
- shattering or bursting of discharge lamps
- thermal overload of the lamp choke due to resonance between choke and capacitor for power factor correction. The effects can be similar to asymmetrical mode (see chapter 6.2.9), which is why the use of a choke with thermal protection can also protect the luminaire from burning.

The installation of so-called choked capacitors (capacitor in series with a filter choke) aims at forcing the resonance frequency of the grid below the frequency of the lowest prevailing harmonic wave. This prevents a resonance between the capacitors and the grid and would thus also prevent the amplification of the harmonic currents. This kind of installation also has a filtering effect by reducing the level of voltage distortion in the grid. It is therefore recommended for all cases where the wattage share of the loads that generate harmonic waves is more than 20% of the total wattage. The resonance frequency of a choked capacitor always lies below the frequency of the 5th harmonic wave.

In the electronic ballast OSRAM POWERTRONIC PTi, the influence of harmonic waves on the lamp is kept extensively at bay by the ballast design which comprises an intermediate circuit. The immunity of the PTi input stage to line-related interference is safeguarded by tests according to the IEC 61000 standard.

Such line-related interference includes e.g.:

- burst as per IEC61000-4-4, 1000V peak, repetition frequency 5kHz, low-energy pulse
- current feed as per IEC61000-4-6, frequency range 0.15-80MHz, 3Vrms
- surge as per IEC61000-4-5, 1000V symmetrical, 2000V asymmetrical, high-energy pulse
- voltage interruptions as per IEC61000-4-11
- voltage fluctuations

3.4 Brief voltage interruptions

When the lamp current falls, the recombination rate starts to exceed the ionization rate, causing a reduction in plasma conductivity. This occurs with magnetic ballasts in every half-wave on passing the zero crossing and results in the so-called re-ignition peak. When recombination of the charged particles has progressed far enough, the remaining quantity of charge carriers is not sufficient enough to generate an adequate quantity of new charge carriers when the voltage increases again – the lamp goes out. The high pressures in the arc tube mean that the ignition voltage is now no longer sufficient to re-ignite the lamp. It has to first cool down for a few minutes before it can ignite again (see also chapter 4.2 *"Warm re-ignition"*).

When the supply voltage is interrupted, both the length and depth of the interruption (100% for complete interruption) and the phasing of the interruption are important. Older lamps with their increase in lamp voltage and higher re-ignition voltage are more sensitive than unaged lamps. The capacitor for power factor correction can act as voltage source during voltage interruptions, at least in the short term, and extend the time in which a voltage interruption is tolerated before the lamp goes off. Voltage interruptions just before the zero crossing are more serious, because the plasma has already cooled down significantly.

3.5 Stroboscopic effect and flicker

Operation of a metal halide lamp on a magnetic ballast under supply voltage with 50 Hz frequency results in periodic fluctuation of the luminous flux with double the supply frequency. When the current flow drops near the zero crossing, the plasma also has far less radiation. But even on passing the zero crossing, the luminous flux does not reach zero so that the plasma still has on-going radiation.

The human eye reacts with differing sensitivity to varying flicker frequencies, and can, for example, no longer perceive fluctuations in luminous flux above 100 Hz. Literature provides differing ways of depicting the sensitivity of the human eye for periodic luminous flux fluctuations at various frequencies. Fig. 17 shows an example according to Kelly and Henger [1].

When operating at 50 Hz, the luminous flux or intensity fluctuates with wattage, i.e. with 100 Hz as shown in Fig. 15. Literature uses various equations to evaluate changes in luminous intensity that can be perceived by the human eye. Flicker is evaluated according to EN 50006 standard, for example, with a flicker factor F10 as

$$F_{10} = \sqrt{\sum_i m^2(f_i) G^2(f_i)}$$

whereby $m(f_i)$ = time-dependent modulation depth of the luminous intensity

G = filter curve for flicker sensitivity depending on flicker frequency

According to Afshar [2], adapting the evaluation also to short-term changes and implementation in a filter for a light signal, such as in Fig. 15, results in values for the flicker factor as shown in Fig. 16. The perceptibility threshold is assumed to be 1. The values in this example remain below 1, i.e. no visible changes can be perceived in the light.

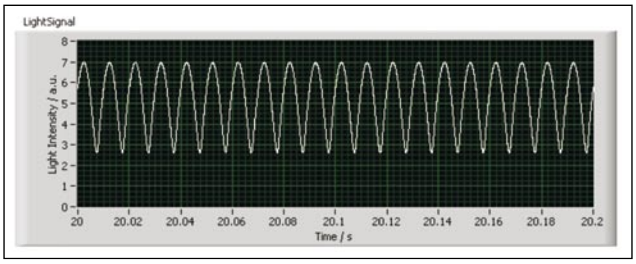


Fig. 15: Luminous intensity of a metal halide lamp at 50 Hz choke operation, shown in arbitrary units

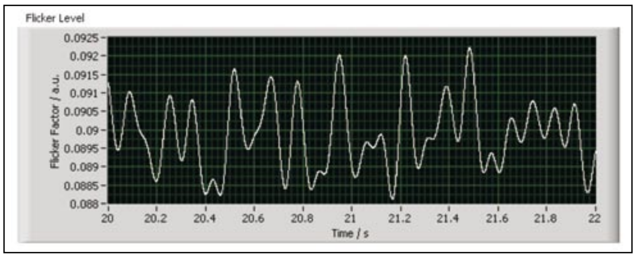


Fig. 16: Flicker factor calculated from the luminous intensity signal for a metal halide lamp at 50 Hz choke operation, shown in arbitrary units

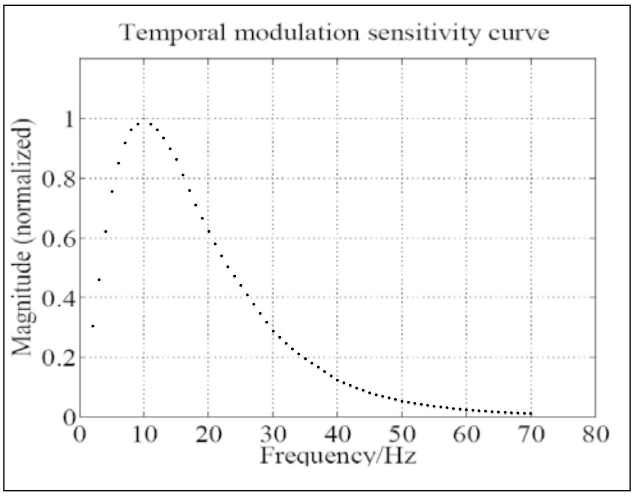
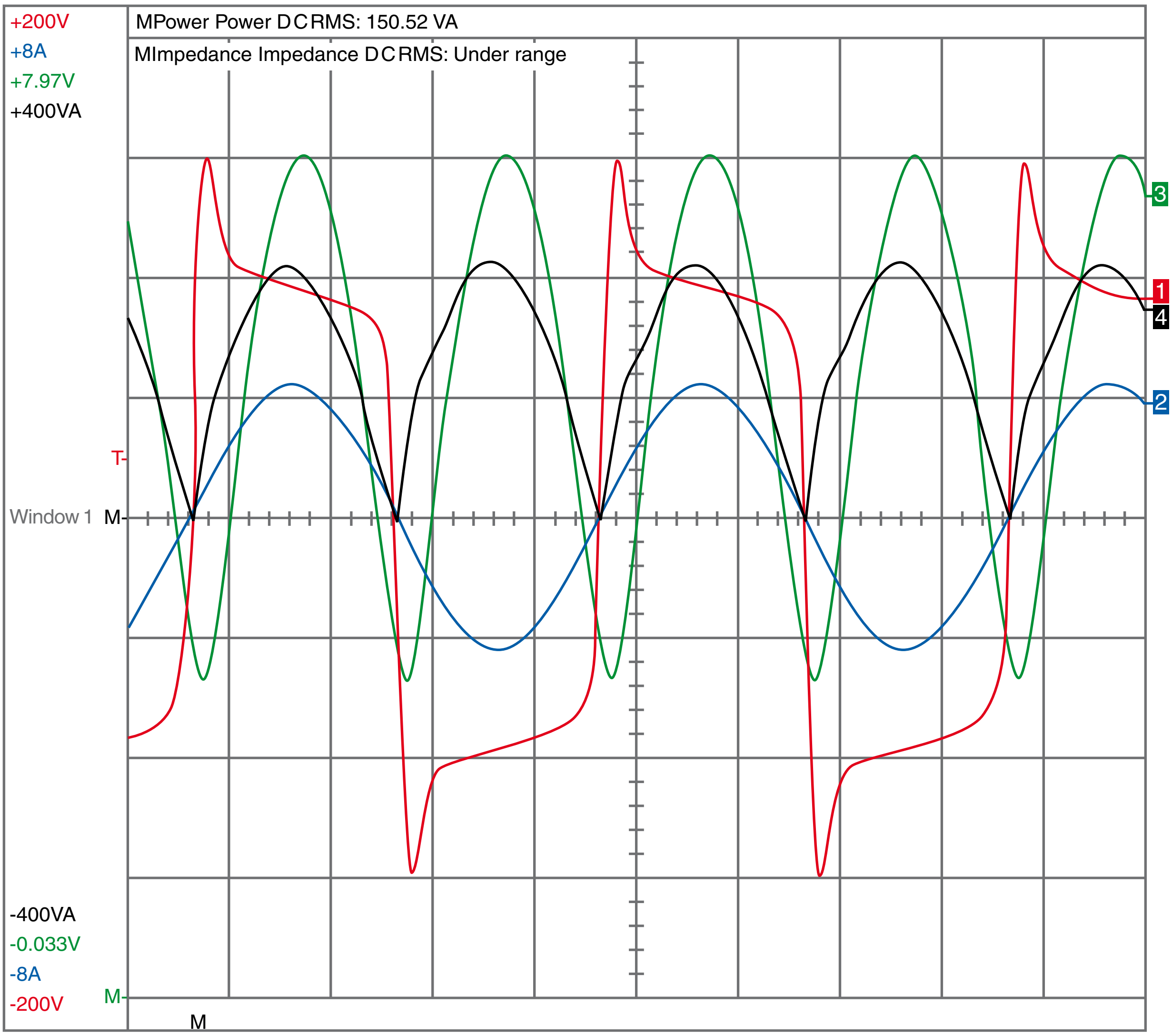


Fig. 17: Eye sensitivity curve for flicker as per Kelly 1960 and Henger 1985

There is a delay of just a millisecond between the current maximum and the luminous flux maximum as shown in the following drawing.



Ch 1 (red): Lamp voltage
Ch 2 (blue): Lamp current
Ch 3 (green): Light signal
Ch 4 (black): Lamp power

Fig. 18: Time curve for light signal and the electric parameters of a metal halide lamp

In fast-moving or rotating objects, the stroboscope effect can cause an optical illusion that the object is moving more slowly or in the opposite direction or even at a standstill.

Stroboscope effects can be reduced or ruled out by operating luminaire groups on three different phases or by using electronic ballasts.

4 Igniting and starting discharge lamps

Some discharge lamps do not require an external ignition unit, as the supply voltage is sufficient to ignite the lamp or because the lamp has an integrated ignition unit. These lamps must **not** be used in installations with an external ignition unit or they will fail prematurely due to internal arcing.

All other discharge lamps must be ignited by an additional unit. Ignition units or circuits of varying types are used for this purpose.

At room temperature, the filling particles are still present in solid form (metal halides or amalgam) or in liquid form (mercury). The arc tube contains the start gas, usually an inert gas such as argon or xenon, between the electrodes. The insulating gas filling in the arc tube must be made conductive in order to generate hot plasma. This is carried out by high-voltage pulses generated by a separate ignition unit or by the ignition unit in an electronic ballast. Constantly available free charge carriers (electrons) are accelerated by high voltage, providing them with sufficient energy to ionize atoms on impact and generate more free charge carriers. This process, similar to an avalanche, finally produces conductive hot plasma within which the current flow excites the partly evaporated metal halide filling such that light is radiated.

The ignition voltage required to generate a breakdown between the electrodes depends on the spacing between the electrodes, the filling pressure of the gas between the electrodes and the type of gas. Examples for using these principles include the use of auxiliary electrodes or the use of Penning gases (see chapter 14.4 *"Ignition at low ignition voltage (Penning effect)"*).

The sockets and cables must be suitably designed for the high ignition voltages. In particular with the E27 sockets for single-ended screw base discharge lamps, care must be taken that a similar socket (E27) for incandescent lamps is not used, which does not meet the requirements.

When lamps are defective or no lamp is inserted, continuous operation of the ignition unit can possibly damage the ignition unit or the luminaire. It is therefore advisable to switch the ignition unit off for a period of time after failed ignition, or to use an ignition unit with timer function.

Preference should be given to using a timer ignition unit.

4.1 External ignition units

4.1.1 Parallel ignition unit

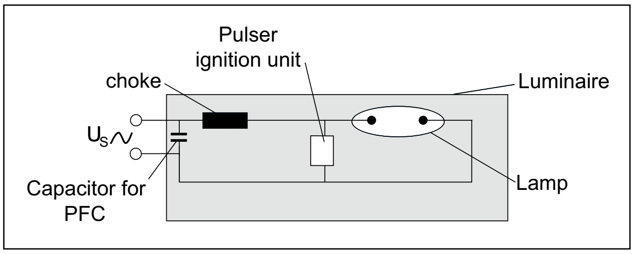


Fig. 19: Simplified circuit diagram for conventional operation of high intensity discharge lamps with pulse ignition unit

With a pulse ignition unit, the choke must be insulated for its surges. The pulse ignition units can normally take a load of 1000 pF, permitting lead lengths of about 15 m between lamp and choke. During ignition, the lead carries high voltage from the choke to the lamp so that care must be taken to ensure that the supply lead, socket and luminaire are adequately insulated for the corresponding high ignition voltage. This type of ignition unit is used in single phase grids.

4.1.2 Semi-parallel ignition unit

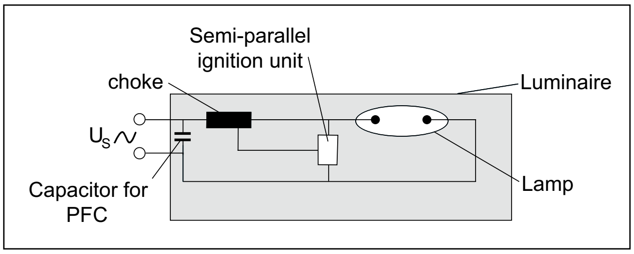


Fig. 20: Simplified circuit diagram for conventional operation of high intensity discharge lamps with a semi-parallel ignition unit

In the semi-parallel ignition unit, part of the choke windings is used to transform the ignition pulses. This means the choke must be adequately insulated for the high voltage and have a tap for the ignition unit. As with pulse ignition units, the ignition unit can generally take 1000 pF or approx. 15 m lead length, and the connection lead between choke and lamp must be insulated for the corresponding voltage levels. A capacitor with minimum capacitance depending on the unit must be provided for compliance with the EMC of the ignition unit.