Dimming of HID lamps

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Based upon its high efficacy high intensity discharge lamps (HID lamps) have become very popular in both indoor and outdoor lighting. Since dimming of these lamps could lead to significant energy savings there has been a growing interest in exploring dimming possibilities for the various types of HID lamps. Especially in outdoor lighting many municipalities and energy service companies have already installed day-night switching cycles where HID lamps are dimmed during late-night hours.

However, dimming always negatively effects the efficacy of HID lamps. Moreover, it influences significantly all major lamp performance parameters as lumen maintenance, life expectancy and colour temperature. Therefore, for all lighting responsibles both, electrotechnological know-how a sound understanding of HID lamps is a key factor in exploring HID dimming.

This article will shed a spotlight on the technological aspects of HID dimming. Therefore, in the following it will be revealed how different types of HID lamps behave under different types of power reduction. All information presented here is based upon studies within the corporate laboratories of Philips Lighting, Europe.

1. electrical circuits for power reduction

The best-known method of power reduction of HID lamps on electromagnetic gear is amplitude modulation (current modulation). Amplitude modulation can be realised by either variable transformer by switching of extra choke ballasts (bi-ballast). However, for electronic gear phase cut-on is used in most cases to realise dimming.

power reduction of HID lamps

electromagnetic gear

- under-voltage (variable transformer)
- variable impulse width (phase cut-on, phase cut-off)
- Extra impedance (bi-ballast)

electronic gear

- variable impulse width (phase cut-on, phase cut-off)

Table 1 shows the dimming options which can be used without losing the product guaranty granted by the major lamp supply companies as Osram and Philips.

lamp type	lamp manufacturer guarantee under dimming (Osram, Philips)
HPL/HQL	no
SON/NAV	bi-ballast, dimmable electronic gear
CDO	dimmable electronic gear
CDM/HCI	no
CDM Elite	dimmable electronic gear
Cosmopolis	dimmable electronic gear
MHN/HQI	no
HPI/HQI	no

table 1 product guarantees for dimmed HID lamps

All other technically feasible dimming options, described in the following will be at the risk of the lighting responsible since damages on the lamps cannot be excluded. A general overview of the behavior of HID lamps under over- and under-voltage is given in table 2 and 3. In the following, all major classes of HID lamps are described in detail.

	Sodium				Mercury	Metal Halide		
	SOX	SON	SON Comf.	SDW-T	HPL, ML	HPI	MHN-TD	CDM/CDO
colour temperature	no	no	very negative	very negative	no	negative	negative	no
colour shift	no	no	no	no	no	no	positiv	no
over lamp life								
ease of starting	negative	no	no	no	no	no	kein	no
lumen maintenance	no	positiv	no	no	negativ	negative	negative	negative
average rated life	negative	positiv	positiv	no	positiv	negative	no	no

table 2 effects of 10% permanent under-voltage on 230V electromagnetic gear on the performance of HID lamps.

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colour temperature	no	no	positiv	no	no	negative	negative	no
colour shift	no	no	no	no	no	no	negative	no
over lamp life								
ease of starting	no	no	no	no	negative	no	no	no
lumen maintenance	no	negative	negative	no	negative	negative	negative	negative
average rated life	no	no	no	no	no	negative	negative	negative

table 3 effects of 6% permanent over-voltage on 230V electromagnetic gear on the performance of HID lamps.

2. High Pressure Mercury lamps (HPL/HQL)

All types of High Pressure Mercury lamps as HPL, HPL Comfort and HPL 4 Pro (fig. 1) show an almost similar behavior under power reduction. This is based upon the fact that the major differences of the above mentioned three lamp classes is in coating of the outer bulb and quality control in lamp manufacturing. Only for HPL 4 Pro lamps the burner is slightly modified. From our studies it becomes obvious that power by under voltage leads to additional 10% - 20% reduction of lumen maintenance during the first 4.000 burning hours. When considering the average rated life of the lamps it will be up to 40%. Moreover, the lower the main voltage the large this effect will be (fig. 2). However, the average rated life and 5% early failure rates which are 10.000 hours for HPL and HPL Comfort and 16.000 hours for HPL 4 Pro are not significantly influenced by driving HPL lamps at under-voltage. If power reduction is not large than 10 % the lamps life expectancies will even slightly increase. However, as depicted in figure 2 lamp efficacy will be significantly reduced when dimming HPL lamps.

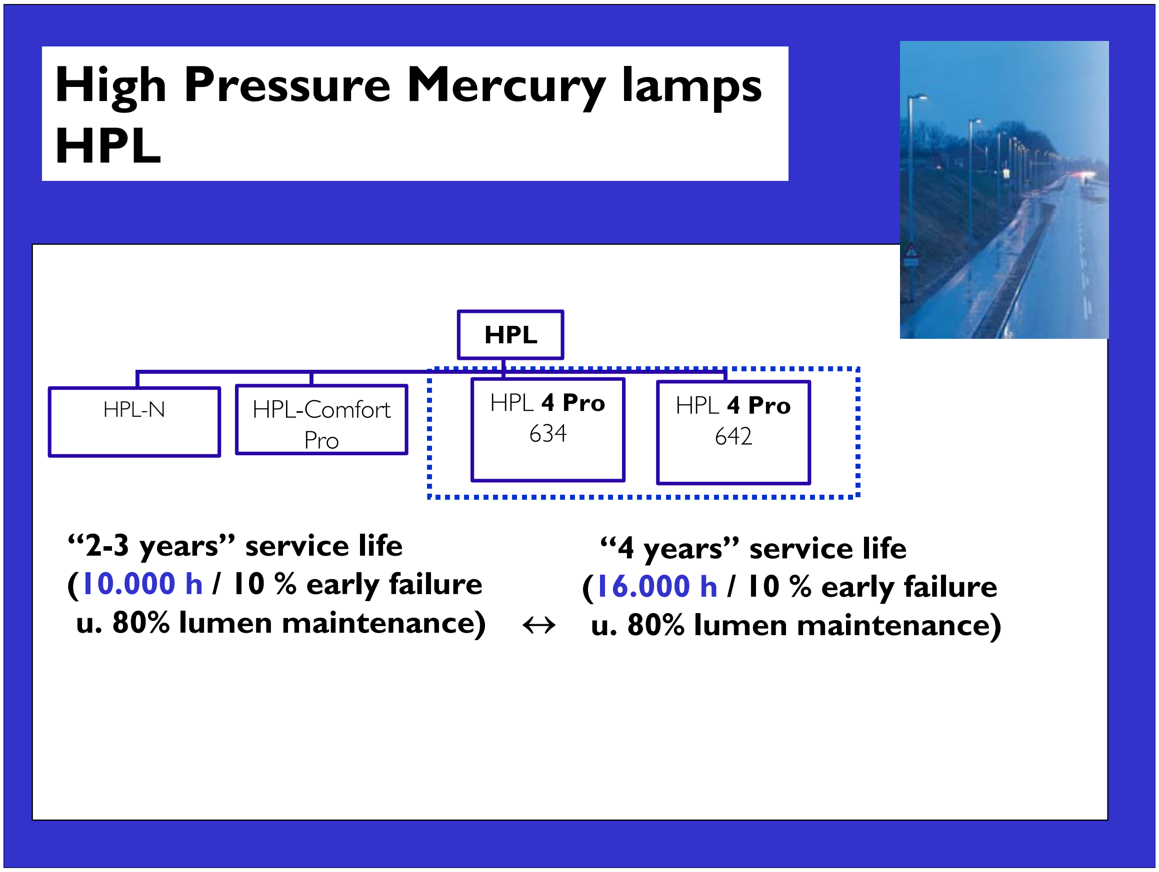

fig. 1 High Pressure Mercury lamps for general lighting

When driving the lamps in the under-voltage mode the 50 Hz re-ignition bias must be maintained. Otherwise the lamp will distinguish. Moreover, one has to take into consideration that the numerical value of the ignition bias will increase over lamp life. Therefore, under-voltage lower than 190 V on a 230 V ballast is not recommended.

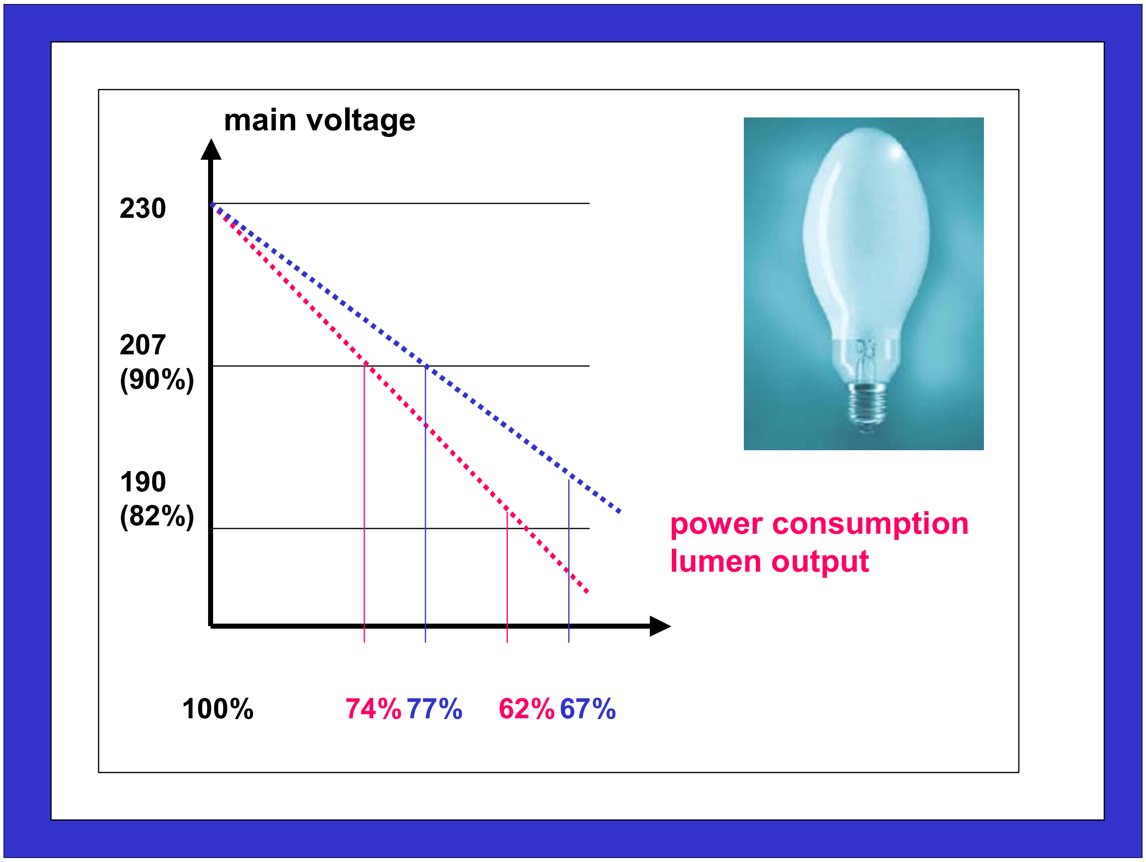

fig. 2 behavior of HPL lamps under power reduction

Since the burner of High Pressure Mercury lamps contains self heated electrodes a minimum power consumption is required for safe lamp operation. For HPL 50W – 125 W this is around 60% nominal lamp power and for 250W – 400W lamps 50% nominal lamp power. Moreover, it is recommended to run up the lamps always under 100% nominal power in order to avoid cold electrode temperatures as much as possible.

An other very common way of HPL dimming in outdoor lighting is amplitude modulation (current modulation) by making use of variable electromagnetic gear. In most cases the ballast configuration consists of two different ballasts (main + additional ballast) since switching between two different ballasts will result in a temporary current break down which negatively influences the lamps' life.

In general the influences on HPL lamps by both, under-voltage and bi-ballast dimming, are very similar. However, bi-ballast circuits allow for even lower power consumptions.

When using phase cut techniques for lamp dimming luminaire capacitors have to be removed in order to avoid negative impact on the modulation system (triac or mosfet circuits)

Phase cut shows a much stronger negative impact on HPL lamps than amplitude modulation. This is based upon the fact that at every single 50 Hz phase cut the lamp electrodes have to bear a current break which significantly cools down the electrode. During the major period of the break the lamp works in a glow discharge mode and in front of the cathode there will be a high cathodic fall and reduced plasma ionization. This leads to an increased re-ignition peak (fig. 3) which harms the electrodes (emitter coated tungsten) by sputtering. Sputtered material than deposits on the wall of the burner (fig. 4) an reduces the lumen output of the lamp (lamp blackening).

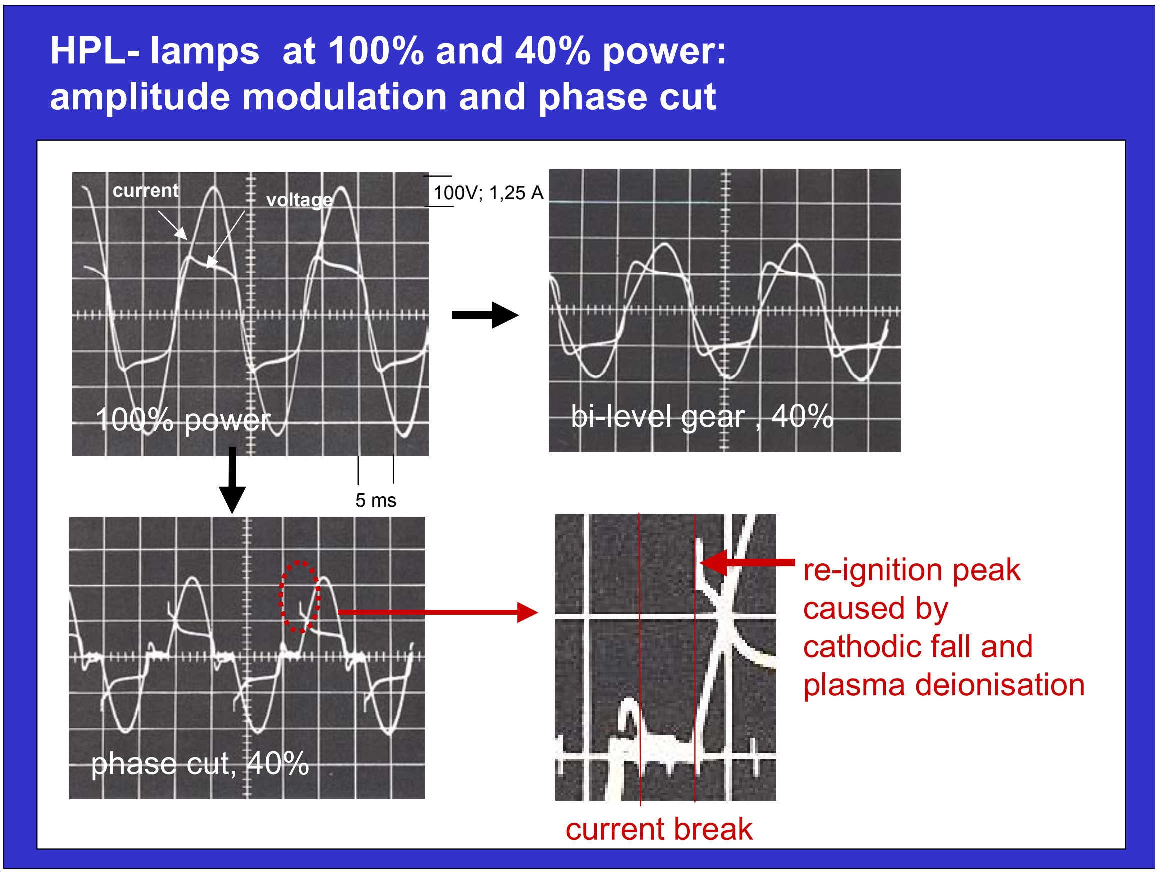

fig. 3 HPL lamps: images of lamp current and lamp voltage under 100% power, and 40% lamp power (bi-ballast, electromagnetic gear) and 40% lamp power (phase cut, electromagnetic gear)

Moreover, the current break increases the visible 50 Hz flickering of the lamps. However, there is also a severe impact on the main supply caused by high frequency arc flickering of the bow. This makes dimmed high discharge mercury lamps to high frequency emitters.

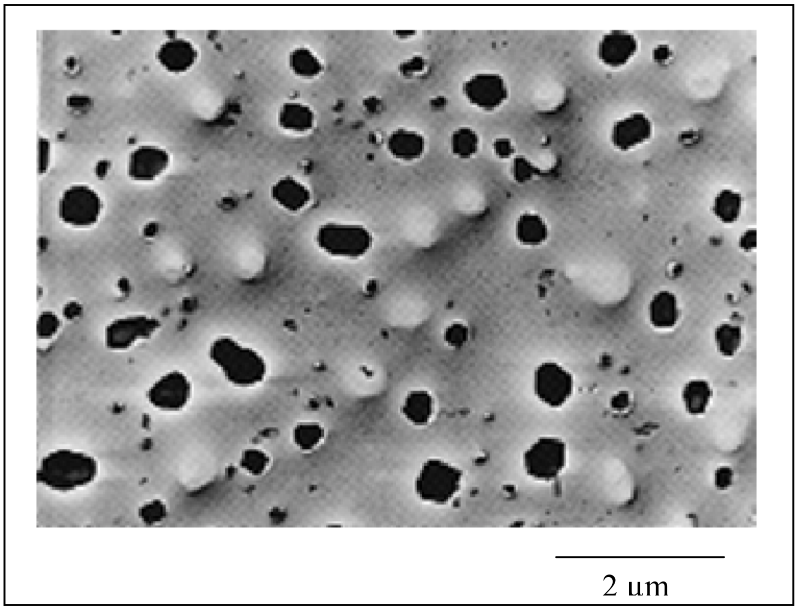

fig. 4 re-crystallized electrode material (Ba/Ca-oxide, $BaWO_4$) on the quartz walls of an HPL burner. Crystallization occurs not as a homogeneous film but in grains on the 100 nm scale. Large quantity of electrode material can be deposited until the lumen output is significantly harmed.

It can therefore be concluded that for HPL lamps amplitude modulation is the more favorable dimming mode. Since for all different forms of HPL dimming the lumen maintenance of HPL lamps will be significantly harmed, dimming of HPL lamps can generally not be advised. If nevertheless HPL lamps shall be dimmed the use of HPL 4 Pro lamps must be recommended since this class of HPL lamps delivers 20 – 30% more lumen output over lamp life which partially compensates the negative impacts of HPL dimming.

3. High Pressure Sodium lamps

The different classes of high pressure sodium lamps as SON, SON Pro and SON PIA Hg-free/Plus (fig. 5) show a very similar behavior when the lamps are driven in a power reduced mode. From our studies it can be deduced that 10% under-voltage does show a slightly positive impact on both average rated lamp life and lumen maintenance. However, for lower main voltages no precise information is available so far.

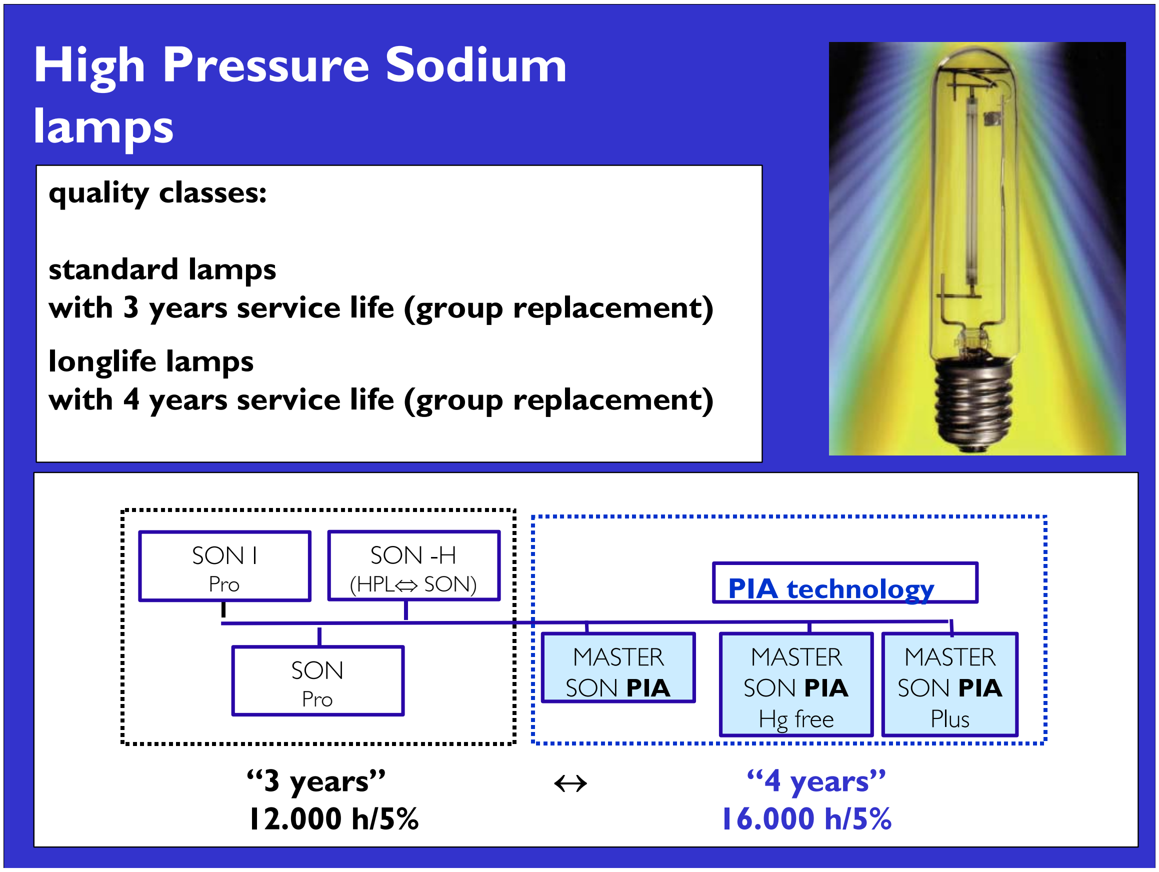

fig. 5 quality classes of High Pressure Sodium lamps

For SON lamps one very common power reduction method is using bi-ballast installations and main voltage variation. In general, the impact of both methods on the lamp performance is very similar although the former can be used for lower dimming levels.

In general, SON installations require not only a ballast but also an external ignitor, which is in most cases a series ignitor. Exceptions are the not very common SON-i and SON-H lamps. For phase cut dimming a risky interaction with the lamp and the series ignitor cannot be ignored. Series ignitors very often contain an internal HF block-capacitor. In the phase cut mode this capacitor will be charged by almost twice the instant bias value. This leads to lamp re-ignition peaks of over 300 V(fig. 6). This effect as well as higher harmonics can make the ignitor working even when the lamp already burns. This can reduce the average rated lamp life to less than 2.000 hours. Therefore, in case of phase cut installations series ignitors must be installed whose capacitors' charge times are long enough to avoid this negative feed-back loops. An alternative option is the installation of semiparallel ignitors and ballasts, e.g. Philips SN....T33. Moreover, semiparallel ignitors offer a smaller electric loss and can be installed at a 10 times larger distance from the lamp.

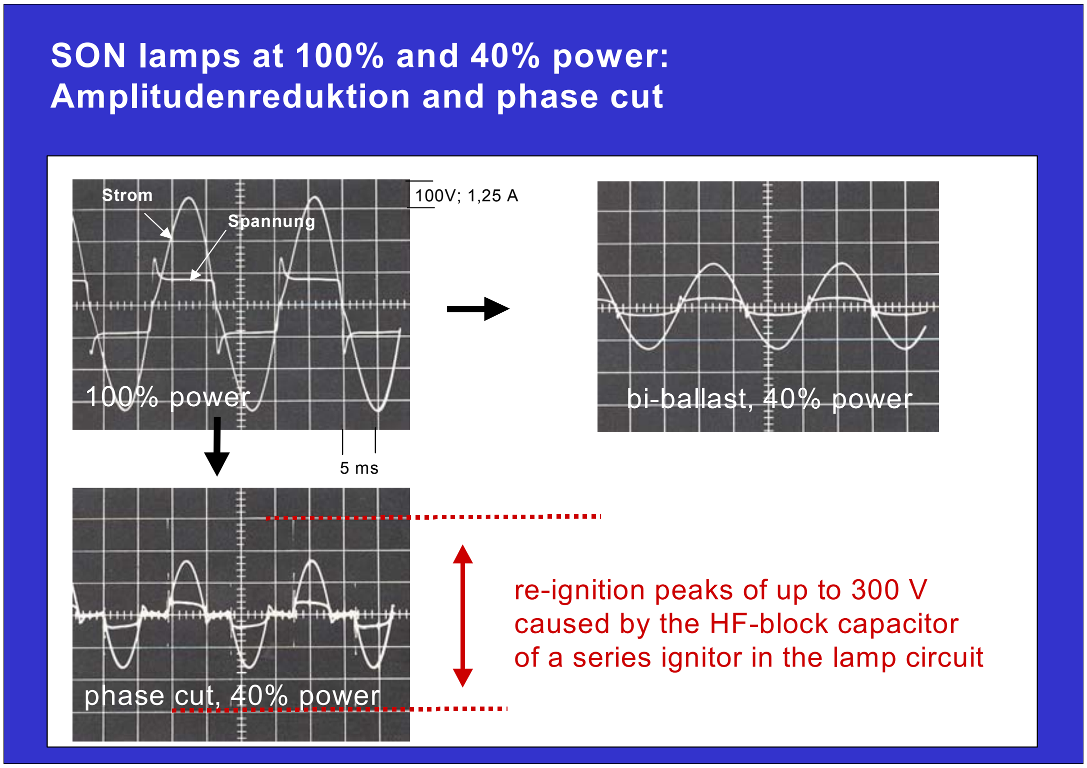

fig. 6 SON lamps: images of lamp current and lamp voltage under 100% power, and 40% nominal lamp power (bi-ballast, electromagnetic gear) and 40% nominal lamp power (phase cut, electromagnetic gear)

If the ignitor problem is under control and only a moderate dimming level is applied (10% power reduction) a positive impact on both, lamp life and lumen maintenance, is observed. Moreover, even for lower power levels (< 60%) damages on SON lamps are observed to be significant smaller than those of HPL lamps. This is based upon the fact that the electrode distance of SON lamps is much longer, resulting in a better lumen maintenance in case of comparable levels of electrode sputtering. While 50Hz flickering occur as in case of HPL/HQL lamps high frequency arc jumps were not observed.

Dimmable electronic gear for SON lamps which allows for a permanent power reduction down to 35% at 20% lumen output is already available from 70 to 150W (Philip HID-Dynavision). However, below 60% power consumption the lamp color changes to a more yellow-red color impression similar to that of a low pressure sodium lamp (SOX) and the lamp's color rendering falls below R_a = 10. Powering SON lamps by electronic gear generally prolongs lamp life by about 30% and leads to a more comfortable light which is free of any visible flickering (ν >130 Hz). In case of electronic gear power reduction is realized by phase cut. However, lamp damages are reduced by the significant shorter current breaks and the out-filtering of higher harmonics in the main supply.

In summary it can be concluded that for power reduction down to 50% bi-level ballasts dimming or the use of dimmable electronic gear is favorable – especially since the product guarantee of the respective SON /NAV lamps will not extinguish.

4a. High Pressure Metal Halide lamps (CDM and CDO lamps with rare earth filling)

CDM-T, -TD, -R, -TT und ET lamps show a similar behavior when dimming is applied. In case of CDM lamps dimming down to 75% nominal power by amplitude modulation leads to an additional loss of lumen maintenance by about 10% during the fist 4.000 hours. However, a negative impact on the average rated of the lamps is not observed. While the color temperature remains almost stable color rendering goes down to $R_a < 80$. On the other hand, over-voltage significantly reduces lamp life by tungsten evaporation and additional thermal stress to the walls and throughfeeds.

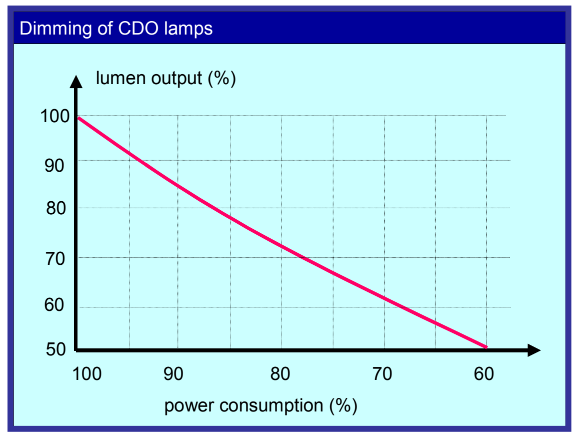

fig. 8 **MASTER White City (CDO)** from Philips Lighting – dimmable metal halide lamps for outdoor lighting.

CDO-lamps are the first metal halide lamps which can be driven in a permanent dimming mode. Figure 7 shows the efficacy of CDO lamps when the lamps are dimmed. Even at 50% lumen output (60% lamp power) no visible change of the color temperature is observed. However, color rendering is reduced to $R_a = 65$ – 70. While dimming by bi-ballast systems is technically also feasible, it is less favourable for CDO lamps. In this case an additional 10% reduction of the lamps' lumen maintenance during the first 4.000 h must be expected.

More detailed investigations have shown that especially for metal halide lamps lamp damages in the dimming mode strongly depend on the working temperature of the very hot non-coated tungsten electrodes. If for 100% power the electrode works already at the upper edge of the temperature regime (e.g. CDO 150W) dimming down the lamp will less harm the electrodes than in the opposite case (e.g. CDO 70W). Therefore, CDM 150W lamps are better suited for dimming than

CDO 70W lamps. Furthermore, in can be expected than in the very near future also different types of CDM lamps in combination with dimmable electronic gear will be available for indoor applications.

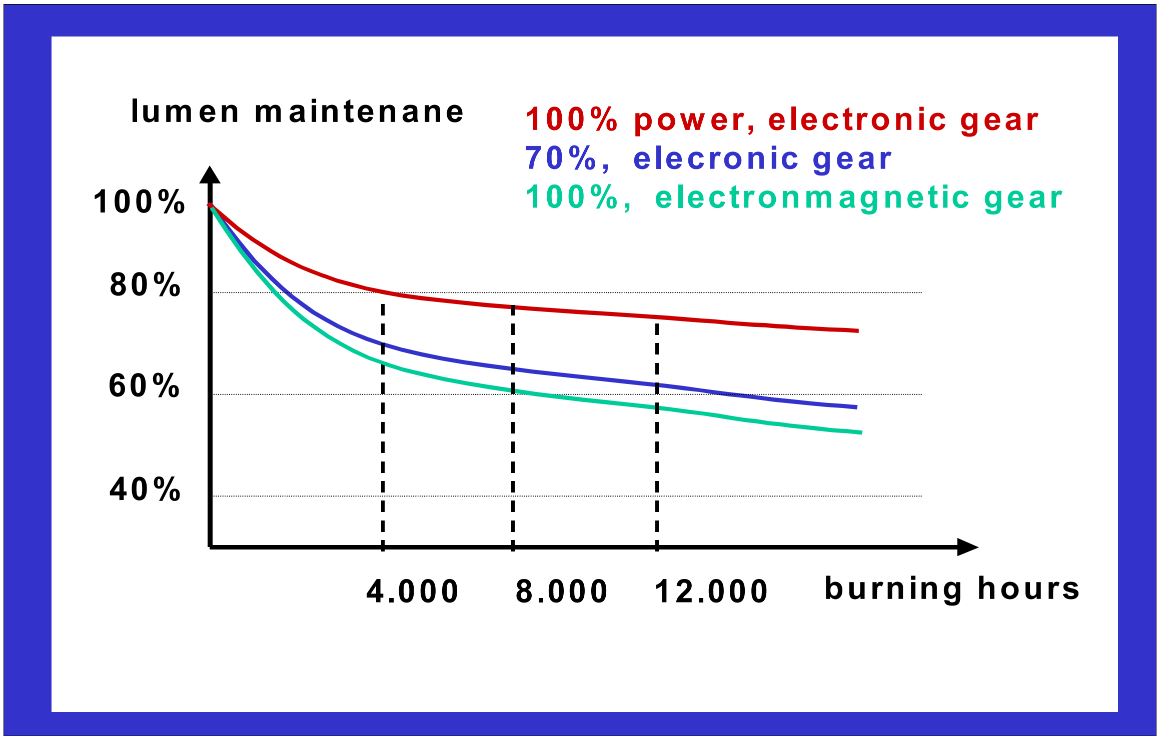

fig. 8 lumen maintenance of CDO lamps depending on consumed power and gear

4b. High Pressure Metal Halide lamps (HPI lamps with NaI, TlI, InI filling)

Main voltage reduction by 10% from 230V to 198V leads to an additional lumen output loss of 10-20% within the first 4.000 burning hours. Moreover, the color temperature rises when the lamp power is reduced. This is caused by differences in vapor pressure of the respective metal iodides within the burner: sodium iodide (yellow-orange), thallium iodide (green) und indium iodide (blue-purple). NaI has the lowest vapor pressure and therefore its relative partial pressure in the gas phase is reduced when the lamp is cooled down. The average rated lamp life is also negatively influenced by the deposition of iodides near the feedthroughs of the lamp.

Conclusion and safety recommendations

Dimming of HID lamps always harms the lamp performance – with one exception: dimming of high pressure sodium lamps to a moderate level of 50%

lamp power. The most negative impact on HID lamps is the reduction of lumen maintenance by electrode sputtering (burner blackening). In case of phase cut dimming the luminaries' capacitors must be removed. Additionally, series ignitors should be used whose HF block-capacitors show sufficiently long charge-times.

For safety reason it is highly recommended to maintain all HID installation by exchanging the respective HID lamps already after 5% to 10% early failure. This maintenance mode (group replacement) significantly reduces end of life risks as lamps cycling or lamp burst. Especially the cycling problem can cause severe damages to the electronic components of the luminaire.

recommended literature

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