To contents 2

contents

contents

Back to contents

1. Introduction

We are living in a rapidly changing world, and technological developments play an important part in this. In the world of lighting, too, new products and applications are being launched all the time in order to provide the best solutions for the continually changing demands of the customer. Issues such as better colour properties, lower power consumption, smaller dimensions, longer lifetime, lower costs, better control and monitoring facilities, and/or more flexibility, are the basis for modern lighting systems.
While new or improved luminaires can help provide an answer to these changing demands, the heart of any lighting system will always be the lamp and its control gear. The lamp circuits have to answer to numerous basic needs, including compliance with national and international safety standards, ease of installation, inter-compatibility and, of course, price/performance ratio.

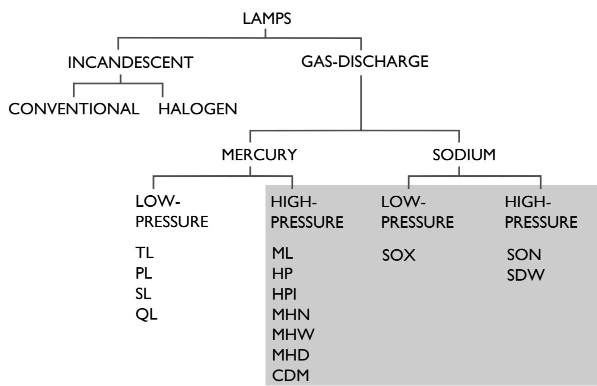
This Guide provides information on those aspects of lamp control that is needed in order to acquire an understanding of the total lighting system. Together with the publications on the Internet and Intranet and the various product data sheets, it will hopefully provide answers to all practical questions. Knowledge of all the ins and outs enables designers, installers, OEMs and end-users to make a good choice when looking for the best possible lamp control gear.

Related Internet sites:
For the home site of Philips Lighting:
http://www.lighting.philips.com/index.htm

For the European catalogue, including lamps and gear:
http://www.eur.lighting.philips.com/products/html/index2.shtml

1.1. Lamp families

Following the main principle of operation, the family of electric light sources can be sub-divided as follows:



This Guide deals with control gear for the HID (High Intensity Discharge) lamps, as indicated in the grey area. With one exception: the ML are the so-called Blended Light/ Self-Ballasted lamps, which do not require any external control gear, since a tungsten filament inside the lamp is connected in series with the gas-discharge tube.

A second guide (Application guide to fluorescent lamp control gear) deals with the Low-Pressure Mercury lamp (including QL) circuits.

Both guides are divided into two parts:

– conventional gear, comprising electromagnetic ballasts, ignitors (starters) and capacitors
– electronic ballasts and controllers

Following the Philips nomenclature, this guide deals with:

LAMP	ELECTROMAGNETIC BALLAST	ELECTRONIC IGNITOR	GEAR
SOX/SOX-E	BSX**	SX**	EXC**
SON/SON-T	BSN**/BSD**/BSH**	SN**/SU**	EC**/SDU**/HID-DV/HID-DVC**
SON-H	BHL**		
HPA	BHA**	SN**	
HPL	BHL**	-	
HPI(-T)	BHL**/BSN**	SI**	
MH	BSN**/BMH**/BHD**	SN**/SU**	HID-PV**
SDW-T	BSL**	-	CSLS**
CDM	BSN**/BMH**	SN**/SU**	HID-PV**

Explanation of the abbreviations:
BSX = Ballast SOX
BSN = Ballast SON
BSD = Ballast SON dim
BSH = Ballast SON dim DynaVision
BHL = Ballast SON-H / HPL / HPI
BHA = Ballast HPA
BMH = Ballast MH / CDM
BHD = Ballast MNN High-power
BSL = Ballast SDW-T
HID-DVC = DynaVision Controller Low-frequency electronic ballast for SON
HID-PV = PrimaVision = Low-frequency electronic ballast for MH /CDM
SX = Ignitor SOX
SN = Ignitor SON / HPA / MH / CDM semi parallel
SU = Ignitor SON / MH / CDM series
SI = Ignitor HPI parallel
EXC = High-frequency ballast SOX
EC / SDU = Electronic switch for dimming SON
CSLS = Electronic control unit SDW-T
HID-DV = DynaVision

1.2. Standards, quality and environmental aspects

Designers, contractors and installers are regularly confronted with a great variety of standards and recommendations in the field of lighting, and lamp control gear is by no means an exception in this respect.
What makes things even more complicated is the fact that such standards and regulations often differ from country to country.
To start with, international worldwide electrical standards for lighting have been laid down by the IEC (International Electrotechnical Commission). There are, for example, IEC standards for the following lamps:
- high-pressure mercury vapour lamps: IEC 60188
- low-pressure sodium vapour lamps: IEC 60192
- high-pressure sodium vapour lamps: IEC 60662
- metal halide lamps: IEC 61167

These standards specify:
- lamp electrical characteristics
- reference ballast characteristics
- lamp starting test
- lamp dimensions
- further information on ballast, ignitor and luminaire design.

Not all types within a lamp family are standardised, and for some new lamp types there are as yet no standards at all. Apart from these worldwide standards there are equivalent European standards as laid down by CENELEC for the EU countries. Normally these EN norms have the same number as the IEC standards, although the contents may differ. The home page of CENELEC can be found on: http://www.cenelec.org/

For HID control gear, relevant IEC standards are:

- lamp caps and lamp holders:	IEC 60061 / 60838
- ballasts for discharge lamps:	IEC 60922 and 60923
- starting devices:	IEC 60926 and 60927
- capacitors for discharge lamp circuits:	IEC 61048 and 61049

The standards are often split up into a Safety and a Performance edition. The Safety edition deals with aspects for operation without danger to the user or the surroundings, while the Performance edition deals with issues such as guarantee for ballast/lamp interchangeability, satisfactory starting and operation, and the like.

As control gear is often built into a luminaire, the most important IEC standard in this respect is: IEC 60598. EMC requirements have been laid down in: CISPR 15. Moreover, there are specific Vibration and Bump tests: IEC 68-2-6 Fc and IEC 68-2-29 Eb.

Copies can be ordered via the IEC Internet address: http://www.iec.ch/

Recently, a new set of IEC Standards has been edited. The set forms the new "Omnibus Standard" for Lamp Control Gear.
The new standards are:

- IEC 61347-1
  General and safety requirements
- IEC 61347-2-1
  Particular requirements for starting devices (other than glow starters)
- IEC 61347-2-2
  Particular requirements for d.c. or a.c. supplied electronic step-down converters for filament lamps
- IEC 61347-2-3
  Particular requirements for a.c. supplied electronic ballasts for fluorescent lamps
- IEC 61347-2-4
  Particular requirements for d.c. supplied electronic ballasts for general lighting
- IEC 61347-2-5
  Particular requirements for d.c. supplied electronic ballasts for public transport lighting
- IEC 61347-2-6
  Particular requirements for d.c. supplied electronic ballasts for aircraft lighting
- IEC 61347-2-7
  Particular requirements for d.c. supplied electronic ballasts for emergency lighting
- IEC 61347-2-8
  Particular requirements for ballasts for fluorescent lamps
- IEC 61347-2-9
  Particular requirements for ballasts for discharge lamps (excluding fluorescent lamps)
- IEC 61347-2-10
  Particular requirements for electronic inverters and converters for high-frequency operation of cold-start tubular discharge lamps (neon tubes)

This set of IEC Standards will replace the safety standards. In general, the contents of this first edition of the "omnibus" is the same as the contents of the "old" standards.

For IEC, the "old" standards remain valid until they are withdrawn, but they will vanish from the list of standards that can be bought.
For CENELEC, there will be definite dates for the validity of the "old" standards.
Amendments and new items will be incorporated in the "omnibus" only from now on.
Note: The performance standards are not affected.

CE is the abbreviation of 'Conformité Européenne'.
It states conformity of products to the most essential requirements of the European Community Directives and as such forms a kind of passport for goods to circulate freely throughout the countries of the European Community. It also enables Market Controlling Bodies to perform their inspection task more easily.
Lighting products are covered by two European directives: the Electromagnetic Compatibility (EMC) Directive and the Low Voltage (LV) Directive.
Philips HID electronic ballasts carry the CE marking on the basis of fulfilling the following standards:
EN 61547 (Immunity), EN 61000-3-2 (Harmonics) and EN 55015 / EN 55022 (RFI). CE is mainly related to safety aspects.

ENEC is the abbreviation of 'European Norm Electrotechnical Certification'. Over twenty Certification bodies from CENELEC member countries joined the 'Agreement on the use of a commonly agreed mark of conformity for luminaires complying with European standards', referred to as the LUM agreement.
It means that if the ENEC marking is provided by one of the Certification bodies, this is also recognised by the other members. The marking can be obtained for luminaires for which a European Norm (EN) exists, barring luminaires for emergency lighting. In 1995 the LUM group and the LVE-AC (Low Voltage Electrical Equipment Advisory Committee) agreed that luminaire accessories such as gear, ignitors, lampholders, electronic converters and capacitors, can also obtain the ENEC marking if they fulfil the harmonised EN standards.
Philips HID electronic ballasts received the ENEC marking on the basis of standards EN 60922 and EN 60923, as well as the ISO 9001 certificate. ENEC is mainly related to performance aspects.
The number in the ENEC marking indicates the test house that gave the approval:

01	AENOR	- Spain
02	CEBEC	- Belgium
03	IMQ	- Italy
04	IPQ	- Portugal
05	KEMA	- Netherlands
06	NSAI	- Ireland
07	SEE	- Luxembourg
08	UTE	- France
09	ELOT	- Greece
10	VDE	- Germany
11	OVE	- Austria
12	BSI	- United Kingdom
13	SEV	- Switzerland
14	SEMKO	- Sweden
15	DEMKO	- Denmark
16	FIMKO	- Finland
17	NEMKO	- Norway
18	MEEI	- Hungary
19	BEAB	- Great Britain
20	ASTA	- Great Britain
21	EZU	- Czech republic

Lighting products always have to comply with the safety, electromagnetic compatibility (EMC), performance and reliability rules as laid down in the relevant standards (e.g. EN 55022A) before they can be introduced onto the market. The examination required guaranteeing such compliance is carried out in Philips' own testing laboratories under official supervision.
In those cases where commercial interests or legal requirements demand additional national approval marks, these must be sought by submitting the products to the test authority concerned. Once approval has been received, the manufacturer is entitled to add the appropriate stamp of approval to the unit and offer it for sale.

For products originating in the Netherlands, the Dutch inspection institute KEMA (Keuringsdienst Electrotechnische Materialen Arnhem - Inspection Institute for Electrotechnical Materials in Arnhem) is the national test authority, and can act as representative for testing authorities such as CSA (Canada) and UL (USA).

To ensure optimum quality of internal procedures, the internationally recognised ISO 9001 system for quality assurance has been implemented and is stringently applied in Philips factories and sales organisations.
For example, for the ballast factory in Oss the ISO certification was obtained in 1991 for electronic gear and in 1992 for electromagnetic gear. It involves virtually all phases of development and production, including after-sales service to Philips customers.

Finally, a few words must be said on environmental considerations. Philips Lighting was one of the first to admit that it has a duty to set a good example when it comes to the proper management of our natural resources. This has led to considerable positive environmental effects throughout the 'cradle-to-grave' product life cycle, which basically consists of four phases: the use of raw materials, the manufacturing of the product, the use of the product and, at the end of product life, the disposal or re-use of the materials.
Aspects that play a role in all this include:
- Raw material mining and refining. Suppliers are requested to provide the relevant environmental information and are expected to meet the same high environmental standards as Philips.
- Materials and energy used for production. Philips has introduced so-called Environmental Management Systems (EMS) and has committed itself to start certification of EMS in all its factories throughout the world.
- Production methods and their side effects. The development and machine construction departments have implemented eco-design procedures to ensure that environmental effects are taken into account in the creation process of new products and technologies. This also involves the reduction and possibly the elimination of eco-toxic materials in existing products and processes. For example, Philips achieved a 25 per cent reduction of its energy consumption in the year 2000 (compared with the 1993 level). Naturally, all this is also true for the packaging materials used.
- Treatment and processing of production rejects. A continuing programme has been started to study the feasibility of recycling and/or effective treatment of auxiliary materials and production waste ('zero-waste' production).

- Energy and material consumption during use of the product. As a result of ongoing development, new, innovative and ever-more efficient lamps, ballasts and luminaires are continually being introduced. We are also currently heavily engaged in developing a whole range of light-control devices that will enable users to tailor their lighting to the needs of the moment, thereby bringing even more energy savings.
- End-of-life disposal of the product. Great value is attached to the efficient disposal of spent products and the use of recycled materials where possible.

To achieve the maximum benefit from all these efforts, we must work together with all parties concerned: our suppliers, our customers, the trade, other manufacturers, and the governing authorities.

1.3. Mains-power supply voltage

Before the end of the year 2003, all European EEC and EFTA countries (except the United Kingdom) will change over to a nominal mains voltage of 230 V ± 10%.
Therefore, the standard range of control gear will be nominally 230/240 V, 50 Hz.
At this nominal voltage, the control gear will perform well within the limits set in the various standards, unless stated otherwise in the relevant data sheets.
To obtain optimum efficiency for the total lighting system at the different mains voltages in use today, control gear is available for 220 V, 230 V, 240 V, 50 Hz and/or 60 Hz.
It is not the purpose of this guide to describe all the effects in the case of differences in the mains voltage and the indicated control gear voltage. Such information can be provided on request by Product Management.
According to the IEC standards, the system must under all circumstances function between 92 per cent and 106 per cent of the rated voltage.
In general, if the mains voltage is too low, the consequences are:
- reduced light output in all cases except SOX / SOX-E,
- colour shift in SON and metal halide lamps,
- ignition problems in extreme cases, especially with low-pressure sodium lamps,
- reduced lumen maintenance, especially with metal halide lamps;

and if the mains voltage is too high:
- reduced lifetime of lamps,
- reduced lifetime of control gear,
- colour shifts,
- increased power consumption,
- possible safety effects, because of the increased risk of arc-tube rupture,
- reduced lumen maintenance.

It is therefore advisable to always operate lamp control gear in accordance with the local mains voltage.
The effects of mains-voltage fluctuations on the lamp are much higher with electromagnetic gear than with HF gear.
In cases where the mains supply voltage has to be changed from 220 V to 230 V nominal, voltage-tapped ballasts can provide a solution for today and the future.
For lamp types for which it is available, electronic control gear with power stabilisation (White SON/CDM) or conventional constant-wattage control gear is recommended.

Effects of mains voltage fluctuations can be seen in Section 4.3.10.

Some lamps are operated at mains voltages of 380 V, 400 V or 415 V (e.g. HPI-T 2 kW, MH* 1800 W and 2000 W) and require control gear for such mains voltages.

For mains voltages or frequencies other than those specified, information can be given on request by the local Philips Lighting organisation.

1.4. Reliability, service life and warranty

Purchase decisions regarding lighting installations – for example, with respect to investment or running costs – are mostly based on a lifetime of 10 to 15 years for the installation as a whole. In practice, however, there are well-constructed installations, which still function perfectly well after 20 to 25 years. Some electronic components, however, can have a shorter lifetime.
It is a well-known fact that good maintenance improves the lifetime of an installation.
Of course, the actual burning hours and the way of switching also have some effect, as do deviations from the nominal rated circumstances.
In general, the system lifetime depends on the lifetime of the individual components, including lamps, luminaires, gear and cabling, as well as that of electrical distribution components such as switches and transformers. In fact, all these components are constructed to function well under nominal circumstances for approximately 10 years of continuous use, except lamps. Obviously, when the installation is not working continuously, the actual lifetime can be proportionately longer.
When the circumstances differ from those rated as nominal, the practical lifetime of the lighting system will change as well. To what extent this is the case, depends on several aspects, such as:

- what component is involved (e.g. under/overloaded lamp, ballast, starter)
- what factor is out of specification (e.g. temperature, voltage, frequency)
- for what period does the deviation last (e.g. for hours or continuously)
- the switching cycle: this too can have a certain influence (heating/cooling).

There is, therefore, no general rule for predicting the lifetime, but when all the components are used within their specifications, the deviations from the average lifetime of 10 years will not be great.
Possible reasons for replacing a lighting system, besides end of lifetime, can be:

- catastrophe,
- renovation,
- the need for a higher performance,
- change-over to newer concepts such as modern light sources or luminaires,
- saving of energy costs,
- environmental aspects.

Details for lamp and gear life can be found in the related sections.

Over the years, the dimensions and specifications of control gear can change, but normally this gives no problems in practice. In the case of questions regarding replacements, information can be given on request by the local Philips Lighting organisation.

Warranty

Warranty is a commercial issue and can vary according to country, production centre, product, or even customer. Philips Lighting Business Unit Lighting Electronics warrants, in general, that the products manufactured shall be free from defects in material and workmanship for a period of two (2) years after the date of sale to the customer, but with a maximum of three (3) years from the date of manufacture of the product.
The warranty and remedies set forth herein are conditional on proper storage, installation, use and maintenance and conformance with any recommendations of Philips.
The standard failure rates for ignitors and HF ballasts are 1 per cent per 5000 h, and for the conventional types 1 per cent per 6000 h. Maximum zero-hour inoperatives are 2500 PPM for the ignitors and HF ballasts and 1000 PPM for the conventional types.

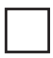
1.5. Date and origin code

In order to be able to identify the place and date of manufacture of Philips lighting products, these are marked with a special code. This can be very useful in the case of after-sales service. The lamps, gear and luminaires are made in a number of different factories, the most important for HID in Europe being:

HID lamps:	Turnhout (Belgium), Hamilton (UK), Pila (Poland)
Lamp control gear:	Oss (Holland), Pila and Ketrzyn (Poland), Istanbul (Turkey)
Luminaires:	Miribel (France), Hamilton (UK), Istanbul (Turkey)

The factory marks or symbols are standardised in the Philips standard ULN-D 1175, while the date markings are described in ULN-D 1745.

Marks:

	Pila
	Turnhout
LA	Oss
	Hamilton
KN	Ketrzyn
MR	Miribel

Most Philips lighting products carry the following date code, although there are some products that, for practical reasons, follow another system.
The date code consists of a number from 0 to 9 in combination with a letter from A to M, with the exception of the letter I. The letter stands for the month in the year: for example, C for March, M for December. The number stands for the year in a particular decade. In one decade the sequence is: letter followed by number. In the next decade the sequence is: number followed by letter. Thus, a certain code will not be repeated until after 20 years. For the nineties the sequence is: number -letter, so 5C means March 1995, whilst March 2005 will be indicated by C5, as was March 1985. With EM ballasts the indication can be found on the bottom plate between the connectors; with ignitors and electronics it is indicated on the marking label.

Another older date code used on, for example, encapsulated ballasts is indicated in Fig. 1. The 12 triangles above the indication of the year represent the 12 months of the year. At the beginning of each production month another dot is placed in the relevant triangle. The last dot thus indicates the production month of the ballast. The example in the figure indicates the production month May 1995.

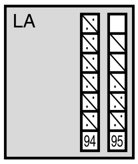


Fig. 1. Date code on encapsulated HID ballasts. The number of dots corresponds with the month of production: e.g. five dots means that the ballast was produced in month 5 = May.

1.6. Developments in lamp control gear

As the control gear is part of the total lighting system, some overall trends in the world of lighting can be distinguished that will also affect the future of the control gear. For example, HID lamps are no longer only used in outdoor applications.
Some aspects:
- **miniaturisation:**
  smaller luminaires require smaller ballasts and control gear, which fit perfectly in the space available. Advance of LED lighting applications
- **fewer components:**
  lamps with starter incorporated, as in SON-I
- **use of electronics:**
  new lamps are developed that can only function well with electronics, such as SOX-E, SDW-T and CDM-TC 70 W lamps
- **introduction of controls:**
  dimming and switching, intelligent (digital) ballasts (DALI), ignitors or luminaires. DynaVision, PrimaVision
- **higher demands on safety/system protection:**
  incorporated fuses and thermal-switches, such as with TS ballasts
- **higher customer demands:**
  customer-tailored connection and mounting possibilities
- **higher environmental demands:**
  self-stopping ignitors, recycling, environment-friendly design, lower energy consumption

- **more indoor applications:**
  White SON, metal halide, PrimaVision, DynaVision
- **more outdoor applications:**
  e.g. low-wattage metal halide,
- **lower costs:**
  the BASIC concept,
- **reduction in maintenance costs:**
  longer life of components, tele-management
- **more attention to system cost approach:**
  the customer purchase is handled more and more as an investment decision, including payback, etc., example: lighting as a production tool in greenhouses
- **tele-management as status information for individual lighting points**
- **universal wiring diagrams**
- **series ignitor, self-stopping ignitor.**

2.

General aspects

2.1. Main ballast functions

The optimum functioning of HID lamps depends largely on the properties of the control gear used. As with all gas-discharge light sources, HID lamps cannot function properly when they are operated directly from the mains supply voltage. Certain electrical and/or electronic devices have to be built into the lamp circuit, either in the lamp itself or externally in the form of what is called control gear.
The control gear performs a number of functions:
- it limits and stabilises the lamp current; a necessary measure in view of the negative resistance characteristic of gas-discharge lamps (viz. when the lamp current increases, the lamp voltage will decrease),
- it ensures that the lamp continues to operate despite the fact that twice during each frequency cycle of the mains supply the voltage is zero,
- it provides the ignition voltage (higher than the normal operating voltage) for the initial lamp starting.

In addition to these basic functions, the control gear must fulfil a number of other, equally important requirements. It must:
- ensure a sufficiently high power factor,
- limit the harmonic distortion of the mains current,
- if possible, present a high impedance to frequencies used for switching purposes in automatic frequency-regulation circuits (AFRC or Actadis) in outdoor applications,
- offer adequate suppression of any electromagnetic interference (EMI) that might be produced by the lamp/ballast system and that could otherwise interfere with other electronic equipment,
- limit the short-circuit current and/or the current during running-up of the lamp, to protect the lamp electrodes from overloading,
- keep the lamp voltage, lamp current and lamp power within the specification during mains- voltage variations.
- control and monitor the lamp status to optimise maintenance and lower cost of ownership.

Finally, there is a third group of requirements dictated by the needs of both luminaire manufacturer and user: to have control gear of small dimensions, long life, low losses (also with a view to controlled temperature), and an inaudible noise level.

With the electromagnetic control gear system, various separate components, including ballast, starter, capacitors and filter coils, help fulfil all these requirements together with the lamp. Resistors, choke coils and (autoleak) transformers can be used as current-limiting devices. They are generally referred to as **ballasts**. Other pieces of auxiliary equipment are **compensating capacitors, filter coils** and **ignitors**.
In some systems an additional series capacitor is used for stabilisation (SOX), whilst in other HID circuits this method is only used in special cases, as in the American constant-wattage circuits.

Semi of fully electronic solutions are becoming more available, particularly for low-pressure sodium lamps (SOX-E) and the smaller wattage HID lamps (MH, CDM).

2.2. Luminaire classifications

There are basically three ways of classifying luminaires as far as their design and construction are concerned:

1. According to the sort of protection offered against electric shock, viz. electrical safety.
2. According to the degree of protection provided against the ingress of foreign bodies (e.g. dust and moisture).
3. According to the degree of flammability of the supporting surface for which the luminaire is designed.

The following are summaries of the classifications detailed in IEC 10598 - Part 1.

2.2.1. Electrical safety (four luminaire classes)

The electrical safety classification drawn up by the IEC embraces four luminaire classes: Class 0, I, II and III.
The official definitions are too long to be reproduced in full here, but can be summarised as follows:

Class 0 - symbol □
(Note: Applicable to ordinary luminaires only, viz. a luminaire without special protection against dust or moisture.)
These are luminaires that are electrically insulated. There is no provision for earthing. The housing may be of an insulating material, which wholly or partly performs the insulating function, or it may be of metal that is insulated from current-carrying parts.
Class 0 luminaires may include parts with reinforced insulation or double insulation.

Class I - symbol ⏚
Luminaires in this class, apart from being electrically insulated, are also provided with an earthing point (labelled) connecting all those exposed metal parts that could conceivably become live in the presence of a fault condition.
Where the luminaire is provided with a flexible power lead, this must include an earth wire. Where this is not the case, the degree of electrical protection afforded by the luminaire is the same as that afforded by one of Class 0.
Where a connection block is employed instead of a power lead, the metal housing must be connected to the earth terminal on the block. The provision made for earthing the luminaire must in all other respects satisfy the requirements laid down for Class I.

Class II - symbol ⧈
Class II luminaires are so designed and constructed that exposed metal parts cannot become live. This can be achieved by means of either reinforced or double insulation, there being no provision for protective earthing. In the case of a luminaire provided with an earth contact as an aid to lamp starting, but where this earth is not connected to exposed metal parts, the luminaire is nevertheless regarded as being of Class II.

A luminaire having double or reinforced insulation and provided with an earth connection or earth contact must be regarded as a Class I luminaire. However, where the earth wire passes through the luminaire as part of the provisions for through-wiring the installation, and is electrically insulated from the luminaire using Class II insulation, then the luminaire remains Class II.

Class III – symbol ⟨III⟩
The luminaires in this class are those in which protection against electric shock relies on supply at Safety Extra-Low Voltage (SELV), and in which voltages higher than those of SELV (50 V AC r.m.s.) are not generated. An AC operating voltage of 42 volt maximum is common.
A Class III luminaire should not be provided with a means for protective earthing.

The standard ballasts are developed for Class I luminaires. Information for other Classes can be obtained from the local Philips Lighting organisation.

The earthing of ballasts with metal housings depends on the class and construction of the luminaire.
See also IEC 10598.

Class 1 luminaire (luminaire has safety earth connection):

1. Metal housing of ballast can be touched during lamp removal.
   Metal housing must be connected to safety earth (via bottom plate or connector).

2. Metal housing of ballast (incl. ignition aid) cannot be touched during lamp removal.
   Only functional earthing is required for proper ignition and EMC.

Class 2 luminaire (luminaire has no safety earth connection):

3. Metal housing of ballast (incl. ignition aid) cannot be touched during lamp removal.
   Only internal functional connection between ballast and ignition aid is needed for reliable ignition and EMC.

Today, many luminaires are Class 1 and the metal ballast housing can be touched during lamp removal.
All these ballasts must be connected to the safety earth via bottom plate or earth connector if available.

2.2.2 Dust and moisture protection (IP classification)

The IP (International Protection) system drawn up by the IEC classifies luminaires according to the degree of protection afforded against the ingress of foreign bodies, dust and moisture. The term foreign bodies includes such things as tools and fingers coming into contact with live parts.
The designation to indicate the degrees of protection consists of the characteristic letters IP followed by two numerals (three numerals in France), indicating conformity with the conditions stated in two tables (here combined into one). The first of these so-called 'characteristic numerals' is an indication of the protection against the ingress of foreign bodies and dust, while the second numeral indicates the degree of sealing against

the penetration of water. The third numeral in the French system indicates the degree of impact resistance.

IEC classification according to the degree of dust and moisture protection

Dust protection			**Moisture protection**		
First numeral	**Symbol**	**Degree of protection**	**Second numeral**	**Symbol**	**Degree of protection**
0		Non-protected	0		Non-protected
1		Protected against solid objects greater than 50 mm	1		Protected against dripping water
2		Protected against solid objects greater than 12 mm	2		Protected against dripping water when tilted up to 15°
3		Protected against solid objects greater than 2.5 mm	3		Protected against spraying water
4		Protected against solid objects greater than 1.0 mm	4		Protected against splashing
5		Dust-protected	5		Protected against water jets
6		Dust-tight	6		Protected against heavy seas
			7		Protected against effects of immersion
			8	..m	Protected against submersion

Example: IP 65 indicates a luminaire that is dust-tight and water-jet proof.

2.2.3 Degree of flammability of the mounting surface

Luminaires cannot be mounted on just any convenient surface. The flammability of that surface and the temperature of the luminaire mounting plate impose certain restrictions in this respect. Naturally, if the surface is non-combustible, or if a certain distance spacer is employed, there is no problem.
For the purpose of classification, the IEC defines flammable surfaces as being either normally flammable or readily flammable.
Normally flammable refers to those materials having an ignition temperature of at least 200°C and that will not deform or weaken at this temperature.
Readily flammable are those materials that cannot be classified as either normally flammable or non-combustible. Materials in this category are not suitable as mounting surfaces for luminaires. Suspended mounting is then the only solution.
The permitted temperature of that part of the luminaire housing coming into contact with the mounting surface is laid down in the so-called F-requirements. Luminaires that satisfy these requirements may bear the symbol F.
On the basis of these requirements, the following classification has been drawn up:

IEC luminaire classification according to flammability

Classification	**Symbol**
Luminaires suitable for direct mounting only on non-combustible surfaces	No symbol, but a warning notice is required
Luminaires without built-in ballasts or transformers suitable for direct mounting on normallyflammable surfaces	No symbol
Luminaires with built-in ballasts or transformers suitable for direct mounting on normally flammable surfaces	F on type plate

2.3. Electromagnetic compatibility (EMC)

Discharge lamps do not only emit optical radiation, they also generate radio-frequency energy in the radio spectrum. This may cause disturbance of the operation of electronic equipment such as radio receivers, hence the name **radio interference**.

As the luminaires in which the lamps are used should meet international requirements such as EN 55015, CISPR 15 and CISPR-22 A or B, the radio interference in practice is sufficiently low to have no harmful effects on the surroundings. Products marked ⓕ conform to VDE 875 part 1. Radio interference is normally generated by lamp electrode oscillations. It has a broadband character, usually with frequencies of up to 1500 kHz. The electromagnetic waves are propagated in two ways: either directly through the mains into the receiver, or via radiation picked up by the aerial.
The latter form of interference will rarely occur with discharge lamps, as the ballast will suppress the broadband signals. The radiation produced by the lamp will nearly always remain below the threshold value at which interference takes place, especially where the lamp is at some distance from the aerial.
The supply cables will not radiate interference, since they are usually buried in the ground or laid in earthed steel piping, which is the best screening against interference. Nevertheless, it sometimes happens that an interference signal reaches the receiver by way of its mains input. The interference signal may consist of high-frequency harmonics of the mains frequency or high-amplitude pulses. The former is generally adequately suppressed in the ballast.
Should additional measures be necessary, a capacitor of 5000 pF/250 V could be connected in parallel with the lamp, with the restriction that this is only possible with HPL-N lamps. In practically all other cases it will be necessary to connect a delta filter between the mains supply and the input to the lamp circuit.

The ignition pulses that are continuously being generated by an untimed ignitor of HID lamps after a lamp has failed may give rise to radio interference, but for such an event no regulations have been laid down. Radiation of this kind can be of a very high level and solutions to suppress it adequately will be rather costly. The best solution is, of course, to replace the lamp. This will not only stop the interference, but it will also bring the lighting back to the original level. Also the use of self-stopping ignitors will reduce this kind of interference.

Fig 2 shows the delta filter used for suppressing radio interference. The apex of the filter must be earthed. More complicated filters are used in three-phase networks.

Avoid earth looping (all earth terminals to one point) and create maximum distance between audio and lighting cabling. If audio and lighting cables have to cross each other, this should take place at right angles. In sensitive applications screening of cabling is necessary.

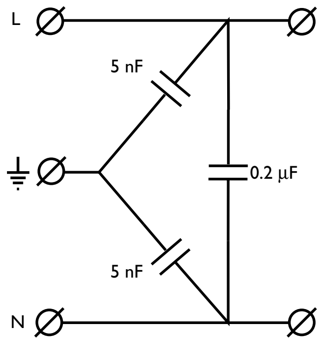


Fig. 2. Delta filter for suppression of radio interference.

Lamps

3.1. Range

The first Philips discharge lamp (SOX), introduced in 1932, was for an installation for street lighting. Nowadays a broad range of HID lamps is used in almost all applications, not only in sport stadiums, along highways, as urban lighting or to light large areas, but also in shops, museums, theatres and even in homes.
Discharge lamps work on the principle that part of the energy released during the discharge through a gas is used to generate light. This happens in the discharge tube with sealed in electrodes, and filled with one or more metals and a starting gas, see fig.3.
A voltage applied to the electrodes affects the free electrons in the gas, which start moving towards the positive pole. In doing so, they collide with the atoms in the gas. This results in heat development, electromagnetic radiation and ionisation. The electromagnetic radiation is of specific wavelengths, depending on the metals employed. Part of this radiation is visible light right away, whilst another part, in the ultraviolet range, may subsequently be converted into visible light by means of a fluorescent layer on the inner wall of the lamp.

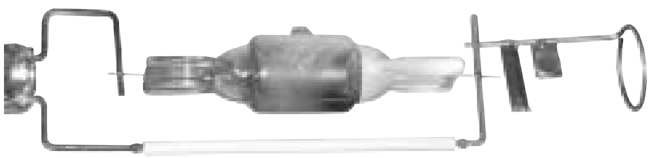


Fig. 3. Discharge tube of an HID lamp.

Lighting characteristics of HID lamps.

Category	Lamp type	Wattage W	Maximum efficacy lm/W	Colour temperature K average	Colour rendering index Ra max.
High-pressure mercury	HPL-N	50-1000	59	4000	45
	HPL Comfort	50-400	61	3500	55
	HPL-R(eflector)	125-1000	52	4000	40
Metal halide	HPI-T(ubular) Pro	1000-2000	95	4300-4600	65
	Master HPI (T) Plus (BU/S/P)	250-400	90	3800-4500	69
	Master MHN-SA* /956	1800 / 2000	86	5600	90
	Master MHN-SA */856	2000	98	5600	85
	Master MHN-LA* /842	1000-2000	108	4200	80
	Master MHN-LA* /956	1000-2000	90	5600	90
	MHW-TD Pro	70-150	92	3000	75
	MHN-TD Pro	70-250	81	4200	80-85
Mastercolour	CDM-T/TD/TC/TP/TT/ET	35-150	93	3000/4200	96
	CDM-R PAR	35-70	70	3000	83
Low-pressure sodium	SOX Pro	37-181	180	-	-
	Master SOX-E(conomy)	18-128	203	-	-
	Master SOX –E on HF ballast	35-85	190	-	-
High-pressure sodium	SON Pro I(nternal ignitor)	50-70	80	2000	25
	SON Pro (External ignitor)	50-1000	130	2000	25
	SON-T(ubular) Pro	70-1000	130	2000	25
	Master SON Plus	100-400	135	2000	25
	Master SON-T Plus	50-600	150	2000	25
	SON(-T) Hg free	150-400	120	2150	23
	SON-H Pro	220-350	97	2000	23
	SON(-T) Comfort Pro	150-400	93	2150	65
	SON(-T) Deco	150-400	72	2500	85
	Master SDW-T	35-100	50	2500	83

The meaning of the characters can be found in the lamp data sheets.
Example HPI –T Plus 400 W BUS-P:

HPI : High Pressure Iodides
T : Tubular shape (otherwise ovoid)
Plus : Compatible with mercury (HPL) and high-pressure sodium (SON) gear
400 : Lamp wattage
BU : Base up
S : Internal ignitor
P : Protected version for open luminaires

For the most common discharge lamps electromagnetic gear is available. The various versions (voltage tapping, impregnated/encapsulated, and type of ignition system) can be found in the OEM catalogue Lamps/Gear/Controls.

Electronic gear is at this moment only available for a limited number of lamp types.

For special HID lamps, such as used for e.g. reprography, studio/disco, suntanning and disinfection, indicated as HPA, HPM, HOK, MSR, MSI, MSD, ballast information can be given on request by the local Philips Lighting organisation.

3.2. Stabilisation

As described in Section 2.1, the main function of the ballast is to stabilise the lamp current, since an HID lamp cannot function properly when it is operated direct from on the mains voltage. The first and foremost function of a ballast is to limit the electric current passing through the lamp to a value prescribed for that particular lamp rating. All discharge lamps need such a current-limiting device because they have a negative voltage-current characteristic (see Fig. 4).

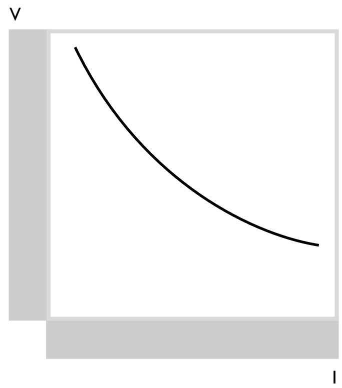


Fig. 4. Current/voltage characteristic of a gas discharge (simplified). The voltage required decreases as the current increases. The characteristic is negative, meaning that the current will increase without limit if no measures are taken.

Without a current-limiting device in the circuit (lamp voltage = mains voltage), the slightest increase of the lamp current would cause a drop in lamp voltage. But as the mains voltage is still applied to the lamp, the lamp voltage cannot decrease, so the current will now increase even further. This process of steeply rising current will soon cause the lamp to fail or the fuse to blow.
On the other hand, at a slight decrease of the lamp current the lamp voltage has to increase. As the mains voltage is still applied, it will become too low for stable operation and the lamp will extinguish.
The presence of ballast between the lamp and the mains-voltage connection (see Fig. 5) limits the current flowing through the lamp. The lamp current – being equal to the ballast current supplied to the lamp – is now fixed by the quotient of the ballast voltage and the ballast impedance.

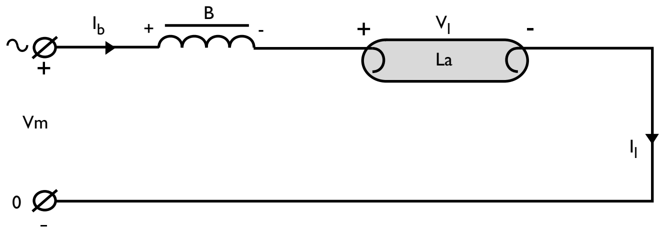


Fig. 5. Current limitation by means of a ballast in a simple discharge circuit.

As the ballast voltage is the difference between the mains voltage and the lamp voltage, the maximum lamp current is limited by the mains voltage. In this way a stable operating point is obtained for all mains voltages higher than the minimum voltage V_{min}, (see Fig. 6).

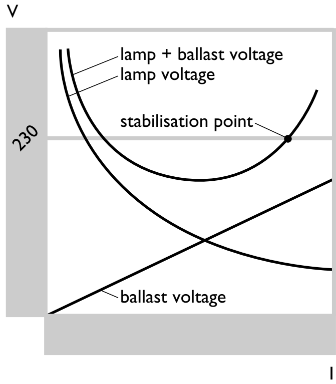


Fig. 6. Current/voltage characteristic of a circuit with a ballast in series with the lamp. Thanks to the ballast, the required lamp voltage increases with increasing lamp current, leading to a stable situation.

$$I_{lamp} = I_{ballast}$$
$$I_{ballast} = V_{ballast} / Z_{ballast}$$
$$\vec{V}_{ballast} = \vec{V}_{mains} - \vec{V}_{lamp}$$
$$\mathbf{I_{lamp} = (\vec{V}_{mains} - \vec{V}_{lamp}) / Z_{ballast}}$$

Another very important function of the ballast is to keep the power consumption of the lamp within certain margins so as to prevent too high a temperature in the cathodes, which would result in a shortened life.
The power of the lamp is equal to the lamp voltage V_{la} times the lamp current I_{la} times a constant, which is called the lamp factor (α_{la}):

$$P_{la} = V_{la} \cdot I_{la} \cdot \alpha_{la}$$

The lamp factor I_{la} depends on the shape of the lamp voltage and the lamp current, and is therefore also called the 'shape factor'. The value depends on the method of stabilisation and is approx. 0.8 for electromagnetically stabilised lamps.
In stable operation the voltage across the lamp is rather constant under all circumstances (except SON). The lamp power (and so the light output) therefore depends mainly on the lamp current.
The level of the mains voltage is important, as well as the impedance of the ballast. The influence of the frequency of the mains voltage is a hidden factor: this variable influences the impedance of the choke ballast, since $Z = \omega L$ with $\omega = 2\pi f$ (f = frequency). The inductance L is depends on the number of copper windings and the dimensions and material of the core of the ballast.
From this it follows that the higher the frequency, the smaller the ballast can be. With the electromagnetic ballast for 50 or 60 cycles we need a 'big' copper/iron ballast, while in the HF ballasts with higher operating frequencies (see Section 3.4) a small ballast with ferromagnetic material can be employed.

3.3. Ignition and run-up

In most cases an HID lamp will not start when the mains voltage is applied. This is because the ignition voltage is usually higher than the mains voltage. Some sort of starting aid is therefore needed to ignite the lamp.
In practice, this involves one or more of the following solutions:

- Providing an external conductor on or near the lamp tube, which is either floating, earthed or connected to one of the electrodes (HPL lamps). The electric field so created facilitates the initial discharge.
- Providing an internal auxiliary electrode in the form of a metallic strip along the discharge tube (SON-PIA).
- Providing a voltage peak sufficiently high to initiate the discharge.
- Use of emitters.
- Increasing the supply voltage by means of a transformer.

The voltage level at which a HID lamp will ignite is called its ignition voltage. In most lamp types special measures have been taken in the construction of the lamp to keep this ignition voltage as low as possible: the use of a starting gas as a Penning mixture (see Fig. 7) and the application of a starting aid to trigger the initial ionisation of the gas are examples of this.
The following factors are important for lamp starting:

- geometry and material of the discharge tube,
- composition and pressure of the gas and vapour filling,
- material and construction of electrodes and auxiliary electrodes,
- influences of the surroundings,
- electrical supply.

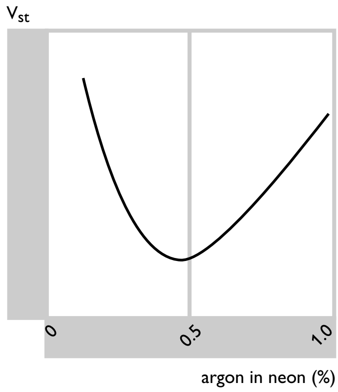


Fig. 7. Starting voltage (V_{st}) as a function of percentage (%) of argon to neon (Penning effect).

In every discharge lamp an inert gas or mixture of inert gases is added to the metal filling to initiate a discharge in the lamp. When a lamp ignites, the starting gas that is being used can be recognised by its colour:

Xenon	: blue/white (High Pressure Sodium lamps)
Argon	: purple (Mercury and Metal Halide Lamps)
Neon and Argon	: orange/red (Low Pressure Sodium lamps)

When the discharge has been initiated by the starting gas, the lamp still does not burn properly: a so-called run-up time is required for this. During this run-up time the temperature of the discharge vessel increases, causing the evaporation of the metal atoms. The starting gases have the property of mainly ionising as a result of the discharge, viz. they produce free electrons. These free electrons then collide with the atoms of the metal vapour, which – although still under very low pressure - are present in the discharge. Initially, these collisions mainly result in a rapid increase in the temperature in the burner, so that more and more metal vaporises and the vapour pressure in the lamp increases. As the vapour pressure rises, the amount of electromagnetic radiation, generated from the discharge, becomes progressively greater and at a given moment a balance is reached in the discharge tube, which is called the operating state of the lamp.
The time to reach 80% of full light output is called the run-up time. This **run-up** time depends on the type of ballast. A ballast with a high short-circuit current will have a short run-up time, but when the short-circuit current is too high, it will overload the lamp electrodes and so shorten lamp life. A maximum current during running-up is therefore specified per lamp type.

If the discharge is extinguished, the vapour pressure remains high for a while until the lamp has cooled down. During this time the voltage available for re-ignition is in most cases insufficient to re-ignite the lamp. The time between the moment of extinction and the moment when the vapour pressure is low enough to permit re-ignition, is called the **re-ignition time** of the lamp. This is, of course, only valid if the mains supply is available. This time depends on the temperature of the discharge tube, the pressure in the discharge tube and the height and energy level of the ignition peak.
Tests with regard to the re-ignition time are made in free-standing air so as to avoid the influence of a streaming airflow over a luminaire. Published figures are related to the standard Philips circuits and components, although the operation of the lamps is not limited to these circuits: the lamps can also be operated on other approved circuits.
For SOX(-E) lamps the use of Philips circuits is, however, strongly advised, because of the strong dependence of the lamp performance on the ballast and ignitor characteristics.

To ensure immediate **hot restrike** of HID lamps, very high re-ignition peaks are sometimes necessary (20-60 kV), produced by special hot-restrike devices. Further, the lamps, lamp bases and lampholders must be specially constructed to handle these high voltages. This means that lamps with standard Edison lamp bases and holders are not suited for immediate hot re-ignition. The lamps must have special lamp bases or must be double-ended (like the MHD-LA and SA types).
Standard luminaires are not designed for the high hot-restrike voltages and one should never try to modify a standard luminaire into a hot-restrike version.

The starting behaviour of individual lamp types is as follows:

1. High-pressure mercury lamps

Fig. 8. High-pressure mercury lamp.

The combination of the gas filling, electrode emitter and auxiliary electrodes makes the lamps start on normal mains supply voltage; there is no need for an ignitor.
There is a relationship between minimum supply voltage and ambient temperature. For example: at 20˚C ambient temperature a supply voltage of 180 V will ignite the lamp, while at -18˚C a minimum supply voltage of 210 V is needed for proper ignition.
There are no special requirements for wiring or cabling.
The re-ignition time is a maximum of 10 minutes.
Immediate hot re-ignition is not possible (Edison fitting).
The run-up time is approximately 5 minutes.
The coating on the outer bulb is a fluorescent layer for converting the UV into visible light.
Because of high lamp-voltage, the lamp only can be dimmed with the risk of extinguishing.

2. High-pressure sodium lamps

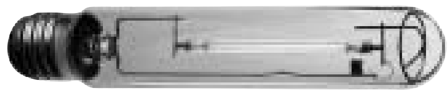


Fig. 9. High-pressure sodium lamp.

To start SON and SON-T lamps properly, a starting voltage is required that has to be not only sufficiently high, but its peak must also have the right shape with a certain rise-time and pulse-width.
SON 50 and 70 W-I lamps have an internal starter with a bi-metal strip, which has to cool down after extinction. Their re-ignition time is therefore approximately 15 minutes.
All other SON lamp types have a re-ignition time of 2 to 3 minutes and a run-up time of approx. 5 minutes.

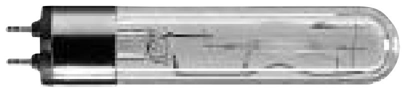


Fig. 10. White SON lamp.

The SDW-T lamp types run up in 2 minutes and the re-ignition time is 1 minute with the CSLS control unit.
The coating on the outer bulb is to spread the concentrated light from the relatively small discharge tube over the much greater surface of the outer bulb.
The SON lamps produce hardly any UV.
Lamps can be dimmed to 50% power with conventional gear and to 35% with appropriate electronic gear.

3. Metal halide lamps

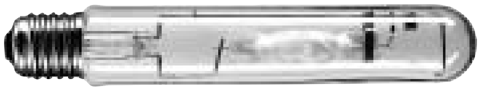


Fig. 11. Metal halide lamp.

The starting peak for proper ignition of HPI and HPI-T lamps does not have the same shape as that for SON and SON-T lamps.
As the maximum ignition voltage peaks are under 1000 V (except for the 2 kW/380 V system, where V_{max} = 1500 V) there are no special requirements for cabling or wiring.
The re-ignition time of HPI(-T) lamps is 15-20 minutes maximum and, due to the use of Edison lamp bases and holders, immediate hot re-ignition is not possible.

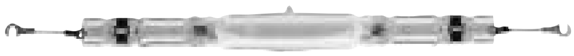


Fig. 12. Double-ended metal halide lamp.

Double-ended metal halide lamps, such as the MHD-LA and SA types, are suitable for hot restrike with devices producing 35 kV to 50 kV. It must be ensured, of course, that the applied luminaire is also released for hot restrike.
To ensure proper ignition of the MHN, MHW and MHD lamp types, higher starting voltages are needed than with the HPI(-T) types. The re-ignition time of these lamps is between 10 and 15 minutes.
All metal halide lamps mentioned have a run-up time of between 3 and 5 minutes.
Because of negative effects on colour-shift, maintenance and lamp life these lamp-types cannot be dimmed.

4. Low-pressure sodium lamps

Fig. 13. Low-pressure sodium lamp.

For low-pressure sodium lamps in particular, the right choice of circuit components is very important for the starting and run-up phase. With the standard Philips circuits all lamps run up in about 12 minutes and they restrike immediately, with the exception of the SOX 180 W and SOX-E 131, which restrike after 10 minutes. The required pulse height for proper ignition is between 1000 and 1400 V, but more important is that the circuit delivers enough energy to pass through the run-up phase.

It is not only the luminous flux and colour characteristics that change during the run-up period: the same happens to the lamp voltage and current. In most lamps the lamp voltage increases and the lamp current decreases during the run-up period. This is due to the pressure build-up as a result of the increasing gas temperature (Fig. 14).

V_l = *lamp voltage*
I_l = *lamp current*
Φ = *luminous flux*

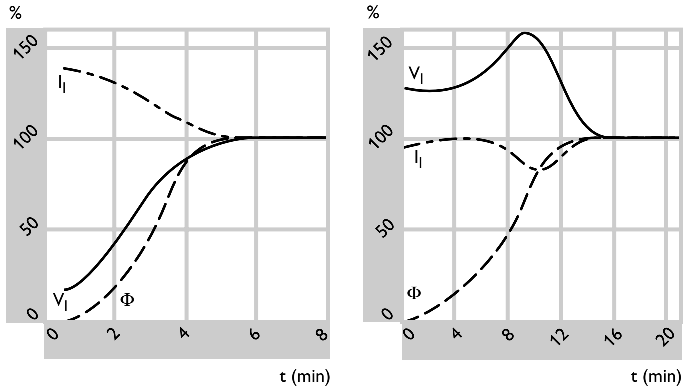


Fig. 14. Comparison between the run-up characteristics of a high-pressure mercury lamp (left) and a low-pressure sodium lamp (right).

In low-pressure sodium lamps and some fluorescent lamps, however, the opposite is true, which can be explained by the change in the composition of the filling gas as a result of vaporisation (see Fig. 14).
SOX lamps cannot be dimmed.

3.4. Lamp behaviour as function of the frequency

HID lamps do not properly function on DC (Direct Current). This is due to the one side emission of the electrodes and the de-mixing of the gas.
Practically all HID lamps are developed for conventional gear on a 50 or 60 Hz mains supply.
Electromagnetic and hybrid solutions (conventional gear in combination with electronics) work on these frequencies. Low-frequency square-wave electronic HID ballasts (LFSW) operate on a frequency between 70 and 400 Hz, which prevents flickering.
Fully electronic ballasts for HID lamps are becoming available with higher operating frequencies (10-500 kHz).
The frequency and waveform of an electronic ballast cannot be chosen freely, but are dependent on lamp type, condition and temperature. A wrong choice of frequency and/or waveform can have a very negative effect on lamp performance and/or lifetime.
Laboratory experiments have shown that the different types of HID lamps can only be stabilised at certain frequency bands. Outside these restricted bands, not only may the efficiency may drop, but the discharge tube may be mechanically damaged by acoustic resonance, or electrodes may break off. Electronic gear units are therefore only suitable for specified lamp types.
Conversely, some HID lamps can only be operated on their electronic gear since there is no conventional alternative.
The sorts of benefits obtained with fluorescent lamps (26-34 kHz) are difficult to achieve.

3.5. Lamp and system efficiency

Lamp efficiency is expressed in a figure called the luminous efficacy. It indicates the efficiency of the lamp in transforming electrical energy into light and is expressed in lumens per watt (lm/W).
The amount of light generated by a lamp is called its luminous flux or lumen output. It is a variable figure,

Back to contents

depending on many factors. In all documentation, the published figure is the **nominal luminous flux**, which is the lamp flux under the following conditions:
- the lamp has already burned for 100 hours (burning-in period) prior to measurement,
- the lamp is burning in free air,
- after switching on, the lamp has had sufficient time to heat up and stabilise for thermal equilibrium,
- the lamp is running at its nominal voltage, nominal current, rated ambient temperature, defined burning position and stabilised nominal mains voltage,
- the nominal luminous flux is based on the average value obtained from a batch of lamps.

The instant one of these conditions changes, the nominal flux changes with it.
Lamp types are indicated with a nominal wattage. This is not always the power actually dissipated in the lamp.
The luminous efficacy is calculated by dividing the nominal lumen output by the actual power dissipated.
The luminous efficacy of all HID lamps increases with the lamp wattage. This is because the power needed to keep the lamp electrodes at optimum temperature is relatively less for higher lamp wattages. For example, for HPL it varies from 36 lm/W for the 50 W type to 59 lm/W for the 1 kW type.
As the published figures for the lamps do not include circuit losses, the efficacy figures for the total system are lower.
The figures published are for lamps stabilised by the electromagnetic circuits. With electronic gear there is a limited increase of efficacy.
The main part of the energy is converted into heat.
A relatively small part is converted into visible light, (see Fig. 15).

1. power in discharge column - 376 W
2. thermal losses at electrodes - 24 W
3. visible radiation - 118 W
4. UV radiation from discharge column - 2 W
5. IR radiation from discharge column - 80 W
6. thermal losses in discharge column - 176 W
7. UV radiation - 1 W
8. IR radiation - 1 W
9. total IR radiation - 221 W
10. convection and conduction - 60 W

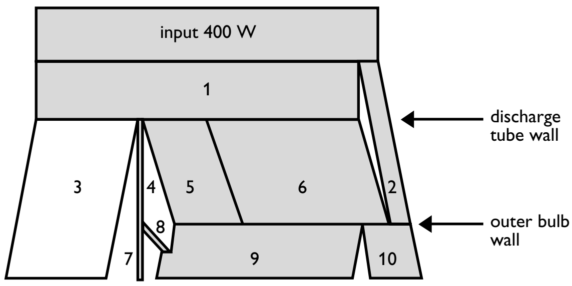


Fig. 15. Energy balance of an SON-T 400 W lamp.

3.6. Effects of temperature

Low temperatures

Although the temperature of the discharge is of prime importance for the operation of discharge lamps, high-intensity gas-discharge (HID) lamps are not very sensitive to changes in the ambient temperature.
There are two major reasons for this:

1. The discharge tube of most lamp types is enclosed in an outer lamp bulb and most of the HID lamps in floodlighting and other outdoor applications are placed in an enclosed luminaire, so that there is no direct contact between the outside air and the gas-discharge tube.
2. HID lamps operate at fairly high discharge-tub temperatures, so that the changes in ambient temperature are relatively small, compared with the actual burner temperature of a working HID lamp.

Provided they are operated on the correct ballast and ignitor, all HID lamps will ignite at temperatures down to -20˚C, while some types will even ignite at -40˚C. SON and SOX lamps even will function without difficulty at temperatures down to -50˚C. The only exception is the mercury lamp: the mercury gas pressure of which is more sensitive to low temperatures.
Due to the electronic components, the permitted temperature range for the Philips ignitors is from -20˚C to +80˚C. Also the compensating capacitors are mostly limited to -25˚C.
In practice there is not much difference in light output within the normal ambient temperature range of -20 to +40˚C during stable operation. Of course the run-up time (time to reach a certain light output) can be longer at lower temperatures.

High temperatures
For all lamps there are two critical values, which are mentioned in the lamp specification:
1. the maximum permitted temperature of the lamp base, dictated by the construction (200˚C for E27 and BY22 due to the cement and 250˚C for E40, due to the mechanical construction).
2. the maximum temperatures of the outer bulb wall are 450-650˚C for the tubular lamp types and 350˚C for the ovoid types. The ovoid types are mostly covered with a powder – diffusing or fluorescent – and these powders reduce in efficacy at temperatures higher than 350˚C.

For lamps with no outer jacket, such as MHD-SA, the maximum values allowed are somewhat higher:
300–350˚C pinch temperature and 920 –980˚C bulb wall temperature.

When built correctly into a luminaire, higher ambient temperatures (which are limited by the luminaire) do not influence the behavior of HID lamps. Common values for indoor luminaires are 25˚C, and for outdoor luminaires 35˚C, while some industrial luminaires can have 45˚C ambient temperature as maximum.
The temperature inside a luminaire will increase when, due to inadequate maintenance the light cannot leave the luminaire unhindered, (e.g. dirty front glass or optics). Then there can be a slight negative influence on lifetime and light output, especially with SON and metal halide lamps.

3.7. Optimum operation

As has been said in Section 3.1, there are many different types of HID lamps, each in different lamp wattages, lamp voltages and lamp currents. Each type has its own advantages and disadvantages, to be found in the lamp data sheets.

What they have in common though, is that they need the correct ballast and ignition system for optimum performance. In fact, each type needs its own specific gear. For this reason one should take care to use the recommended gear in combination with the chosen lamp. Especially when using electromagnetic ballasts, the combination must be correct for the available mains voltage (220, 230 or 240 V / 50 or 60 Hz). HF ballasts cover a wider mains-voltage range, which can be found in the product data sheets.
When the wrong components are chosen, one can expect problems: for example, with:
- lifetime of lamps and gear
- temperatures
- starting/run-up
- stable burning
- radio interference
- light output

The burning position has also to be taken in account for correct operation.

3.8. Lamp life and depreciation

There are various different definitions of the lamp life:
- **the technical, individual life** is the number of hours after which one particular lamp fails. This greatly depends on the practical circumstances, and is therefore of no practical use.
- **the guaranteed life** is a certain agreement by contract between the supplier and the user. The operating conditions are specified in the contract. This lifetime can differ from the concepts of life normally used.
- **the average rated life** time is the number of burning hours which have elapsed when 50 per cent of a large batch of lamps have failed. This life-expectancy figure is normally published by the lamp manufacturers
- **the economic life** is the number of burning hours after which the total light output of an installation, under specific conditions, suffers a depreciation of about 30 per cent.
- **the economic life, based on running costs** is the number of operating hours between group replacements of lamps for which the calculated running costs are the lowest, without the lighting level dropping below a specified minimum value.

The most important cause of light depreciation (declining luminous flux) is the blackening of the discharge tube by particles from the electrodes: emitter and tungsten.
A certain amount of lamp blackening during life is normal and unavoidable. The blackening is caused by a thin layer of electrode material deposited during life on the inner wall of the discharge tube. However, accelerated blackening can also occur when radiation (infrared) is reflected back to the discharge tube by the optical system or when the volume of the optic is too small for a proper heat balance. A second reason for light depreciation is when a fluorescent powder is used.
The powder ages due to photochemical reactions; the crystals will slowly lose their ability to transform the UV into visible light.

The data published by lamp manufacturers for life expectancy and lumen depreciation are obtained from large representative groups of lamps in laboratory tests under controlled conditions (Figs. 16 and 17).

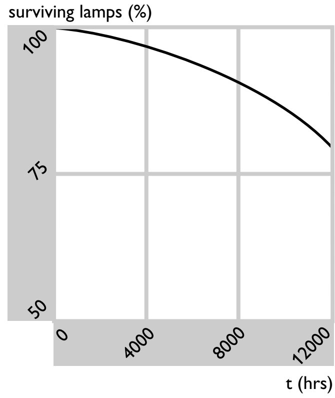


Fig. 16. Life expectancy curve of high-pressure mercury lamps when operated under standard conditions.

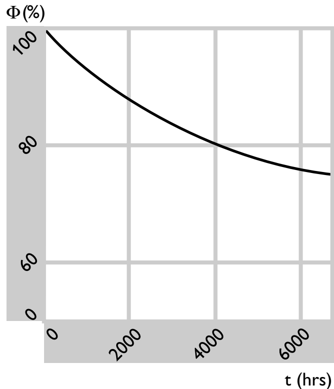


Fig. 17. Example of lumen maintenance curve of a metal halide lamp.

These tests include, amongst others:
- nominal supply voltage and appropriate circuitry,
- specified burning position,
- specified switching cycle,
- free burning, mounted on test racks (not in a luminaire, except for some MHN lamps),
- no vibrations or shocks,
- specified ambient temperature, mostly 25°C.

Any change in these circumstances will affect the lifetime. The major end-of-life causes and related behavior of a HID lamp are:

1. The many chemical reactions that are taking place in the discharge tube, causing the tube to leak. The hot gasses will flow through this leak into the outer bulb, noticeable as a weak discharge in the outer bulb.
   In very rare cases, the discharge tube will break and hot parts may cause a rupture of the outer bulb. In general, HID lamps will reach end of life passively, without shattering of the outer bulb.
2. The chemical composition changes or the operating temperature is too high: the lamp voltage rises and the lamp starts cycling and/or extinguishes.
3. The outer bulb or discharge tube leaks very slowly: the lamp changes colour and will fail to operate in a short time span.
4. An overload, such as a short-circuited ballast or, say, a 35W lamp in a 70W installation, will result a short life, with a possible shattering of the outer bulb. Until now, it was not possible to protect the lamp against such an overload situation.

5. Rectification (DC current) can occur when one electrode is worn out and the other is still emitting electrons. This will introduce DC current in the circuit with possible overheating of the ballast. A protection device in the circuit, such as a thermal switch, built in into the ballast, will protect the circuit when this happens (see IEC 61167).
6. A loose contact in the circuit or lamp can cause uncontrolled current in the circuit. Also here a thermal switch or another device will protect the system.

In the case of quartz lamps there is a risk of explosion at end of life due to the re-crystallization and weakening of quartz material at the hottest part in the burner. As a precaution against this risk, it is always recommended that a front glass be used with this type of lamp. Very few burners will shatter at the end of life because of a sudden overload (caused by a problem/short circuit in the gear). However, because shattering cannot be excluded, some types of lamps must be burnt in a fully enclosed luminaire that is able to contain all the broken (hot!) parts of the lamp. With some other types, all broken parts will be contained in the reflector or outer envelope and therefore these lamps can be used in open luminaires.

With the exception of SOX (-E) lamps, the type of circuitry has no influence on lamp life or lumen maintenance, provided, of course, that the gear is designed to the relevant standards and specifications. For the SOX (-E) lamps the circuitry chosen will have a bearing on lamp life and even more so on lumen output.

Dimming is only permissible with SON (-T) lamps. Provided that lamps are always started at nominal conditions and that dimming to less than 50 per cent of the nominal power is carried out slowly.
Operating a lamp with a 220 V ballast on a 230 V mains must be seen as over-running and will reduce both lamp life as well as ballast life.

3.9. Influence of switching cycle

Nowadays HID lamps may be required to be switched on and off more than only a few times per 24 hours, especially when they are used in combination with controls, such as movement detectors or light cells. Since frequent switching generally has a negative influence on the lifetime of HID lamps, the lamp lifetimes as published by the manufacturers are usually based on tests with a specific switching frequency. For lamps, used in sports lighting installations, the cycle on which the figures are based are, for instance, 5 hours on and 1 hour off, whereas for other outdoor applications and indoor use a sequence of 11 hours on and 1 hour off is mostly used. Especially when the switching frequency is so high that the lamp has to restart while it is still warm, problems are particularly to arise. The control gear will repeatedly try to re-ignite the lamp. This will continue until the vapour pressure is sufficiently low for the lamp to restart.

The 'average' lamp-life data presented are typical values. They are the average of different tests. Batch deviations occur due to deviations in the materials used and in lamp processing, and to different types and batches of gear. Differences in 'application parameters', such as mains voltage, ambient temperature and starter, can also have a negative influence on lamp life.

The standard deviation of the 'typical' lamp life values is 10 to 20 per cent. The lifetimes quoted are only valid for 'Philips' lamps and 'Philips' ballasts. The 'Philips' combination is tuned to give the best result.

3.10. Stroboscopic effect, flicker and striations

The stroboscopic effect is the apparent change of motion of an object when illuminated by periodically varying light of the appropriate frequency.

There are various sorts of flicker. The light output of a lamp varies with the level of the mains supply voltage. Therefor there are restrictions set in IEC 61000-3-3 for voltage fluctuations as caused, for example, by a varying electrical load, (see Fig.18). The disturbing effect depends not only on the magnitude of the voltage fluctuations, but also on the repetition rate.

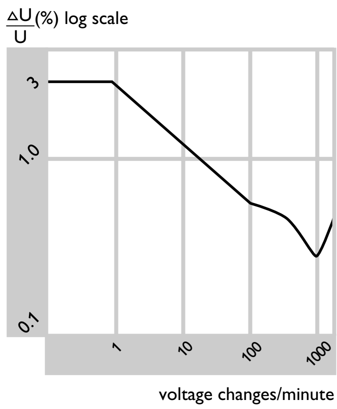


Fig. 18. Magnitude of maximum permissible voltage changes with respect to number of voltage changes per minute.

The most dangerous frequency is between 2.5 and 15 periods per second. Car drivers can experience this when driving along a tree-lined road when the sun is low at the horizon. It can also happen in a tunnel when the luminaires are badly spaced in relation to the speed of the traffic.

An asymmetric lamp voltage results in a light flicker with the mains frequency (50/60Hz). In normal situations the lamp voltage is symmetrical. This kind of flicker can occur at the end of the life of a lamp, when an ignitor abusively comes in every positive or negative period or when the electronic ballast has a defect. Lamps burning in vertical position are more sensitive than horizontal burning lamps
Another sort of flicker is that caused by the fluctuation of the light output of the lamp on account of movement of the discharge arc on the electrodes. Although the length of the arc remains constant, the place where it strikes the electrode may vary. This 'dancing' of the arc has no constant frequency and depends on various factors, including lamp position, supply voltage, temperature, age of the lamp (electrode).
This phenomenon is also called flatter and has an irregular low frequency (< 50 Hz).

Striations are noticeable as a pattern of more or less bright regions in the (elongated) discharge tube and only occur in low-pressure lamps (TL and SOX).

This pattern can move along the discharge tube. It may appear when the lamp is cold or when the lamp is dimmed down too much.

An HID lamp operating on an alternating current will exhibit a fluctuating light output, as the lamp extinguishes and restrikes every half cycle of the supply. The lamp current goes through zero twice per period and the light output varies to some extent with these cyclic changes in the lamp current. So this light alternation (light ripple) has double the mains frequency and may cause the stroboscopic effect, (see as example Fig. 19).

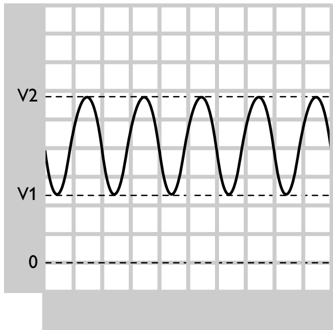


Fig. 19. Light output of MHD-LA 2000 W lamp.

The effect is different for mercury/metal halide and high-pressure sodium lamps.

HPI, MHN, HPL and CDM lamps

Here the fluctuation of the light output is noticeable and may cause a stroboscopic effect, created by the pulsating light. The solution is to spread the lamps over the three phases of the supply (see Fig. 20), so that the minimum light output of one lamp coincides with high light outputs of the two other lamps.

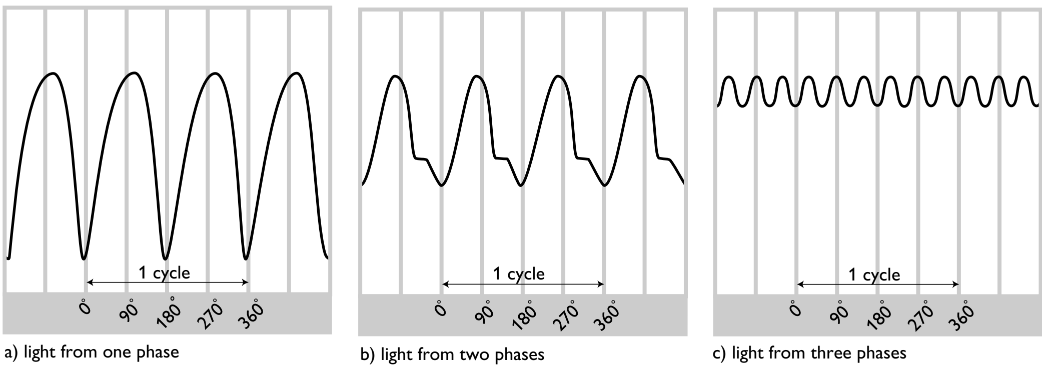


Fig. 20. Prevention of the stroboscopic effect by spreading the lighting over the three phases of the supply.

Low-power lamps are more sensitive to flicker than lamps with higher power. This is one of the reasons why dimming of these lamps is not recommended on conventional gear e.g. SON 50 and 70 W lamps.
With the fully electronic HID-DynaVision and HID-PrimaVision ballasts for low-wattage metal halide lamps there is no flicker at all. HPL lamps with the fluorescent layer on the outer bulb also contain some phosphorescent substance with after-glow properties, thus eliminating the light ripple to a large extent.

SON lamps

Here the fluctuation of the light output is scarcely noticeable. This is because the sodium discharge exhibits a certain degree of after-glow, which is normally sufficient to bridge the dark periods in the 50/60 Hz cycle of the mains voltage.
Although these lamps are less sensitive to flicker than the previous group, some stroboscopic effect may sometimes occur, as, for example, with aged lamps.

HID lamps and cameras

Light fluctuations in HID lamps may also have an effect on the quality of camera pictures.
This phenomenon may become apparent when CCD colour cameras operate in auto-shutter mode and the lighting of the area is predominantly with HID lamps. The auto-shutter mode is normally selected when the cameras are equipped with manual or fixed iris lenses and the automatic light response is controlled by an electronic shutter system in the camera. The greater the amount of light, the shorter the shutter time, and hence the shorter the period of light integration in the sensor. For example, with a shutter time of 1/1000th of a second, the light integration of the CCD sensor is only 1 ms. Within the normal CCIR scanning period of 20 ms (50 Hz) the 1/1000th of a second the light integration time is just a snap-shot in the normal frame scanning period. Hence, the sensitivity of the camera is reduced. As described before, the light output of HID lamps varies continuously from minimum (at zero crossing) to maximum during the positive and negative phases of the mains voltage, twice during one mains voltage cycle.
In other words: the HID lamp is flashing 100 times per second. Due to the inertia of our eyes, viewing a scene illuminated with HID lamps, gives the impression of a white and continuous light output.

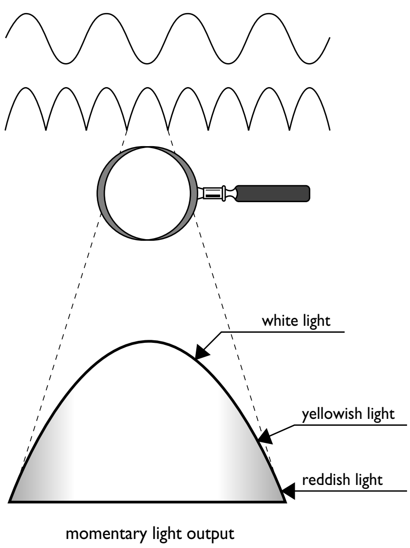


Fig. 21. Colour shift during the 100 Hz light ripple of a HID lamp.

The light ripple of a HID lamp is illustrated in Fig. 21. When the automatic shutter in the camera is switched off, the two light ripples of the lamp are integrated during the normal 20 ms frame integration time of the sensor and consequently the light impression is white. This is illustrated in Fig. 22.

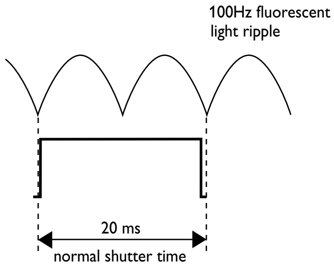


Fig. 22. The 20 msec frame integration time of a CCD colour camera with the automatic shutter switched off, compared with the 100 Hz light ripple.

Using the automatic shutter in sufficiently illuminated scenes, the shutter speed increases. Consequently, light integration in the sensor takes place during a shorter period of time. Depending on the position where the light integration (snap-shot) takes place with respect to the mains phase (light ripple), it is now possible that a TV frame is shot during the non-standard excitation of the light, (see Fig. 23).

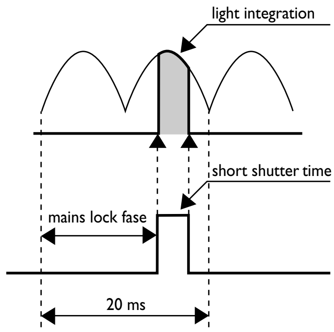


Fig. 23. Using the automatic shutter and with the camera locked to mains frequency, it is possible to shoot stable and white pictures.

It can be said that the light at this point in time is not white and that the light output is less. If the phase of the camera shutter remains constant with respect to the mains phase, the automatic light control and the white balance circuits in the camera will compensate for these effects and stable pictures are produced. This situation is obtained by locking the camera frame synchronisation to the mains (mains lock).

When there is no fixed phase relationship between the scanning frequency of the camera (free running) and the mains frequency, the camera will take a snap-shot of the scene at varying phases of the lamp light output.

This causes a colour fading to become visible.

The extent of colour fading depends on the type of light in the area. In applications where the scene is illuminated with just one lamp, stabilised by conventional gear, the risk of colour fading is at its maximum.

It is recommended that cameras be locked to the mains frequency and that the phase of the camera synchronisation be adjusted such that the camera signal output is maximum. If mains lock is not possible in such an application, the lens iris should be closed to the point where the colour fading just disappears. Now the shutter speed is less (full frame integration) and there is the additional benefit that the sensor smear effect is less.

This method cannot be used in applications that need short shutter speeds to suppress movement blur.
In other cases (three-phase installation or high-frequency stabilised) this phenomenon will not occur.

3.11. Dimming

SON
For SON, dimming to 50% lamp power (flux at 35%) has no influence on lamp life or lumen maintenance, and there are no pronounced colour point changes. Below 50% lamp power the colour will shift and the output approaches a monochromatic colour. Recent experience with the modern electronic DynaVision family shows that dimming to 35% lamp power (20% flux) has no significant effect on lifetime and maintenance.

Other HID lamp types
The other HID lamp types do not offer benefits with regards to dimming. On the contrary, mostly exhibit a dramatic shortening in lifetime, sometimes with extreme colour shifts.

3.12. Shocks and Vibrations

The length of the discharge arc, together with the vapour pressure in the discharge tube, determines the lamp voltage. If the balance of the discharge arc is disturbed by shocks or vibrations, the arc will nevertheless try to maintain itself. But to do that, it has to travel a longer path than when it is an undisturbed line, and therefore it requires a higher voltage. If that higher voltage is not available, the lamp will extinguish. After some time the lamp will start automatically. But until that happens, the electrodes will have had to withstand the high ignition voltage and current, which are reducing the lamp's life. Due to their greater arc length, low-pressure sodium lamps are more sensitive to vibrations than other HID lamps.
In general, HID lamps have a superior resistance to shocks and vibrations compared to incandescent and halogen lamps.

3.13. Burning position

Some lamp types, such as HPL-N and SON, can operate in any position. Others are subject to certain restrictions, as can be found in the product information of the HID lamps. These restrictions ensure proper functioning of the lamps and/or influence the lamp life (positively). Metal halide lamps (MH-TD) in general are to be operated horizontally, unless specifically designed for vertical burning, as in the case with HPI BU(S) (BU = base up). CDM-T and TC have universal burning position.
When metal halide lamps are used in positions other than specified, the different metals in the gas mixture will start to separate. They 'float' on top of each other, which causes layers of different coloured light: a rainbow effect. In that case, the lamp colour normally shifts.
Low-pressure sodium lamps are also best operated horizontally. The lower wattage lamps may be used vertically, but the base should then be at the top. This is to prevent a cool area being created behind the electrodes which would affect lamp life in two different ways: the sodium, which would collect there, would

attack the electrodes and the even distribution of the sodium over the discharge tube would be disturbed. The lamp voltage of a horizontal operating lamp is somewhat higher than when vertical operated. Due to convection the discharge arc is curved upwards, giving a longer length. Therefore a horizontal lamp will extinguish earlier in lifetime than vertical operated.

3.14. Colour rendering and colour shift

The colour properties of HID lamps can be characterised by the following parameters:

- chromatic co-ordinates (colour points X, Y),
- correlated colour temperature (Tk),
- general colour rendering index (R_a).

The colour properties of HID lamps depend mainly on the gases used and the temperature of the discharge tube.

The low-pressure sodium lamp mainly emits radiation with a wavelength of about 589 nm -a radiation perceived by us as orange-yellow. This radiation is characteristic for low-pressure sodium.

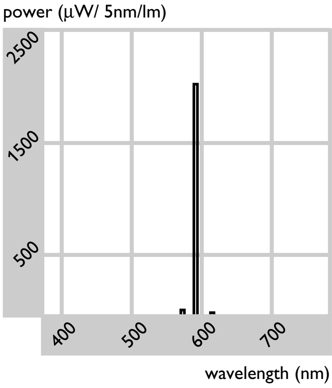


Fig. 24. Spectrum of a SOX lamp.

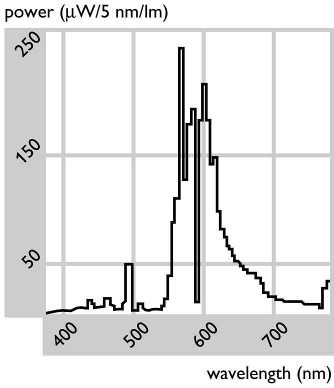


Fig. 25. Spectrum of a SON-T lamp.

When the pressure in the sodium discharge is increased, the monochromatic spectrum changes into a "multi-line" one, and the typical low-pressure sodium colour changes into golden-white light.

The radiation of mercury vapour lamps is distributed over the spectrum, in the UV, violet, blue, green and yellow ranges, so that the light of the mercury discharge makes a whiter impression than that of the sodium discharge.

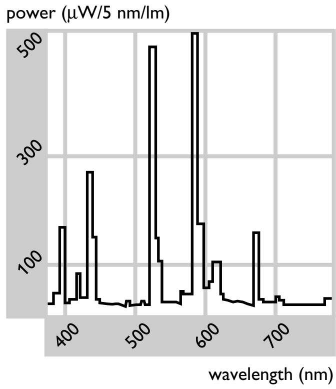


Fig. 26. Spectrum of a HPI lamp.

The more wavelengths there are in the visible part of the spectrum of a gas discharge and the more they are distributed over the spectrum, the more natural the light of that lamp appears to us. For that reason use is also made of mixtures of a number of metals.
An example of this is the HPI-lamp.

The chromatic co-ordinates X, Y and Z represent the amount of red, blue and green in the light.
As X+Y+Z = 1, only X and Y are published.

The correlated colour temperature defines the appearance of the white light and is expressed in Kelvin. Low colour temperatures (< 3300K) give a warm impression (yellowish), while a high colour temperature (>5000K) gives a cool impression (blue).

With these two figures we can place any lamp in the Colour Triangle, (see Fig. 27):

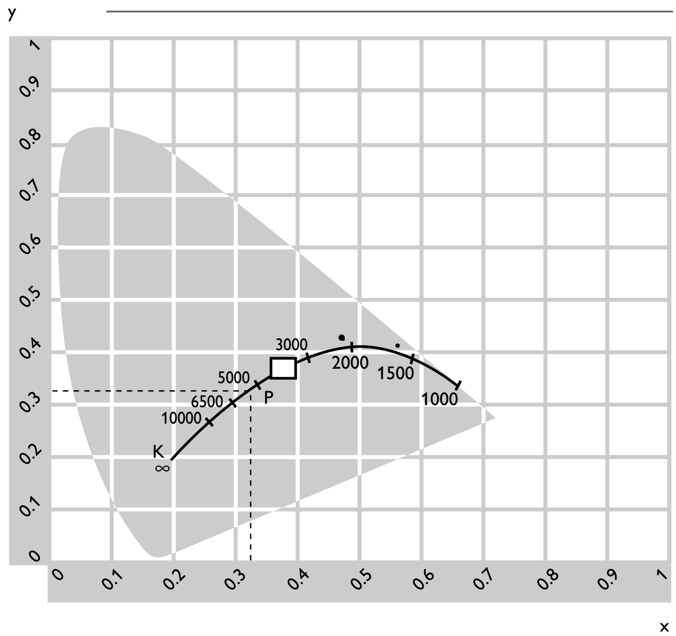


Fig. 27. CIE Chromaticity Diagram (Colour Triangle).

P White point • SOX lamps
● SON lamps ☐ HPI lamps

- **SOX** low-pressure sodium lamps: correlated colour temperature of about 1700K,

- **SON (- T)** high-pressure sodium lamps: correlated colour temperature of about 2000K, □ **HPL-N** high-pressure mercury lamps and **HIP(- T)** metal halide lamps: correlated colour temperature between 3200 K and 4700 K.

The Colour Rendering Index (R_a) gives an indication of how colours appear under a given light source.
The colour-rendering index of most HID lamps is fairy low. In the case of the SOX low-pressure sodium lamp there is absolutely no question of colour rendering.
The SON (-T) high-pressure sodium lamps have a R_a of 20 to 60.
The newest lamps, such as MHN(W)-TD and CDM lamps, have colour rendering indices that make them suitable for applications in which proper colour rendering is required.
HID lamps with poor colour rendering will have to be used in applications where colour is of secondary importance and where these lamps are preferred on account of other positive properties.

Changes in the discharge tube temperature cause shifts in the composition of the metal vapour mixture, which then result in colour point and consequently colour temperature shifts.
The usual manufacturing tolerances already give a certain spread in the chromatic co-ordinates, especially with metal halide lamps. As lamp life progresses, the discharge temperature will rise, e.g. owing to blackening, so that the colour temperature will become lower. External factors such as the mains voltage, the ambient temperature, the spread in ballast impedance or the burning position (metal halide lamps) can have some effect.
Conventional control gear cannot correct for these phenomena. But by monitoring the actual mains voltage, lamp voltage and lamp current, electronic ballasts can regulate and supply the lamp with, for example, a constant lamp power. Or a constant colour temperature can be realised (e.g. White SON). Or a certain lamp can have two different colour temperatures, when supplied with two different lamp currents.

3.15. Photochemical reaction (PET, D.F.)

Within the spectrum of electromagnetic waves that are produced by a discharge we can distinguish three groups of radiation: Infrared, visible and ultraviolet (UV).
Sometimes the lamp is so designed that it passes a part of the UV radiation:
- on purpose for lamps where the UV is used for photochemical processes: e.g. some of the reproduction techniques are based on it, as is suntanning of the skin, and dermatological treatments of the skin
- unintentionally, in which case special filters must be used to protect against this kind of radiation.

This unintentional output of UV is of importance in areas where people work, where materials are used that are sensitive to UV, or both.
In order to quantify the impact of UV, two factors are introduced:

- **PET**: Permissible Exposure Time at an illuminance level of 1000 lux, i.e. the time that an average person can be exposed to 1000 lux without any harmful or negative consequence. If this factor is 24 (hours) or more, no damage is to be expected
- **D, D.F.** or **fc**: Damage Factor, expressing the damage that is done to exposed objects, e.g. fading of textiles.

Both figures can be found in the lamp specifications.

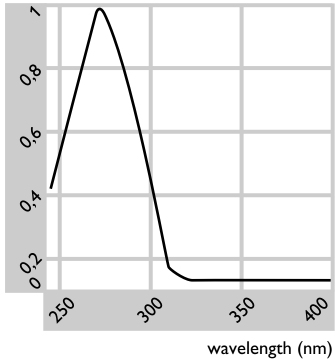


Fig. 28. Relative spectral effectiveness versus wavelength.

The time needed to acquire this maximum dose can be calculated from the spectral power distribution of the light source and an assumed illuminance level of 1000 lux. This time is called Permissible Exposure Time (PET).
It is clear that the time humans are exposed to the light should not exceed the PET.
From the so-called NIOSH-curve, see fig 28, it can be seen that the relative effectiveness of UV depends on the wavelength. The effectiveness is especially high for short wavelengths, viz. 250-320 nm.

Another effect of UV (and blue light) is the risk of fading (= losing colours) of the goods illuminated by it.
This fading risk depends on:
• the type of material that is being illuminated. Studies show that some materials are extremely sensitive to UV radiation.
• the illumination level, defined by the lighting design: very high beam intensities look theatrical, but also involve very high fading risks.
• the exposure time until fading becomes visible.
• the damaging effect of the UV emitted by a light source. The damaging effect of the source can be expressed by a damage factor (D/fc).

It must be noted that not only UV causes fading, but also the radiation in the visible part of the spectrum, where blue is most damaging and red has a low damaging effect.
The relation between these variables is:
Fading risk = E*t*D/fc
in which:
E = illuminance value on the objects
t = exposure time
D/fc = damage factor of the light source

The UV radiation emitted by the discharge tube can be filtered by the outer bulb, by a fluorescent layer on the outer bulb, by the UV blocking front glass of a luminaire or by special UV filters.
When the radiation is not properly shielded, or when exposure times are exceeded, harmful effects can occur to people: conjunctivitis ('welding eyes' or heavy irritation of the eyes), skin irritation etc.

3.16. Nomenclature

There are various methods employed for coding lamps. First there is the Philips internal commercial code: examples are SOX, SON, HPL.
Recently this code has been extended to include some lamps with MASTER at the start of the coding or PRO at the end. MASTER is the best product, followed by PRO and the others, without extra indication, close the range.
Then there is the Philips 12 NC (twelve numeral code), unique for every product.
The EAN (European Article Code) is the bar code on the packaging (13 digits).
The EOC (European Order Code) is the ordering code for customer (6 digits).
Different lamp manufacturers tend to use different nomenclature for the various types of high-intensity discharge lamps that they produce.
To assist the reader, the principal lamp families, with their code names as employed by the relevant manufacturers, are shown in the table below.

HID lamp nomenclature of different manufacturers

ILCOS	**Philips**	**Mazda**	**Osram**	**Sylvania**	**Thorn/GE**	**Tungsram**	**Radium**
SE	SON	MAC	NAV	SHP	LU,SON	TC	RNP
STH	SDW	SANTINA	-	-	LU	-	-
MD	MHN	MTIL	HQI	HSI	MQI	HGMIS	HRI
MD	MHW	MTIL	HQI	HSI	-	HGMIS	-
ME	HPI	MAIH	HQI	HSI	MBI	HGMI	HRI
QE	HPL	MAF	HQL	HSL	HR,MBF	HGLI	HRL
LS	SOX	SIO	NA	SLP	SOX	-	-

ILCOS = International Lamp Coding System, as described in Technical Report IEC 61231.
A survey of the short version of ILCOS:

L

Low-pressure sodium lamps

- LS Single-capped lamp
- LD Double-capped lamp
- LSE Single-capped lamp of the E-type

S

High-pressure sodium lamps

- ST Tubular clear lamp
- SE Elliptical diffuse coated lamp
- SC Elliptical clear lamp
- SD Double-ended clear lamp
- S-Q For high-pressure mercury equipment
- S-M Colour-improved lamp
- S-H High colour rendering index
- S-T Twin arc tube lamp

Q

High-pressure mercury lamps

- QT Tubular clear lamp
- QE Diffuse coated elliptical lamp
- QC Clear elliptical lamp
- QG Globular coated lamp
- QR Reflector type lamp
- QB Self-ballasted lamp
- QBR Self-ballasted lamp with reflector

M

Metal halide lamps

- MT Tubular clear lamp
- ME Diffuse coated elliptical or BT bulb
- MC Clear elliptical or BT bulb
- MR Reflector type lamp
- MD Clear double-ended lamp
- MN Double-ended lamp without outer bulb

4.

Electromagnetic lamp control gear

4.1. Ballasts

4.1.1 Main ballast functions

In Section 2.1 of this Guide, General aspects – Main ballast functions, the main functions of ballasts have been described. The term **'ballasts'** is generally reserved for current-limiting devices, including resistors, choke coils and (autoleak) transformers. Other items of auxiliary equipment are **compensating capacitors**, **filter coils** and **starters or ignitors**. Some systems (SOX) use an additional series capacitor for stabilisation. With all these components all the control functions that are necessary for the operation of standard HID lamps can be carried out.
Special arrangements such as autoleak, constant wattage and dimming circuits will also be briefly described too in this Guide.

4.1.2 Stabilisation

In Section 3.2, Stabilisation, the need for current stabilisation for HID lamps has been described, resulting in the following two formulae:

$$I_{lamp} = (\overrightarrow{V_{mains}} - \overrightarrow{V_{lamp}}) : Z_{ballast}$$

and: $$P_{lamp} = V_{lamp} \cdot I_{lamp} \cdot \alpha_{lamp}$$

where
I_{lamp} = the current through the lamp
V_{mains} = the mains voltage
V_{lamp} = the voltage across the lamp
$Z_{ballast}$ = the impedance of the ballast
P_{lamp} = the power of the lamp
α_{lamp} = a constant called the lamp factor

From these formulae it can be concluded that the power of the lamp (and therefore the light output) is influenced by:
- the lamp voltage V_{lamp}, which in turn is highly dependent on the operating temperature (see Section 4.3.9: Ambient and operating temperatures) and on the lamp current, according to the negative lamp characteristic (see Section 3.2: Stabilisation).
- the lamp current I_{lamp}, which is dependent on the mains voltage (see Section 4.3.10: Effects of mains voltage fluctuations), the lamp voltage and the linearity of the ballast impedance.

Stabilisation of the lamp power, or rather: suppression of its possible variations, is therefore of the utmost importance.

Perfect suppression, however, is impossible with the standard EM ballasts, and it is important to know the margins within which the lamp power varies – for example, when calculating the maximum power capacity needed for an installation.
There are two tools for indicating the influences of the factors mentioned: the ballast and lamp lines, and the so-called trapezoidal or quadrilateral diagram.

Ballast and lamp lines

A set of ballast and lamp lines is shown in Fig. 29.
The ballast lines indicate the relationship between the lamp voltage and the lamp power for a given ballast (viz. a given ballast impedance) and for three levels of mains voltage: the rated level of the ballast, 95 per cent of the rated level, and the rated level plus 10 V. There is a set of such lines for each type of ballast, available at the ballast manufacturer. The figure gives the lines for a typical choke coil ballast. Four so-called lamp lines are also plotted in the diagram (dotted lines). A lamp line gives lamp voltages and lamp powers for different levels of mains voltage.
For example, the first lamp line gives lamp voltages and lamp powers at the 100-hour condition of the lamp (L_{nom}).

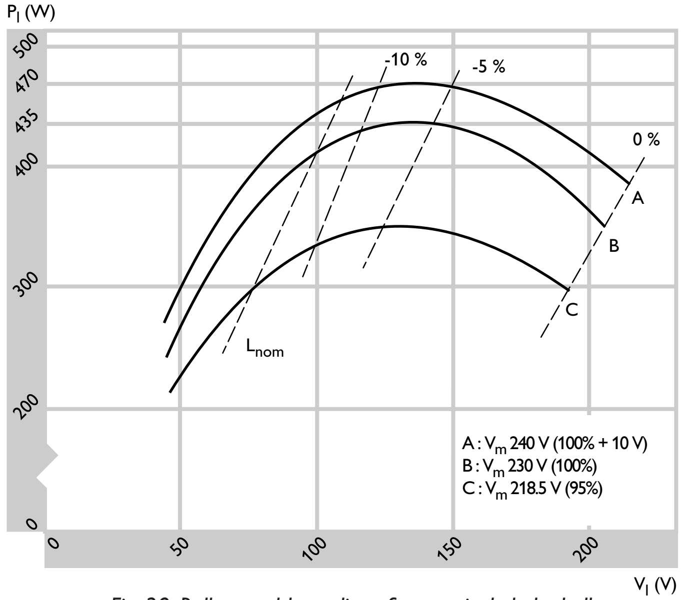


Fig. 29. Ballast and lamp lines for a typical choke ballast, based on 230 V mains voltage.

The line marked 0% gives lamp voltages and lamp powers above which lamp operation is not possible. It is called the extinction line: it indicates the set of extinguishing lamp voltages (at which the lamp starts cycling) at different levels of the mains voltage, provided that these are steady.
If, on the other hand, the mains voltage is not steady, and should suddenly drop by 5% or 10%, the extinguishing voltage will drop with it. The lines marked -5% and -10% give the extinction voltage for these situations.

The operation point of a HID lamp lies at the point of intersection of the relevant ballast line and lamp line. Since the lamp voltage of high-pressure sodium lamps increases during life, the actual lamp line will shift to the right of the initial one.

For a given electrical circuit (ballast + mains voltage), this means that the operating point will travel along the ballast line during lamp life. According to the rate of increase of the voltage, the lamp power will first rise and after some time fall again.

Quadrilateral diagram

The limits within which the operation point must stay for satisfactory lamp performance can be conveniently specified by means of a so-called quadrilateral (or trapezoidal) diagram, especially for SON lamps, (see Fig. 30).

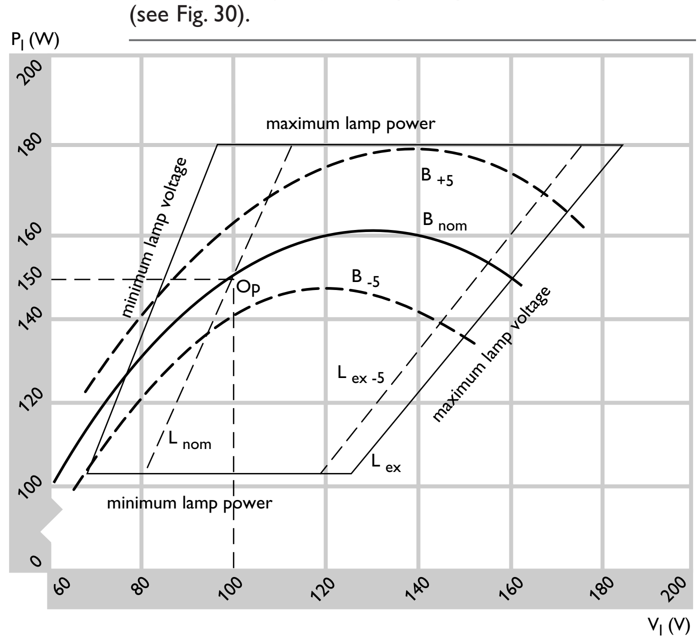


Fig. 30. Quadrilateral diagram of 150 W high-pressure sodium lamp.

B_{nom} = *ballast line for nominal mains voltage*
B_{+5} = *ballast line for 5% over-voltage*
B_{-5} = *ballast line for 5% under-voltage*
L_{nom} = *lamp line for nominal operating conditions*
L_{ex} = *lamp line for maximum lamp voltage (extinguishing line)*
L_{ex-5} = *extinguishing line for 5% under-voltage*
Op = *operating point*

The upper boundary defines the maximum permissible power dissipated in the lamp, for which its lifetime is still acceptable. The lower boundary, marking the minimum permissible power in the lamp, is to ensure an acceptable luminous flux and a satisfactory warming-up time.
The left-hand boundary defines the lowest permissible lamp voltage, and its position is marked by a lamp line. This line is not very critical, but remaining within this boundary can indirectly prevent an excessive lamp current. The right-hand boundary is also marked by a lamp line and indicates the highest permissible lamp voltage, above which the lamp will extinguish. In view of the possible occurrence of mains voltage surges, the lamp should always be operated well within this boundary line.

In order to avoid undesirable variations in light output as a consequence of mains-voltage fluctuations, the lamp voltage must be not more than approximately half the value of the mains voltage (100 to 130 V), and the impedance should be as linear as possible.

Responsibility of ballast and luminaire manufacturers

Two of the main factors influencing lamp performance have been dealt with: the ballast properties and the operating temperature. Obviously, the first factor is of concern to the ballast manufacturer, whilst the second is chiefly determined by the design and construction of the luminaire.
Thus, together with the lamp manufacturer, the ballast and luminaire manufacturers impose certain limitations on their products so as to ensure that they operate within specification.

When selecting the lamp circuit and determining the design of a ballast, the ballast designer will make sure that variations in the supply voltage - caused by ballast tolerances and mains voltage fluctuations - will under no circumstances cause the ballast line to cross the lower or upper boundaries of the quadrilateral diagram.
The lamp designer, meanwhile, has to keep the initial value of the lamp voltage to the right of the left-hand boundary line, by taking care that the tolerances on lamp voltage are as tight as possible. He must also ensure that the lamp voltage does not cross the right-hand boundary line before the lamp has reached its predicted life span.
Similarly, it is the responsibility of the luminaire manufacturer to ensure that the discharge tube cannot reach so high a temperature that the operation point exceeds, or even lies near to, the right-hand boundary line of the quadrilateral diagram.

4.1.3 Ignition and re-ignition

Ignition

In Section 3.3, Lamps, Ignition, the need for ignition of an HID lamp has been described.

Basically, there are four different ignition systems (for wiring diagrams, see section 4.2.4):
1. no external ignitor,
2. two-pole parallel ignitor,
3. three-pole semi-parallel or impulser ignitor,
4. three-pole superimposed pulse or series ignitor.

The role of the ballast in the ignition process depends on the ignition system:

ad 1: a) The lamp can ignite on the available open voltage:
I) The mains voltage is high enough, as with HPL lamps.
The ballast has no special ignition function.
II) The mains voltage is not high enough. The ballast must produce the required open-circuit voltage, as with the autoleak transformers for SOX lamps.
b) The lamp cannot ignite on the available open-circuit voltage:
An internal starting device must produce the necessary peak voltage, as with the glow-switch starter in SON(-I). The peak voltage L dI/dt depends on the ballast impedance, so ballast and starter must be specific to the lamp type.

ad 2: The ballast impedance determines the current for charging the ignitor capacitor and so the ignition peak. Ballast and parallel ignitor are therefore a fixed combination for a certain lamp type (SOX, HPI-T).

ad 3: With the three-pole semi-parallel ignitor system the ballast also reacts as a voltage transformer to transform the ignitor capacitor voltage up to the required peak voltage.
The location of the tapping on the ballast is therefore very critical, as it is situated in such a way that one semi-parallel ignitor can be used for several lamp types (SON) with the appropriate ballasts.

ad 4: In the three-pole superimposed pulse or series ignitor system, the ballast has no special function during ignition.

In all cases the ballast has to limit the current through the lamp to the specified value during ignition and run-up of the lamp. Except in case 4, the ignition peak voltage is present on the ballast terminal that is connected to the lamp.

Re-ignition

Energy is supplied to the discharge in the form of electrons. The lamp current, just like the mains voltage, is sinusoidal, with a frequency of 50 Hz or 60 Hz. If the energy flow is zero (at lamp current reversal), the lamp stops burning and in theory would have to be re-ignited. This could be done by supplying additional energy to the electrodes via a higher lamp voltage, as is done when initially starting the lamp. But from the moment the lamp has reached its stationary condition, the lamp voltage is constant.
And yet, in practice, the lamp does not extinguish at current reversal. The reason for this is that the phase shift introduced by the inductive element of the ballast ensures that the mains voltage is not zero at the moment that the lamp current is zero. Because of the inductive properties of choke coil ballasts, a phase shift occurs between the mains voltage and the lamp current (see Fig. 31). So, at the moment of current reversal, the lamp voltage would be equal to the mains voltage, since the voltage over the ballast is zero. The difference (gap) between the mains voltage and the momentary lamp voltage as a consequence of the phase shift ensures proper re-ignition of the lamp at the moment the current passes the point of reversal (zero-point A in Fig. 31).

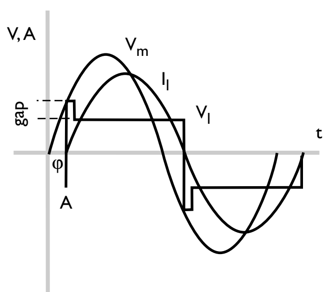


Fig. 31. Lamp current (I_l), lamp voltage (V_l) and mains voltage (V_m) as functions of time.

If now the lamp voltage rises during its lifetime, the gap between the mains voltage and the average lamp voltage decreases.
In the end it will become too small to ensure re-ignition (see Fig. 32), and the lamp extinguishes. It has to cool down before it can start again. After restarting, the lamp voltage quickly rises to the extinguishing level again. The lamp starts cycling and has to be replaced.
By using self-stopping ignitors this cycling process can be interrupted.

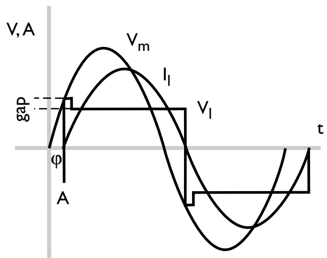


Fig. 32. Voltage gap between Vm and Vl being too small to re-ignite the lamp.

4.1.4 Types of ballasts

1 Resistor ballasts

Current limitation by means of resistor ballasts is a very uneconomic form of current limitation. This is because electrical energy is dissipated in the form of heat in the resistor.
Limitation of lamp current by means of a simple resistor is only used in self-ballasted blended-light lamps (ML), where a filament is connected in series with the discharge tube. This filament, incorporated in the lamp, also takes part in the light production of the lamp.
For this reason, the luminous efficacy of blended-light lamps is lower than that of other HID lamps. On the other hand, the advantage of this system without external ballast is that an installation with incandescent lamps can easily be converted to a system with a much longer life by simply replacing the incandescent lamps by blended-light lamps. An extra advantage of such an exchange is the higher efficay of blended-light lamps compared to the equivalent incandescent versions.

2 Capacitor ballasts

A capacitor used as a ballast causes only very little losses, but cannot be used by itself, as this would give rise to very high peaks in the lamp current wave-form at each half cycle. Only at very high frequencies can a capacitor serve satisfactorily as a ballast.

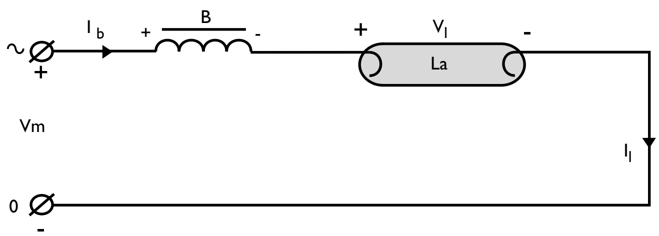


Fig. 33. Schematic diagram of a HID lamp operated on a choke ballast.

3 Chokes, inductive or reactor (R) ballasts

Choke coils are frequently used as current limiting devices in gas-discharge lamp circuits (see Fig. 33). They cause somewhat higher losses than does a capacitor, but produce far less distortion in the lamp current at 50 Hz. Moreover, in combination with an ignitor, they can be made to produce the high voltage pulse needed to ignite the lamp.
In practice, a choke ballast consists of a large number of windings of copper wire on a laminated iron core.
Current limitation by means of resistor ballasts is a very uneconomic form of current limitation. This is because electrical energy is dissipated in the form of heat in the resistor.
It operates on the self-inductance principle. The impedance of such a ballast must be chosen to suit the mains supply voltage and frequency, the lamp type and the voltage of the lamp, to ensure that the lamp current is at the correct value. In other words, for each supply voltage, each type of lamp requires its own choke as a ballast with a specific impedance setting.
Heat losses, occurring due to the ohmic resistance of the windings and hysteresis in the core, much depend on the mechanical construction of the ballast and the diameter and length of the copper wire.
The right ballast for a given lamp and supply voltage should be chosen by consulting documentation and/or ballast markings.
The Philips standard range of ballasts is for supply voltages of 220/230/240 V and for frequencies of 50/60 Hz.
Ballasts can have taps for different lamp types (e.g. for HP 50/80 W or SON 50/70 W) or for different supply voltages (e.g. 230/240 V or 380/400/415 V).
In some cases several ballasts can be combined to form a new ballast (e.g. two parallel HP 1000 W, 220 V ballasts form one HP 2000 W, 220 V ballast).
But the ballast for a 400 W HP lamp is not the same as that for a 400 W SON lamp.
Some ballasts may have another tapping for the connection of a semi-parallel ignitor. It is important to use the correct ignitor/ballast combination and to connect these items according to the wiring diagram on the ignitor.

The most important value for stabilisation is the ballast impedance. It is expressed as the voltage-current ratio in ohms (Ω) and is defined for a certain mains voltage, mains frequency and calibration current (normally the nominal lamp current).

Chokes can be used for virtually all discharge lamps, provided that one condition is fulfilled: the mains voltage should be about twice the arc voltage of the lamp. If the mains voltage is too low, another type of circuit should be used, such as the autoleak or constant-wattage circuits.

The advantages of a choke coil are:
- the wattage losses are low in comparison to those of a resistor,
- it is a simple circuit: the ballast is connected in series with the lamp.

The disadvantages of a choke coil are:
- the current in a lamp with choke circuit exhibits a phase shift with respect to the applied voltage, the

current lagging behind the voltage, resulting in a power factor of ca. 0.5 inductive (see also Section 4.3.4: Power factor correction).
- a high starting current: in inductive circuits the starting current is about 1.5 times the rated current.
- sensitivity to mains voltage fluctuations: variations in the mains voltage cause variations in the current through the lamp.

4 Autoleak transformers or high-reactance autotransformers (HX)

If the mains voltage is lower than about twice the arc voltage of the lamp - as is the case with low-pressure sodium lamps - the mains voltage has first to be stepped up. This could of course be done by a separate step-up transformer. A better solution is to combine the functions of transformer and choke in one piece of equipment. Autoleak transformers perform this combined operation: part of their secondary winding acting as a choke coil (Fig. 34). This configuration saves on windings and thus on wattage losses, space and weight. It also improves the re-ignition of the lamp, thanks to the higher open circuit voltage.

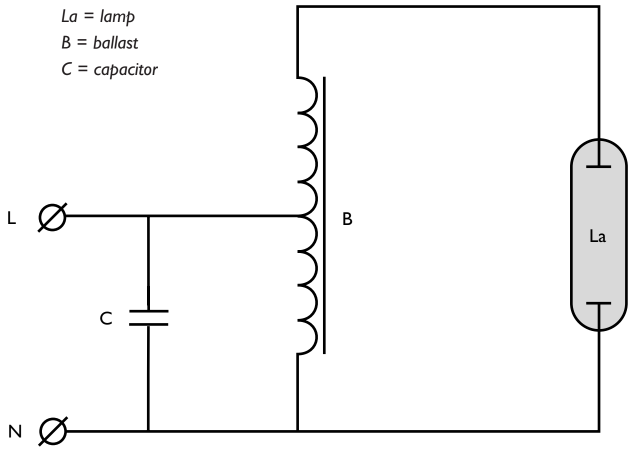


Fig. 34. Circuit diagram of a low-pressure sodium lamp with an autoleak transformer.

Just as with the choke coil, compensation capacitors may be necessary in order to improve the power factor. Autoleak transformers for low-pressure sodium lamps also fulfil the function of an ignition device, making a separate ignitor superfluous.
Compared with normal choke ballasts, the autoleak transformer has the advantage of a higher open-circuit voltage (no ignitor). The disadvantages are: higher wattage losses, because such ballasts are larger and more expensive.

5 Constant-wattage hybrid circuits (SOX)

The constant-wattage hybrid circuit is shown in Fig. 35. The primary circuit consists of a linear self-inductance Z1 in series with a saturated inductance Z2. The voltage across Z2 is transformed up to the required voltage. The secondary circuit consists of a capacitor in series with the lamp. The capacitor value is well-defined with a narrow tolerance (± 4%) for stabilisation of the lamp current.

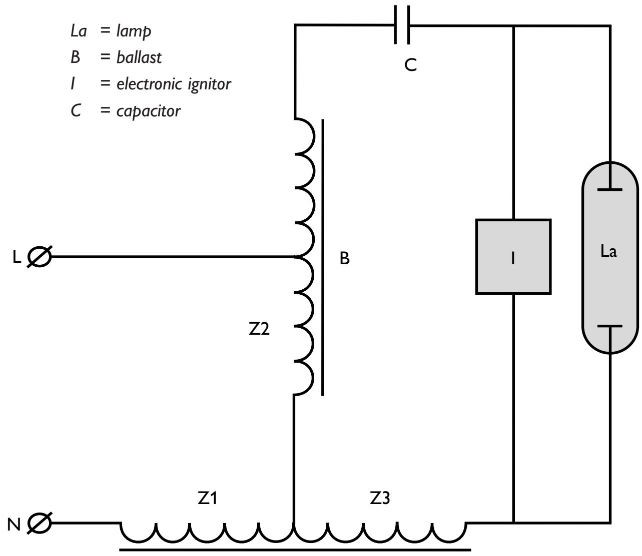


Fig. 35. Constant-wattage hybrid circuit.

Z3 is necessary to avoid flickering of the lamp, especially during run-up.
An electronic ignitor with built-in capacitor is placed in parallel to the lamp and provides the voltage peaks required to ignite the discharge. It also essential for the quick re-ignition of the lamp.

The advantages of the constant-wattage hybrid circuit are:
- the system supplies a squarer lamp-current waveform, so that the dark period in each cycle is reduced, resulting in smooth re-ignition,
- mains-voltage fluctuations have little influence on the lamp wattage, because the circuit is of the constant-wattage type,
- re-ignition of the lamp when warm is no problem, thanks to the electronic ignitor,
- suppression of audio-frequency signals is done by the coil-capacitor combination, so no extra filter coil is needed,
- little mains current distortion occurs, because harmonics from the lamp are attenuated in the ballast circuit,
- a good power factor.

The constant-wattage hybrid circuit has no real disadvantages, although it is more complicated and physically larger than a normal choke.

6 Constant-wattage circuit

In the USA, the constant-wattage circuit is widely used in lighting systems with mercury and high- pressure sodium lamps, (see Fig. 36). It consists of an autoleak transformer with a capacitor in series with the lamp. Use of the capacitor allows the lamp to operate with better wattage stability when the supply voltage fluctuates. It performs a double function here: it takes part in the ballasting of the lamp circuit and it corrects the power factor.

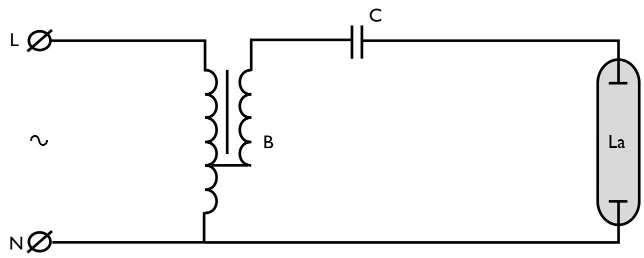


Fig. 36. Constant wattage autotransformer circuit.

The advantages of the constant wattage circuit are:
- variations in the mains voltage up to some 10 per cent have virtually no effect on the lamp current.
- a favourable power factor.
- a low run-up current.

The system does, however, also have its disadvantages:
- the wattage losses in the transformer are high.
- the autoleak transformer is large, heavy and expensive.
- arc-voltage fluctuations result in considerable wattage fluctuations: the changes have to be "dissipated" by the ballast.

4.1.5 Ballast specification and marking

There are two ways of selecting the right ballast for a certain lamp or for comparing various ballasts:
1. the ballast marking,
2. the manufacturer's documentation.

As all ballasts have to comply with the norm IEC 60922/923, some data has to be marked on the ballast and other data can be mentioned in the documentation.

On the ballast can be found:
- marks of origin, such as the manufacturer's name or trade mark, model or reference number, country of origin, production date code,
- rated supply voltage and frequency, nominal ballast current(s),
- type(s) of lamp with rated wattage,
- type(s) of ignitor with wiring diagram and peak voltage if this exceeds 1500 V,
- t_w and Δt (see Section 4.1.6),
- maximum cross-section of mains or lamp cable; e.g. 4 □ means 4 mm^2,
- symbols of the officially recognised certification institutes, such as ENEC ,VDE, SEMKO, SEV, KEMA, if applicable; CE marking for safety,
- in the case of an independent ballast: the symbol ; an independent ballast is a ballast that is intended to be mounted separately outside a luminaire and without any additional enclosure,
- a symbol such as → TOP if there are mounting restrictions,
- F-marking ▽F if the ballast fulfils the specific IEC F-requirements; this means it is suitable for direct mounting on normally-flammable surfaces,
- TS, P-marking ▽P or ▽* if the ballast is thermally protected (* = thermo-switch temperature in degrees Celsius),
- indication of terminals: L for single phase, N for neutral, ⏚ for protective earth (PE), ⏚ for functional earth,
- rated voltage, capacitance and tolerance of separate series capacitor.

In the documentation can be found:
- weight,
- overall and mounting dimensions,
- power factor (λ, P.F. or cos φ),
- parallel compensating capacitor value and voltage for λ = 0.85 or 0.9,
- mains current nominal and during running-up, both with and without power factor correction,
- watt losses (normally in cold condition),
- description of version, e.g. open impregnated, 'plastic' encapsulated, potted or compound filled.

This information suffices for finding the right ballast for a given application. Additional information can be obtained on request or can be found in special application notes. Philips ballasts are designed for use with IEC standardised HID lamps and can be found on the website catalogue.

4.1.6 Maximum coil temperature t_w (lifetime) and ΔT

A ballast, like most electrical components, generates heat due to its ohmic resistance and magnetic losses.
Each component has a maximum temperature that may not be exceeded. For ballasts it is the temperature of the choke coil during operation that is important.
The maximum permissible coil temperature t_w is marked on the ballast. Coil insulating material, in combination with lacquer, encapsulation material, etc., is so chosen that below that temperature the life specified for the ballast is achieved. A t_w value of 130˚C is usual nowadays with a coil insulating class F (150˚C) or class H (180˚C).

Under standard conditions, an average ballast life of ten years may be expected in the case of continuous operation at a coil temperature of t_w ˚C. As a rule of thumb, a 10˚C temperature rise above the t_w value will halve its expected life (see Fig. 37). If, for instance, the operating temperature is 20˚C above the t_w value, one may expect a ballast life of 2.5 years of continuous operation. If no t_w value is marked on the ballast, a maximum of 105˚C is assumed for the coil temperature. As the ballast normally does not function continuously, the actual life of the ballast can be very long.

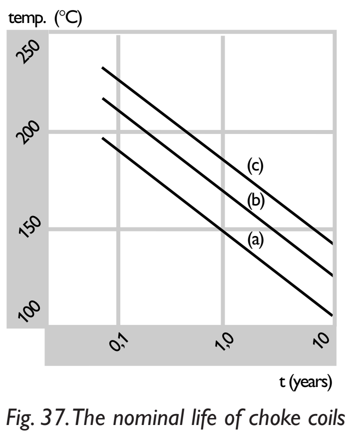


Fig. 37. The nominal life of choke coils in relation to the permitted rated maximum operating temperature of a ballast winding tw, dependent on insulation material:
a) class A: t_w 105˚C,
b) class E: t_w 120˚C,
c) class F or H: t_w 130˚C.

It also takes some hours before the thermal equilibrium is reached in the ballast, which again increases the practical ballast lifetime.
To verify the t_w marking, accelerated lifetime tests are done at ballast temperatures above 200°C for 30 or 60 days.

Another value marked on the ballast is the coil temperature rise Δt. This is the difference between the absolute coil temperature and the ambient temperature in standard conditions, and is measured by a method specified in IEC Publication 60922 (EN 60922). Common values for Δt are from 50 to 70 degrees in steps of 5 degrees.
The coil temperature rise is measured by measuring the ohmic resistance of the cold and warm copper coil and using the formula:
$\Delta t = \{(R_2 - R_1)/R_1\} \times (234.5 + t_1) - (t_2 - t_1)$
or:
$\Delta t_c = R2/R1 \times (t_1 + 234.5) - 234.5$ (IEC 10598-1 Appendix E)

where R_1 = initial cold coil resistance in ohm (at start of measurement)
R_2 = warm coil resistance in ohm (at end of measurement)
t_2 = ambient temperature at measuring R_2 in Celsius
t_1 = ambient temperature at measuring R_1 in Celsius
t_c = calculated warm coil temperature in Celsius
$\Delta t = t_c - t_2$ in Kelvin

The value 234.5 applies to copper wire; in the case of aluminium wire, the value 229 should be used.

So a ballast marked with t_w 130 and Δt 70, will have the specified 10 years average life in continuous operation at standard conditions at an ambient temperature of 130°C - 70°C = 60°C. When the ambient temperature around the ballast is higher, a shorter ballast life has to be accepted, or sufficient air circulation or cooling has to be applied.
The so-called ambient temperature mentioned in this section is not the room or outside temperature, but the temperature of the micro-environment of the ballast. Built into a luminaire or ballast box, the air temperature around the ballast is higher than the outside ambient temperature. This higher temperature has to be added to the coil temperature rise Δt to find the absolute coil temperature: $t_c = t_2 + \Delta t$, (see fig. 38).

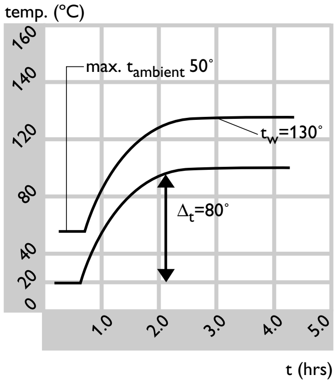


Fig. 38. Relation between tw , Δt and absolute ballast temperature.

4.1.7 Watt losses

Ballast losses are real losses: they do not contribute to the system efficiency. The losses are built up of copper and iron losses. The copper losses (I^2R) depend on the ballast current and the length and diameter of the copper wire. The iron losses depend on the amount, the quality and the thickness of the core laminations and the induction. For lower losses more iron and/or thicker copper wire must be used, which makes the ballast bigger, heavier and more expensive, but also cooler.
The ballast designer therefore has to find a compromise between watt losses, temperature rise (Δt), volume and price.
Ballast losses are normally published as 'cold' values, meaning that the ballast is either not energised, or at most only very briefly, and the ballast winding is at ambient temperature (25˚C). In practice the ballast will more or less reach the marked Δt value and then the copper resistance is ca. 25 per cent higher than in the 'cold' situation. In practice, therefore, the 'warm' losses will be 10 - 30 per cent higher than the published values.

4.1.8 Thermally-protected ballasts

HID lamps can have the property of starting to operate in an asymmetrical current mode. There are two phenomena:
1. A rectifying effect due to poor functioning of a lamp electrode, e.g. towards the end of lamp life or, in case of a broken electrode, with the lamp still burning. This can happen with all HID lamps and is clearly noticeable during ignition of the lamp.
2. Due to leakage in the discharge tube, gas may escape, causing a discharge in the outer bulb. Obviously this phenomenon can only occur in lamps with a vacuum outer bulb, such as SON, CDM and MHN-LA lamps.

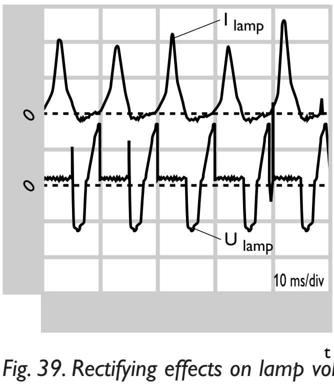


Fig. 39. Rectifying effects on lamp voltage and lamp current.

The rectifying effect causes a high direct current component, (see fig. 39), which is only limited by the resistance of the ballast windings. Without any measures taken to counter this, this high current will cause the winding temperature of the ballast to rise rapidly (see Fig. 40) until in the end the insulation material of the wire is destroyed and the ballast becomes short-circuited.
This phenomenon is most likely to take place with metal halide lamps (see warning in IEC 61167), so that protection rules for luminaires have been set up

(see IEC 10598-1 paragraph 12.5.1). Similar rules for SON lamps are described in IEC 10662.

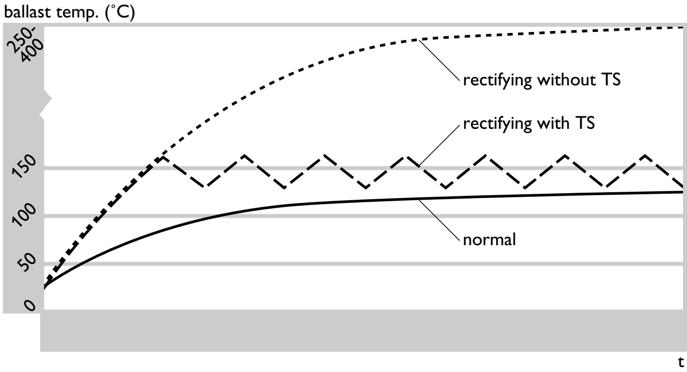


Fig. 40. Rectifying effect with and without thermo-protected TS ballast.

A fuse or mains circuit beaker (MCB) in series with the lamp will not always detect the higher current and there are only a few types of HID lamps with an internal fuse in the lamp base (SON 250 and 400 W).
For reasons of good thermal coupling of the protection of the windings, luminaire manufacturers mostly prefer thermally-protected ballasts of combating the rectifying effect. In theory, as far as the design of such ballasts is concerned, a thermo-fuse or a thermo-switch may be used.
A thermo-fuse can react only once to an excessive ballast temperature by breaking, and the fuse or even the whole ballast has to be replaced after such an event. As this is of course unacceptable an automatically resetting thermo-switch is preferred.

Philips ballasts marked with TS are protected against an excessively-high winding temperature by means of a thermo-switch. The switch interrupts the line connection of the mains when the rectifying effect occurs and is automatically reset afterwards. The TS ballast must be connected in series with the line conductor.
For optimum safety, self-stopping semi-parallel ignitors should be used instead of series ignitors.

4.1.9 HID ballast nomenclature

For ballasts there is no international coding system as there is for lamps (see 3.16 ILCOS).
In section 4.1.5 the technical specification printed on a ballast label has been dealt with. All ballast manufacturers use their own nomenclature.
The Philips nomenclature, in other words the naming convention, also gives information on the type of ballast concerned and its use.
This can best be illustrated by means of a practical example from the Philips ballast range.
A typical ballast code number is, for instance:

BSN 150 L 407 I TS LT

Ballast electromagnetic

Lamp type:
- SN = SON
- MH = Metal halide
- HD = Metal halide (extended)
- HL = High-pressure mercury
- SL = White SON
- SD = SON Dual power
- SH = SON Hybrid (with HID-DynaVision controller)
- HA = HPA
- SX = SOX

Lamp power (W)

Type of circuit:
- L = Low power factor (< 0.85)
- H = High power factor (> 0.85)

Number of electrical terminals

Type of contacts:
- 0 = screw contacts
- 2 = insert contacts

Voltage and frequency:
- 0 = 220 V 50 Hz
- 1 = 220 V 60 Hz
- 2 = 230 V 50 Hz
- 3 = 230 V 60 Hz
- 4 = 240 V 50 Hz
- 6 = 220/230 V 50 Hz
- 7 = 230/240 V 50 Hz
- 8 = 220/240 V 50 Hz
- 12 = 230/240/250 V 50 Hz

- I = Ignitor tap
- TS = Thermo-switch
- LT = Low temperature

4.2. Starters / Ignitors

4.2.1 Main ignitor functions and operation

Basically, there is only one function for an ignitor: to deliver the proper ignition voltage for starting the discharge in an HID lamp. But different ignitor types are required because different HID lamps require differing ignition voltages: the shape of the voltage peak, the number of voltage pulses within a certain period, the instant of application of the voltage itself, the amount of energy available and the amplitude, they all play a part in creating an optimum situation for establishing a discharge. Besides which, there are various ignition systems in use. After ignition the ignitor has to stop producing ignition peaks. This can be controlled by sensing the lamp voltage or lamp current and/or by a timer function.

The voltage level at which an HID lamp will ignite is called its ignition voltage. In most lamp types special measures have been taken in the construction of the lamp to keep this ignition voltage as low as possible: the use of a starting gas as a Penning mixture (see Fig. 41) and the application of auxiliary electrodes to trigger the initial ionisation of the gas are examples of this. In the case of high-pressure mercury lamps, these measures are sufficient: these lamps will start on the mains voltage. Therefore, no separate ignitor is required and the ballast has no special function in the ignition process either. In other cases an internal glow-switch starter, built into the lamp, is sufficient to ignite the lamp, as with the low-wattage SON(-I) lamp.

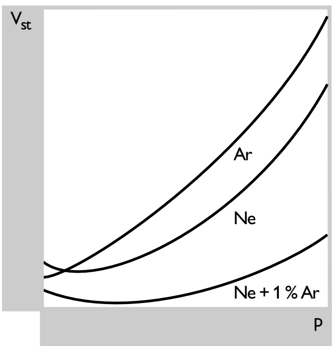


Fig. 41. Starting voltage curve: dependence of starting voltage (V_{st}) on gas pressure (p) for neon, argon and a mixture of the two. The addition of argon to neon clearly leads to a lower starting voltage level (Penning effect).

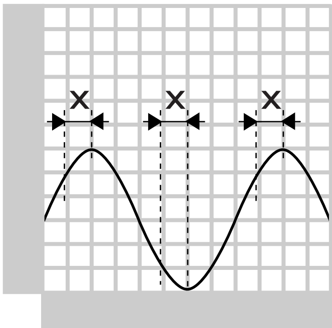
But all other types of HID lamps, including metal halide and low and high-pressure sodium lamps, require an external ignition device, either as an integral part of the ballast, or as an separate item of the control gear. This external ignition device must supply the voltage peaks necessary for starting the gas discharge. Mechanical switches such as relays or bi-metal switches may be used,

but due to the high costs of replacement in outdoor applications, these have never become popular. Electronic ignitors prove to be the solution. They are based on the principle of a capacitor which is first charged via a diode and then discharged via a thyristor and so producing ignition peaks.
When autoleak transformers are used as a ballast, a separate ignitor is not required, since the transformer already supplies the necessary starting voltage.

With cold lamps the required voltage pulses are of the order of 1kV to 5 kV, while the maximum permitted amplitude of the pulse is limited by the lamp construction and by the type of lampholder. The ignition takes place immediately after the ignition pulse occurs.
Required minimum and maximum peak voltages:

HPL 50-1000 W	0,3 kV
HPI 250-2000 W	0,6...1,4 kV
SOX 35-90 W	0,7...1 kV
SOX 135-180 W	0,7...1,4 kV
SON (CDM-TT) 50-70 W	1,8...2,5 kV
SON 100-1000 W	2,8...5,0 kV
CDM/MH 35..2000 W	3,2...5,0 kV

Apart from the peak amplitude also the peak width, the number of peaks and the position of the pulse in the mains sine wave are important, see for example Fig. 42.



In the marked areas 'X' lamp voltage is high enough to take over the lamp current after ionisation (typical position 30-90 degrees.)

Fig. 42. Pulse position for reliable ignition.

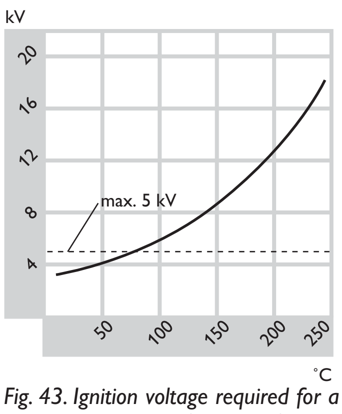


Fig. 43. Ignition voltage required for a typical high-pressure mercury lamp as a function of lamp temperature.

In the case of hot lamps (see Fig. 43) that have extinguished because of a power failure, accelerated

ignition is possible at a certain stage as the lamps cool down. Hot metal halide lamps, for example, restart after 5 to 15 minutes and high-pressure sodium lamps without bi-metal after about 1 minute. The ignitors used in the hybrid circuit of SOX lamps enable the lamps to restart immediately when they are still warm.
To restrike hot HID lamps, peak voltages of between 20 kV and 70 kV (depending on lamp type) are necessary. These peak voltages are produced by the Hot Restrike device, which in fact is just a special ignitor. Philips does not produce such HR devices, but they are available on the market (BagTurgi for example). The ballasts and compensating capacitors are the same in standard and HR circuits. The difference is that the lamp, lampholder, lamp cabling and luminaire must be able to stand the high ignition voltages. This means employing a double ended lamp (no Edison fitting) and ensuring that there are sufficient creepage and clearance distances in the luminaire. In the Philips range there are only a few types double ended lamps (CDM-TD, MHN-LA, MHN-SA) and only one floodlight (ArenaVision MVF406/MVF403) that are suitable for HR.
HR devices stop producing the high ignition peaks when the lamp is ignited or, by use of a timer, after a few seconds. The wiring diagram differs from that of standard ignitors.
Not only the lamp-HR device combination, but also the applied luminaire must be released for the HR application.

4.2.2 Ignitor types

In principle, there are three different types of ignitors or ignition systems: semi-parallel, series and (full) parallel.

Semi-parallel (impulser) type ignitors

The preferred type of Philips ignitors are of the semi-parallel impulser type (SN** type). This means that one ignitor terminal is connected to a ballast tapping (see Section 4.2.4). In this way the ballast acts as a voltage transformer to create the high ignition voltage. It is therefore essential to use the ignitor in combination with a properly tapped ballast. With this type of ignition the ballast coil is exposed to the high pulse voltage and must have sufficient insulation quality to withstand the high voltage energy. By making use of the ballast coil instead of a separate ignitor coil (as described below) with the series ignitor, the total system of ballast and ignitor can be cheaper and the ignition pulse has a higher energy content, which results in more reliable ignition.

Series or Superimposed pulse type ignitors

The second family of ignitors is of the superimposed pulse type (series ignitor, SU** type). Here the high voltage peak is generated in a separate transformer in the series ignitor (see Section 4.2.4). The ballast therefore has no ignitor tap and the coil is not exposed to the high pulse voltage peak and so the ballast can be cheaper. Nevertheless, the total system (ballast and ignitor) may be more expensive than the semi-parallel system. This is because the lamp current is passing through the ignitor,

resulting in higher watt losses and possible hum, also during stable operation. In general this type of ignitor has to be mounted close to the lamp.
Philips ballasts with ignition tap are also suitable for use in series ignitor circuits.

Parallel ignitors

The third group of ignitors is called parallel ignitors (SI** and SX** types), as the ignitor is connected directly across the lamp (see Section 4.2.4). The ballast has no extra ignition function. No high peak voltages can be created by this system (typical 500-750 V for HPI-T, maximum 1500 V for BSX 180) and so the ballast is not exposed to high voltages.

Self-stopping ignitors

Standard ignitors keep on functioning when the lamp is not ignited, when the lamp is defective or when the lamp is cycling. During the lifetime of SON, MH and CDM lamps, the lamp voltage will rise, depending on the lamp type with, by between 1 and 4 volt per 1000 burning hours. At a certain moment, the available mains voltage will be too low for stable operation and the lamp will extinguish. But after cooling down, the lamp will restart again, runs up to its high lamp voltage, and again extinguish. This repeating sequence is called cycling.
In normal situations the effective ignition time of the ignitor is very short, but in the cycling situation the effective ignition time is extended dramatically. This can lead to early ballast and/or ignitor failures.
Therefore self-stopping versions, which stop after 5 or 15 minutes, are available to avoid the cycling behaviour (see Fig. 44) at the end of lamp life (SN**T5/15 type).

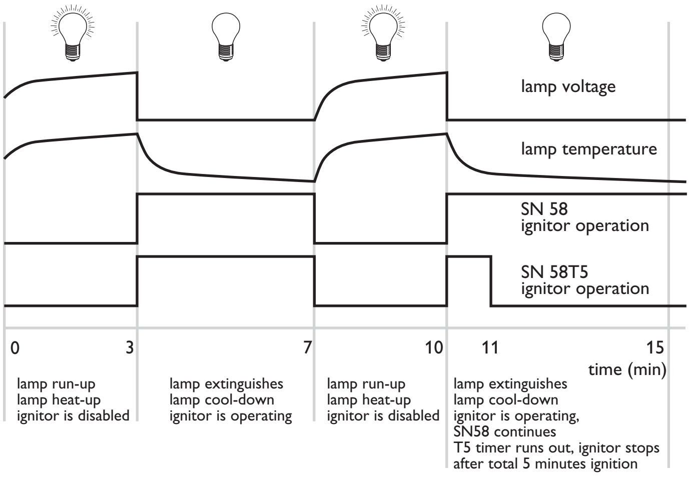


Fig. 44. Cycling behaviour at the end of lamp life with a normal (SN 58) and a self-stopping (SN 58T5) ignitor.

Type of self-stopping ignitor	For lamp types
SN 57T5 / SN57T15	SON Plus 50 W and 70 W / CDM-TT 70 W
SN 58T5	SON(-T) Plus 100-1000 W
SN 58T15	MH 35-1800 W
	CDM 35-150 W
	HPA 400 W
SU 10T2	SON 50-70 W
SU 20T20	SON 100-250 W
	CDM/MH 35-400 W
SU 40T10	SON 400 W

The operation of the SN**T* and SU**T* ignitors is controlled by the lamp voltage. Counting down from the minutes indicated by the number after the T, the timer holds as soon as the lamp has ignited, whilst the remaining time is retained in the memory. The memory function has been implemented to allow for re-ignition if the lamp extinguishes as a result of temporary voltage dips. Consequently, these ignitors are resistant to voltage dips within the timer setting. Resetting the mains supply (disconnecting) for a minimum of 20 seconds is necessary to be able to again restart with the full ignition time available.

Reasons for applying self-stopping ignitors:
- no annoying cycling, and so reduction of radio interference,
- reduced risk of creating of the DC-current, which leads to possible overheating of the ballast,
- prolonged lifetime of ignitor.

Comparison between semi-parallel and superimposed (series) ignition systems

For the ignition of lamps such as high-pressure sodium or metal halide lamps, the choice basically exists between two systems previously mentioned namely:
- semi-parallel, IMP, also called impulser (see Fig. 45) or
- superimposed pulse, SIP, also called series (see Fig. 46).

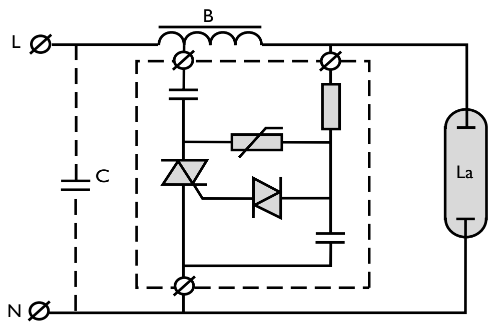


Fig. 45. Semi-parallel ignition system.

La = lamp
B = ballast
C = capacitor

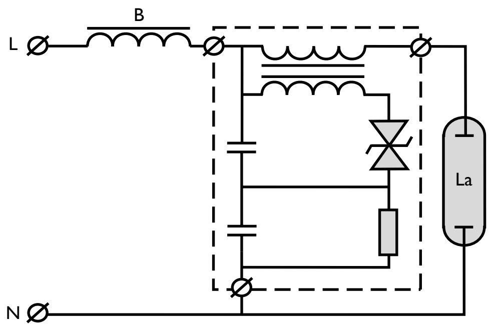


Fig. 46. Superimposed ignition system.

La = lamp
B = ballast

The semi-parallel system is an arrangement in which the ballast and ignitor form a matched pair: the one cannot operate without the other. The ignitor uses the ballast to generate the ignition pulse for the lamp. The series ignitor works more or less without the ballast.
In many cases the two systems are seen as being interchangeable. However, when they are closely compared, a number of differences become evident:

1. During normal lamp operation, the semi-parallel ignitor is no longer part of the current-carrying section of the electrical circuit. This implies that the ignitor does not consume any power and is therefore not self-heating. The series ignitor, on the other hand, is connected in series with the lamp and so always consumes some power.

2. Because the semi-parallel ignitor uses the ballast to generate the ignition pulse, it can fulfil this task very effectively. This high energy content ensures reliable lamp ignition. Furthermore, it permits of considerable distances between ballast/ignitor and lamp, so enabling the gear to be located more remotely: distances of 20 m, under nominal conditions, are no exception. The series ignitor produces smaller ignition peaks with less energy and must be connected close to the lamp.

3. As the semi-parallel ignitor is making use of the ballast to generate the ignition pulse, it contains no transformer. This means that there are no components inside the ignitor, that could otherwise cause irritating hum in the longer term. For indoor applications in particular this is an important consideration. The series ignitor makes use of a transformer in series with the lamp.

4. Some lamps can display a rectifying effect towards the end of their technical life. Metal halide lamps, more than high-pressure sodium types, tend to exhibit this, but there is always a chance of occurrence. A semi-parallel ignitor is not connected in the current-carrying section of the circuit and will therefore not be affected by this phenomenon. Series ignitors will be damaged by the DC current, unless special precautions are taken. For lamp types that do exhibit rectifying effects at the end of life, so-called thermo-switch ballasts are recommended, because the built-in thermo-switch will then protect the ballast from any hazardous lamp behaviour (see Section 4.1.8).
   Hence, when a thermo-switch ballast is required, it is advisable to employ a self-stopping semi-parallel ignitor system. In this way, maximum circuit protection can be assured.

5. Also from a commercial point of view too, the semi-parallel system offers many benefits. In principle, the ignitor is power-independent: one ignitor can be used for a large number of lamps. This results in logistical advantages as well as financial gain (especially with higher wattage circuits) since the price of the ignitor does not rise with increasing lamp wattage.

It should be noted, by the way, that a perception exists that in the semi-parallel system the ballast might be destroyed should the lamp does not ignite (for whatever reason). The ignition pulse would adversely affect the ballast and ultimately destroy it. However, in practice, there is however no noticeable difference between the performance of the semi-parallel system and the superimposed system. In the semi-parallel circuit, the ballast is stressed by the ignition pulse, whilst in the superimposed circuit the ignitor is stressed. But all components are developed and constructed to withstand this situation.

4.2.3 Lifetime

Under normal conditions, an ignitor actually operates for only a few cycles, once every day, when the lights are switched on. The ignitor case temperature at this time is the ambient temperature. Under these conditions, the actual ignitor life expended is insignificant (less than one second per day, see Fig. 47).
Even if the lights were turned off momentarily, once each day, it requires only about one minute of pulsing by the ignitor to re-ignite the lamp. Assuming an ignitor case temperature of 90˚C (worst case), an operating period of one minute per day would total to only about five hours of actual operation per year. Since average ignitor life at 90˚C is 800 hours, the use of five hours per year is only an insignificant portion of the total lifetime.

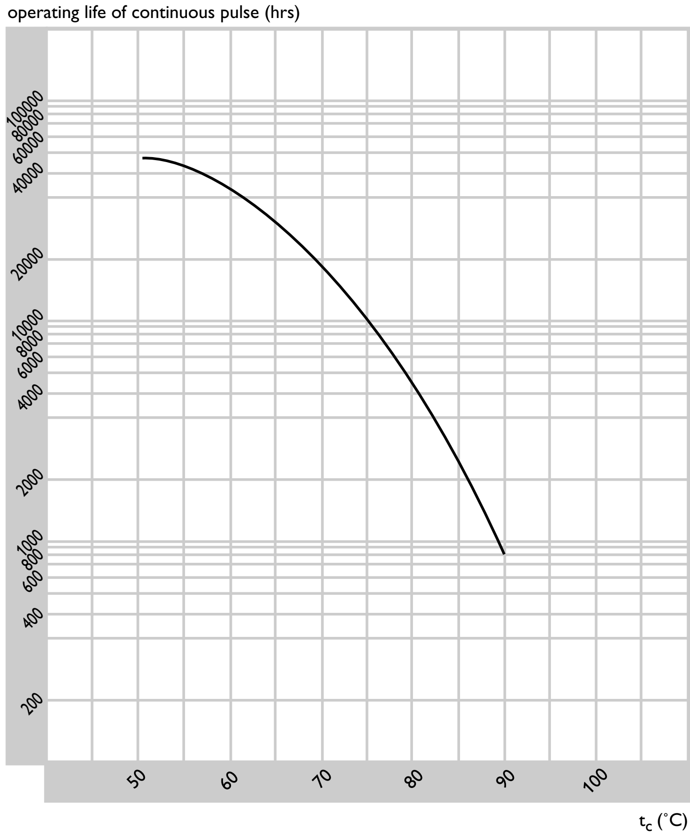


Fig. 47. Estimated operating life of ignitors as a function of case temperature.

On the other hand, ignitor life can be used up at a significant rate when an inoperative lamp remains in an energised socket for extended periods of time. In this instance, the ignitor may be pulsing from 8 to 24 hours per day, depending on the lighting application.

Experience has shown that ignitor case temperatures typically run about 15˚C above the luminaire ambient temperature. Assuming a very severe application with a 75˚C case temperature, a total of 10 000 hours of proper functioning can be expected. If, however, the ignitor were pulsing 24 hours per day (i.e. continuously), this would result in a shorter ignitor life. The ignitors are specified for 30 days, but tested for 60 days continuous operation.

The situation is slightly different with series ignitors, as the transformer coil is stressed by the lamp current. Although the specification is the same for series and semi-parallel ignitors, in some applications the series ignitor is replaced together with the defective lamp.

4.2.4 Wiring diagrams of HID ignitors

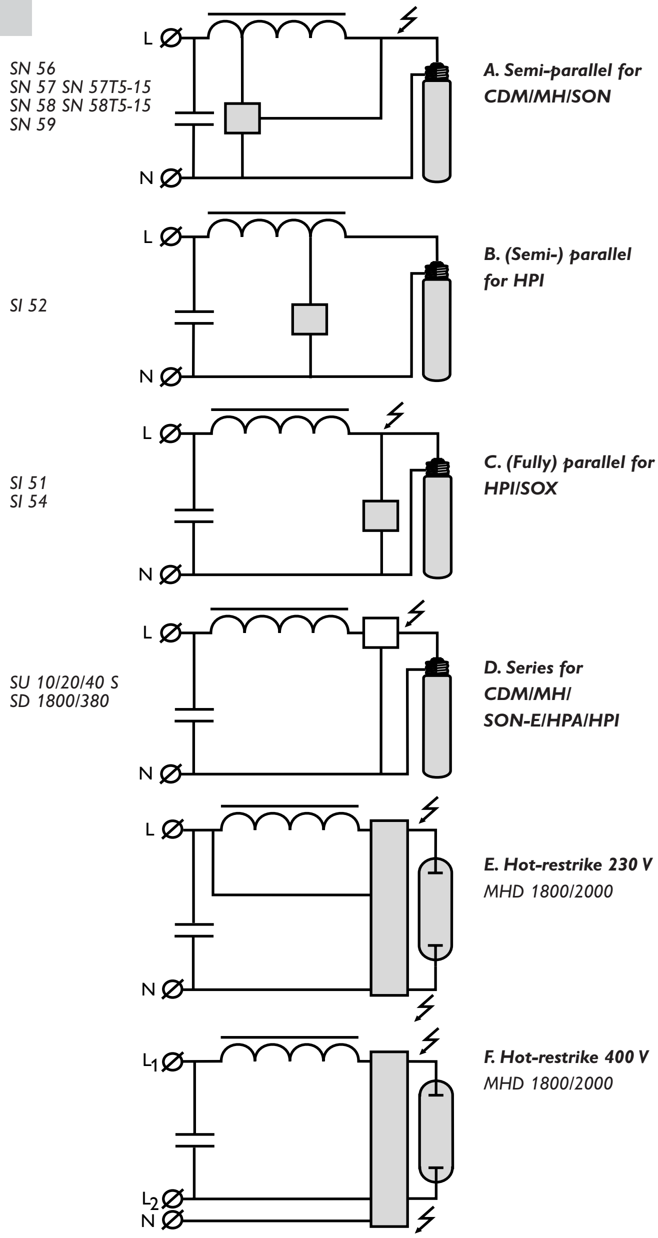


Fig. 48. Wiring diagrams of HID ignitors.
Note: For reasons of safety, the central contact of the lamp must be connected to the high-voltage lead.

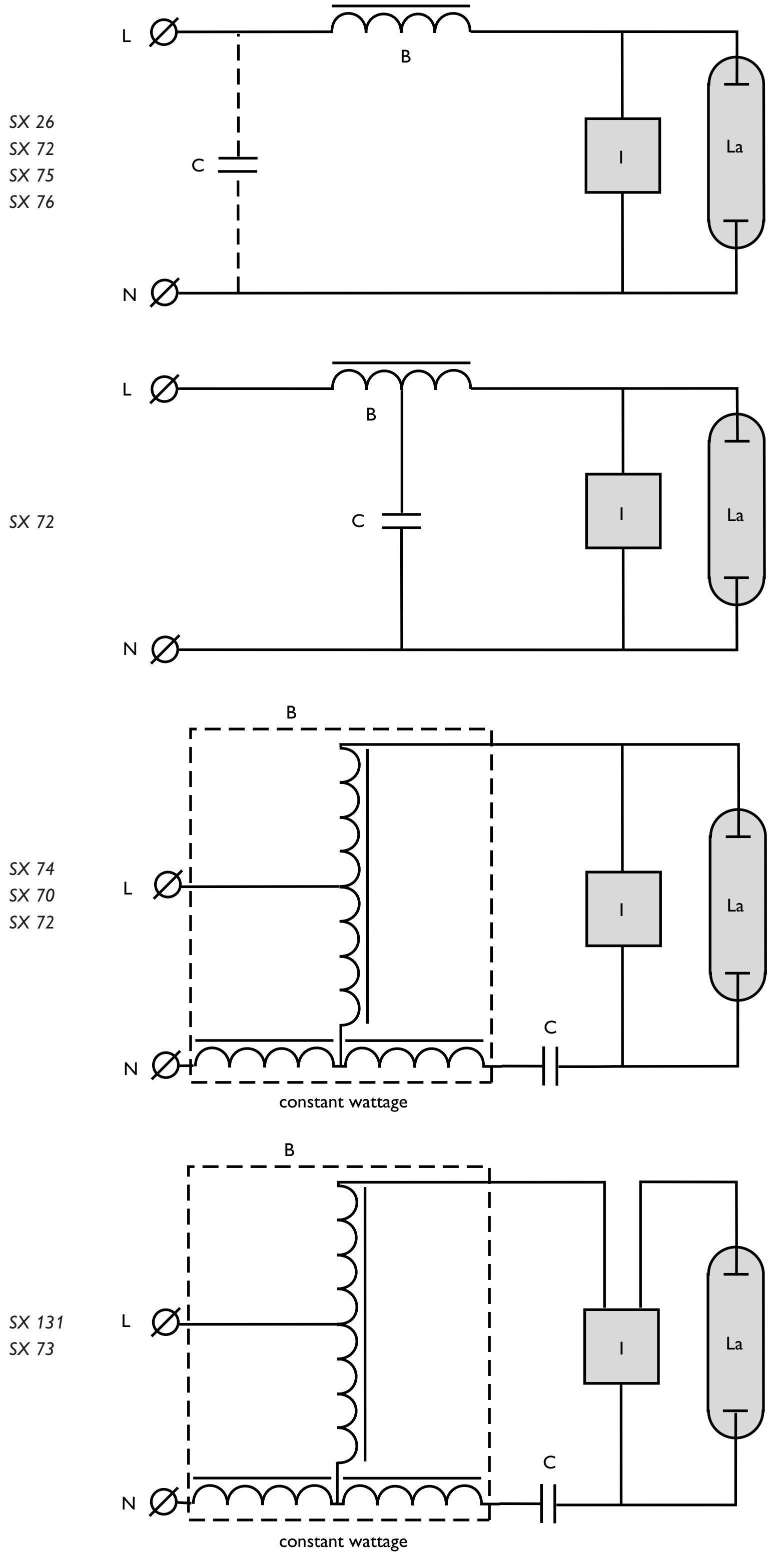


Fig. 49. Basic wiring diagrams for SOX/SOX-E lamp circuits.
La = lamp
B = ballast
I = ignitor
C = capacitor

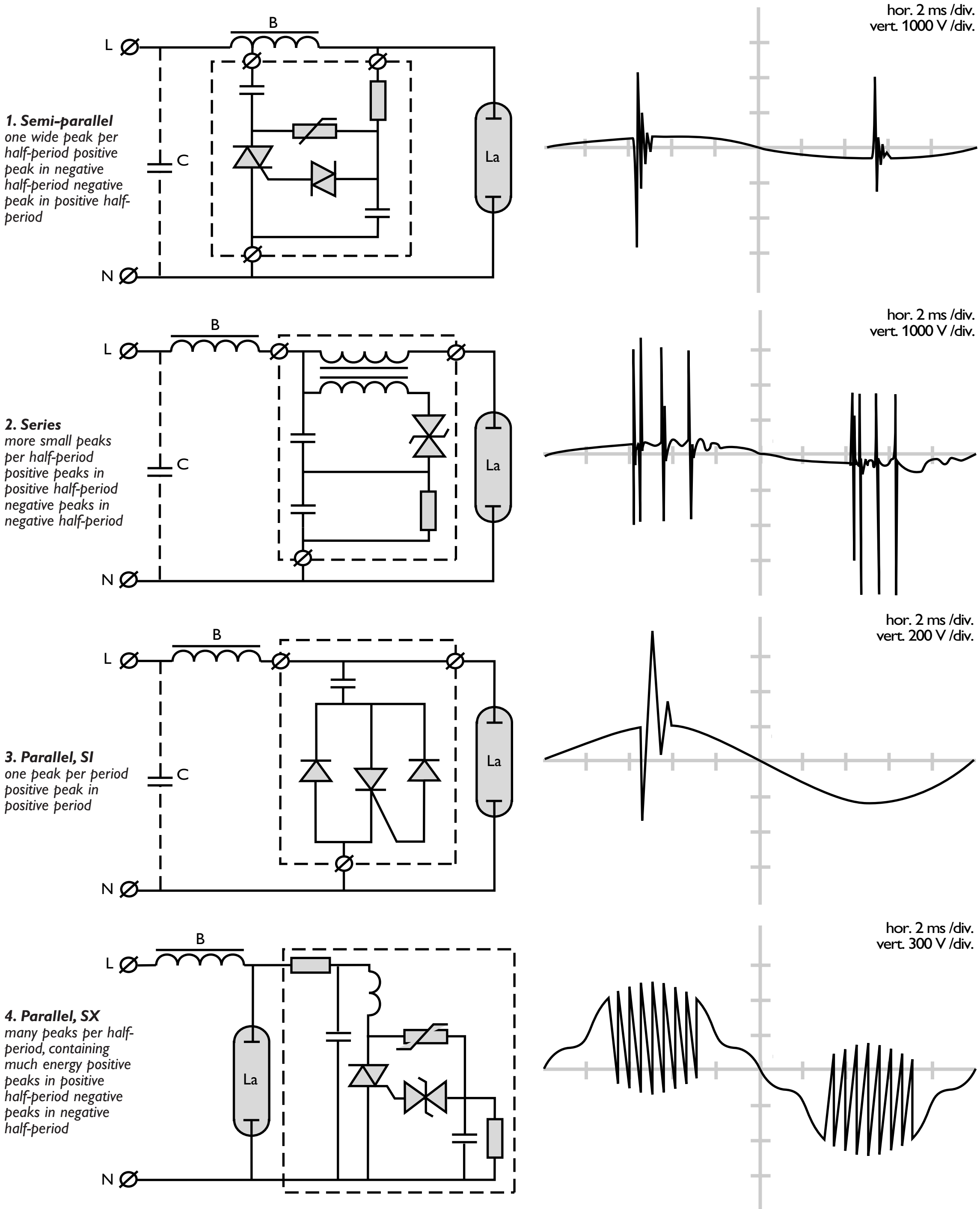


Fig. 50. Principal ignitor circuits and ignition peaks.

4.2.5 Ignition peaks

Substantial energy content in the semi-parallel ignition pulse.
Because the ignitor uses the ballast to generate the ignition pulse, the energy content of the pulse is particularly high. This high-energy content ensures reliable lamp ignition. Furthermore, it allows considerable distances between ignitor and lamp, enabling the gear to be located more remotely: distances of 20 m, under nominal conditions, are very common. A further advantage is the low influence of cabling in the luminaire since the ignition voltage is measured and regulated.

4.3. Systems

4.3.1 Components

A customer is primarily interested in finding a solution to his lighting requirements. Basically, he needs two things, both of which must completely meet his specifications: a design and components. To make sure that the installation works properly under all circumstances, the right components must be chosen and selected in combination with each other.
In principle the following components are required in a lighting installation:
- lamps
- lampholders
- luminaires
- gear (ballasts, ignitors)
- compensating capacitors
- cabling
- fusing and switching devices
- filter coils (if necessary)
- dimming equipment (if possible and required)
- locations on which to mount the components (cabinets, masts)

Information about **lamps** can be found in the lamp documentation, where also the type of **lampholder** or lamp cap is mentioned. Be sure to use the appropriate lampholder, as there are many different types.
For example: there are two types of E27 lampholders, one for SON lamps maximum 2500 V and another for CDM maximum 5000 V.
Lamps with different wattages are in principle not interchangeable in a given circuit, even though they may have the same lamp cap and fit in the same lampholder.
Also lamps of different families are not interchangeable. For example, a SON 50 W lamp will not function well in an HPL 50 W installation. One exception is the SON-H lamp, which is specifically designed to be directly interchangeable with mercury vapour lamps, without any change of gear. This offers an immediate improvement by using less energy and producing more light.
Also some HPI-T Plus BU lamp types can be used with HPI-T gear, as well as with, under some conditions, SON gear.

The **luminaire** documentation contains information as to which lamp types can be used. When installing other than specified types, electrical, thermal or lighting problems may arise. The luminaire documentation also states whether or not the gear is incorporated in the luminaire and what the cable entries and connections are. Also available gear trays and gearboxes can also be found here.

The **gear** documentation contains information on the electrical terminals and the electrical wiring diagrams. The value and the voltage range of **capacitors** are also mentioned here.

The remaining system-related components and subjects mentioned above will be described in the following sections.

4.3.2 Capacitors

Two types of capacitors are found in HID lamp circuits. One type is the parallel compensating capacitor for power factor improvement, connected across the mains 230V / 50 Hz or 60 Hz, between live and neutral, or across the two phases of a 380/400V mains supply. Capacitors are necessary for power factor correction, as the power factor of an inductively stabilised circuit is approximately only 0.5. The parallel capacitor does not influence the lamp behaviour. It normally has a capacitance tolerance of ± 10%. In semi-parallel ignition systems this capacitor also plays a role for reliable ignition.

The second type of capacitor is the series capacitor, which also determines the lamp current. Series capacitors are only used in SOX constant wattage circuits and are connected in series with the SOX lamp.
In these circuits the voltage across the capacitor is higher than the mains voltage, usually more than 400 V.
So normally they should be marked with 450 V, with a capacitance tolerance of ± 4%.

In the relevant ballast documentation, values can be found for the capacitance in microFarad (μF) and for the capacitor voltage needed for a certain combination of lamp and supply voltage to achieve a power factor of ≥ 0.9.
Every user can in fact create his own solution for obtaining the necessary capacitance.

To do things well, certain design aspects have to be considered:
- First of all, capacitors for discharge lamp circuits have to fulfil the requirements as specified in IEC publications 61048 and 61049 with amendments 1 and 2.
- The capacitor shall carry the ENEC mark and the mark A or B according IEC 61048.
- Normally every lamp circuit is compensated by its own capacitor, but in some special cases can group or central compensation for a number of lamp circuits prove a better solution.
- It is possible to build up a greater capacitance by connecting smaller ones in parallel.

- In the case of failure of the parallel capacitor (open or short-circuited), the lamp behaviour is not affected. Regular control of the mains currents and/or power factor (λ or cos φ) is advisable.
- In the case of failure of the series capacitor, the lamp behaviour is immediately affected. This type of capacitor must create an open circuit in case of failure, so that the lamp will be extinguished.
- The lifetime of capacitors depends on the capacitor voltage and capacitor case temperature. Used within the specifications, capacitors will have a lifetime equal to that of ballasts: 30 000 hours or 10 years.
- If a specified parallel capacitance value is not available, the next higher value can be used, provided that the value is not more than 20 per cent above specification.

Two general types of capacitors are currently in use: the wet and the dry type.
The **Wet** capacitors currently available contain a non-PCB oil and are equipped with internal interrupters to prevent can rupture and resultant oil leakage in the event of failure. So a clearance of at least 15 mm above the terminals has to be provided to allow for expansion of the capacitor. The metal case of an oil capacitor must be connected to earth.
In the case of failure, these capacitors will result in an apparent open circuit, which means that in the case of a parallel capacitor the mains current drawn by the circuit approximately doubles. This can cause a fuse to blow or a circuit breaker to open, but will have no further detrimental effect.
Used as a series capacitor, the open circuit of the failing capacitor will extinguish the lamp.
Most oil capacitors have a 90˚C case temperature rating.

Dry, metallised-film capacitors are relatively new to the lighting industry and are not available in all ratings for all applications. However, they are rapidly gaining popularity because of their compact size and extreme ease of installation and are, therefore, widely used nowadays.
There are basically two families of metallisation material: pure aluminium and zinc. During its lifetime the aluminium type of capacitor gradually loses its capacitance.
Dry capacitors are more sensitive to voltage peaks than are wet capacitors. In critical applications (mains supplies containing peaks, frequent switching, high level of humidity or condensation), the wet capacitor is advisable.

The material of the capacitor enclosure can be of metal or plastics. In both cases a safety device must be included that opens the electrical circuit at over-pressure inside the capacitor. For metal can capacitors this requirement is no problem (expansion rills), but with a plastics cap this is more difficult to achieve. It can result in the enclosure not being fully watertight. It is therefore advisable to employ metal-can capacitors in humid or aggressive environments.
Capacitors for lighting applications must have a discharge resistor connected across the terminals to ensure that the capacitor voltage is less than 50 V within 1 minute after switching off the mains power. In special cases the voltage level must be 35 V within 1 second, see IEC 60598-8.2.7.

4.3.3 Filter coils

In some countries, including Belgium, The Netherlands and France, the electricity distribution network is used for transmitting messages. This falls under the responsibility of the local energy supply authority. Superimposed sinusoidal voltage signals are sent over the electricity supply network for a number of purposes: to switch road lighting, to call up fire brigades and the police, to switch night-tariff kWh-meters, and so on. It is important, therefore, that this signalling system is not disturbed, which may occur when parallel power factor correction capacitors for lamp circuits are employed. Capacitors present a low reactance to the 110-3000 Hz ripple control signals employed for signalling, with the result that these are in danger of being short-circuited by the capacitive circuit. To avoid this, a coil must be connected in series with the capacitor connected parallel to the mains. This filter coil, as it is termed, presents a reactance that increases with rising signal frequency. The coil reactance is therefore so chosen as to balance out the reactance of the capacitor at approximately 200 Hz (the resonance frequency, see Fig. 51), although types with a different resonance frequency can be found on the market.

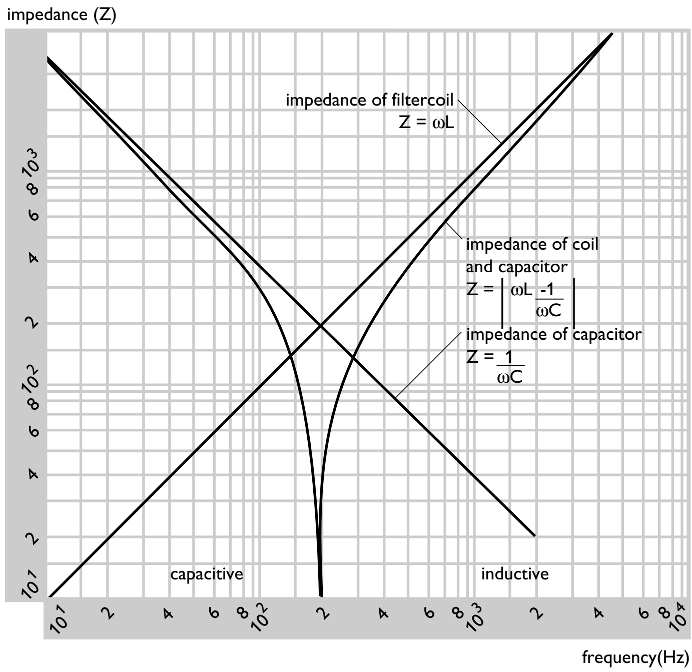


Fig. 51. Impedance of a filter coil, a capacitor and a coil/capacitor combination as a function of frequency.

For currents with a frequency of 50 Hz, the L-C combination is predominantly capacitive, which is necessary for power factor correction. Above 200 Hz the circuit becomes predominantly inductive, which is necessary for the blocking of audio-frequency signals. At 200 Hz the impedance is formed only by the ohmic resistance, mainly of the filter coil. As can be seen from the graph, the filter coil is effective for audio signals of 300 Hz and higher, because then the impedance of the coil/capacitor combination is higher than the impedance of the capacitor on its own.

Filter coils should not be used when the audio signals are 300 Hz or lower.
When the audio frequency is high (say >1200 Hz), a physically smaller filter coil can be employed by fixing the resonance frequency not at 200 Hz but at, say, 400 Hz.

There are other advantages to be gained from employing filter coils. The parallel capacitor can cause troublesome switching phenomena to occur, which can give rise to very large current surges. Although these surges are of only very short duration (a few milliseconds), they are nevertheless sufficient to cause switching relays to stick or circuit breakers to switch off. The filter coil serves to prevent this problem by damping the very short, high-amplitude pulses in the current.
The type of filter coil needed depends on the capacitance of the capacitor employed. So in fact every capacitor needs its own filter coil. In some cases, however, it is possible to group the capacitors and match them with the corresponding filter coil. For example: two capacitors of 4 μF connected in parallel can be placed in series with one filter coil of 8 μF (see Fig. 52).
Although the voltage across the filter coils is rather low (ca. 14 V to 20 V), the filter coils have to be regarded as ballasts, as they are connected direct to the mains. They also cause some additional watt losses.
The voltage across the parallel compensating capacitor will increase by between 5 and 7 per cent as a result of adding a filter coil.

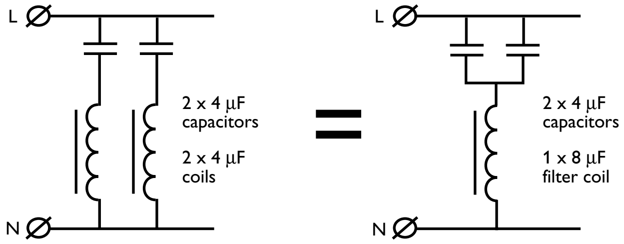


Fig. 52. Different ways of grouping capacitors to match them with the corresponding filter coil.

The amount of third and fifth harmonics in the mains **current** will increase in cases where the mains supply **voltage** is disturbed by these harmonics, when employing a filter coil. The total impedance for the combination of capacitor and filter coil is lower than the impedance of the capacitor alone for these frequencies (see Section 4.3.7: Harmonic distortion and Fig. 51).
When the percentage of the 3th or 5th harmonic in the mains voltage is more than 5 percent, the capacitor current can rise considerably with the risk of capacitor failure.

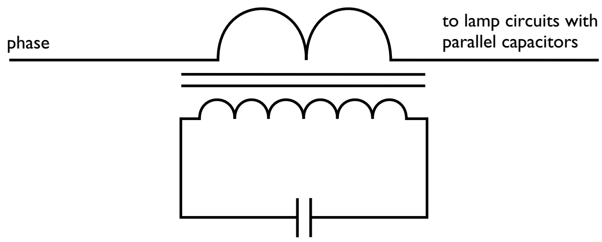


Fig. 53. Basic scheme of a central blocking filter.

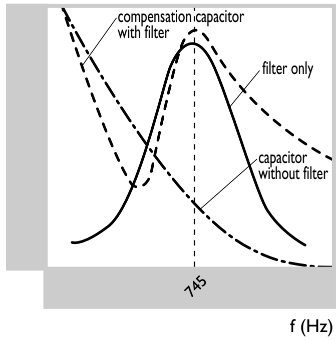


Fig. 54. Impedance of central blocking filter as function of frequency.

Central filter coil systems also exist where a filter system in the supply system blocks the applied signalling frequencies. In principle this system consists of a transformer and a capacitor, (see FigS. 53 and 54).
The primary of the transformer has a few windings of thick wire, situated in the phase line. The secondary wiring together with the filter capacitor form the resonance frequency, which has to be blocked.

4.3.4 Power factor correction

Circuits with gas-discharge lamps are stabilised with inductive ballasts and compensated for a good power factor with a parallel compensating capacitor (mono-compensation, Fig. 55).

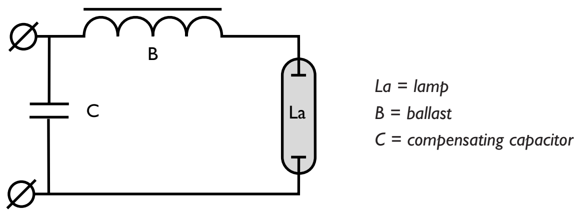


Fig. 55. Power factor correction with a parallel compensating capacitor.

Without the capacitor the inductive ballast causes a phase shift of the current, which is lagging behind the applied voltage.
This can be seen in Fig. 56, which shows the lamp current I_l, the lamp voltage V_l (both in phase with each other), and the sinusoidal form of the mains voltage V_m.

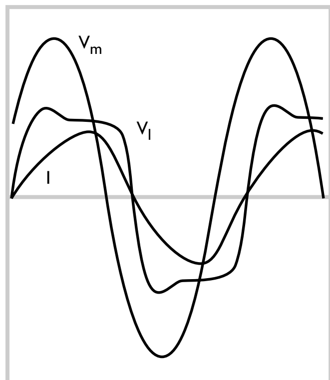


Fig. 56. Lamp current (I), lamp voltage (V_l) and mains voltage (V_m).

The power factor of the circuit can be calculated by dividing the total wattage by the product of mains voltage and current. Expressed in an equation:

$P.F. = (W_l + W_b)/(V_m \times I_m)$ (1)

where W_l = lamp power and W_b = ballast losses.

Without the parallel compensating capacitor, the power factor of a gas-discharge circuit is ca. 0.5.
For the fundamentals of the voltages and current a so-called vector diagram can be made (see Fig. 57).
Lamp voltage and lamp current are in phase and the voltage across the ballast is leading the current by 90 degrees. The vectorial sum of lamp voltage and ballast voltage gives the mains voltage. Now we see that $\cos \varphi = V_l/V_m$, which is less accurate than (1).

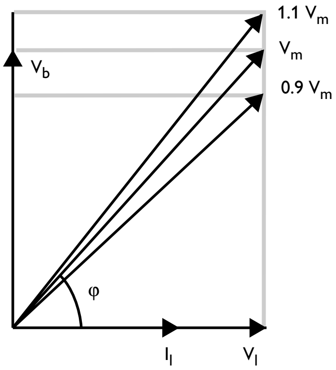


Fig. 57. Vector diagram showing lamp voltage (V_l) and lamp current (I_l) in phase.
Voltage across ballast (V_b) is leading 90 degrees;
V_m = mains voltage.

In any case, the energy supply authority has to deliver an apparent power of $V_m \times I_l$ to the system on which the distribution network must be based (cabling, transformers).
The standard energy meter only records the in-phase component $V_m \times I_l \cos \varphi$, so the supply authority does not get paid for the so-called 'blind' part:
$I_l \sin \varphi . V_m$ (see Fig. 58).

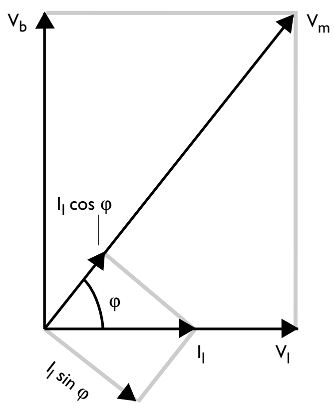


Fig. 58. Uncompensated circuit with lamp current (Il) and mains voltage (Vm) out of phase.

It is for this reason that the supply authority insists on compensation of the phase shift.
Where in general the 'unadjusted' power factor is about 0.50, it has to be compensated to a minimum of 0.85, or even 0.90. This is achieved by adding a capacitor across the mains. In contrast to an inductive ballast, the capacitor current is leading the capacitor voltage (which is the mains voltage) by 90 degrees. So the capacitor current has the opposite direction of $I_l \sin \varphi$ (see Fig. 59).

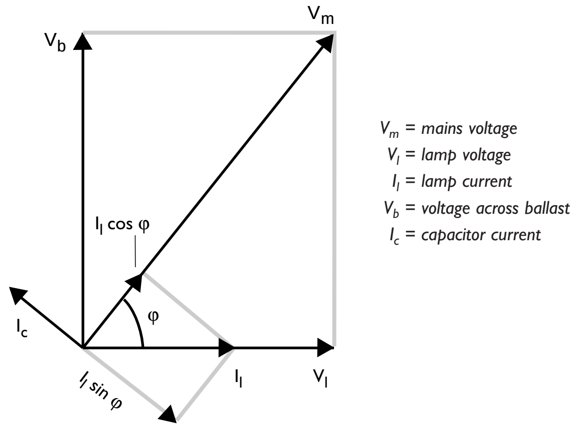


Fig. 59. Compensated circuit.

Maximum compensation is achieved when the current through the capacitor $I_c = I_l \sin \varphi$; the power factor is then 1. This is purely theoretical, as the vector diagram is only valid for the fundamentals of the currents. Due to distortion in the lamp current (see Section 4.3.7: Harmonic distortion), the maximum practical power factor is between 0.95 and 0.98. This explains the difference between power factor and cos φ.

The term THD (Total Harmonic Distortion) is defined as:

$$THD = \sqrt{\sum_{n=2}^{\infty} \left(\frac{I_n}{I_1}\right)^2} = \sqrt{\frac{1_2{}^2+1_3{}^2+1_4{}^2+\ldots}{1_1{}^2}}$$

which means the root mean square of the sum of all the higher harmonics divided by the fundamental. It can be calculated from the values obtained by a spectrum analyser. Nowadays even with a very simple hand-held instrument this value can be measured very well.
The power factor can be derived from the THD by means of the formula:

$$P.F. = \cos \varphi / \sqrt{[1 + THD^2]}$$

where THD = distortion in mains current, assuming that the THD in mains voltage is zero.

Another equation also gives the relation between the power factor and the phase shift:

$$P.F = \cos \varphi \,.\, I_1 / I_{eff}$$

The power factor is the result of the quotient of the actual wattage and the product of mains voltage and mains current, including the harmonics, and can be calculated as follows:

Power factor (P.F.) = total wattage / (mains voltage x mains current)

The angle φ is the phase shift angle between mains voltage and mains current and can be found and calculated by means of the vector diagram. This is only valid for the fundamentals and does not take into account the harmonics.

The same analogy is valid for the lamp: there is practically no phase shift between lamp voltage and lamp current: both are zero at the same time. So the phase angle α is zero and cos α = 1.
The product of lamp voltage and lamp current does not equal the lamp wattage; the difference is called the lamp factor:

Lamp factor = lamp wattage / (lamp voltage x lamp current)

and has a value between 0.8 and 0.9. For the same lamp type, the lamp factor is higher for higher wattages – which is the same for the lamp efficacy.

During the ignition and run-up period the power in the lamp rises from a low value to the stabilised lamp power. The lamp current during this period is higher than the nominal value. Therefore the power factor starts at a low (inductive) value (0.2 - 0.3) and it takes the run-up time of several minutes to reach the nominal value of 0.85 - 0.9.

During the lifetime of SON, MH and CDM lamps, the lamp voltage will rise and so the lamp current will decrease. The capacitor current, however, will not change. This means that the power factor will first rise to its maximum, after which it will decrease and become capacitive (see Fig. 60).

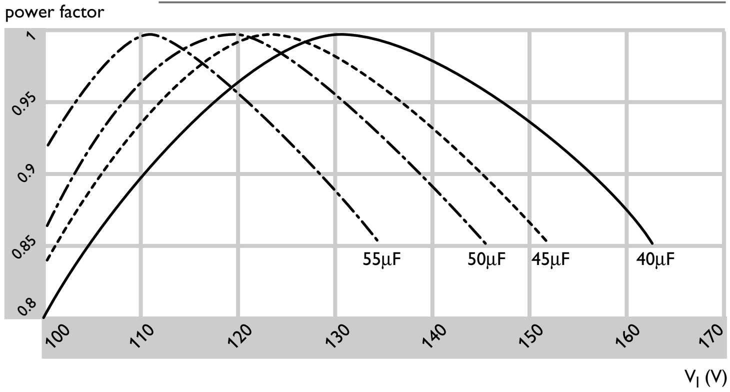


Fig. 60. Power factor as function of the lamp voltage for various capacitor values.

In most applications this hardly is a problem.
In horticulture (glasshouses), however, all lamps are replaced after some years, and are often powered by a Total Energy plant (stand-alone generator). Generators cannot normally smoothly handle a capacitive power, so here good recording of the power factor is advisable.

Practical determination of the capacitor value

To determine the capacitor value needed to obtain a more favourable power factor, proceed as follows.
1. Determine the current strength in the lamp circuit, and hence cos φ, with no correction applied.

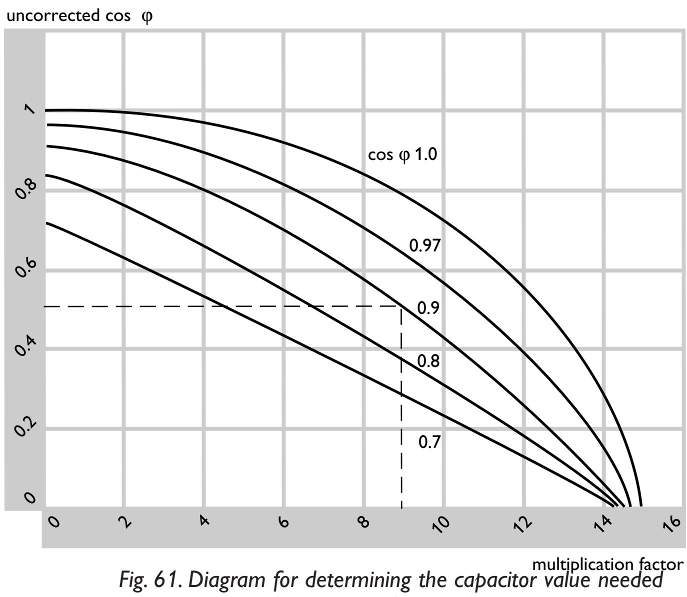


Fig. 61. Diagram for determining the capacitor value needed to obtain a specified degree of power factor correction.
Example:
Lamp current = 17.3 A
Uncorrected cosΦ = 0.5
Desired cosΦ = 0.9
whence C = 17.3 . 9 = 156 μF

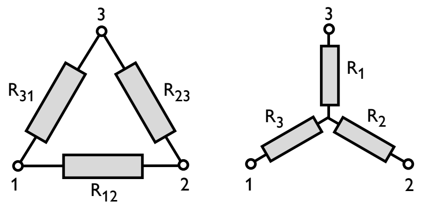
This information can be found in the table of technical data for the ballast concerned.

2. Locate this uncorrected cos φ value on the vertical axis of Fig. 61 and draw a horizontal line from this point to intersect the curve representing the desired cos φ value.
3. From this point of intersection draw a vertical line down to the horizontal axis.
4. Multiply the uncorrected current strength in amperes by the multiplication factor thus found on the horizontal axis to obtain the capacitor value in μF needed to obtain the desired degree of correction.

The operating current after correction can be found by multiplying the uncorrected current by the quotient of the original and the new cos φ.
The starting current changes as well. The new supply current during starting can be found by subtracting a maximum of 0.069 A from the uncorrected starting current for each microFarad of capacitance employed for correction.

Compensating between phases

Most circuits are connected in a star network, where the load is connected between neutral and the phase (normally 230 V). Some circuits are connected in a delta network between two phases (normally 380 or 400 V).
If the load is well balanced across the three phases, compensation can be realised between the phases and neutral or between the phases. For the mains current and the power factor there is no difference between the two possibilities, as long as the capacitance in star is three times higher than the capacitance in delta, according to the star-delta transformation (see Fig. 62).
So $C_{230V} = 3 . C_{400V}$ in μF.



$$R_3 = \frac{R_{31} \cdot R_{23}}{R_{12}+R_{23}+R_{31}}$$

$$R_{12} = R_{23} = R_{31} = R$$

$$R_3 = \frac{R^2}{3 \cdot R} = \frac{R}{3}$$

Fig. 62. Star-delta transformation.

The cheapest way of compensating is between the phases. But then provisions in the switching part of the installation have to be made so as to avoid resonance; see following section.

4.3.5 Neutral interruption and resonance

Normally each lamp circuit has its own compensating capacitor. In this way every luminaire can be switched separately without influencing the power factor. For the same reason, lamp circuits based on phase-neutral (230 V), are compensated with capacitors connected between each of the phases and neutral.
In the phase-neutral network, failure of one phase has no other effect than to switch off the circuits on that phase. But if the neutral is not connected, resonance will occur. For example, the current from phase R via ballast and lamp 3 (see Fig. 63) can pass via capacitor C1 to phase T. So lamp 3 is energised by 400 V and stabilised by a ballast **with a capacitor** in series. This is bound to destroy components. **A good neutral is essential**.

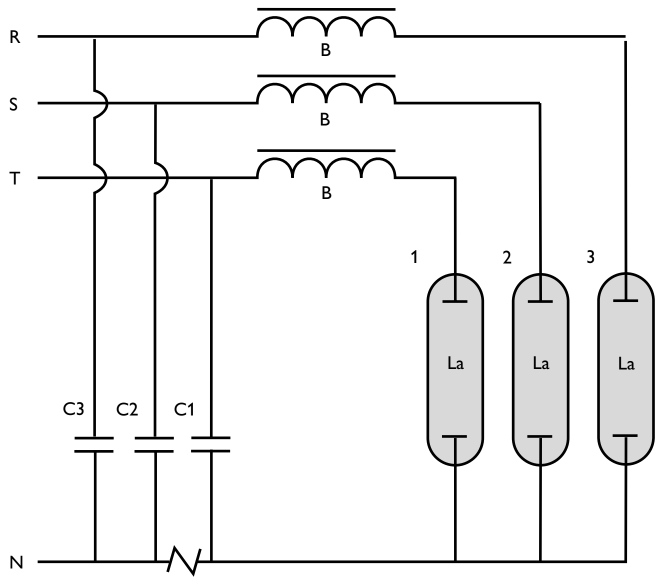


Fig. 63. Phase/neutral network.

Moreover, when the neutral is interrupted and the loads on the phases are not completely balanced (viz. the same wattage), then the voltage across the smallest load will increase and much more power will be consumed by that load. This, too, is bound to damage lamps and/or ballasts (see Fig. 64).
Suppose there are five loads of 1000 Ω, one connected between L1 and neutral and four connected between L2 and neutral.

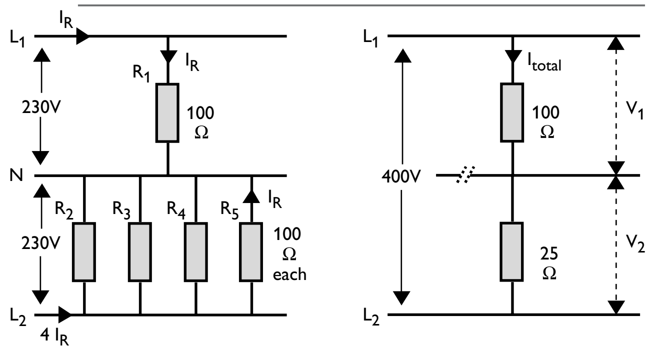


Fig. 64. The consequences of interrupted neutral in a phase/neutral network.

The current from L1 will be 230/1000 = 0.23 A and the power in the load will be 230 x 0.23 = 53 W. The current from L2 will be four times higher (0.92 A) as will the power: 212 W. If the neutral is interrupted, the phase-phase voltage of 400 V will result in a current, which can be calculated from the resistances: 1000 Ω in series with 4 times 1000 Ω parallel.
This makes 1000 + 250 = 1250 Ω. So the current will be 400 / 1250 = 0.32 A. The voltage across R1 will be 0.32 x 1000 = 320 V (V = I x R), so the power in R1 will be 320 x 0.32 = 102 W. The voltage across the four parallel resistors is 0.32 x 250 = 80 V, so the power in each resistor is 80 x 0.08 = 6.4 W.
Now it is seen that the smaller load (R1) is overloaded by a higher voltage (320 V instead of 230 V) **and** a higher current (0.32 A instead of 0.23 A). The higher load (R2 to R5) is greatly underloaded.
In practice, the circuits are not this simple, but the essential aspect is that in the case of a floating neutral, the smallest load will receive a higher voltage and a higher current and so will be overloaded.

In the phase-phase network failure of a phase also can result in resonance. Suppose phase S (see Fig. 65) has failed. Then the current from phase R via ballast and lamp 1 can pass via the capacitance 3 to phase T.

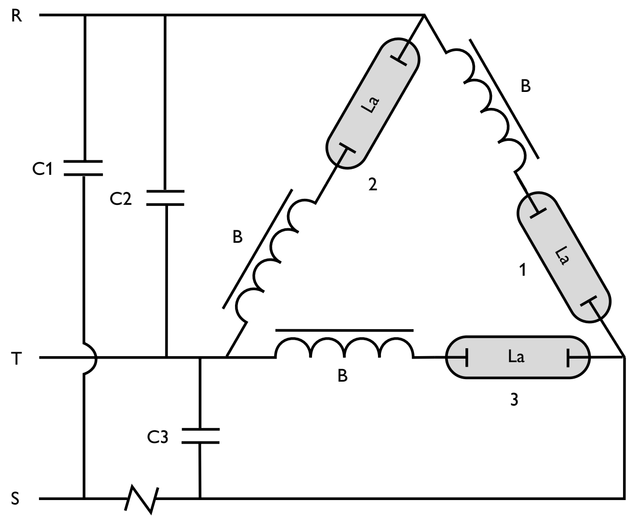


Fig. 65. Phase/phase network.

Depending on how many capacitors are connected between the phases S and T and on the ballast impedance, quite high currents can occur, which can destroy components. Therefore: **if one phase fails, the other two phases of the same group must be switched off too.**

To avoid this resonance, compensation can be realised by three capacitors between the phases and the neutral (see Fig. 66). The capacitance of these 230 V capacitors has to be three times higher than the capacitance of the 400 V capacitors.

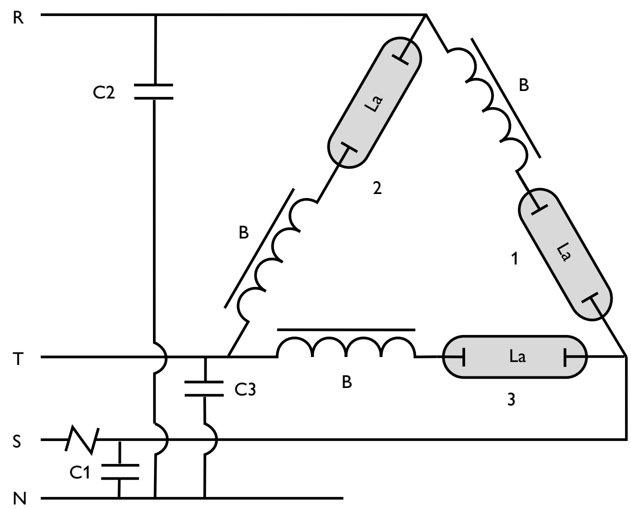


Fig. 66. Compensation with three capacitors between the phases and the neutral.

If now phase S fails, the current from phase R via ballast and lamp 1 will flow to the neutral via capacitance C1. The lamp is fed by 230 V, which will be noticeable by the lower light output or by the lamp extinguishing.

Sometimes three lamps, connected to the three phases and the neutral, can be considered and switched as one group. In that case the compensating capacitors can be connected between the phases with a capacitance of $C_{400V} = C_{230V} /3$ (see Fig. 67).

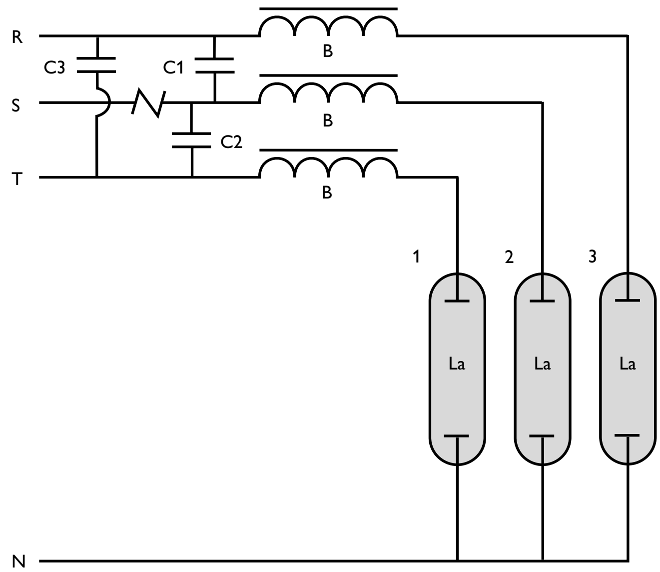


Fig. 67. Compensating capacitors connected between the phases.

If in this case a phase fails, there is again the resonance phenomenon: if phase S fails, the current from phase R via C1 can pass through the ballast and lamp 2 to the neutral. Depending on the ballast impedance and the total capacitance between phases R and S quite high currents can flow through lamp 2. Therefore here too it applies: **if one phase fails, the other two phases have to be switched off too.**

4.3.6 Mains voltage interruption and short-circuiting

For various reasons, the supply voltage can be subject to fluctuations; therefore a certain degree of deviation from the rated value has been taken into account everywhere. With gas-discharge lamps deviations of up to ± 10 % of the rated supply voltage normally have no detrimental effects.
In practice, three possible effects can be distinguished:
1. Short-circuit of the mains voltage.
2. A dip in the power supply voltage.
3. Interruption of the power supply current.

These phenomena may, for instance, occur during a thunderstorm, when switching from one power supply source to another or when switching heavy loads on the mains, and are usually of very short duration. Nevertheless, a single dip of 10 milliseconds (half a cycle) or even less, may have a significant effect.
The lamp will extinguish if the de-ionisation of the discharge medium has progressed so far that the available voltage is not sufficient for re-ignition. The lamp must then first cool down before it can be re-started. Typical re-ignition times can be found in Section 3.3: Ignition and run-up.
In order to find out what dip or interruption time a lamp can cope with, the following points have to be considered:

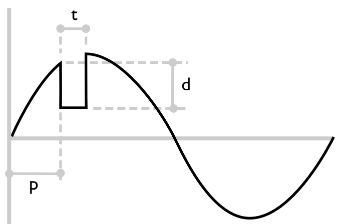


Fig. 68. Definition of a mains voltage dip.

- The dip itself: the dip (see Fig. 68) can be defined by three parameters:
  1. the depth d (= 100% for interruption),
  2. the duration in milliseconds,
  3. the phase p in relation to the zero-passage.
- The frequency: a single dip has less influence than repetitive dips.
- The lamp: viz. whether an aged or a new - older lamps usually need higher re-ignition voltages than new lamps, due to higher lamp voltages and/or cathodes losing emitter material.
- The circuitry: for example, the parallel power factor correction capacitor reacts as an extra power supply for the lamp at the moment of mains voltage dips and interruptions, and will therefore enlarge the permissible interruption time or dip, compared to an inductive circuit.

- The practical use: the kind and quality of the power supply source (transformer/generator) and circuit (cabling, fusing, switching) influence the effect.

From theory and tests it is known that high-intensity gas-discharge (HID) lamps are the most sensitive to voltage interruptions and dips at the moment that the lamp current passes the zero-line.
To find statistically reasonable results, the tests have to be done with more than one lamp; in one batch the individual results may vary considerably. On the other hand, it is hardly possible to test all characteristics of all discharge lamps, as this requires computerised test circuits and time-consuming tests.

Some conclusions from tests done by Philips with Philips lamps and circuitry are as follows:

1. All gas-discharge lamp circuits are very sensitive to **short-circuiting of the mains** voltage. Permissible short-circuit time: max. 1-2 milliseconds.
2. **Supply voltage** dips of more than 20% can extinguish the lamps.
3. Permissible **mains current interruption** times (indicative) in milliseconds:

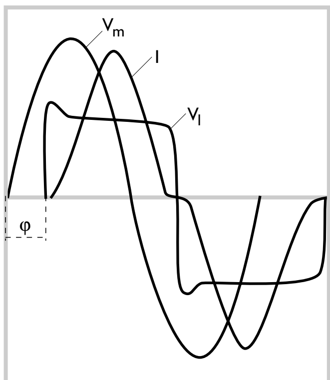
Lamp	**SON(-T)**	**HP(L)**	**MHN-LA HPI-T**	**MH 1800 /230 V**	**MH 2000 /400 V**	**SOX**
Inductive	3-4	6	4	2	8	unlimited
Compensated	10	10	8	6	10	unlimited

Only with high-pressure mercury lamps is there a relatively simple way of mitigating the effects of the voltage dips. By connecting a 3.6 μF/420 V capacitor in parallel across the lamps, short voltage dips will not cause the lamp to extinguish, as the capacitor will discharge during such a dip and thus keep the lamp ionised.

Self-stopping ignitors SN**T5/15 are resistant to voltage dips within the timer setting of 5 and 15 minutes respectively.

4.3.7 Harmonic distortion

All gas-discharge lamps stabilised by copper/iron ballasts have harmonics in the lamp current. The first reason for this is that the lamp voltage (= the voltage across the discharge tube) is approximates a square wave of changing polarity every half cycle (see Fig. 69).



V_l = lamp voltage
V_m = mains voltage
I_l = lamp current.

Fig. 69. Square wave form of lamp voltage.

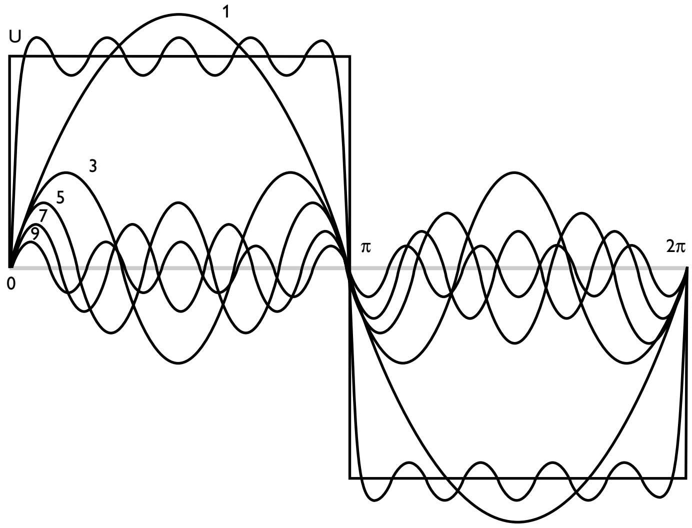


Fig. 70. Lamp voltage wave form built up from the odd harmonics from one to nine, according to the formula: $f(t) = \frac{4U}{\pi} \cdot (\sin \omega t + 1/3 \sin 3\omega t + 1/5 \sin 5\omega t + ...)$.

This is graphically represented as a square wave voltage, made up by Fourier analysis as the fundamental sine wave of the mains supply and a large number of odd harmonics (see Fig. 70).
The voltage across the ballast is the vectorial difference between the supply voltage and the lamp voltage, so the harmonics of the lamp appear in the ballast voltage.
As the ballast determines the current, there will be only odd harmonics in the lamp current. Even harmonics are not present.

The second reason for the presence of harmonics in the lamp current is the hysteresis of the ballast coil. With the aid of the relationship between ballast voltage and ballast current (B-H curve of the ballast coil, see Fig. 71), the resulting current can be found for any ballast voltage. Even with a pure sine-wave ballast voltage there will be some harmonics in the ballast current, but this effect is small compared with the harmonics caused by the lamp.

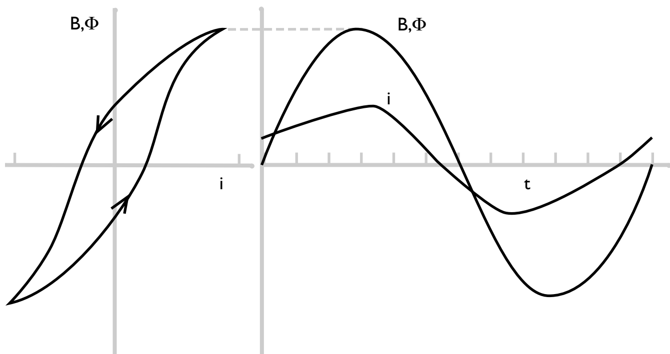


Fig. 71. Hysteresis curve of a typical copper/iron ballast.

The impedance of the coil becomes higher for higher frequencies, so in practice only odd harmonics up to the seventh are of any importance for the lamp current. Practical values as a percentage of the fundamental for most inductively stabilised discharge lamps are:

fundamental:	100%
third harmonic:	10%
fifth harmonic:	3%
seventh harmonic:	2%
ninth and higher harmonics:	1% or lower

When the supply voltage contains harmonics, these values can change somewhat, but the ballast coil prevents dramatic increases.

International requirements have been laid down for the proportion of the harmonics in mains supply currents. According to IEC 61000-3-2, for lighting equipment having an input power >25 W the maximum percentage of harmonics for the input current are:

second harmonic:	2 %
third harmonic:	30 . P.F. %, where P.F. = power factor of the circuit
fifth harmonic:	10%
seventh harmonic:	7%
ninth harmonic:	5%
$11 \leq n \leq 39$	3%

All Philips inductively compensated lighting circuits (P.F. = 0.5) comply with this standard.

To obtain a good power factor (0.9) of the system with gas-discharge lamps, parallel capacitors are mostly used. The **effective** mains current will then be nearly half, so the **percentage** harmonics will automatically be doubled. Again, there will be no problems in fulfilling the requirements.
A capacitor, however, has lower impedance for higher frequencies and therefore the capacitor current is very sensitive to harmonics in the **supply voltage**.

The quality of the supply source influences the amount of higher harmonics in the mains voltage and consequently in the mains current. The lamp is only responsible for roughly 20 per cent third harmonics in the current of the phase-conductor. When the amount of seventh or higher harmonics in the phase current is too high, a solution could be found in connecting filter coils in series with the capacitors. But adding the filter coils will result in higher third and fifth harmonics, because the total impedance for the combination of capacitor and filter coil is lower for these frequencies than the impedance of only the capacitor (see Fig. 51 in Section 4.3.3). So a filter coil does not help to suppress third and fifth harmonics.

The presence of harmonics has consequences for the mains wiring.
Calculations of the currents and harmonics can be made for the various wiring diagrams. Lighting installations connected to three-phase supplies having a common neutral conductor, need particular attention.
The neutral conductor carries a current equal to the vector sum of the currents through the three phase conductors. In a well-balanced system (equal effective phase-currents), the fundamental frequencies of these currents add up to zero, but the third, ninth and fifteenth harmonics are in phase and thus amplify each other (see Fig. 72).

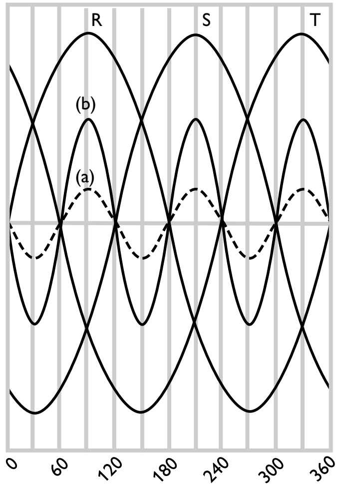


Fig. 72. Fundamental and third harmonic in a three-phase mains.
R, S and T are the fundamentals in the three conductors. Owing to the phase shift, a zero current in the neutral lead results.
(a) = third harmonic of a phase
(b) = third harmonic of all three phases in the neutral lead; the individual currents reinforce each other.

The neutral will therefore carry at least about 3. 20 = 60 per cent of the phase current. For this reason the neutral conductor must have the same cross-section as each of the phase conductors.
In the case of a poorly designed system or different load on the three phases, the current in the neutral can be higher than one of the phase currents.
In the case of a supply voltage containing some distortion, the current through the neutral can also grow rapidly due to higher capacitor currents. This can be of great importance when the supply voltage is coming from a separate generator. Special filters are on the market to reduce the third harmonic current in the neutral (see Fig. 73:

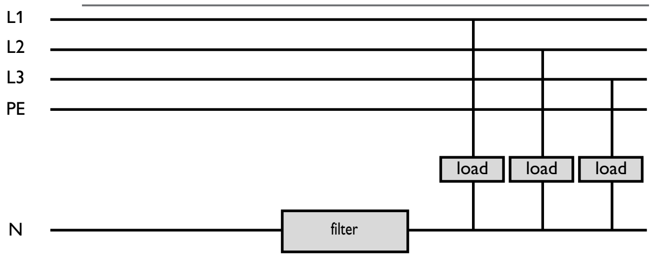


Fig. 73. Blocking filter for third harmonic in neutral.

Measurements of harmonic content

Harmonics in the current are normally measured in a single-lamp circuit. Most HID lamp circuits are compensated with a capacitor across the mains supply. And then there are the three-lamp circuits on three phases. Thus, three different harmonic measurements are possible:

1. Harmonics of the normal single-lamp circuit (also called: inductive).
In all cases, the values obtained from these measurements are low, and easily fulfil the international requirements. Due to the high impedance of the ballast coil such measurements are not very sensitive to disturbances in the mains voltage waveform.

2. Harmonics of the compensated single-lamp circuit.
With an ideal mains supply sine wave form and an ideal capacitor the percentage harmonics in the mains current will increase, as the nominal mains current is lower than the lamp current, while the absolute values (in amperes) of the harmonics in the lamp current do not change.
In practical situations the capacitor is not ideal and there is always some distortion in the mains supply waveform. Normally there are no problems in fulfilling the international requirements.
If there is noticeable distortion in the mains supply it is possible that the limits are exceeded.

3. Harmonics in a three-lamp circuit with three phases.
Here two different situations can be distinguished:

a) Star network with neutral (230 V circuits, see Fig. 63).
In the phases the same harmonics will be measured as in measurement 2. In the neutral, however, the situation is different: the currents here ad up. For the fundamental this results in zero, as the currents are shifted by 120 degrees. However, the third, ninth, fifteenth, etc. harmonics are added together, so are three times bigger than in measurement 2. As the harmonic content is expressed as a percentage of the fundamental, the values of especially the third harmonic can have a high value (much more than 100 percent).

b) Delta network (400 V circuits, see Fig. 65)
The phase currents will be √3 times the values of the single-lamp measurement (compensated, effective). Due to the delta circuit the harmonics 3rd, 9th, 15 th, etc. will stay in the delta (this is the lamp/ballast/capacitor circuit) and are not present in the phase currents. The values of the 5^{th}, 7^{th}, 11^{th} and 13^{th} harmonic components are very sensitive to the mains voltage waveform and greatly depend on the supply impedance. The 5^{th} and 7^{th} components, especially, can give problems in practice.

Example of effective harmonic measurements in various circuits

Harmonic	Required (%)	Inductive	Compensated single-lamp	Three-phase three-lamp Star phase	Star neutral	Delta phase
Effective absolute		100	52	52	40	√3 . 52
Effective %		100	100	100	100	100
1	100	99.7	95	95	10	99
3	< 30 . P.F.	7.5	15	15	1000	< 0.5
5	< 10	2	6	6	17	8
7	< 7	1.5	1.5	1.5	15	13
9	< 5	< 0.5	< 0.5	< 0.5	18	2
11<n<39	< 3	< 0.5	< 0.5	< 0.5	16	

As was seen previously, non-linear loads, including HID lamps, result in harmonics in the mains current, which are subject to international requirements. The set limits are valid when the mains supply voltage has a good sine wave form. As quality of the supply voltage for the IEC measurements (test house conditions), the Total Harmonic Distortion (THD) is limited to a maximum percentage of 2% (IEC 1000-3-3), with:

third harmonic	0.9%
fifth harmonic	0.4%
seventh harmonic	0.3%
ninth harmonic	0.2%
second - tenth harmonic	0.2%
> eleventh harmonic	0.1%

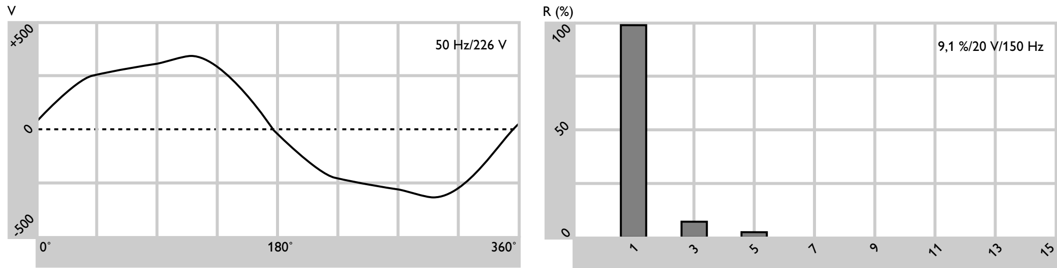


Fig. 74. Example of mains voltage wave form with distortion, resulting in...

In practice, however, the power supply voltage does not always have such a good waveform, and the amount of distortion can be much higher (see Fig. 74).
In EN 50160, Voltage Characteristics of Electricity Supplied by Public Distribution Systems,
the limits are set (for 95 percent of the time) as:

second	2%
third harmonic	5%
fourth	1%
fifth harmonic	6%
seventh harmonic	5%
ninth harmonic	1.5%
with a maximum THD of	8%

The amount of harmonics in practical projects can therefore differ from published values.
Harmonics in the mains supply voltage influence hardly, if at all, the behaviour of the lamp - the impedance of the ballast increases with increasing frequency. But the impedance of the parallel compensating capacitor is decreasing at higher frequencies. The capacitive current will therefore rise if the mains supply voltage is distorted. A 5 percent seventh harmonic component will increase the current through the capacitor by 7 x 5 = 35 percent. This can lead to a lower power factor and higher phase currents, containing more harmonics than allowed (see Fig. 75).

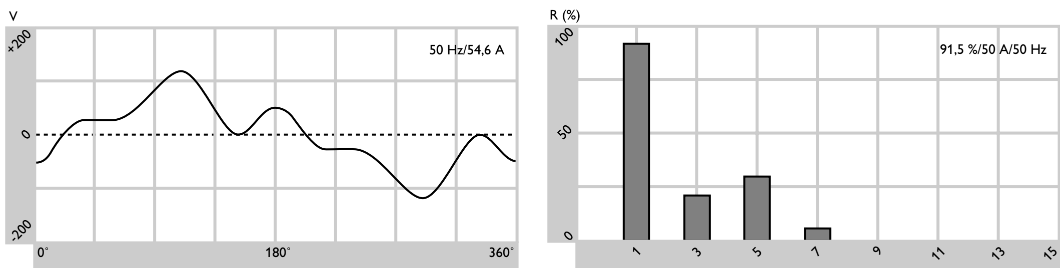


Fig. 75 ..... mains current with high content of harmonics.

This hardly influences the heat dissipation in the cabling and the fusing, as long as the frequencies are less than 15 000 Hz and the cable core is less than 50 mm^2.
But transformers can be overloaded and therefore a derating factor should be applied to avoid damage if the mains supply voltage has a THD of more than 3 per cent.

A special system problem can arise in installations with a lot of lamp circuits, as, for example, in glasshouses and sports stadiums. Seen from the mains all compensating capacitors from one phase are connected in parallel. The mains transformer or generator on its own has a certain inductance (L in henries). This inductance can form a series resonance circuit with the parallel capacitors (see Fig. 76) according the equation $\omega^2 LC = 1$, where:
L = inductance of generator/transformer
C = overall parallel compensating capacity
$\omega = 2\pi f$ with f = resonance frequency

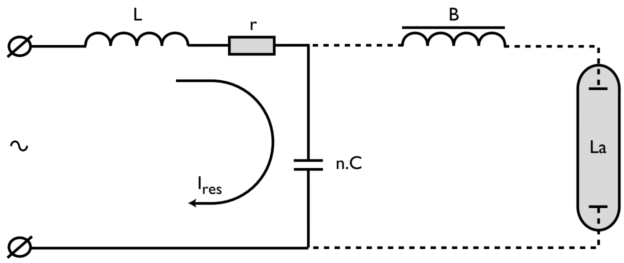


Fig. 76. The inductance of a mains transformer or generator can form a series resonance circuit with the parallel capacitors.
L = inductance of generator/transformer
nC = total parallel compensating capacity
r = ohmic resistance
I_{res} = resonance current

At certain combinations of mains supply inductance and number of compensating capacitors it is possible that the resonance frequency is exactly one of the frequencies of the distorted mains supply voltage (150-250-350 Hz). In that case there is no resulting impedance, except the ohmic resistance (r) of the cabling, and high mains currents may then occur. This results in tripping circuit breakers, failing fuses, overloaded cabling or even damaged transformers or generators. There are three different ways of overcoming such a problem:
1. use a transformer/generator with a higher capacity (change L),
2. remove part of the compensating capacitors (change C),
3. add a special filter (change f).

4.3.8 Lifetime

When used within the specifications, the various components of an HID lamp installation will last for many years with no more failures than ca. 1 percent failures per year (except lamps).
In principle, indoor systems are designed for an average lifetime of 10 years and outdoor systems for 15 years. Most of the time failures in the gear components are caused by external circumstances, including incorrect wiring or connections, short-circuiting, extreme heat or humidity, mains voltage peaks, poor maintenance and the like.

For example, according to IEC 61049, capacitors for lighting installations must achieve a lifetime of 30 000 hours at their indicated voltage (250 V or 450 V) and their maximum case temperature (85˚ or 100˚C). Higher voltages will shorten the capacitor life as follows:

Voltage (times V mark)	1.15	1.25	1.30	1.35	1.40	1.45	1.50
Lifetime (h)	8500	4000	2900	2000	1500	1100	780

A failure rate of 5 per cent is then accepted, and the capacitance loss must be less than 10 per cent for parallel and 5 per cent for series capacitors.
Temperatures above the indicated maximum capacitor case temperature will halve its lifetime for every 8 degrees temperature rise. If there are too many failures with capacitors, this may be an indication that they become too hot or that the applied voltage is (momentarily) too high.

For electronic devices such as ignitors, the most relevant factor is the maximum permitted ambient temperature, or the maximum case temperature. Exceeding these temperatures will shorten the lifetime dramatically. Proper mounting with respect to heat sources is essential.

4.3.9 Ambient and operating temperatures

In general, ambient temperature is of prime importance for the proper functioning of discharge lamps. High-intensity gas discharge (HID) lamps, however, are not very sensitive to changes in this (see Section 3.6).
For the total system, however, the ambient temperature is of great importance. This is due to the fact that certain minimum and maximum operating temperatures are specified for the various components.

Minimum temperatures

Lamps
Supplied with the normal voltage, HID lamps will operate quite satisfactorily at temperatures down to - 30˚C (- 40˚C for SON, - 20˚C for HP(L) lamps). Below these temperatures smooth ignition cannot be guaranteed. Once ignited, the lamp warms up its surroundings and, after run-up, the low ambient temperature has no influence on the lighting performance.

Gear
The minimum temperature for some electronic components and for compensating capacitors is - 25˚C, the capacitance of capacitors declining steeply below this temperature. For this reason gear should be installed at places where the ambient temperature will not fall below - 25˚C.

Luminaires
The construction of a luminaires and its optical system is in general not affected by low ambient temperatures down to - 25˚C. Of course, plastics parts such as clips are more brittle at low temperatures and should then be handled with care.

Maximum temperatures

Lamps

For HID lamps there are two critical values: the maximum specified temperature of the lamp base and the maximum bulb temperature. Both values can be found in the lamp documentation.
It will be clear that the actual lamp base and bulb temperature very much depend on the luminaire in which the lamp is placed. Lamps must only be used in luminaires that are constructed for that particular type of lamp. For maximum and ambient temperatures, see **Luminaires** below.

Gear

a) Ballasts

The main ballast temperature parameters T_w (maximum permissible coil temperature) and Δt (coil temperature rise in standard test) are described in Section 4.1.6.
Ballasts can be mounted in different ways: direct into a luminaire, into a ballast box, into cabinets or on gear trays for mounting in poles or high masts. Thus, in practice, the actual ballast coil temperature depends on the cooling properties of the ballast surroundings, e.g. material of mounting surface, type of fixing, standing air or ventilation. It is therefore impossible to predict the actual ballast-coil temperature without doing an in-situ temperature test. Normally, the lower its losses and/or the lower its Δt value and/or the larger its dimensions, the cooler the ballast will be.
Connections to a ballast are sometimes made by means of a terminal block. Terminal blocks have their own temperature limits (usually maximum 120˚C), which should not, of course, be exceeded.

b) Ignitors

Since electronic ignitors incorporate semi-conductors and capacitors, they have a maximum operating temperature. This value is marked on the ignitor and is usually 80˚ or 90˚C. In most applications, the ignitor case temperature will not exceed this limit. The semi-parallel ignitors, in particular, will produce scarcely any heat by themselves. Series ignitors have somewhat higher losses, and can therefore experience a temperature rise of 10 to 15 degrees.
However, when the ignitor is incorporated in the luminaire or placed near the hot ballast, its temperature can rise considerably. It is advisable to mount the ignitor on the coolest spot possible. If the resulting ignitor case temperature cannot be predicted and is critical, additional temperature measures are advisable.

c) Electronic gear

Electronic gear has a lifetime of 50 000 hours, with a failure rate of approximately 1 per cent per 3000 hours. These figures are valid at T_{nom}. To know what the temperature is in practice, there is a specific measuring point indicated on the case of the ignitor, called T_{case}. And the temperature must be measured at this point in a proper way, for example, by employing a thermocouple well-glued to the case. The temperature will, of course, depend on the application.
Also indicated on the gear casing is the temperature T_{max}, which should never be exceeded.
For an example of T_{max} = 115˚C and T_{nom} = 90˚C, (see Fig. 77).

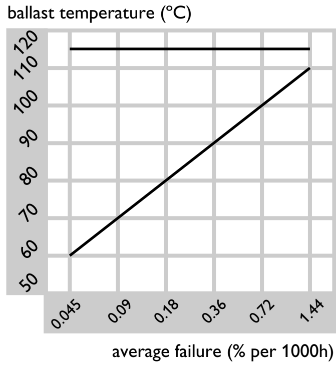


Fig. 77. Failure as function of ballast temperature.

d) Capacitors
Capacitors have a maximum permissible temperature, which is marked on the case and is usually 85 or 100˚C. Above this temperature they can break down or lose capacitance. They produce scarcely any heat by themselves and must be placed away from the hot ballast or luminaire. Again, additional temperature measures are advisable when the expected capacitor case temperature is unknown and can be critical.

Luminaires

Professional luminaires are, like ballasts, designed and constructed to have (under standard conditions) an average lifetime of at least 10 years in continuous operation with the appropriate (maximum-wattage) lamp type.
The volume of the luminaire, the choice of materials, the cooling properties, etc., are chosen in such a way that, at an ambient temperature of 25˚C in indoor applications, no part of the luminaire will exceed its specified maximum temperature. In practice this ambient temperature limit is sufficiently strict to cope with most applications and non-nominal circumstances, as long as the latter are within the specifications. In situations where the ambient temperature is (momentarily) higher than 30˚C, the most critical part of the luminaire may exceed its maximum specified temperature. Of course, this shortens lifetime, but to what extent is in general hard to say. It depends on the part in question (e.g. front glass, mirror optics, cabling, lamp bulb, lamp base, etc.).
In outdoor applications a natural air circulation around the luminaire is assumed, which gives a cooling effect of about 10˚C. The same luminaire that has an indoor ambient temperature limit of 25˚C, will in practice have an outdoor ambient temperature limit of 35˚C. If an ambient temperature T_a is stated for outdoor luminaires, this naturally refers to the outdoor situation.

Heat dissipation

The gear parts must be mounted in such a way that heat can easily be dissipated. When mounted in the foot of a lighting column, there are usually no problems, the mast acting as a chimney to provide sufficient air circulation. The units should be mounted with their connections downwards, so that no water can seep in.
When mounted in closed compartments, temperature control is of paramount importance.

There are three methods of heat dissipation:
1. radiation, related to the volume of and the free space around the device,
2) convection, related to the air circulation around the device,
3. conduction, related to the way the device is mounted.

In order to achieve optimum conditions for heat dissipation, attention should be given to the following aspects:
1. always mount the components on heat-conducting material (metal); preferably the entire cabinet should be made of such material,
2. mount the unit that generates most heat at the top; the order then is, from top to bottom:
   - ballasts
   - filter coils
   - capacitors
   - ignitors
   - connection terminals and fuses,
3. provide sufficient natural ventilation by leaving ventilation holes in the cabinet bottom and top,
4. make sure that no heat conduction from hot ballasts and filter coils to cool components such as capacitors and ignitors can take place,
5. when several ballasts are mounted in one cabinet, the free space in all directions between the ballasts should be approx. 150 mm,
6. the ratio of ballast to free space volume should be at least 1:5.

The inner temperature of a cabinet or box, containing electric components such as ballasts, capacitors and the like, can be calculated according to two equations:

$T_i = T_u + \Delta T$ and $P_s = \Delta T \cdot A \cdot k$

where T_i = inner temperature of the cabinet (°C)
T_u = ambient temperature of the cabinet (°C)
ΔT = maximum temperature difference between permissible inner cabinet temperature and ambient temperature (K)
Ps = power of radiation of the surface of the cabinet (W)
A = total free-standing cabinet surface (m^2)
k = heat conduction coefficient of the cabinet material
(e.g. for enamelled steel 5-6, for plastics 3.5 ($W/m^2 \cdot K$)

The permissible inner cabinet temperature T_i may be restricted by the maximum temperature of components such as ignitors and capacitors. For ballasts, the temperature restriction is imposed by the difference between the T_w and Δt marking (see Section 4.1.6).

Example:
Thirty-four ballast units, each producing 100 W, have to be built into a cabinet with maximum inner temperature of 60°C, at an ambient temperature of 25°C.
The permissible ΔT = 60 - 25 = 35 K.
The necessary cooling surface:

$A = P_s/(k \cdot \Delta T)$ where P_s = total ballast power
$= 32 \times 100 / (5.5 \times 35)$
$= 17\ m^2$

A cabinet with a height of 2.5 m, width of 2 m and depth of 1 m, has a free-standing cooling surface of:
(2 x 2.5 x 2 + 2 x 2.5 x 1 + 1 x 1 x 2) = 17 m^2.
When using such a cabinet (with ventilation holes), forced air-cooling is not necessary, but when using a smaller cabinet, a fan must be installed.
The necessary air-flow volume (m^3/h) of this fan can be calculated with the equation:

$V = 3.1 \times \{P_v / \Delta T - (A \times k)\}$ where P_v = total power installed

So when in the same example a cabinet with, say, 10 m^2 cooling surface is used, the necessary airflow will be:

V = 3.1 x {3200/35 - (10 x. 5.5)} = 113 m^3/h

In practice the calculated average values have to be higher, as in a cabinet the upper part will be hotter than the lower part and the air stream in the cabinet is obstructed by the various components of the installation. Moreover, the ventilator capacity range often doubles for the next higher type. For example a range of ventilators can consist of 48 - 103 - 220 - 500 m^3/h types, so for the calculation example above the 220 m^3/h type is advised. The ventilator has to be built into the lower part of the cabinet and the air outlet in the upper part, both preferably equipped with a dust filter.
Normally the ventilator is switched by a thermo-switch, set at the maximum temperature, so as to avoid continuous operation of the fan. The dust filters have to be cleaned or renewed regularly, e.g. once a year, but depending on the degree of pollution the interval may have to be shorter.

4.3.10 Effects of mains-voltage fluctuations

High-pressure mercury lamps (see Fig. 78)

Since the arc voltage is almost independent of the loading, the changes in the former caused by mains voltage fluctuations are so limited that they can be regarded as being independent of the mains supply. The lamp current, on the other hand, is controlled by the type and design of the ballast. The current goes up and down with the mains voltage, and the same applies to the lamp loading (viz. wattage) and to the luminous flux (Figure78 applies to lamp operating on an inductive ballast).

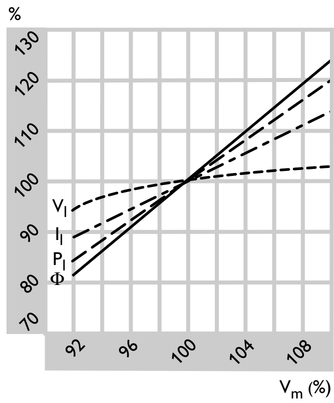


Fig. 78. Effect of mains voltage fluctuations on lamp voltage (V_l), lamp current (I_l), lamp power (P_l) and luminous flux (Φ) for a high-pressure mercury lamp.

In spite of its relatively low light output compared with other lamp types, the mercury lamp is often found in those countries where the power supplies on which they must operate are rather poor. Where more economical lamps, when run on such supplies, may be prone to premature failure or are even unable to function at all, the mercury lamp is untroubled in this respect.

Metal halide lamps (see Fig. 79)

Metal halide lamps are more susceptible to mains-voltage fluctuations than are high-pressure mercury lamps, although both lamp types exhibit a relatively stable lamp voltage with changes in lamp current and thus in lamp wattage. A mains voltage fluctuation outside the tolerance of ± 10% will result in colour shifts. Besides, a lamp voltage that is too high will also shorten lamp life. Tolerances on the ballast impedance also play a role in this respect. Philips lamp documentation states minimum and maximum limits of power dissipated in the lamp for which the performance characteristics will be within the specification.

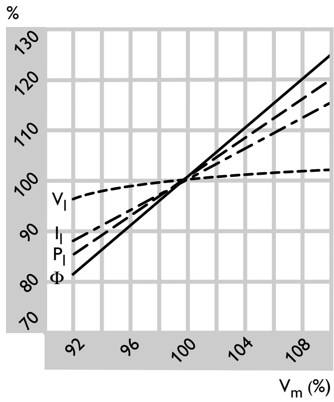


Fig. 79. Effect of mains voltage fluctuations on lamp voltage (V_l), lamp current (I_l), lamp power (P_l) and luminous flux (Φ) for a metal halide lamp.

Low-pressure sodium lamps (see Fig. 80)

Variations in mains voltage have an opposite effect on the lamp voltage of SOX lamps when compared to the two types of lamps mentioned above.

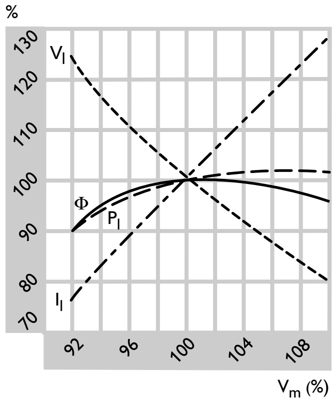


Fig. 80. Effect of mains voltage fluctuations on lamp voltage (V_l), lamp current (I_l), lamp power (P_l) and luminous flux (Φ) for a low-pressure sodium lamp.

Although there are some differences in behaviour between the various SOX circuits, the net result is that the lamp wattage, and to a certain extent also the luminous flux, remain nearly constant over a wide voltage range.

High-pressure sodium lamps (see Fig. 81)

The reaction of high-pressure sodium lamps to mains-voltage fluctuations differs considerably from that of the other HID lamp types. The excess of amalgam present in the discharge causes the lamp voltage to increase as the lamp wattage goes up. Too high a lamp voltage makes the lamp to extinguish, too low a voltage results in the lamp not reaching its specified light output.
The latest electronic DynaVision and PrimaVision ballasts for HP, sodium and metal halide lamps have a regulation system that regulates the lamp power over a wide voltage range (200-250V/ 50-60Hz) within a narrow tolerance.

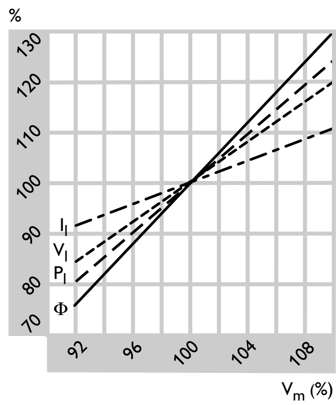


Fig. 81. Effect of mains voltage fluctuations on lamp voltage (V_l), lamp current (I_l), lamp power (P_l) and luminous flux (Φ) for a high-pressure sodium lamp.

4.3.11 System cabling

Introduction

When selecting the cable for a lighting installation, the electrical consultant or contractor has to consider several aspects, in order to achieve the optimum in the cable design and in the overall lighting design. These include the nature of the environment, electrical load, voltage drop, maximum and fault currents, rating factors and the costs. The lowest initial installation cost will often prove not to be the lowest system cost over the life of the installation. By opting for a greater cable size (accepting a higher initial cable cost) the voltage drop and losses along the cable length will be lower. Thus the cable installation can be optimised and the light output of the lamps increased. In large installations the number of light points may even be reduced in this way, providing additional savings.

The environment

The environment is the most important aspect to consider when selecting the sort of *cable insulation*. Determining factors here may include humidity, mechanical and chemical resistance, UV (daylight)

durability, flame retardance, ambient temperatures, situation (e.g. ground cable or flexible cable where some movement must be possible, as in street poles or high masts).
To fulfil the specific requirements, the consultant or contractor can make a choice from basically four families of cable:
a) rubber (mostly synthetic), flexible at low and high temperatures,
b) polyvinyl-chloride (PVC), for general use, various flame-retardant qualities available,
c) ethylvinyl-acetate (EVA) in combination with cross-linked polyethylene (XLPE), especially for higher temperatures,
d) polyurethane (PUR), UV- and chemical-resistant, flexible.

Each type of cable insulation has its own specifications, and due to the different circumstances prevailing in various sorts of lighting installations, there is a use for each type.

The electrical load

Electric cable is specified with a figure U_0 / U,

where U_0 = voltage between phase and earth
U = voltage between the phases

The normalised range is: 300/300 V - 300/500 V - 450/750 V - 0.6/1 kV - 1.8/3 kV - 3.6/6 kV and so on. Besides which, cable manufacturers publish the cable test voltage in steps of 500 V.

As far as lighting installations are concerned, there are no very special requirements placed for the power supply cables employed; 300/500 V or 450/750 V cable with a test voltage of 2000 V or 2500 V is quite sufficient.

No electronic ignitor, or series ignitor circuits

For the cabling between Philips control gear and lamp the same cable quality can be used for systems without an electronic ignitor (such as high-pressure mercury (HPL) or systems with a series ignitor (such as the MHD 1800 W/400 V system). With metal halide lamps (HPI-T) too, the same cable can be used, since the ignition peak voltage is rather low (max. 750 V) and is normally of short duration.

Semi-parallel ignitor circuits

In circuits with high-pressure sodium lamps (150 W to1000 W) and the ArenaVision 230 V system, the semi-parallel ignitor employed produces starting peaks of between 2.6 kV and 4.5 kV. Normally, the peak duration is short (a few milliseconds, max. 2 seconds), but when, for example, a lamp fails to ignite, the ignitor produces this ignition peak continuously. Although the energy in the pulse is rather low, the cable must be capable to withstand this peak voltage throughout its lifetime. It is not necessary to use high-voltage cable, such as the 3.6/6 kV type. In practice, 0.6/1 kV cable with a test voltage of 3500 V or higher is often used without problems, but this also depends on how the cables are installed - e.g. avoid sharp bends or squeezed cables should be avoided.

Rating of cables

Initially, a cable diameter is rated so that the conductor operates at its maximum current below a set temperature level, usually 60˚C for rubbers, 70˚C for PVC, and 90˚C for XLPE. The life of a cable depends on this temperature limit. Also, the real resistance (and thus the cable losses) depends on the actual cable temperature, according the equation:

$$R_t = R_0[1 + \alpha(T_1 - T_0)]\ \Omega$$

where R_t = resistance at actual temperature T_1
R_0 = resistance at published temperature T_0, usually 20˚C
α = temperature coefficient of the conductor material (for copper, $\alpha = 0.00393$)

Under stable conditions, the heat produced by the cable (I^2R_t) is absorbed by the environment. The national and international standardisation bureaus publish tables of so-called derating factors. These are based on various factors, including insulation type, actual ambient temperature, way of mounting of the cables, number of cores in the cable, number of and distance between the cables. These factors are employed at the cable design stage when calculating the right cable diameter for a given current strength. At this stage, it is not always known whether two or more cables will share a cable rack or trench, and even the way of mounting may be unknown.
The impedance of the cable can also vary, depending on the method of installation (in metal or PVC conduit, busways, tracks).
The correct choice of cable type belongs specifically to the task of the contractor.

Maximum and fault currents

In lighting installations, cables are selected to carry the load current. The run-up currents (which are ca 1.5 times the nominal currents) do not normally play a part in the choice of the cable diameter, as they last only a few minutes. Cables in air can withstand 1.3 times the rated load current for several hours before cable failure, and 1.5 times the rated load current when buried in the ground. Fault currents do not influence the cable core size either, as the protective devices (e.g. fuses or circuit breakers) will protect the cables and the load from excessive currents. In order to ensure the correct functioning of the protective devices, standardisation offices restrict the maximum permissible cable length for the various core diameters in combination with defined fuse ratings.

The voltage drop

Supply cables

Cables are selected to carry the load current, and to do so at the lowest possible cost. This often means that the minimum copper core diameter will be used, and this will lead to a maximum voltage drop. In most countries the voltage drop between the starting point of the installation and the point where the loads are installed must not be more than 5 per cent of the nominal voltage.
The resistance and reactance per metre of cable length can be found in tables. Then, when the load current and

the length of the cable are known, the voltage drop can be calculated. This is an easy matter when there is only one single load, but when the load is complex, each part of the load and each section of the cable must be considered separately. The individual voltage drops are cumulative, and their sum must be within the specified limits.
Normally, the supply cable has three phases, a neutral and an earth conductor. In a well-balanced system (equal phase currents) there are two equations with which the phase current and the voltage drop, respectively, can be calculated:

$$I = P/\{\sqrt{3} \times U \times \cos\varphi\} \quad (1)$$

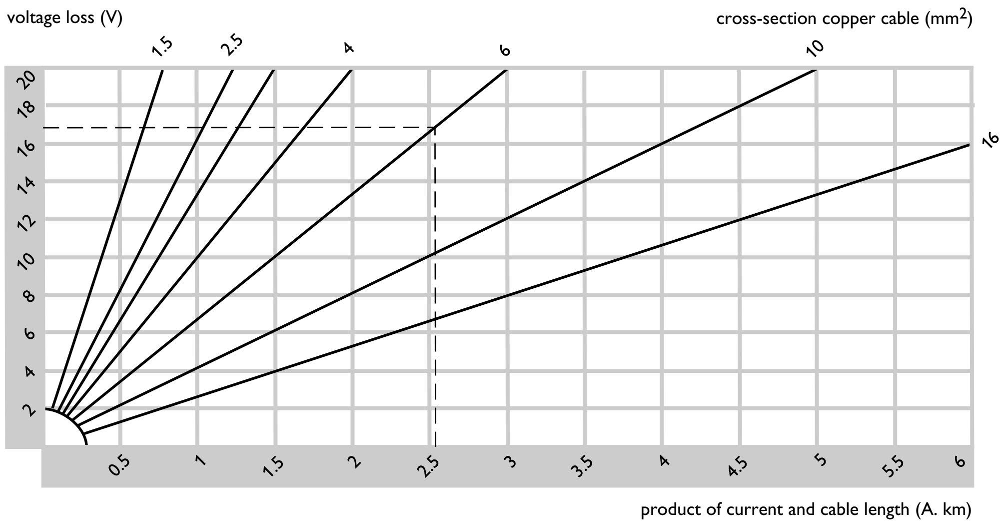
where I = phase current (A)
P = power of the load (W)
U = phase-phase voltage (V)
$\cos\varphi$ = system power factor

and

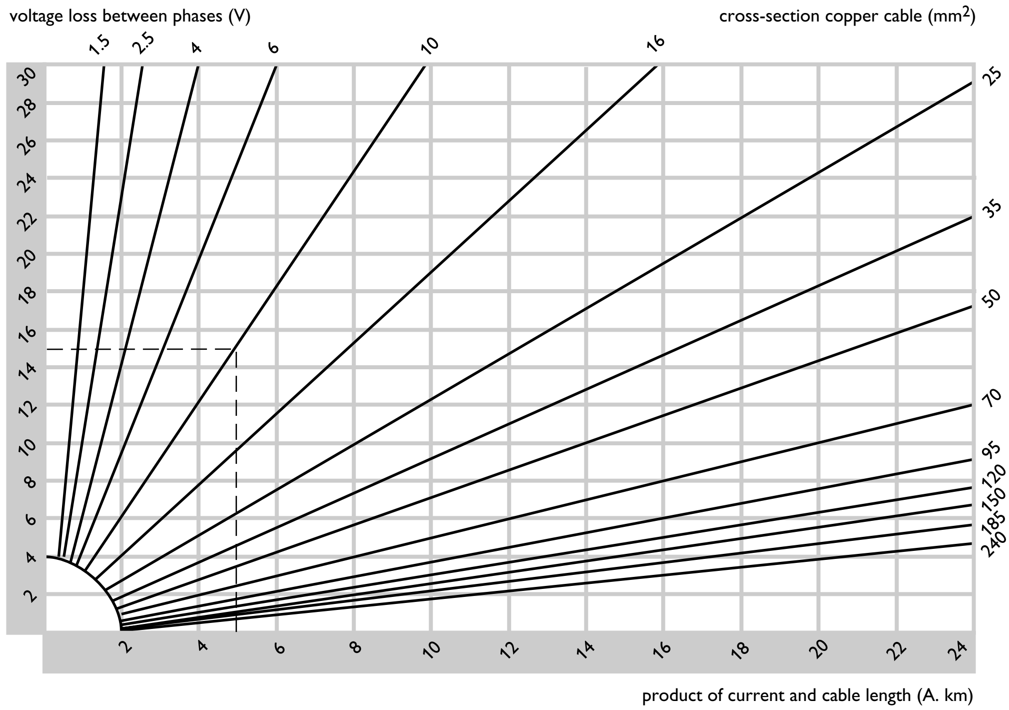
$$U_d = \sqrt{3} \times I \times L \,.\, (r\cos\varphi + x\sin\varphi) \quad (2)$$

where U_d = voltage drop over the length of the cable, measured between the phases (V)
I = phase current (A)
L = length of the cable (km)
r = resistance of the cable core (Ω/km)
x = reactance of the cable core (Ω/km)

With these two formulae the cable core diameter and the voltage drop can be calculated for a given load and cable length.
If the reactance x of the cable is unknown, the value of 0.1 /km may be assumed.
Practical graphs to establish the cable voltage loss can be found in Fig. 82.



a) Voltage loss in a 2-core copper cable, one-phase AC, cos φ = 1.
Product of current and cable length in A . km.
Example: copper core 6 mm², current 50 A, cable length 50 m.
Hence: 50 A . 0.05 km = 2.5 A . km, therefore voltage loss ≅ 17 V.



b) Similar graphs for a 3-core copper cable, three-phase AC, cos φ = 0.8.

Fig. 82. Practical graphs to determine cable voltage loss.

The heat dissipation P in the cable can be calculated from:

$P = 3 \times I^2 \times R_t$ (3)

where $R_t = r \times L$ (see also: Rating of cables)

These equations are valid when the current in the neutral is zero. In installations involving only lighting with gas-discharge lamps, there are a considerable number of harmonics in the phase current (see Section 3.3.7: Harmonic distortion). The third and ninth harmonics are added in the neutral, so the current in this conductor is **not** zero.
A practical value of the current in the neutral conductor is 70 per cent of the phase current. For this reason, the neutral conductor must have the same diameter as the phase conductors. Consequently, the heat dissipation in a three-phase + neutral cable is about 16 per cent higher than in a three-phase cable:

$P = 3 \times I^2 \times R_t + (0.7 \times I)^2 \cdot R_t$ (4)

The supply cables in lighting systems with three-phase-plus-neutral supply must be 16 per cent thicker (or the supply current 8 per cent lower) than in the three-phase system, to have the same heat dissipation in the supply cables.
For the calculation of the voltage drop, the harmonics in the neutral have scarcely any influence, so equation (2) is still valid in multiple-lamp installations.
The calculated (and measured) voltage drop leads to a lower supply voltage for the lamp circuits. In the lamp/ballast documentation information can be found on the behaviour of the lamp circuits at deviations from the mains voltage.

To give an idea of what the effects of a **5 per cent lower mains voltage** are on the lumen output of some HID lamps:

Lamp	Lamp power decrease (%)	Lamp lumen decrease (%)
SON-T 1000 W	12.5	15
HPI-T 2 kW/220 V	8	12
HPI-T 2 kW/380 V	10	15
MHN-TD 250 W	10	17
MHN 1800/230 V	9	12
MHN 2000/400 V	9	12

If, for example, the lumen output loss is unacceptably high, there are some possibilities to compensate for the lumen loss:
a) install more floodlights,
b) use thicker supply cables,
c) apply a higher supply voltage (e.g. by means of a tapping on a transformer),
d) use a different ballast (appropriate for the lower supply voltage).

The best solution is, of course, to supply the lamp circuits with the correct nominal voltage and to compensate for the cable voltage drop in the power supply source. If this is not possible, one of the other solutions must be chosen, leading to extra costs. Nevertheless, in the total project it may be wiser to go for thicker supply cables. An example of this will be given farther on.

Lamp cables

The current for the lamp cables is the published lamp current.
The voltage drop can be calculated from:

$$U_d = 2 \times I \times L. (r\cos\varphi + x\sin\varphi) \qquad (5)$$

The question now is: what voltage drop can be accepted? There is no guidance from international recommendations to find the answer to this question, as is the case for the power supply cabling.

If there is a voltage drop along the cable, there is less voltage for the lamp and ballast, so the lamp current drops. A lower lamp current gives less lamp power, but the extent of the power decrease differs from one lamp type to another. SON lamps, for instance, are more sensitive in this respect than are HPI-T lamps, as the lamp voltage decreases with decreasing lamp current. Also, high-voltage types (380/400 V) are less sensitive to a given voltage drop than are low-voltage types (230 V).
To give an impression of what the effects of **a lamp cable voltage loss of 10 V** are on the lumen output of some HID lamps:

Lamp	Lamp power decrease (%)	Lamp lumen decrease (%)
SON-T 1000 W	10	12
HPI-T 2 kW/220 V	7	10
HPI-T 2 kW/380 V	5	8
MHN-TD 250 W	7	10
MHN 1800/230 V	7	10
MHN 2000/400 V	4	5

Naturally, the voltage loss should be kept to a minimum, as it has direct consequences for the light output of the lamps. In the lighting design stage cable losses are not separately taken into account, as cable core dimensions and cable lengths are not always known at this stage. Moreover, cable connections and switching and protective devices also introduce some voltage drop, so in practice the overall voltage drop will be higher than the one calculated with equation (5). To avoid excessive differences between calculated and practical light values a calculated light output drop of no more than 5 % should be accepted.

The relationship between cable length/core diameter and lamp lumen output for some HID lamps can be found in Fig. 83.

1 = MHN-TD	*250 W*	*230 V*
2 = HPI-T	*1000 W*	*230 V*
3 = HPI-T	*2000 W*	*400 V*
4 = MHN-LA	*1000 W*	*230 V*
5 = MHN-LA	*2000 W*	*400 V*
6 = MHN-SA	*1800/2000 W*	*400 V*
7 = SON-T	*1000 W*	*230 V*
8 = MHN-SA	*1800 W*	*230 V*
9 = HPI-T	*2000 W*	*230 V*
10= SON-T	*600 W*	*230 V*

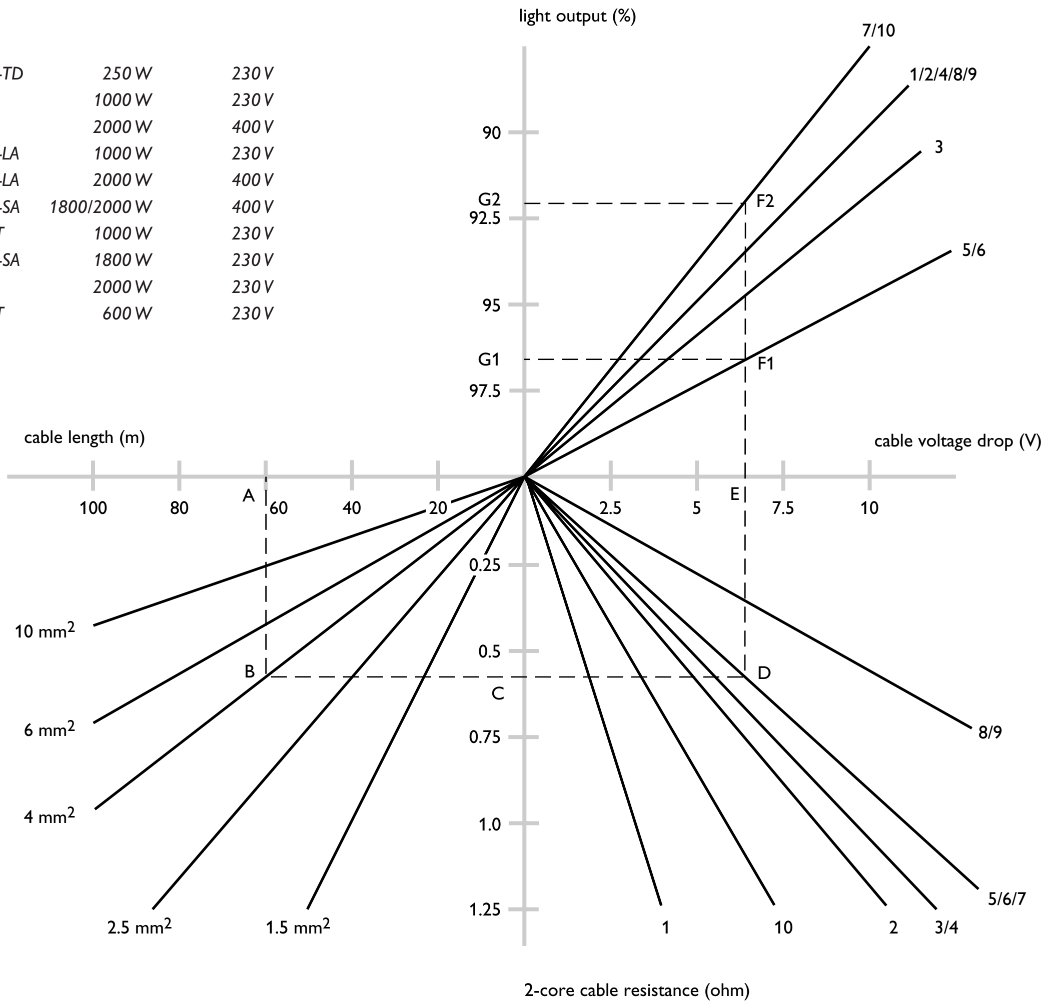


Fig. 83. Relationship between cable core and cable length and relative light output for various HID lamp types.

By means of the graphs shown in Fig. 83, for a given cable length and core diameter (and thus cable resistance) the resultant cable voltage drop and consequent lamp lumen output for a given lamp can be determined.
Or, conversely, on the basis of a given cable core diameter, the maximum permitted cable length can be determined, starting from an acceptable voltage drop.

Example:
1. Choose, starting from a given cable length (60 m, point A), a cable core size (4 mm², point B).
2. From there, find the cable resistance (point C) and point D.
3. Find, for the given lamp type, the cable voltage drop (point E) and point F1 or F2 for the same lamp type on line 6 or 7, respectively.
4. From there, go to point G1 or G2 on the vertical axis to find the relative light output.

See for points ABCDEFG Fig. 83
or:

1. Find, for a given relative light output (point G) and for a certain lamp type (point F), the permissible voltage drop (point E) and for the same lamp (point D) the maximum cable resistance (point C).
2. Make a choice for a cable core size (point B) and find the maximum permitted cable length (point A).

Similar to what was said in the previous section, it may be wiser to choose for a greater lamp cable diameter in order to reduce the cable losses and to increase the lamp lumen output, see example further on.
When there is a choice between 230 V and 400 V systems (as with ArenaVision), priority should be given to the high-voltage solution, as in that case the cable costs are much lower. First of all, the lamp cables may be thinner since the lamp current of a high-voltage lamp is lower than that of a low-voltage lamp. The ArenaVision MHN 1800/230 V lamp, for example, has a lamp current of 17.3 A, whereas the 400 V version has a 10.3 A current.
Moreover, the power supply cable size can also be reduced by about 16 per cent (see previous section) and the neutral conductor is superfluous (three-core + earth instead of four-core + earth).

Combining lamp cables

In order to keep the installation as simple as possible, the best solution is to supply each lamp with two supply conductors (+ earth).
In high-voltage circuits it is of no use to combine lamp cables, as three lamps on three phases need six wires (three phases plus three ballast connections), (see Fig. 84), left.

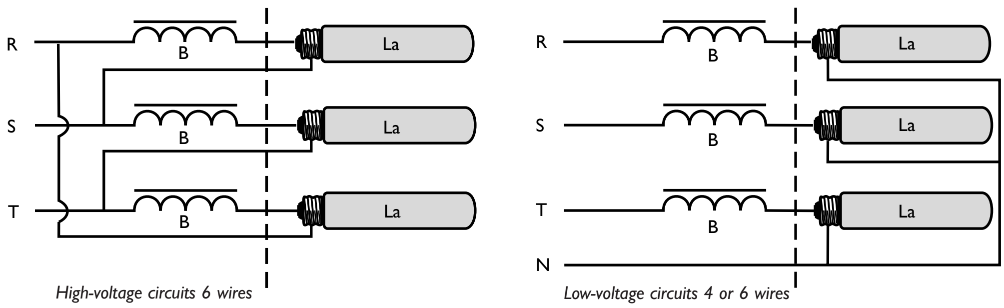


Fig. 84. Number of lamp cables.

In low-voltage circuits, on the other hand, three lamps on three phases can be combined and supplied with one common neutral (see Fig. 84, right).

It must be kept in mind that the current in the neutral is not zero, but about 70 per cent of the phase current, if the three lamps are functioning. If only one lamp burns, the current in the neutral is equal to the phase current and if two lamps are functioning the current in the neutral is about 1.3 times the phase current. Special attention should be given to the correct nominal neutral cable diameter in this case. The best solution is a provision for automatic switch-off for the group of three lamps if one lamp fails.

Cable costs

Rather than minimise the **initial** costs of cabling, it is better to select a cable size that will minimise the costs over the **life** of the installation. This requires that both the initial costs (for a given light output) and the costs of the losses throughout the life of the cable to be considered. Perhaps future growth or expansion of the installation should be borne in mind as well. To do the calculations properly, the effects of inflation, interest rates on capital, present and future energy prices, and running costs should be taken into account. Depending on the desired payback time and the expected running hours, the outcome will be an optimum cable core diameter, which will often not be the minimum possible as far as the initial cable costs are concerned.

Comparison of two different lamp cable cores

As an example, a calculation has been made for a lighting installation equipped with the ArenaVision 230 V lamp (lamp current 17.3 A) on a 50-metre-high mast. Solution A is with the minimum lamp cable size, solution B with two core sizes bigger. Calculations have been made as detailed on the previous pages.

Solution	A	B
Lamp cable size (mm^2)	2.5	6
Copper resistance (Ω/km)	7.5	3.1
Cable resistance, 2 cores (Ω)	0.75	0.31
Cable voltage drop (V)	13	6
Lumen output drop (%)	13	7
Cable watt losses (W)	224	93
Assumed cable price per metre (Euro)	1.5	3

Solution A is cheaper than solution B in initial cable costs: Euro 1.5 . 50 metres = Euro 75 per light point.
Solution A gives 13-7 = 6 per cent less light output than solution B, so 6 per cent more light points have to be installed for the same light output.
Assume that the lighting installation comprises 100 light points and that the total costs per light point (i.e. floodlight, mast, lamp, ballast, cabling, transformer, labour, etc.) is Euro 2000 to 2500.
Then the saving in cable costs in solution A (100 x Euro 75 = Euro 7500) is by far cancelled out by the fact that (starting from the same overall light output), solution B requires 6 per cent fewer light points, giving a saving of 6 . Euro 2000 = Euro 12000.
And what also remains is that solution B gives 224 - 93 = 131 W lower cable losses per light point, which is about 7 per cent of the total energy consumption per light point (1800 W for the lamp and 100 W for the ballast). It has to be remembered that this saving is valid throughout the lifetime of the installation. Besides, the power supply transformer and the distribution system can be 7 per cent smaller as well.

4.3.12 Cable capacitance

When a price quotation for a lighting installation is prepared, the costs of the cabling play an important role. This is particularly so when it concerns high-mast lighting the cabling is of decisive importance. Design calculations should therefore be made with the utmost care.
Consider, to begin with, the maximum cable length permitted. With the exception of HPL and ML lamps, all discharge lamps are operated in conjunction with electronic ignitors, which provide the voltage peaks necessary for lamp ignition. Such a peak can best be thought of as a high-frequency voltage.
A capacitor presents a low impedance to high frequencies, so lamps that are started with the aid of ignitors must not have a capacitor connected in parallel. But cable has a capacitance of between ca 0.05 nF and 0.2 nF per metre, and if the cable is too long, the voltage peaks from the ignitor will be over attenuated. As a result, the lamp will not start.
The cable capacitance per metre depends on the size and construction of the cable (copper core diameters, distance between the cores, number of cores) and the dielectric constant of the materials used for the insulation and coating (see Fig. 85).
The practical cable capacitance is also influenced by the way the cable is used: is the cable shielded, is it connected to earth or is one of the conductors used as an earth wire?
Typical cable capacitances can be obtained from the cable suppliers.
If there is no earth cable shielding or no earth conductor, the real cable capacitance depends on how it is fixed.
To give some indicative figures:

1. normal PVC cable, 2.5 mm²:	100 pF per m,
2. same cable, fixed on an earthed conduit or in metal pipe:	250 pF per m,
3. same cable, within 3 mm that conduit:	180 pF per m,
4. same cable, within 15 mm of that conduit:	120 pF per m.

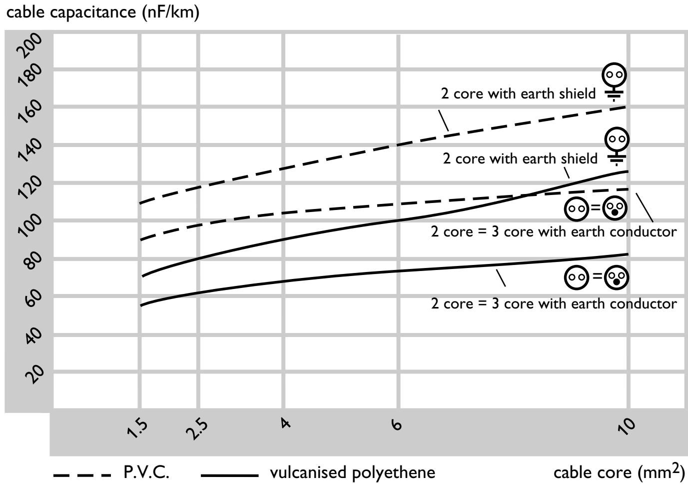


Fig. 85. Relationship between cable capacity and cable core for different types of cable.

The maximum permissible cable capacitances (C_{max}) for the various lamp/ignitor systems with the standard Philips ballasts are given in the table below.
Once the capacitance per metre (C_{cable}) for the selected cable type is known (this is specified by the cable manufacturer), the maximum permissible length (L_{max}) of cable between ballast/ignitor and lamp can be calculated from the formula:

$L_{max} = C_{max}/C_{cable}$ (m)

For example, a typical 3 . 2.5 mm^2 cable (with earth wire) has a capacitance of 100 pF per metre. For a SON 400 W lamp with SN 58 ignitor the permissible cable length between ballast and lamp, using this cable, is 2000/100 = 20 metres. Sometimes the required cable between lamp and ignitor cannot be of an ordinary type. One solution is to use cable with a lower capacitance per metre. Another solution is to use separated lamp wires, some centimetres free from earth (metal parts) and keeping ca. 20 mm distance between the two wires.

Maximum cable capacitance between lamp and ignitor for various lamp types

Lamp	Lamp wattage (W)	Ignitor	Max. cable capacitance (pF)
SON, SON-T	50-70	SN 57, SN 57T5	2000
	50-70	SU 10S	200
	100-600	SN 58, SN 58T5	2000
	100-150	SU 20S	100
	150-400	SU 40S	100
	1000	SN 59	3000
	1000	SN 61	6000
SON, SON-T Plus	250-400	SN 58, SN 58T5	1000
White SON	35/50/100	CSLS unit	50
HPI, HPI-T	250-400	SI 51	150 000
	1000-2000	SI 52	35 000
	2000/380 V	SI 54	120 000
MHN-SA	1800-2000/230 V	SN 59	4000
	1800-2000/230 V	SN 56	min. 4000 - max. 10 000
	2000/400 V	Bag Electronics	200
	1800-2000/230 V	Hot-restrike	50
	2000/400 V	Hot-restrike	50
MH/CDM	35-250	SN 58, SN 58T15	1000
	35-150	SU 20S	100
	250-400	SU 40 S	100
MHN-LA	2000	Bag Electronics	200
		SN 59	2600
SOX, SOX-E	All	All	5000

Fig. 86 shows the effect of cable capacitance on two common lamps: HPI and SON 400 W. It can be seen that the influence of cable capacitance on SON lamp installations is distinctly the greater of the two, due to the high transformation ratio of the winding.

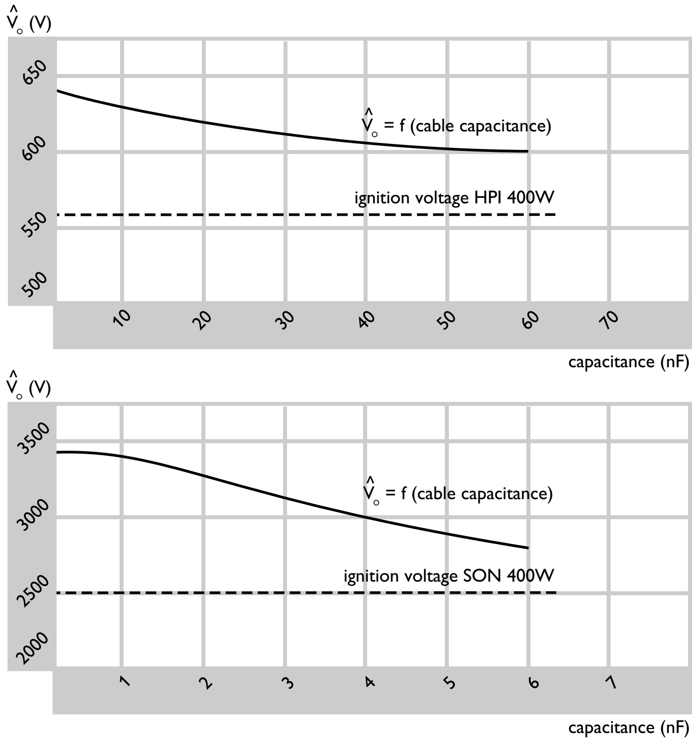


Fig. 86. The influence of cable capacitance on the open-circuit voltage of an HPI 400 W lamp and of a SON 400 W lamp.

4.3.13 Hum

Lamps, ignitors, capacitors and even floodlights in general do not produce any disturbing noise level if correctly used in their application. Nevertheless, in some instances some hum or rustling can be noticed during the starting process, especially with series ignitors. If hum is noticeable, it is almost invariably caused by the ballast or to a lesser extent by the ignitors. Series ignitors generate more hum than do semi-parallel ignitors do, as they operate continuously in the circuit. But when used indoors, e.g. in shops, the hum level should be low.
The electric current passing through the coil of a ballast or the transformer of a series ignitor creates a magnetic field, which orders the otherwise disorderly elementary magnetic particles of the ballast iron. Consequently, magnetostriction and magnetic poles are to be found in the iron.
The ordering of the elementary magnets causes some deformation of the iron (magnetostriction), resulting in the iron expanding in certain directions. This process is repeated every half cycle when alternating current is used, which results in a noise of 100 Hz and higher harmonics. The magnetic poles exert forces of attraction in the air gap of the ballast core, another source of noise of 100 Hz and higher harmonics.
The generation of these magnetic vibrations can largely be suppressed by a suitable design of the ballast. Air-gap filling and ballast encapsulation in particular can contribute to lower noise levels.
But the magnetic field also spreads outside the magnetic core. All magnetic metal parts in the immediate

surroundings of the ballast, such as the ballast case, the sheet-steel of the luminiare, etc., are subject to forces in this magnetic field and may cause a noise.
In order to avoid this unpleasant humming noise, constructions for the ballast mounting, as well as the ballast mounting itself, must be as rigid as possible. Avoid loose metal parts, create distances between ballasts and metal parts, close cabinet doors and so on. If the noise must be restricted to a minimum the ballasts will have to be built into a separate room, or sound-absorbing materials must be used.
The Philips Heavy Duty type ballasts exhibit a lower hum level than the Basic type.
Apart from ballasts and ignitors, other parts of the electrical installation, such as relays and power switches, can also cause.

4.3.14 Dimming

The dimming of HID lamp is becoming even more in demand for lowering power consumption, lengthening lamp life, and reducing maintenance costs and light pollution, especially with environmental-minded authorities. And lamp dimming is also a way of providing attractive, dynamic scenery lighting.
But there are some aspects that make they dimming of HID lamps less favourable:
- By reducing the lamp power the colour of the light will shift. With incandescent and halogen lamps the dimmed light source looks warmer (or lower in correlated colour temperature). With metal halide lamps, on the other hand, a drastically higher colour temperature will be the result, starting from 80% lumen output, which shifts the colour to blue-green with clear lamps. The light of phosphor-coated lamps starts changing at about 60% lumen output. With high-pressure sodium lamps the colour shift will be almost negligible down to 50% lumen output; at lower levels the colour of the light will shift towards the yellow tinge of the low-pressure sodium lamp.
- The efficiency of lamps and systems goes down as dimming percentages go up. Incandescent, halogen and metal halide systems show much lower efficacies when dimmed, and high-pressure sodium, mercury and fluorescent systems have an only slightly reduced efficacy when dimmed. For example (see Fig. 87).

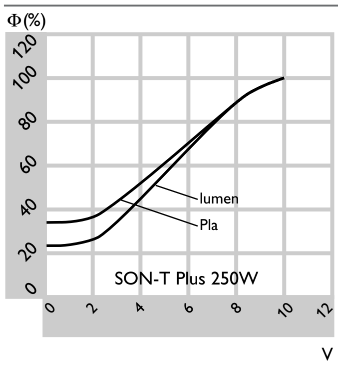


Fig. 87. Lamp power and light output as function of control voltage.

- The power factor of all lamp-dimming systems can be greatly or slightly reduced, depending on system design. At 50% power level some systems have power factors of 0.90 while others have 0.50.

When parallel compensation is employed, the power factor may shift from inductive to capacitive.
- Lamp life can be affected too, mainly depending on the method of dimming. Incandescent lamps will have a longer lifetime when dimmed, but with mercury and metal halide lamps the lifetime may be shortened.
- By changing the lamp power or dimming level the stabilisation time for the lamp lumen output may become much longer.

The conclusion from what has pointed out above is that SOX. HPL, HPI, CDM and MH lamps cannot be dimmed in a proper way. Good results can only be obtained with SON lamps.
Gas-discharge lamps cannot, in general, be dimmed by means of a variable series resistor or by lowering the supply voltage.
There remain, in fact, three possibilities: regulation by means of phase cutting, regulation by means of a twin-ballast circuit, and regulation by increasing the frequency.

1. Regulation by means of phase cutting

This method for dimming fluorescent or incandescent lamps has been known for many years, and some experience with this system used for HID lamps has been gathered as well. Apart from the setbacks dealt with previously, there are a few more points to be made, explaining why this method is not really popular:
- phase cutting introduces mains supply current distortion (higher harmonics), which is difficult to suppress,
- phase cutting introduces more conducted and radiated radio interference,
- the phase-cutting device (dimmer) must be set or trimmed for a specific lamp type and for a certain power for optimum functioning. This may either be done in the factory (leading to a lot of different dimmer types) or it must be done in the installation by the contractor.

At the moment there is one HID solution with phase cutting: The HID-DynaVision controller can, in combination with the dimming ballast BSH 2540L36, dim the light level of all SON 250 W and 400W lamps continuously between 100 and 50 per cent (see Section 5.7.1).

2. Regulation by means of a twin-ballast circuit

Here, an additional dimming choke L_2 is connected in series in the lamp circuit, in combination with the normal ballast L1 (see Fig. 88). With this rather simple system dimming levels of approx. 50 per cent can be obtained without any side effects. This one-step dimming is particularly popular with high-pressure sodium lamps from 70 W up to 400 W in, say, street lighting, In this instance, a power reduction of approx. 35 per cent is achieved.
By opening a parallel switch (triac) across the extra dimming choke by means of an electronic switch (EC 01/EC 11), the dimming choke L_2 is included in the circuit. The dimming control signal for the EC controller can be 100 - 250 V DC or 198 - 264 V 50/60 Hz AC.
Built into a three-phase supply system, the control system can be switched to either one of the phases in the same mains supply cable.

Also the Chronosense (see Section 5.8.3) can be used. The HID-DynaVision controller can, in combination with the dimming ballast BSH 2540L36, dim the light level of all SON 250 W and 400 W lamps continuously between 100 and 50 per cent (see Section 5.7.1).

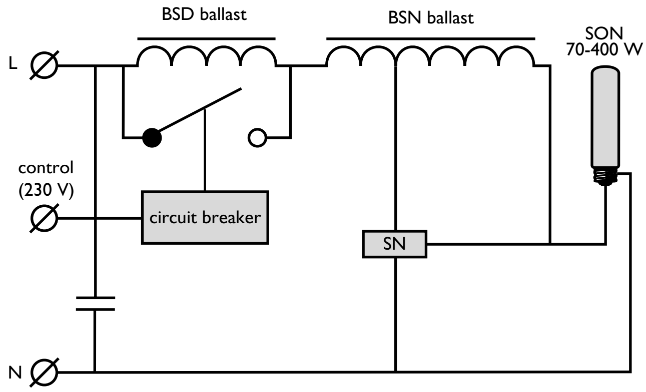
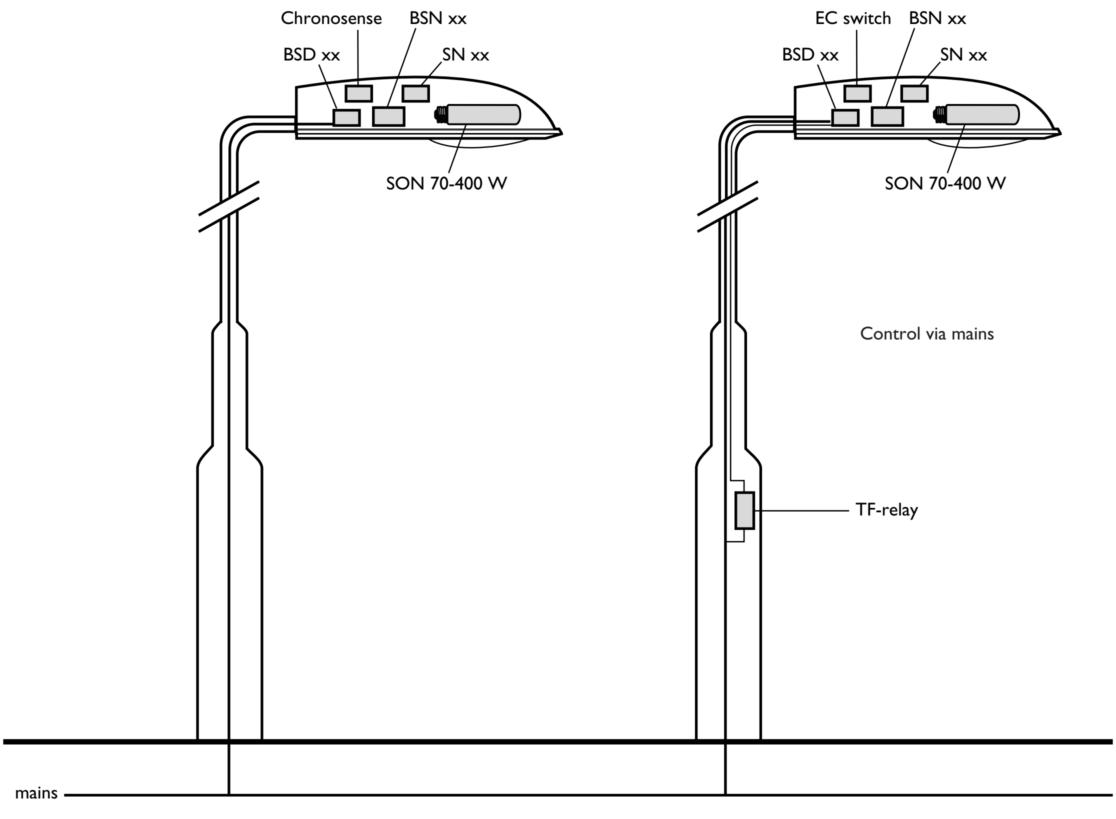


Fig. 88. Light regulation with a twin-ballast circuit.

See Fig. 89 for some possibilities for building the dimming ballast into a luminaire.



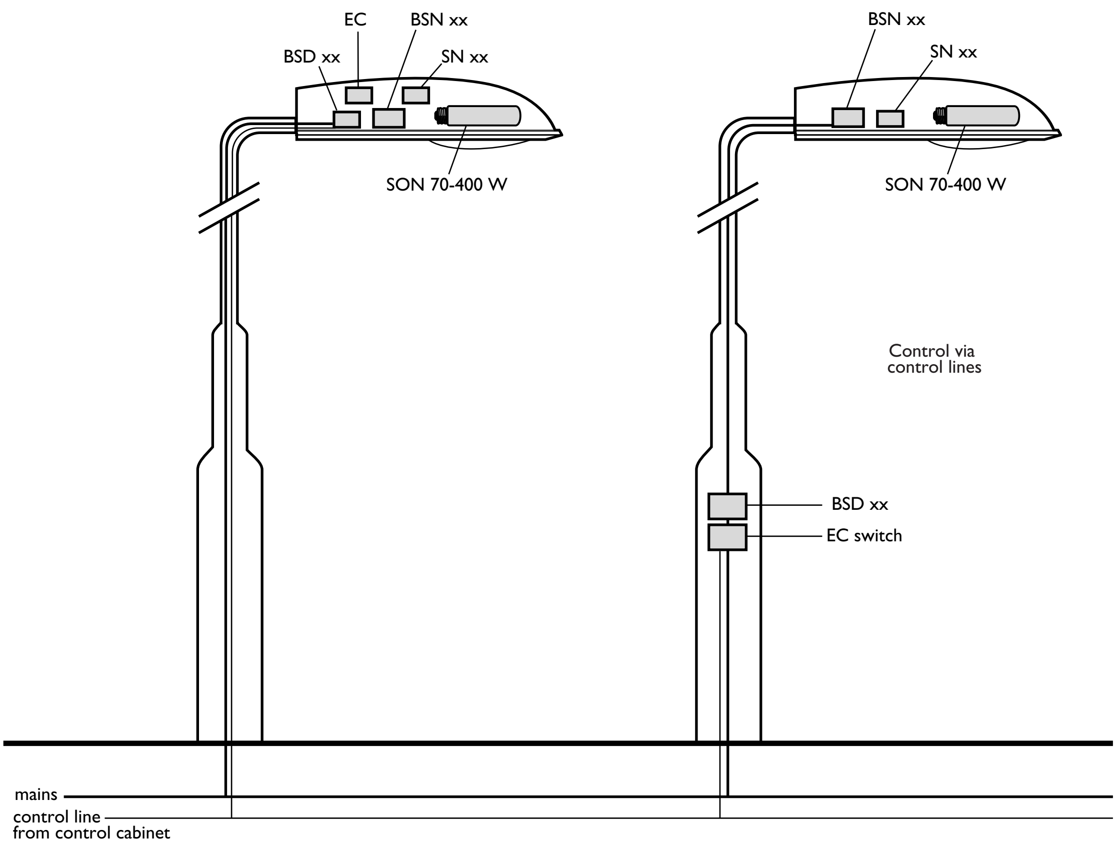


Fig. 89. Some possibilities for building the dimming ballast into a luminaire.

3. Regulation by increasing the frequency

The impedance of the ballast coil will increase by changing to a higher frequency. Consequently, lamp current and lamp power will decrease. This is how modern fluorescent lamps are dimmed.
At this moment there is one solution: The HID-DynaVision electronic regulating ballast HID-DV150 can dim the light level of all SON 150 W lamps continuously between 100 and 20 per cent due to its operating frequency of 130 Hz (see Section 5.7.2).

Because of slow-warm-up and hot-restrike delay characteristics of HID lamps, all dimming methods use an automatic procedure, whereby the lamp is started at full power and any dimming is delayed by 3 to 10 minutes until the lamp is fully warmed up.

4.3.15 Circuit breakers, fusing and earth leakage

Standard conditions

Under normal conditions the highest current that can occur is the current during the run-up phase. Immediately after lamp starting, the metal vapour pressure in the discharge tube is very low, so the voltage across the lamp is also very low (except with low-pressure sodium lamps). Practically the entire supply voltage is therefore across the ballast, resulting in a high current and a low power factor. The fuses must be capable of coping with this high initial current for several minutes. For most of the gas-discharge lamps stabilised with copper/iron ballasts, this run-up current is about 1.5 times the normal operating current.

During switch-on, a few other processes are going on as well (see Fig. 90):
- the (empty) parallel compensating capacitor will be charged with a high inrush current,
- depending on the magnetic saturation of the ballast a voltage induction will take place in the ballast,
- gas-discharge lamps may have some rectification or DC component in the lamp current.

These phenomena occur in the very first 3 to 5 milliseconds and may result in a peak current of 15 to 25 times the nominal starting current. This surge current will depend on the lamp and ballast type and the number of lamps per circuit as well as, of course, the resistance and impedance of the lamp and supply cables and the impedance of the mains supply network. This latter part varies greatly in practice. It is recommended that a surge current of 20 to 25 times the nominal current during the first 3 milliseconds be used and 1.7 times the nominal current for the first 2 seconds for parallel-compensated circuits as a guide for selecting fuse ratings.

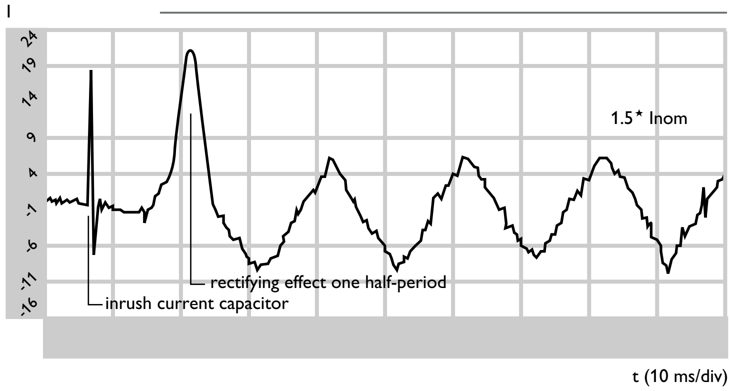


Fig. 90. Mains starting current of a cold SON lamp.

Devices for switching and fusing must be capable of handling these currents correctly. This means that for fuses slow-acting gl types (normal general purpose types for cable fusing) have to be used (German name: gL). The main purpose of the fuse is to protect the cable and the distribution part of the lighting installation from damage in the case of a failure in the installation. So the fuse rating is primarily related to the cable core used in the installation.

As the various national electrical safety rules differ slightly, the recommended fuse ratings for lighting equipment published by the various lamp, gear and fuse suppliers are not always the same. Moreover, there are differences in the various brands of fuses. As a guide, it is recommended to load gl fuses to not more than 50-70 per cent of their rating.

Characteristics of fuses are often published as shown in Fig. 91. These graphs provide hardly any information on the inrush currents during the first few milliseconds. Besides, fuse characteristics have a tolerance area, so it is better to use graphs that take these aspects into account, as shown in Fig. 92.
As a guide, the table below recommends gl fuse ratings for the range of Philips discharge lamp circuits based on 230/240 V circuits.

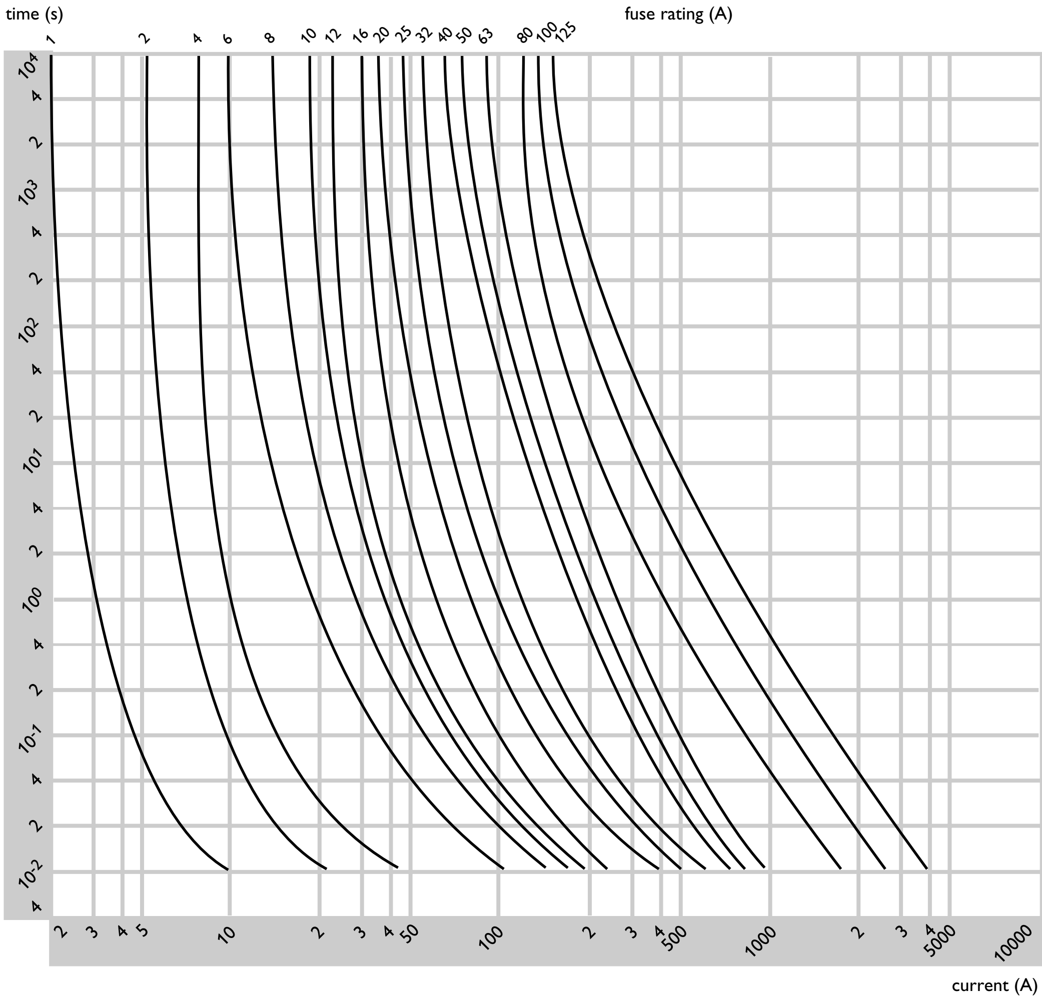


Fig. 91. Time/current curves.

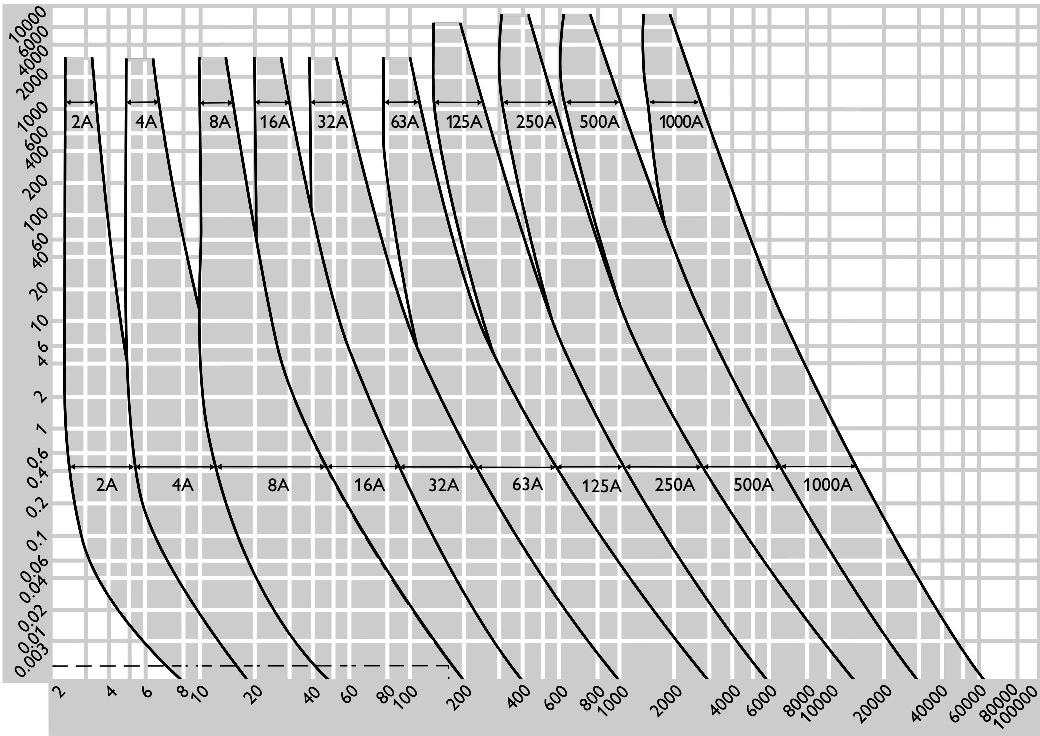


Fig. 92. Choosing the right fuse by means of these (improved) time/current curves.

HV stands for the 380/415 V circuit.

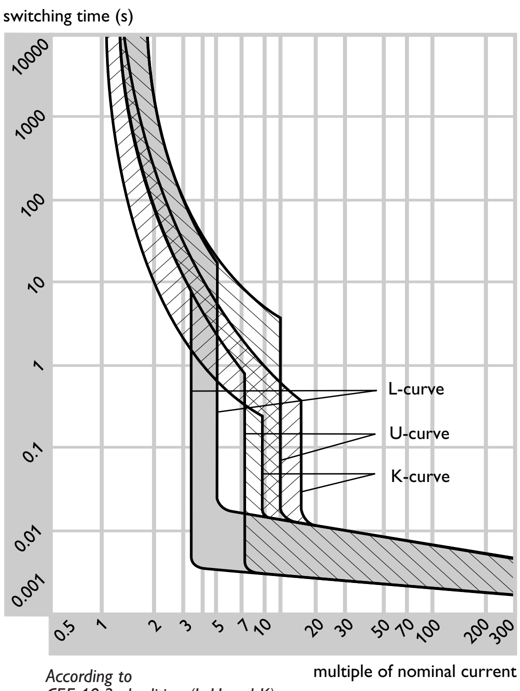
Fuse rating (A)	Single-circuit lamp load (W)	Maximum lamp load in multiple circuits (W)
4	up to 100	100
6	125	250
8	150	320
10	250	600
16	400	1000
20	1000 2000 HV	1400 2000 HV
25	2000	2000

The table is based on a power supply with very low impedance, short cabling and parallel-compensated circuits. In practice, the fuses often have to carry a greater load than that indicated in the table. In fact, especially when filter coils are used in series with the compensating capacitors, the recommended fuse ratings can be twice as high. In practice, there will be some cable resistance in series with the fuse. Whether or not the fuses will blow or not depends greatly on this cable resistance in the circuit.

When designing an electrical installation, the fuse rating is established by using the time/current curves (Figs. 91 and 92). This is primarily to ensure that the required disconnection time is achieved and the electrical installation is protected against overload. Having decided on the appropriate rating of the fuse, a check should be made to ensure that it can cope with the surge current. This can again be done by consulting the relevant time/current curve for the fuse concerned.

Example:
A 400 W SON lamp circuit has a starting current of 3.6 A. The surge current for a single circuit would be 25 x 3.6 = 90 A. For two circuits, a surge of up to 2 x 90 = 180 A would have to be allowed for.
Assume that a fuse rating of 8 A was initially chosen based on the starting current. In the time/current curves of Fig. 64 it can be seen that the surge of 180 A for 3 milliseconds only just falls inside the range of an 8 A fuse, and so it would be advisable to move up to a 16 A rating. This of course means that the required fuse rating may be higher than the expected value if just the starting current(s) are considered. Opting for a higher fuse rating will also mean that the size of the cable used in the installation should be checked, to ensure that it is compatible with the higher fuse rating.
Apart from calling for specific fuse ratings, surge and starting currents should also be taken into consideration when choosing switching equipment needed to control discharge lighting equipment. Switches should be rated for inductive currents, sometimes denoted by the letter X in the rating.
The same applies to mains circuit breakers (MCBs). Despite the fact that the switching characteristics of MCBs have been laid down in recommendations such as CEE-19-2nd edition, the individual properties of different types and brands may vary considerably.

Circuit breakers are tested and calibrated to carry 100 per cent of their rated current in open air at a specified temperature, normally 25°C. When they are mounted in an enclosure, the ambient temperature may be higher. For this reason, circuit breakers are only permitted to carry a continuous current of 80 per cent of their current rating. The technical information given by the manufacturer should be carefully reviewed with regard to the exact capabilities of a specific breaker.



According to CEE-19-2nd edition (L, U and K)

According to EN 60898/VDE 0641 (B, C and D)

Fig. 93. Switching characteristics of various types of mains circuit breakers.

Mains circuit breakers operate on two principles:

1. The thermal part, a bi-metal strip, which is heated by the passing current. The switching-off characteristic is similar to that of a fuse, and is influenced by time and current values. It is effective after a minimum of some 2 to 5 seconds for the smaller overload currents.
2. The electromagnetic part, a magnet coil, which is effective for the high overload currents and reacts within milliseconds (see Fig. 93).

For lighting applications, the less sensitive types of circuit breakers are advised, such as the U, K, C or D types. Taking the 10 A MCB type C as a reference (1), the other types can handle loads as shown in the following table:

Current rating	C type	B type	L type	U type	K type
10 A	1	0.6	0.7	1.3	1.5
16 A	1.6	1	1.1	2.1	2.5

Information on what lighting load a certain MCB can handle can be given by the MCB supplier, provided that data on cable layout, lamp type and circuit is available. As a guide a practical value for the figure (1) of the 10 A MCB type C represents a 1500 W lighting load on the conventional gear.

Fault conditions

A gas-discharge lamp circuit normally comprises four parts: lamp, ballast, ignitor and compensating capacitor. The effects of short-circuiting each of these elements are as follows:

Short-circuiting of the lamp

This has already been described: the mains current will be ca 1.5 times the nominal value, which leads to an extra temperature rise of the ballast and cabling by a factor $1.5^2 = 2.25$. There is no immediate damage or danger and the situation can last for minutes, hours and even days, depending on the ballast design. HID ballasts are not constructed to withstand this situation: they may become very hot, except the TS versions (see Section 4.1.8: Thermo-protected ballasts). In most cases the mains fuse will not blow and the situation can only be solved by good maintenance.

Short-circuiting of the ballast

1. During operation

As there is no current limit, the lamp current will rise immediately to an undefined high level. If the current is not switched off by the mains fuse, the lamp will normally become an open circuit because of melting of (one of the) sealed-in pinched leads; this may prevent the lamp from exploding. In most cases this process is so quick that there will be no extra danger or damage. In practice, however, it may happen that the ballast is partially short-circuited inside the copper coil, for example at the end of the ballast lifetime. This results in a higher ballast temperature and a higher lamp power. This process is cumulative and normally the mains fuse will not blow as the ballast gets hotter and hotter, until a fatal earth or winding breakdown occurs.
The ballast must be mounted in such a way that it can cause no harm during end-of-life failure.
Good maintenance can prevent blown-up lamps and burned-out ballasts.

2. During switching on
In most Philips parallel and semi-parallel ignitor circuits an important function of the ballast is to transform the available open voltage to the much higher ignition peak. With a (partly) short-circuited ballast the required voltage level will not be generated, so the lamp will not ignite.
It is possible that the ignitor continues producing ignition peaks, and the mains fuse will not blow, as the current through the mains is only the capacitive compensating current.
As the ignitor can be damaged during the short-circuiting of the ballast, it is advisable to replace both ballast and ignitor.

Short-circuiting of the ignitor
As there are different wiring arrangements and components inside the ignitors, many different forms of short-circuiting must be considered, but any fault will result in an incorrect ignition peak, so in most cases the lamp will not ignite.
The ignitors are constructed in such a way that in the case of a failure no dangerous situations can occur. Most ignitors have an internal fuse or de-rated wiring to switch off the ignitor in the event of excessive currents.
Normally, the ballast will not be affected by the faulty ignitor.
Again, good maintenance will prevent severe problems.

Short-circuiting of the parallel compensating capacitor
This results in a complete short-circuit of the mains, so the mains fuse will react. In fact, short-circuiting of the capacitor will not occur in practice, since capacitors for lighting applications must have a switch-off mechanism that results in an open circuit during excessive capacitor currents. The circuit is then not compensated, so the mains current will rise.
Regular control of mains current and/or power factor is advisable.

Earth leakage

There are two different earth classifications:
1. Protective earth (PE) with symbol add symbol, which must ensure safety in case of (human) contact with accessible metal parts that can become live, e.g. at the end-of-life of the component.
2. Functional earth with symbol add symbol, which must be connected for reasons other than safety.

Fig. 94. Typical capacitor with metal stud fixing.

With HID lamp control gear only protective earth has to be dealt with, which is permissible by mounting the gear on an earthed metal support.
Capacitors and ignitors in metal housings can often be mounted by means of a metal stud (see Fig. 94).
As the metal bottom plate or can of a ballast may be capacitively charged to a high potential, these parts must be earthed correctly by fixing to metal or by using a separate earth terminal, if present (see Fig. 95).

Fig. 95. HID lamp ballast with separate earth terminal.

Earth leakage currents in lighting circuits depend on the quality of all system components and on the circumstances (humidity, dust, age). With respect to luminaires, IEC 598 restricts these currents to 0.5 mA or 1 mA, depending on the insulation classification. The earth connection may consist of an earth lead or the capacitance between the luminaire and its surroundings. The earth leakage current of a ballast is normally very low: all ballasts undergo a high-voltage insulation test of 2500 V (HP) or 3000 V (SON) to check their insulation resistance. This can be done with a Megger (Megohm meter) of minimum 500 V DC, which should measure an insulation resistance of over 2 Megohm. Tests with burning HID lamps can give earth leakage currents of about 1 mA to 2 mA per lamp circuit. In older installations these figures can be somewhat higher due to humidity, dust, cable capacity or during the starting period. The earth leakage current should, however, under no circumstances be higher than 5 mA per lamp circuit.
There are two different applications for earth leakage devices:

1. to protect people from direct contact with live parts; reacting to the current through the human body there are 10 mA and 30 mA devices,
2. to protect people and earthed installations; reacting to the direct current to earth there are devices of 300 mA and higher.

Electrostatic discharges can be caused by people, for example by walking over a synthetic floor. A high potential can therefore exist. Then, for example, when touching a luminaire, the effect depends on the height of the potential: 1-2 kV: noticeable, 4-6 kV: unpleasant, 6-8 kV: painful.

4.3.16 Fault finding

When a lighting installation is out of order, a complex and thorough trouble-shooting procedure may prove rather too time-consuming. If this is the case, a simple check of the power switches lamps and gear may provide the quickest response to the problem. In other instances it may prove necessary to isolate the problem systematically and perform complete electrical tests in order to restore the lighting properly.
It is also important to know if the installation or individual isolated lighting points did function well before the failure.

There are four basic categories of failures:
1. lamp related: not starting, cycling, too bright or dim, flashing
2. gear related: too hot or damaged ballast, capacitor, ignitor,
3. installation related: cable too hot, terminals or lampholder damaged, blown fuses, contactors or circuit breakers tripped,
4. supply voltage related: too high, too low, wrong frequency, poor voltage wave form.

There are also four basic methods of trouble-shooting, preferably in this order:
1. visual inspection,
2. quick fix for restoring lighting,
3. trouble-shooting checklist,
4. electrical tests.

1. Visual inspection

Lamps
The end-of-life of mercury and metal halide lamps is characterised by low light output and/or colour changes, and/or intermittent starting. Visual signs include blackening at the ends of the arc tube and electrode tip deterioration.
Old SON and MHN lamps will tend to cycle at the end of life. This is because the lamp voltage increases two or more volts per 1000 burning hours. After starting, they will cycle on and off, as the lamp requires a higher voltage to stabilise and operate the arc than the system is capable of providing. Visual signs also include a general blackening at the ends of the arc tube. The lamp may also exhibit a brownish tinge (sodium deposit) on the outer glass envelope.
Additional lamp checks may reveal:
- broken arc tube or outer lamp jackets,
- lamp broken where glass meets the base,
- broken or loose components in lamp envelope,
- arc tube blackening,
- deposits inside outer glass envelope,
- lamp type and wattage not corresponding to that required by ballast label,
- lamp orientation not as specified (e.g. base up instead of base down),
- loose internal connection, e.g. on discharge tube.

Components
Visual inspection of components may reveal:
- damaged ballast, ignitor or capacitor,

- evidence of moisture or excessive heat,
- loose, disconnected, pinched or frayed leads,
- incorrect wiring,
- ballast, ignitor or capacitor not in accordance with lamp type and lamp wattage for the actual mains supply voltage.

Installation
Inspection of the installation may reveal:
- damaged or incorrect wiring,
- high-voltage lead (with ignitor pulse) not connected to central lamp contact,
- blown fuses, activated circuit breakers or contactors,
- hot cables,
- damaged lampholders,
- signs of flashover.

Mains supply
Verify that the correct line voltage is being supplied.

2. Quick fix for restoring lighting

After the visual inspection, replace any defective component, starting with the lamp.

3. Trouble-shooting checklist

When a failure still persists after having established that the right components, wiring diagram and supply voltage are employed, the next step is to consult the following trouble-shooting check-list:

Fault 1: The lamp shows a bright flash and does not ignite again.
Possible cause:
- no ballast, incorrect ballast, short-circuited ballast
- capacitor across the lamp instead of across the mains.

Fault 2: Newly replaced lamp does not ignite.
(Note: In the case of a self-stopping ignitor, the mains voltage must first be switched off)
Possible cause:
- cable capacity too high
- high humidity
- faulty component.

Remedy:
Disconnect ignitor and measure mains voltage and open-circuit voltage at the lampholder; in case of a linear coil, these must both be equal,
- if equal, replace the ignitor
- if not equal, replace the ballast
- if equal and there is still no ignition after replacing ignitor and lamp, check lampholder and circuit contacts.

Fault 3: Lamp remains in glow stage, does not ignite properly.
Possible cause:
- lamp was damaged in previous overload
- ignitor defect.

Fault 4: Lamp cycles
Possible cause:
- end of lamp life, check as at fault 2
- floodlight design problem: lamp temperature too high, back radiation from reflector too high
- mains voltage irregular: nearby high power equipment switched on-off.

Fault 5: Lamp flickers
Possible cause:
- lamp operating voltage too high, end of lamp life
- low supply voltage, check ballast connection
- burning position not according to specification.

Fault 6: Strong blackening of lamp, reduced light output.
Possible cause:
- overload operation
- wiring/ballast defect
- capacitor across lamp instead of across mains.

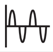
Fault 7: Fuse blowing shortly after switch-on.
Possible cause:
- fuse rating too low or fuse not of the slow-acting type
- wiring defect, overload operation.

Fault 8: Lamp exhibits colour differences.
Possible cause:
- widely-varying burning positions in an installation
- underload
- lamps of different operating ages or of different brands.

Electrical tests

Persons performing voltage and current measurements may be exposed to dangerous voltages. Only qualified personnel should perform such measurements.
To measure the correct effective values, true RMS voltmeters should be used. Measurements made with non-true RMS meters may give up to 50% lower values, especially when measuring lamp voltage or other non-sine-wave voltages (see table below):

Current measurements on different waveforms

Description	Waveform	Average (RMS calibrated)	Peak (RMS calibrated)	True RMS
Sine wave		100	100	100
Square wave		100	63.6	90
Triangular wave		100	125	103.3
Single-phase electronic load current		100	400	199.4
Single-phaseel ectronic plus 30% linear load		100	200	120

The **parallel compensating capacitor** can be measured in two ways:
1. Measure the mains current and lamp current.
   If they are the same, the capacitor is open circuit and has to be replaced.
   If the mains current is about half the lamp current, the capacitor is in order, giving a power factor of ca 0.9.
2. Disconnect the capacitor from the circuit and discharge it by short-circuiting the terminals.
   Check the capacitor with an ohmmeter switched to the highest resistance scale. If the meter indicates a very low resistance which then gradually increases, the capacitor is in order.
   If the meter indicates a very high resistance, which does not diminish, the capacitor is open circuit and should be replaced.
   If the meter indicates a very low resistance, which

does not increase, the capacitor is short-circuited and should be replaced.

Due to the high peak voltages involved, measurement of the starting-pulse voltage of an **ignitor** is beyond the capability of most instruments available in the field. The only practical solution is to replace the suspect ignitor. With the semi-parallel type of ignitor in particular, a delicate tinkling noise at the ignitor and ballast can be noticed when the ignitor is operative.

Measurements on the **ballast** can be done in two steps. After disconnecting the ballast from the circuit:

1. Check with an ohmmeter across the terminals. Resistance should be low (0.2-20 Ω, depending on the lamp power). If it is high, the ballast is open circuit.
2. Connect the ballast to the mains supply (well fused!) and measure the short-circuit current. This should be approximately 1.5 times the nominal lamp current.

Due to the high peak voltages involved, measurements on the **lamp** can only be done if the ignitor is not operative. As the lamp voltage is not a sine wave and due to the tolerances in the total circuit, measured lamp voltages give only a rough indication of correct functioning. The lamp current can be measured rather accurately.

Measurements of the **mains supply** normally involve measuring the effective value of the supply voltage and mains current, and sometimes the frequency. When pulses, interruptions, harmonics (waveform) may play a role, laboratory instruments are required, with measurements performed over an extended period, while storing or noting the readings. In order to check the balance of the load, it is advisable to measure the various phase currents in an installation. Also measurement of the current in the neutral in a star network will provide an indication of the quality of the total system. Due to harmonics in the lamp current, the current in the neutral is not zero, but should be between 50 and 70 per cent of the phase currents. If the current in the neutral is higher than in the phases, the balance in the load is not correct or the mains supply does not have a good sine wave form. This may lead to overload of the neutral cable. For the sake of safety and good ignition, it is essential that the luminaires and the electrical system be earthed. Check the system current to real earth (see Section 4.3.15: the paragraph on earth leakage). The voltage between real earth and the neutral conductor is not limited by safety regulations, but normally lies between 0 V and 6 V.

Apart from all these electrical tests, a check should also be made to see that all components are used within their specifications, special attention being paid to the maximum permitted temperatures.

4.3.17 Maintenance

Gear components are in fact designed to be maintenance-free. Regular control of the tightness of the screw terminals may prevent problems as a result of open circuits or sparking. Loose ballast mounting screws can cause hum. In very dusty surroundings the ballast may become overheated and should therefore be cleaned from time to time.

4.3.18 Installation aspects

1. The live side of the mains must be connected to the correct terminal of the ballast. The neutral side of the mains must be connected to the side contact on the lamp socket. Both connections are important because ballast and lamp construction relies on this convention for maximum creepage path and correct ignition.
2. Interchange of phase and neutral connections may cause higher radio interference, higher earth leakage currents and/or ignition problems.
3. It is recommended that the bottom plate of the ballast be connected to earth. This is especially important in circuits with high ignition peaks to avoid the chance of a build-up of static electricity. The static charge is in itself not dangerous, but contact with the charged metal of the can in the potted version could, for example, cause an unpleasant jolt to the senses, possibly with undesirable consequences. Encapsulated versions of SON ballasts have an earth terminal, whilst in the BASIC version no separate earthing is required: earthing-while-mounting. The wire used for earthing purposes must be of the low-resistance type, viz. at least 2.5 mm^2.
4. In SON semi-parallel circuits there must always be a capacitor of at least 1 TF across the mains for reliable ignition. Normally the parallel compensating capacitor is connected, but if not, (as, for example, in a test set-up), a capacitor must be connected.
5. In two or three-phase networks with a neutral conductor, this neutral must have the same diameter as the phases (see Section 4.3.7: Harmonic distortion).
6. Use stranded wire in situations where vibrations may occur or where the wire must be able to bend in use, as in a spotlight.
7. HID lamps are also referred to as high-pressure lamps. This high pressure is only reached when the lamp is operating. When the lamp has cooled down, the pressure in the burner is lower than the normal air pressure.

4.3.19 Non-standard supply voltages

Provided they are operated on the correct gear,
HID lamps can function perfectly well on a wide range of supply voltages. The floodlight itself is not limited to certain supply voltages either.
For non-standard voltages appropriate gear components should be selected:

- Ballasts must be designed for the proper supply voltage and frequency as well as the chosen lamp type.
  So ballasts for a mains supply frequency of 50 Hz are different from those for 60 Hz, even if the mains voltage and the lamp type are the same. If the desired ballast type is not in the standard Philips range, the best solution is to find a local alternative.
- Ignitors are related to lamp type, ballast and supply voltage.
  The Philips range of ignitors cannot be used for voltages other than those for which they are specified. All ignitors are suited for both 50 Hz and 60 Hz. Series ignitors for non-standard voltages can be obtainable.
- Capacitors are specified by their voltage and capacitance (in μF).

As long as the working voltage is lower than the indicated capacitor voltage, the capacitor can be used. There is no difference in capacitance between a capacitor designed for a 50 Hz and one designed for a 60 Hz supply-voltage frequency. The capacitance necessary for power-factor correction purposes can be calculated (see Section 4.3.4: Power factor correction): for parallel compensation it must be 5/6 smaller for 60 Hz supplies than for 50 Hz supplies.

- Filter coils are related to a capacitance (inµTF) and the frequency to be blocked. As long as the power supply voltage is lower than the indicated filter-coil voltage, the filter coil can be used.

In large lighting installations, a non-standard voltage can normally be transformed centrally into a standard voltage. In small projects a local solution has to be found.

4.3.20 Frequency deviations

Frequency deviations do not normally occur in public electricity supplies, but if someone generates his own electricity (e.g. because there is no access to a public mains or in order to bridge power cuts), it is often difficult to keep the frequency sufficiently constant.
But a constant frequency is of importance for reliable operation of discharge lamps. The lamp itself can cope with a broad frequency range, but this is not so for the combination of lamp and ballast connected in series.
The impedance of chokes and capacitors is frequency-dependent.

The inductive impedance of a choke diminishes with decreasing frequency, and the (lamp) current rises.
The reaction to a higher current is not the same for all discharge lamps. A higher lamp current gives higher lamp power in all cases, but the extent of the power increase differs from type to type. The higher lamp power increases the load on the power generator, which leads to a further drop in frequency. The circle is now closed: current, power and generator load rise, the frequency drops even further, and so on. Without control this process can lead to serious consequences: lamp and ballast failures and overloading of the generator.
Furthermore, a lower frequency causes a lower power factor. The impedance of the capacitor in parallel with the mains increases with decreasing frequency.
The compensation current becomes weaker, so there is less compensation than before. In other words, the power factor is lower.

Too-high frequencies also have adverse effects.
The impedance of the capacitor will drop and the compensation current becomes higher. The lamp current will be lower due to a higher series inductance. As a result, the lamp will be under-run and the power factor will be reduced.

For all these reasons it is necessary to ensure that the frequency of the mains supply does not deviate from the rated value by more than 5 per cent.

4.3.21 Gas-discharge lamps and generator power supply

Where the power supply voltage for gas-discharge lamp circuits is generated by a separate motor/generator set, special attention must be paid to the right choice of the generator/alternator type. Not all types of generators can correctly handle the changing power factor and/or the harmonics in the phase current.
Supplies with a neutral conductor (230 V supply in three-phase star network), in particular, should be checked as regards the current in the neutral conductor (see Sections 4.3.7: Harmonic distortion, and 4.3.11: System cabling).

Minimum recommendations for the motor/generator set, based on no-load and full-load conditions:

1. Frequency variation restriction in case of a 50 Hz mains: ± 4% (48-52 Hz); switch-off under 47.5 Hz or over 52.5 Hz.
2. Voltage variation restriction: ± 2.5% (for 230 V installations ca 6 V); switch-off under 95% and over 105% of nominal voltage.
3. Maximum installed load: 90% of rated generator power.
4. Generator power (rated) minimum 110% of rated power of diesel engine.
5. Total acceptable mains voltage distortion: max. 2% THD in no-load, max. 3.5% THD in full-load.
6. Neutral and phase conductors must have the same diameter.
7. The source must be able to adequately handle the third harmonics in the neutral (which are approx. 70% of the phase current in a well-balanced system), to fulfil the requirements as mentioned in point 5; an extra filter (Z-coil) may be necessary.
8. The source must be able to handle effectively the variable power factor during run-up of the lamps.

Choosing the right diesel generator set is a task for specialists, as the following aspects have also to be considered:
- short-circuit situations,
- switching behaviour,
- power factor regulation,
- start and run-up conditions.

Back to contents

5.

Electronic lamp control gear

5.1 Introduction

Electronic systems for HID lamps are fairly new. Based on the experience and knowledge gathered with electronic systems for fluorescent (viz. TL) lamps, new electronic circuits have been developed to make electronic operation of HID lamps feasible (next to the traditional ballast/ignitor/capacitor configuration). Compared with the TL lamp, this is not an easy matter, for a number of reasons:

- As the market for TL lamps and circuits is much larger than that for HID lamps and circuits, the attention was first focussed on electronic gear for fluorescent lamps.
- TL installations are used mainly indoors, whereas HID lamps are used in many outdoor applications as well, with heavier demands on ambient temperatures, humidity, reliability, and so forth.
- There are many different HID lamp types (SOX, SON, HPL, HPI, MH, CDM) with different sorts of electrical behaviour with respect to starting, run-up and stabilisation, which makes one universal circuit impossible.
- There is a wide lamp power range (from 35 W to 2000 W), which imposes restrictions on the electronic components due to the high (starting) currents and (starting) voltages employed.
- Compensation for the changing behaviour of an HID lamp during its lifetime is much more complicated than with TL lamps (rising lamp voltage, rectifying effect, shifting colour point, end-of-life effects (EOL).

Putting all this aside, the electronic configurations should bring the customer some extra benefits in addition to those gained by the use of the traditional electromagnetic systems. In this respect, the efforts are worthwhile, as one or more of the following advantages are to be gained, largely on account of the better lamp-power regulation:

- increased lamp life
- improved lamp behaviour, including:
  - reduction of colour differences initially and/or during lamp life
  - reduction in lumen spread
  - elimination of visible lamp flicker
  - more stable and/or faster run-up
  - increased lamp efficacy
- better system efficiency (lower energy consumption),
- less sensitivity to temperature or mains-voltage fluctuations
- fewer, lighter, and smaller components, less wiring
- additional features, including possibility of dimming, hot-restrike, choice of colour temperature, automatic switch-off in the event of failures or end-of-life effects
- one electronic system for a wider range of lamp powers and/or mains voltages
- lower maintenance costs, for example by tele-management.

Obviously, not all these benefits are obtainable simultaneously. Besides, not all existing lamps are suitable for realising an optimum result for the total (electronic) lighting circuit. In some instances, the traditional electromagnetic system is better, as with high-pressure mercury (HPL) lamps. In other cases the possible efficiency improvement is too small to outweigh the higher cost price of the electronic gear. Due to the high currents involved, electronic circuits for lamp powers of more than approximately 400 W are relatively expensive, but such circuits are in development and will come onto the market in the future.

Laboratory experiments have shown that the different types of HID lamps can only be stabilised in certain frequency bands. Outside these restricted bands, the efficiency may drop, but also the discharge tube may be mechanically damaged by acoustic resonance, or electrodes may break off. Electronic gear units are therefore only suitable for the specified lamp types. Conversely, some newly developed HID lamps can only be operated on their electronic gear, since there is no conventional alternative.

The gear for HID lamps can be completely electronic, but so-called hybrid systems are also possible. In the latter case, one or more functions are integrated in the controller, as for example the ignition function for the White SON.

Due to the trend towards smaller luminaires with smaller lamps for better optical control, it is becoming more and more important to more accurately control the lamp behaviour, especially as the lamps get older.
No doubt electronics for lamp control will play an increasingly more important role in future developments.

5.2 Available products and systems

Although more products are available for special applications (e.g. electronics for Micro Power lamps in automotive applications, power supplies for projection or UHP lamps), the standard electronic gear consists at the present time of the following products:

1. Hybrid ballast systems for White SON lamps, CSLS control unit and BSL ballast. Fully electronic gear for Mini WhiteSON 50 W and 100 W
2. Fully electronic ballasts for low-pressure sodium (HF SOX) and metal halide lamps (HID-PrimaVision)
3. Dimming solutions for SON lamps: HID-DynaVision (fully electronic), HID-DynaVision controller (hybrid)
4. Control devices SDU/HSU
5. Tele-management systems.

5.3 General information

A great deal of information given before in the chapter on electromagnetic gear is also valid for the electronic gear. For example, questions are often asked concerning the use of cabling between ballast and lamp. For this cabling an identical specification as for electromagnetic gear is required. There are, however, two major issues related to electronics that differ considerably from electromagnetic gear, viz. lifetime and temperature.

5.3.1 Lifetime

With electromagnetic ballasts the lifetime is related to the absolute coil temperature (see Section 4.1.6: T_w and Δt). As a rule of thumb, over a wide temperature range every 10 degrees increase halves the lifetime, and so failures can be more or less predicted.
With electronic ballasts, the temperature range is more limited. The end of life of individual components and the total circuit depends on many factors, including electrical load, mechanical connections, vibrations, temperatures and temperature changes, number of components, humidity, and so forth.
Individual components are tested at their maximum specifications, and figures are available for the failure rate, expressed in the percentage of failures per 1000 hours. Also, the influence of temperature or applied voltages/currents, for example, is well known. With this information, calculations can be made for all the components together to find the expected failure rate for a specific total circuit. The same procedure can be followed for the so-called early failures, which are caused mainly by faults in the various production stages or, of course, by faulty or incorrect components. However, finding the end of lifetime of the components and the total product is a more complicated matter.
Tests under specified conditions are made to verify the calculated failure-rate curves before they are published. A common way of expressing the lifetime of electronics is the MTBF: the Mean Time Between Failures, or, for non-repairable circuits, the MTTF: the Mean Time To Failure. These figures are published for a specified ambient temperature and are expressed as a percentage failures per 1000 hours. The MTBF depends on the chosen components, the ¨stress factor¨ (circuit design) and the temperature.
The commercial lifetime for electronics is defined as the time when 10 per cent of the ballasts have failed in practical situations (see Fig. 96). For outdoor applications, this lifetime should be more than 50 000 hours, for offices 50 000 hours is long enough, while for shops 40 000 hours is acceptable.

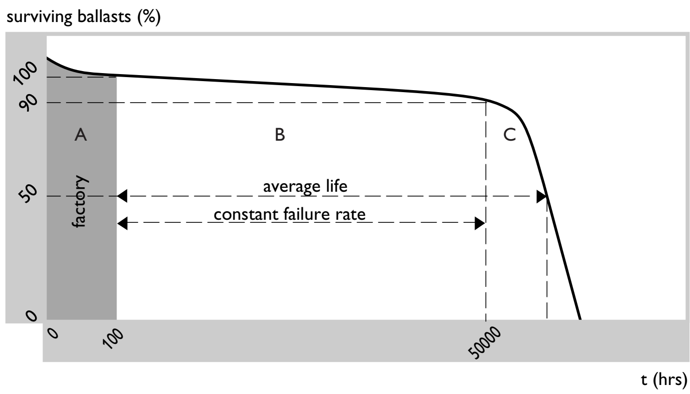


Fig. 96. Typical lifetime curve (logarithmic scale).
A = burning-in (100 hrs theoretically)
B = low failure rate = high MTBF
C = increasing failure rate = decreasing MTBF
MTBF = 1/failure rate = calculated by technicians

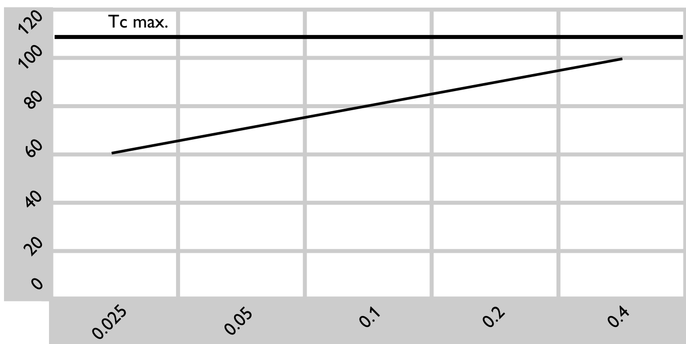
5.3.2 Temperatures

All lighting components may be expected to function properly when they operate within their specifications. This is also true for electronic circuits. When, on the other hand, they are not used within their specifications, they will normally have a (very) short life. This is especially true for the applied voltages/currents and for the absolute temperature of the components. But the electric connections on the printed-circuit board, which are usually soldered, are also subject to an absolute maximum temperature. So the maximum specified temperature Tc max should never be exceeded.
Under normal conditions, the watt losses in the total circuit are rather low and therefore the self-induced temperature rise of an open circuit will be fairly low.
But even then, some components may reach considerable temperatures.
When the electronic circuit has been built into an enclosed compartment (e.g. gear box or luminaire), the temperature of the air inside will rise. In order to keep the [absolute] temperature of the electronics below the permitted maximum, electronic devices can only be used up to a certain maximum ambient temperature. Exceeding this limit will in most cases cause the device to be damaged or to fail very quickly. When the device is functioning below the maximum ambient temperature, its lifetime will be longer, but not to the same degree as with electromagnetic ballasts. This ambient temperature is not the actual room or outdoor temperature, but the temperature around the electronic device in its housing.
Just as described for the electromechanical ballasts, the maximum permitted ambient temperature Tamb is given by:
Tamb = Tc max - Δt.
A minimum ambient temperature is also specified, sometimes split up into a storage and a working temperature.

As electronic devices are often built into enclosures, such as luminaires, the expected ambient temperature cannot be predicted exactly. For this purpose, a test point is usually defined on the outside of the enclosure, and a maximum temperature Tc max is specified for this test point. As long as the temperature Tc of this point remains below the specified maximum, the components will not be harmed. But should Tc rise to above this maximum, the lifetime of the device will decrease dramatically.
The published lifetime of the electronic device is related to the temperature Tc life of the test point.
As the enclosures of the electronic devices are often made of some type of plastic, the temperature of the test point must be measured very carefully. The use of an unduly large test finger, as supplied with some multimeters, will undoubtedly indicate temperatures that are too low.
The test point temperature must be measured by means of thermocouples, which must be firmly glued to the surface (and not, for example, with adhesive tape).

The lifetime of electronic ballasts (failure rate) strongly depends on the temperature of the components, see Figs. 97a and 97b for example:

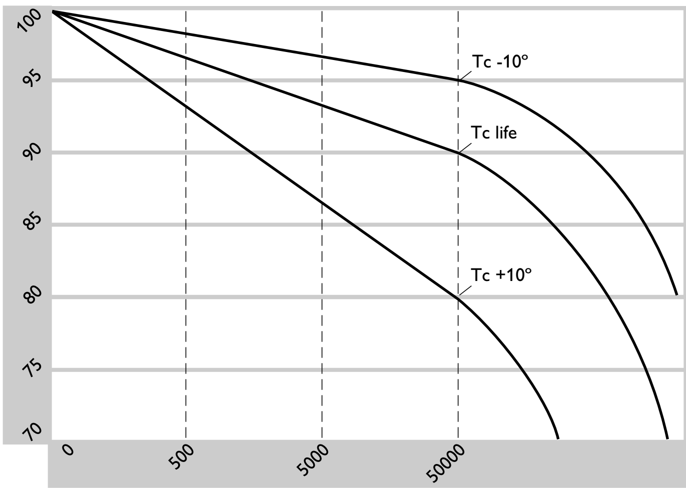
ballast temperature (°C)



average failure (%/1000 hrs)

Fig. 97a. Failure rate as function of the ballast temperature.

survivors in %



lifetime (hrs)

Fig. 97b. Survivors as function of the ballast temperature (logarithmic scale).

An electronic dimming ballast will have different temperatures at different dimming levels. The total failure rate can be calculated if the burning hours and the ballast temperatures for the various dimming levels are known:

Light level (%)	Average temp. ballast (˚C)	Average failure rate (%)	Burning hours (hours)	Calculated failure rate (%)
0	20	0.001	38	0.00038
20	30	0.01	12	0.0012
50	50	0.02	8	0.0016
75	75	0.13	17	0.0221
100	80	0.18	25	0.045
TOTAL				0.07

This means that after one year (8760 hours), 0.6% (0.07 x 8.76) of the ballasts will fail.

5.4 Circuits for White SON lamps 35 W, 50 W and 100 W and Mini WhiteSON 50 W and 100 W

5.4.1 Components

More than 15 years ago, the first electronic gear for HID lamps from Philips was introduced as the controller for the White SON circuit. The main function of the circuit is to stabilise the colour point of the lamp in respect to mains voltage fluctuations and during the lifetime of the lamp.

The hybrid White SON circuit consists in principle of four components (see Fig. 98):

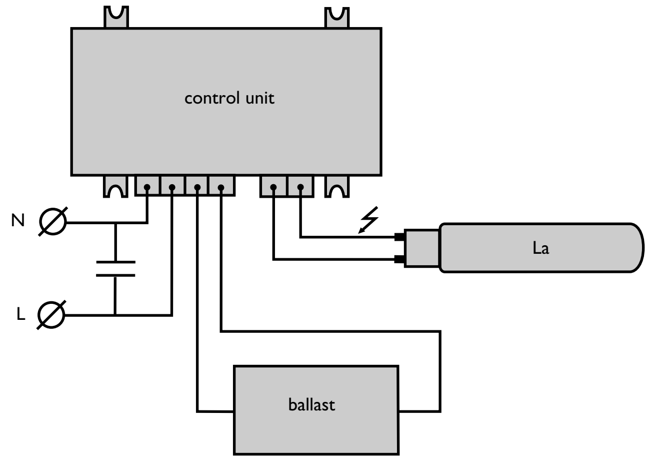


Fig. 98. Wiring diagram of a White SON lamp system.

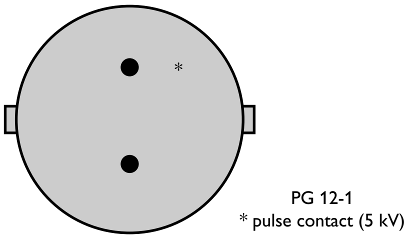


Fig. 99. SDW-T lamp base, showing the position of the "keys" (bottom view).

1. An SDW-T lamp with a bi-pin base type PG 12-1 (see Fig. 99), which has to be used with a dedicated ¨push-in¨ lampholder type PG 12-1. This holder ensures that the eccentricity of the lamp remains within very small tolerances and eliminates the risk of using an incorrect lamp. The PG 12-1 lampholder is equipped with two pinholes, one with a small and the other with a large diameter. The large hole is insulated for the pulse voltage and has to be connected to the screw contact with the 4.5 kV indication.

2. A normal electromagnetic copper/iron ballast BSL**, available for different mains voltages and frequencies. The information given in Section 4.1: Ballasts, is also valid for these ballasts.
   For the proper functioning of the total system it is important to use a ballast that suits the actual mains voltage. The tolerance range for the mains voltage is from -10 V to + 20 V.

3. A normal parallel compensating capacitor across the mains if a high power factor (> 0.85) is required. The power factor without compensating capacitor is 0.4.

4. The lamp controller or current stabiliser CSLS**. The controller has two functions: to ignite the lamp and to regulate the lamp current so that the lamp colour temperature is as constant as possible.

Recently, the first compact, one-piece, electronic ballast for built-in (/S) or stand-alone (/I) applications with 50 W and 100 W Mini White SON SDW-TG lamp was introduced onto the market.
The so-called HID-PrimaVision (HID-PV) SDW-TG ballast operates on low frequency (typically 130 Hz), eliminating all visible lamp flicker. Improved colour stability is obtained by the U-processor Colour-Control, which compensates for colour shifts due to mains and lamp-voltage tolerances and variations. Also, optimum end-of-life protection is obtained by an automatic stopping circuit and thermal cut-off in the event of failures.

5.4.2 Ignition

The integrated ignitor provides a pulse height of 4.5 kV nominal (3.5 kV minimum), while the peak width at 90% of pulse height is 0.35 µs.
The CSLS ignition technology is based on the series circuit, so it requires no extra tap on the ballast.
The cable capacity between the lamp and the CSLS unit must not exceed 50 pF (see also Section 4.3.12: Cable capacitance). In practice, this corresponds to a distance of ca 60 cm. After the actual ignition, the lamp passes through the run-up phase (see Fig. 100).
The maximum permitted cable capacity for the HID-PV 100 SDW-TG is 200 pF.
When there is no lamp in the socket or the lamp is defective, the CSLS device continues to produce ignition peaks (no stop circuit). To avoid possible damage to the various components it is advisable to replace a defective lamp as soon as possible. With HID-PV fully electronic ballasts, the ignition pulses are applied to the lamp only during specific time periods, which will stop after some 15-20 minutes. Significant advantages are reduced EMC, lower cable load and elimination of lamp flickering for end-of-life lamps.

Hot re-ignition after a mains supply interruption is possible within 30 seconds.

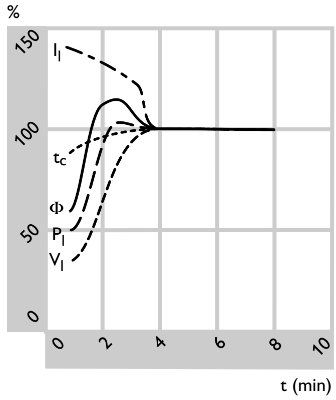


Fig. 100. Ignition and run-up phase of a White SON lamp circuit.

5.4.3 Regulation

The lamp current and the lamp voltage are both monitored in the CSLS control unit. Depending on the instantaneous levels, a triac in the lamp current circuit regulates the lamp current according to a set limit, to make sure that the colour temperature of the lamp is always between 2400 K and 2600 K. In this way the effects of lamp voltage and mains voltage fluctuations are kept to a minimum (see Fig. 101). Without the control unit, the colour temperature of the White SON lamps can vary between 2200 K and 3200 K. Power regulation also ensures that the specified long lamp life will be achieved. Through the inclusion of a microprocessor, even better control is achieved with the HID-PrimaVision ballasts for Mini WhiteSON lamps.

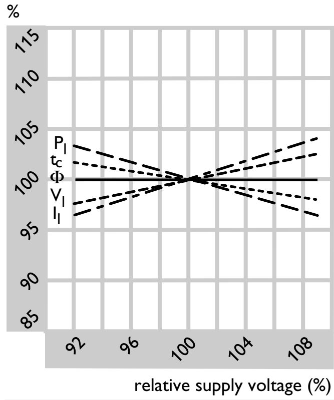


Fig. 101. Effects of mains voltage fluctuations on lamp voltage (V_l), lamp current (I_l), lamp power (P_l) and luminous flux (Φ) for a White SON lamp (compare with Figs. 78 and 79).

5.4.4 Temperatures

A test point has been defined in the centre at the back of the control unit. With the unit installed, the temperature at this point (t_c) shall not exceed 90˚C, measured under the most unfavourable conditions. For the White SON control unit this is defined as being measured with the correct ballast at test voltage 1.06 x V_{nom} at an ambient temperature around the luminaire of 50˚C.
The temperature on the remaining surfaces of the control unit should also not exceed 90˚C. This could happen when heat is radiated or conducted from hot parts of the luminaire onto one or more of the other sides of the control unit. For this reason, the luminaire should be so designed that at an ambient temperature of 25˚C and measured with 106% of V_{nom}, the test point temperature is below 65˚C (see also Section 5.4.8: Installation aspects).
The minimum permissible ambient temperature is -25˚C.

5.4.5 Ballast expected life and failure rate

The average lifetime of the lamp controller at its maximum permissible case temperature is 40 000 hours. The calculated failure rate at t_c = 90˚C is 0.6% per 1000 hours. At lower temperatures, the average lifetime – and the reliability – of the control unit is higher.

Also the call rate (or failure rate) will decrease at lower test point temperatures. This is why the luminaire should be so designed as to keep the test-point temperature of the control unit as low as possible. All other surfaces must be below 90˚C as well.

5.4.6 Fusing of the mains supply

In practice, the mains current during the first few seconds of the starting process is twice the level of the nominal stable operating current in circuits without compensating capacitor. As the power factor without compensation is only 0.4, parallel compensation is required.
With compensating capacitors, the figures during starting are some three times higher during the first few seconds with a high inrush current of about 25 times the nominal current during the first milliseconds. Slow-acting **gL** fuses or circuit breakers with U, K, C or D-characteristic must be used (see also Section 4.3.15: Circuit breakers, fusing and earth leakage).

Recommended maximum number of compensated circuits for gL fuses:

Fuse rating	10 A	16 A	20 A
CSLS 35 W	18	30	40
CSLS 50 W	9	15	20
CSLS 100 W	6	10	14

Recommended maximum number of compensated circuits for MCB type B

MCB rating	10 A	16 A	20 A
CSLS 35 W	26	42	52
CSLS 50 W	13	21	26
CSLS 100 W	9	14	18
HID-PV 50 W	10	15	20
HID-PV 100 W	4	6	8

For safety reasons, a non-replaceable fuse of 3.15 A is built into the CSLS unit to switch off the system in abnormal circumstances.

5.4.7 Humidity

Both in the CSLS controllers and in the HID-PrimaVision ballast, discrete and miniature SMD components are used on the printed-circuit board, and the enclosure is potted with heat-transfer compounds. The resistance to humidity therefore complies with IEC 68-2-3: protected outdoor use.
The White SON gear is designed for built-in situations or in appropriate luminaires or separate gear boxes.
The luminaire must provide sufficient protection in outdoor applications.

5.4.8 Installation aspects

Given its relatively high lumen output, combined with excellent colour properties, the CSLS controller and White SON lamp system mainly finds application in indoor accent lighting, such as in uplighters, downlighters and spotlights. Due to the restricted cable length between lamp and controller (ca 0.5 m for a 100 pF/m cable), the controller will be mounted in or near the luminaire. The screw contacts are suitable for solid core, stranded, or flexible wires. The maximum diameter is 2.5 mm^2.

There are no special restrictions for the ballast and the compensating capacitor, and they can be mounted further away from the luminaire.

The maximum specified temperatures must not be exceeded. The best answer is to mount the controller so that it is surrounded by free-flowing air. With convection, the temperatures will be about 15 degrees lower than when this type of heat dissipation is not possible.

When the unit is completely enclosed, heat dissipation can only take place by radiation and conduction. If this is the case, there must be good thermal contact between the components (bottom plate of the controller) and the luminaire housing, without air gaps (see Fig. 102).

It is also recommended that a thermal barrier be created between the hot lamp compartment and the gear.

The housing in which the gear parts are mounted must be as cool as possible. For this reason, conduction of lamp heat into the gear housing should be prevented.

The HID-PrimaVision is especially designed for optimum operation of the new compact Mini WhiteSON SDW-TG lamps. For this system, the maximum permitted cable length is 2 m for 100 pF/m cable.

Comparable thermal measures as with CSLS controllers have to be taken into account.

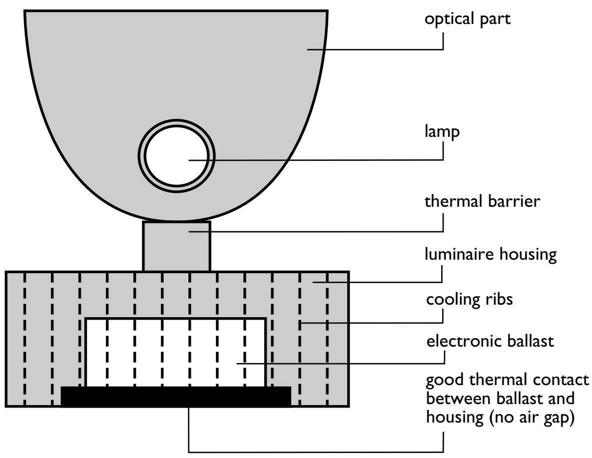


Fig. 102. Good thermal installation of a White SON lamp.

5.5. Circuits for compact metal halide lamps 35 W, 70 W and 150 W

5.5.1 Introduction

Metal halide lamps have been widely used for many years in applications where white light with excellent colour rendering is required, combined with a long lamp life and good system efficiency. Examples include sports lighting, floodlighting, accent and decorative public lighting. Until some years ago, only lamps with high lumen packages were available, with lamp wattages varying from 250 W to 2000 W.

Continuous development in lamp manufacturing has led to smaller metal halide lamps. A breakthrough has been

realised by replacing the miniaturised quartz discharge tube by a ceramic tube. This technology is copied from the superior Philips SON technology realised in metal halide lamps. This has improved the performance of compact metal halide lamps so much so that they can now also be used in uplighters, downlighters and spotlights, especially in indoor applications such as accent lighting in shops.
Most metal halide lamps can be ignited, stabilised and compensated with electromagnetic gear circuits: a ballast, ignitor, and compensating capacitor. This system has some disadvantages, which can usually be accepted in outdoor applications, but which can be rather disturbing in indoor situations:

- Due to the production process, there is a noticeable initial lumen and colour spread in the individual lamps.
- There is a noticeable colour shift during the lifetime of the lamp, which gives rise to a different colour impression in lamps with different burning hours.
- There is a visible flicker, both with new lamps and with aged lamps.

Apart from these disadvantages, in indoor applications the overall dimensions of the gear and its total weight are more critical than in outdoor applications.

The electronic gear range HID-PrimaVision offers a fully electronic circuit for CDM lamps and all types of single and double-ended ceramic metal halide lamps of 35 W, 70 W and 150 W.

5.5.2 Benefits and features

As most low-wattage metal halide lamps can be ignited and stabilised both with conventional gear (ballast, ignitor, capacitor) and with fully electronic gear, a comparison between the two systems can be made.

The electronic system offers the following benefits and features:

- increased practical lamp life for quartz burners: 50% for MH and 30% for CDM lamps, resulting from elimination of influence of mains-voltage variations and faster and controlled lamp ignition.
- improved lamp performance:
  - elimination of visible flicker
  - negligible influence of mains variations and temperature
  - reduction of colour differences both initially and during lamp life
  - reduction of initial lumen spread
  - better behaviour at End Of Life (EOL)
  - more stable and faster run-up of the lamp
- reduced work load for the Original Equipment Manufacturer:
  only one type, suitable for mains voltages from 220 V to 240 V, 50/60 Hz
  - less wiring needed
  - fewer components to assemble
  - very low weight
  - long distance from lamp to gear allowed
  - compact dimensions.

The losses in the electronic gear are lower than those in the conventional gear, so the system efficiency is higher:

Lamp	Electromagnetic		Electronic	
	Losses (W)	Efficiency (lm/W)	Losses (W)	Efficiency (lm/W)
35	8	72	5	78
70	14	78	7	83
150	18	85	16	86

5.5.3. Components

Unlike most electromagnetic HID ballasts, which have a separate core and coil, ignitor and capacitor, an electronic ballast integrates all the key ballast functions in the ballast enclosure. The electronic system does not require a power factor correction capacitor, since it has a power factor of more than 0.95 (typical 0.99), see Fig. 103.

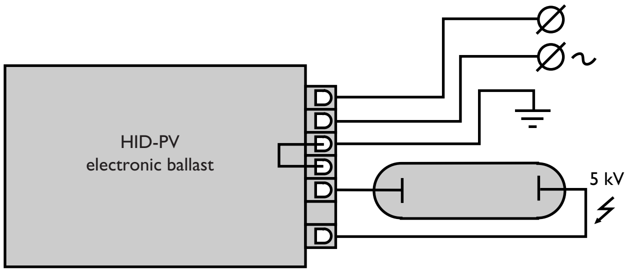


Fig. 103. Wiring diagram for HID-PrimaVision ballast.

5.5.4 Ignition

The integrated ignitor provides a pulse height of between 3 kV and 5 kV. The ignition technology is based on the series circuit. The cable capacity between the lamp and the electronic ballast must not exceed 120 pF for the 35 W and 70 W versions and 200 pF with the 150 W version and 50 W and 100 W Mini WhiteSON. After ignition, the lamp passes through the run-up phase, which takes about 3 minutes for CDM and 3 to 5 minutes for MH lamps to reach full power. The mains current during run-up is lower than the stabilised nominal current.
When there is no lamp in the socket or when the lamp is defective, the electronic ballasts for 35 W and 70 W continues to produce ignition peaks for a maximum of 20 minutes. However, at the end of the life of a lamp (EOL) a speed-up timer will reduce the maximum ignition time to a few minutes to avoid damage to the components or wiring. The HID-PV 150 has microprocessor control which realises the so-called burst-mode timing (30 sec ignition followed by 2 minutes rest, followed by a sequence of 15 sec ignition / 30 sec rest for a maximum of 20 minutes). The mains voltage must be switched off and on to reset the ballast.
It is advisable to replace a defective lamp as soon as possible in order to prevent possible damage to the various components.
Automatic restart after a mains supply interruption or voltage dips may take up to 18 minutes, depending on the cooling down condition of the hot lamp.

5.5.5 Low-frequency square wave lamp operation

The electronic unit contains a mains filter for radio interference suppression and electronics to create a 130 Hz square-wave lamp current (see Fig. 104).

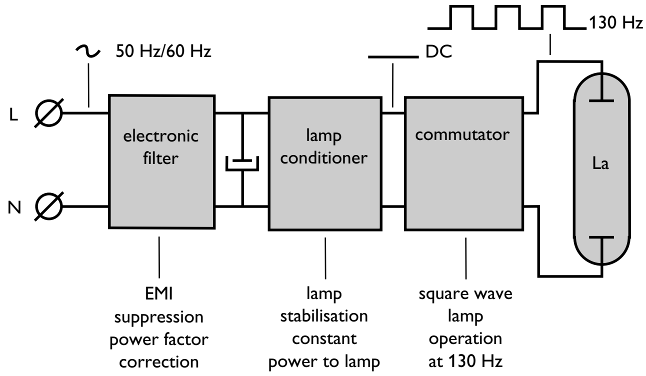


Fig.104. Electronic circuit for compact metal halide lamps.

The lamp voltage is constantly monitored and the lamp current is regulated in such a manner that the lamp power is always constant (see Fig. 105). Thus the lamp wattage is nominal ± 3% with the HID-PrimaVision at lamp voltages between 75 V and 115 V for the 35 W and 70 W lamps (nominal lamp voltage 85 V) or between 85 V and 125 V for the 150 W lamps (nominal lamp voltage 95 V). The lamp power is nominal ± 2% at mains voltages between 200 V and 240 V, 50/60 Hz at the nominal lamp voltages.

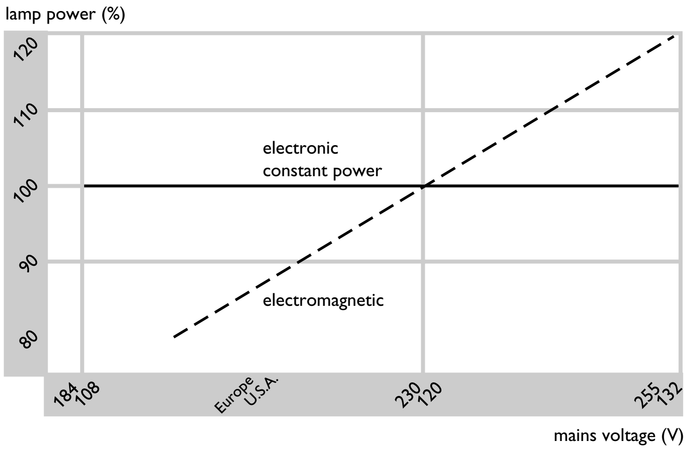


Fig. 105. Constant-power operation in a regulated low-wattage metal halide system.

Thus, the variations in the lumen output and the colour properties are greatly reduced during the lifetime of the lamp. Also the flickering effect, noticeable in conventional circuits, is eliminated by this electronic system (see Fig. 106).

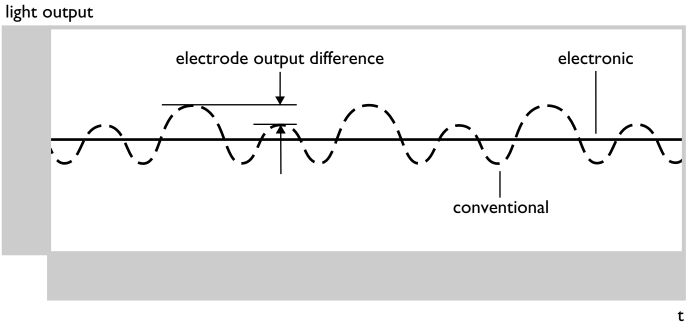


Fig. 106. A 2% difference in light output between the electrodes of metal halide lamps is already visible as a 50 Hz flicker. This flicker is eliminated when electronic gear is used.

5.5.6 Temperatures

A test point is indicated on the ballast, marked as Tc max. With the unit installed, the temperature at this point (t_c) shall not exceed 70˚C for 35 W, 75˚C for 70 W and 100˚C for 150 W, measured under the most unfavourable conditions, specified as tested with 0.92 x V_{nom}.
Given the watt losses of the unit itself, the maximum ambient temperature around the electronic ballast is limited to 55˚C for the 35 W version, 45˚C for the 70 W version and 50˚C for the 150 W version.
The luminaire should be so designed that, at an ambient temperature around the luminaire of 25˚C, the test point temperature of the ballast is at least 10 degrees below Tc max. This is to ensure that there is sufficient tolerance for unfavourable conditions.
The minimum permissible ambient temperature for ignition and operation is -20˚C.
The circuit switches off when the temperature at the test point Tc max is about 5 degrees above its marked value.

5.5.7 Fusing of the mains supply

The mains current during the first few seconds of the starting process will in practice be twice the level associated with nominal stable operation, with a very high inrush current during the first few milliseconds. Slow-acting fuses or circuit breakers must be used.
In almost all type of electronic ballasts for HID lamps, an electrolytic capacitor is incorporated in the input circuitry for stabilising the internal voltage in the ballast. When mains power is applied to the ballast, the charging of this capacitor leads to a very high inrush current within the first millisecond. The magnitude of this inrush current can be up to 80 A during typically 200-400 ms.

The magnitude and width of this inrush current depends on a number of parameters:
• the value of the mains voltage
• the value of the electrolytic capacitor in the ballast
• the impedance of the filtering circuit in the ballast
• the value of the internal impedance of the mains, reference value is 400 mOhm
• the moment the ballast is connected to the mains. The highest inrush current is when the ballast is connected to the mains at the peak of the mains voltage – this is the worst-case situation.

In general, the higher the wattage of the electronic ballast, the higher the value of the electrolytic capacitor and the higher the inrush current. The problem of the high inrush current in practical applications is that it will trip automatic Mini Circuit Breakers. This depends on the type and specification of the circuit breaker. Maximum numbers of circuits for MCB type B are as recommended in the following table, assuming they will be switched on at the same moment. These numbers can be doubled if slow-acting gL fuses are used.

Fuse rating	10 A	16 A
HID-PV 035	12	18
HID-PV 070	6	9
HID-PV 150	4	6

Two simple measures are possible to increase the number of ballasts per MCB:

1. Using inrush current limiter units, for example, from Busch & Jaeger. The best quality is to be found in the types based on zero voltage switching.
2. Using AC mains voltage relays after each group of a maximum number of permissible gear units. The relays have to be wired so that they close when the mains voltage is applied. Because of the time delay of the relay, the inrush of the next group of gear units will occur later than the inrush current of the first group of gear units. In this way the inrush current is split into multiples which do not interfere.

For safety reasons, a non-replaceable fuse of 2 A (35-70 W) or 3.15 A (150 W) is built into the unit.

5.5.8 Humidity

Discrete and miniature SMD components are used on the printed-circuit board of the HID-PV units.
The resistance to humidity complies with IEC 68-2-3: protected outdoor use.
The electronic ballasts have been designed to be built in, either in appropriate luminaires or in separate gear boxes. Versions with an additional strain relief are also available, permitting them to be used as independent/ stand-alone units. The luminaire must provide sufficient protection in outdoor applications (IP>54 for HID-PV 35 W and 70 W, IP>23 for the completely potted 150 W).

5.5.9 Installation aspects

With its small dimensions and relatively high lumen output, combined with its excellent colour properties, the compact metal halide lamp mainly finds application in indoor accent lighting, for example in Class I or II uplighters, downlighters and spotlights. Due to the maximum cable capacity between the lamp and the electronic ballast (120 pF for 35/70 W and 200 pF for 150 W, which means about 1.2 m and 2 m respectively for a 100 pF/m cable), the unit will be mounted in or near the luminaire. The ballast can in many cases be mounted inside, e.g. in the foot of a standing uplighter. The stand-alone version can be mounted on (suspended) ceilings without additional provisions, as they have the F and marking (see Section 4.1.5: Ballast specification and marking).
In the independent application, connection to earth is

essential and the appropriate strain relief must be used. The 35 W and 70 W versions are for indoor applications, where the relative humidity is low. The 150 W version is fully potted and therefore suitable for outdoor applications.
If the output wires are short-circuited to earth, or the input and output wires are inadvertently interchanged, the ballast will be destroyed.
For proper EMC, wiring inside the luminaire should be as straight as possible, and mains wiring should not run parallel to lamp wires.

5.6 Circuits for low-pressure sodium lamps 35 W, 36 W, 55 W, 66 W and 91 W

5.6.1 Introduction

The SOX(-E) lamps are still the most energy-efficient light sources available today. Because of this, and the fact that they contain no mercury, they represent the most environment-friendly HID lamps.
They are used where energy cost tips the scale in the ¨efficiency versus colour quality¨ balance, for example on motorways and main roads, and in security and area lighting.
The EXC*** S/50 high-frequency ballast range saves an extra 15 to 35 per cent on energy compared to conventional operation.
The Philips SOX(-E) lamps have been further optimised in order to utilise fully the advantages to be gained with the use of high-frequency control gear, without influencing their performance on conventional 50 Hz gear.

5.6.2 Product range

The present range of electronic ballasts for SOX(-E) lamps comprises the following types:

Lamp type	HF ballast
SOX-E 36	EXC 036 S/50
SOX-E 66	EXC 066 S/50
SOX-E 91	EXC 091 S/50
SOX 35	EXC 035 S/50
SOX 55	EXC 055 S/50

E = Electronic, X = SOX, C = Converter
S = Standard, 50 = 220-240 V, 50/60 Hz AC

5.6.3 System description

With a SOX(-E) high-frequency electronic system the functions of the conventional ballast, ignitor and capacitor are united in a single electronic ballast, as described in Fig. 107.
The functions of the main components in the circuit are as follows:
- The RFI filter prevents mains pollution and ensures robustness of the ballast for mains-voltage surges
- The UP-converter with its control unit:
  - converts the rectified mains voltage into a higher DC voltage

- ensures constant wattage, independent of mains-voltage fluctuations between 202 V (220 V - 8%) and 254 V (240 V + 6%)
- controls the power factor (> 0.95), making a separate capacitor superfluous

- The half-bridge converter changes the DC voltage into the high-frequency operating lamp voltage (45-55 kHz, depending on the ballast type); it also supplies the ignition voltage to the lamp.
- For safety reasons, the ignition voltage supply is stopped after a few seconds by the start/stop circuit if the lamp fails to ignite (self-stopping provision).

  The SOX HF gear is less sensitive to mains-voltage fluctuations, and is suitable for 220 V to 240 V (+ 6%, - 8%) input. The lumen output of the lamp remains constant during the lifetime of the lamp, whilst the power consumption of the lamp does not change, unlike conventional ballasts.

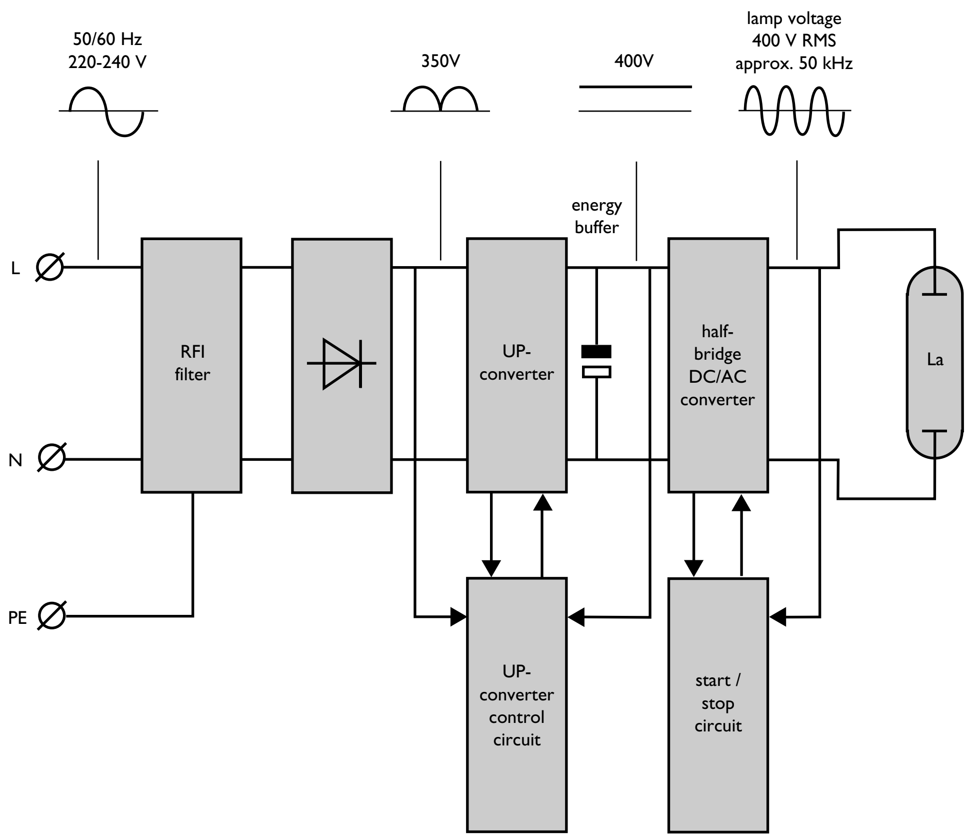


Fig. 107. Electronic circuit for high-frequency (50 kHz) SOX(-E) lamp operation.

5.6.4 Technical aspects

Temperatures

The SOX HF ballast should be built into the luminaire in such a way that the temperature at the measuring point tc, indicated on the case of the ballast, does not exceed the maximum specified case temperature (65° or 70°C).

Failure rate and lifetime

The calculated average circuit lifetime at an operating temperature of t_c = 65°C is 50 000 hours, and the calculated failure rate at this temperature will be below 0.35% per 1000 hours.
At lower test-point temperatures, the lifetime and reliability of the electronic ballast will be higher, so that it is advisable to build the ballast into the luminaire in such a way that the test-point temperature remains as low as possible.

Inrush currents

Typical inrush currents are:
40 A at 185 μs half-value time (SOX-E 36 W, 66 W and SOX 35 W and 55 W),
50 A at 220 μs half-value time (SOX-E 91 W).

Fusing of the mains supply

The nominal mains current (In) indicated on the ballast is the value during stable operation. During the run-up time of the lamp (ca 15 minutes) the mains current is about 25% higher.

Humidity

With regard to humidity, the SOX(-E) HF ballasts satisfy the requirements of IEC 60928 paragraph 12 and IEC 68-203-Ca. As said before, they must be mounted in luminaires complying with IP 54 classification or better.

5.6.5 Electromagnetic compatibility

1. Radio interference
The SOX(-E) HF ballasts fulfil all EMI requirements laid down in EN 55015 (conducted) and EN 55022 (radiated) class A (in SRS 201).
Attention should be paid to the following points:
- the wiring inside the luminaire should be straight and as short as possible
- the mains wires should never run parallel to the lamp wires
- the ballast housing should be mounted on a metal plate and be properly earthed.

2. Harmonics
The total harmonic distortion complies with EN 60555-2.

3. Transients and voltage dips
Voltage dips of maximum 30% during 10 μs will not cause the lamp to extinguish.
The EXC** /S50 SOX(-E) HF ballasts meet the transient requirements laid down in IEC 929 paragraph 15.

5.6.6 Installation aspects

- The ballast must be mounted in a luminaire complying with IP 54 classification or better.
- The maximum cable length between the lamp and the SOX HF ballast is about 2m for a 100 pF/m cable.
- Before replacing a defective lamp, the mains voltage should always be switched off.

During lamp replacement, the minimum off-time of the mains voltage must be 45 sec. to allow the start/stop circuit to reset.
If the mains is not switched off (or on again after less than the specified 45 sec.), the start/stop circuit remains activated and the lamp will only ignite after the next mains voltage interruption of 45 sec. or more.

- With a three-phase mains supply system, the neutral should never be disconnected. To do so could result in damage to the electronic ballast.
- The primary connections phase and neutral must be short-circuited before carrying out a high-voltage test.

To avoid voltage surges, the test voltage should only be applied after the connections to the test instruments have been made.
No more than half the prescribed voltage should be applied to begin with, after which it should be gradually increased to the full value.
Maximum test voltage: 2 times the mains voltage + 1000 V AC 50/60 Hz for minimal 1 minute between the short-circuited input and the housing.
The fully electronic ballast has a ¨capacitive¨ behaviour. The relative impedance at different frequencies of the audio-frequency signal is indicated in Fig. 108 (as a percentage of the impedance at 50 Hz). A simple way of roughly calculating the impedance at 50 Hz is:
$Z = U_{mains}^2 : P_{lamp}$.
For example: with U_{mains} = 230 V and P_{lamp} = 66 W, the impedance at 50 Hz is about $230^2 : 66 = 800\ \Omega$.
The ¨capacitive¨ behaviour means that audio-frequency signals in the mains circuit can be short-circuited (special blocking filters are to be employed).

- The connector blocks for mains connection permit a maximum 2.5 mm² solid wire.

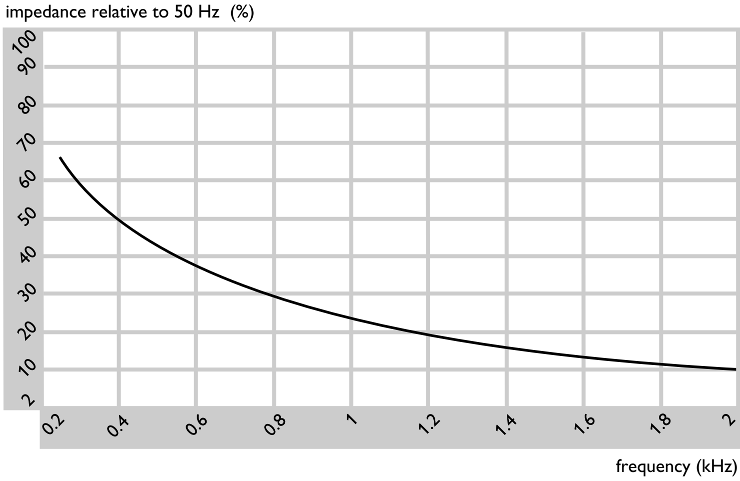


Fig. 108. Relative (to 50 Hz) impedance for audio-frequency signals of an HF SOX(-E) lamp circuit.

5.7 Dimming solutions for SON lamps

5.7.1 Twin ballast circuits

1. One-step dimming (100-50% light level) for SON 70 W to 400 W

In Section 4.3.14 the various dimming possibilities are described. The most common dimming circuits nowadays are the circuits with the extra dimming ballast. There are separate dimming ballasts for SON 70 W, 100 W and 150 W lamps, and there is a combination ballast for 70 W, 100 W or 150 W lamps, and one dimming ballast for all kinds of SON 250 W or 400 W lamps.
The lamp circuit is operating at 100% level when the dimming ballast is short-circuited.
The lamp circuit is operating at approximately 50% light level when the dimming ballast is connected in series with the standard ballast. The mains power level is then approximately 65%.
The parallel compensating capacitor is connected directly across the mains supply and will not change during dimming. The power factor of the system will therefore change.

Switching of the dimming ballast can be realised by the compact electronic circuit breaker EC 01, EC 11 (for 70 W to 250 W) and EC 03 (for 400 W), see Fig. 109.
The EC 01 and EC 03 switch to 50% if there is no voltage at the control input, while the working of the EC 11 is just the opposite: no voltage on the control input means 100% light output.
The control voltage for the EC is 230 V phase voltage, either the same circuit phase or from a different line.
The lamp will always start (and restrike) with this circuit breaker at 100% and will maintain this level for 3 minutes, giving the lamp enough time to run up.

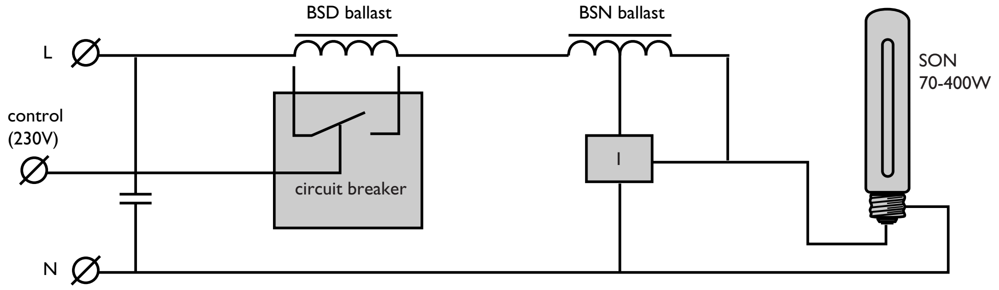


Fig. 109. Circuit for one-step dimming SON lamps.

The losses in the circuit breaker are about 5 W when closed and 2 W when open.

2. Continuous dimming (20-100% light level) for SON 250 W and 400 W

At this moment there are two solutions for all kinds of SON 250 W or SON 400 W lamps, except the Deco and Comfort types. There is no need for different ballasts for SON 250 W or SON 400 W lamps, as the control unit detects the kind of lamp and regulates the power needed.
The dimming ballast BSH250/400 can also be connected in series with a standard 250 W or 400 W SON circuit, so the system can be used in an existing installation.
In that case, the parallel compensating capacitor must be connected directly across the mains supply.
The controller contains a thermal switch-out protection.
The HID-DynaVision controller regulates by means of phase cutting, so that the dimming ballast is short-circuited for a part of the time, see Fig. 110a, but the lamp-current wave shape stays almost sinusoidal by means of this sophisticated adjustable impedance, see Fig. 110b.

With this system the lamps can be dimmed to 20% light output at 35% lamp power. Due to the built-in fading time, there is enough time for thermal equilibrium of the lamp. During the first 5 minutes of operation (run-up of the lamp), the dimming coil is short-circuited by the triac switch of the controller (viz. triac is ON during full mains period). Only after this 5 minute period is the power stabilisation routine enabled (setting the lamp power at nominal 255 W or 400 W). The lamp power is stabilised independently of the level of the mains and the lamp voltage. Power stabilisation only functions at mains over-voltage (0% to +10%).
For dimming (down and up), a dim fader is employed to prevent extinguishing of the lamp. If the lamp power is reduced too rapidly, the re-ignition voltage of the lamp will initially rise (cooling down of the burner), and this could lead to the lamp extinguishing.

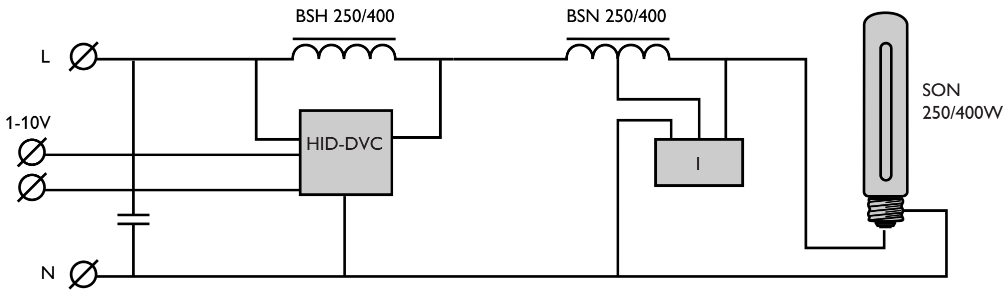


Fig. 110a. Circuit for continuous dimming of SON 250-400 W lamps.

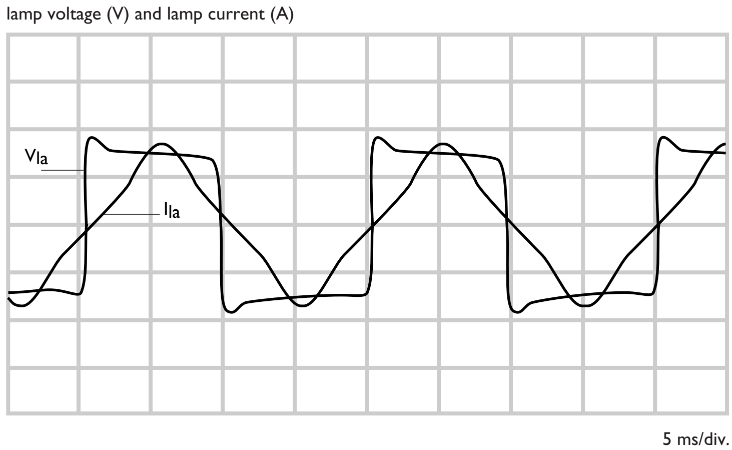


Fig. 110b. Lamp voltage and lamp current at minimum power level.

The control voltage, 1-10 V DC, regulates the output power, see Fig. 111. (At a later date, DALI (digital interface) will also be available.) The power factor decreases at decreasing light level, due to the fixed parallel compensating capacitor, see Fig. 112.
There is Constant Power control from 225 V to 254 V mains supply for constant light output.
The HID-DVC has a rated lifetime of 60 000 hours with 20% failures and a failure rate of 0.25% per 1000 hours at T case = 85˚C. The maximum case temperature is 100˚C. The controller is fully potted and can therefore be used in outdoor applications.

The HID-SDU switching device unit (see chapter 5.8.2) can be used when there is no possibility for a separate DC control voltage and only the normal phase voltages are present, see Fig. 113. With the control voltage of

198-260 V, the dimming system can be switched from 100% to 50% light level. Again there are two possibilities: the SDU 01 gives 50% when there is no control voltage, while the SDU 11 is at 100% without control voltage.

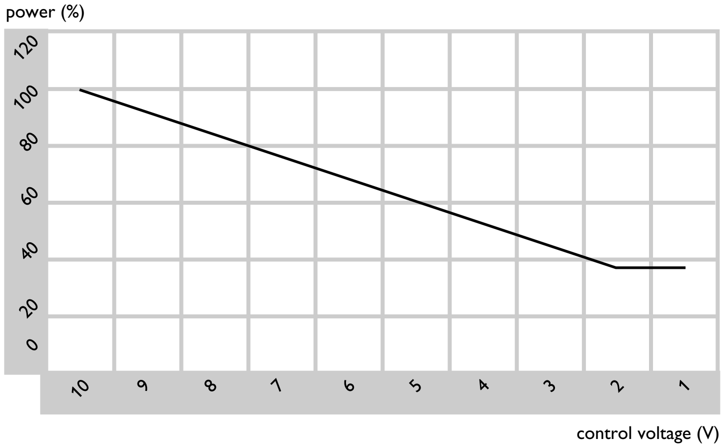


Fig. 111. Lamp power as function of control voltage level.

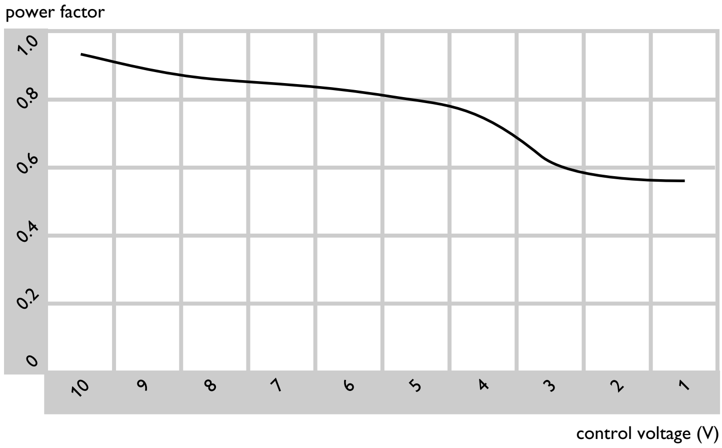


Fig. 112. Power factor as function of control voltage level.

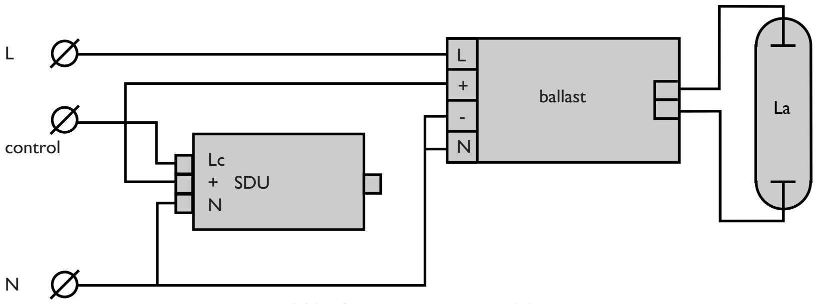


Fig. 113. Control by means of SDU switching device.

5.7.2 Fully electronic dimming ballast for SON 150 W

The HID-DynaVision regulating ballast for SON 150 W lamps is a compact, one-piece, electronic dimming ballast for built-in (/S) or stand-alone (/I) applications with all sorts of SON 150 W lamps, except the Deco and Comfort types. The ballast has an analogue input of 1-10 volt (or a DALI input in future).

The ignitor in the ballast is self-stopping after 5 minutes and must be reset by switching the mains supply off and on again. The self-resetting thermoswitch protects the ballast and the installation against fault conditions.
The lamp will restart automatically after lamp replacement or a voltage dip.
The lamp always starts at 100%, and dimming will only start after 5 minutes. The mains current during run-up is lower than in the stabilised situation.
The operating frequency for the lamp is 130 Hz.
By means of high-frequency switching, the light level can be regulated between 20% and 100% (mains power between 35% and 100%). The included fading rate for dimming up is a few seconds. The fading rate is longer for dimming down and can be 2 minutes when dimming from maximum to minimum. The power factor is more than 0.8 over the total power range.
The constant power regulation makes the lamp power independent of the mains voltage and lamp voltage. The circuit switches off when the lamp voltage is more than 150 V, see Fig. 114.

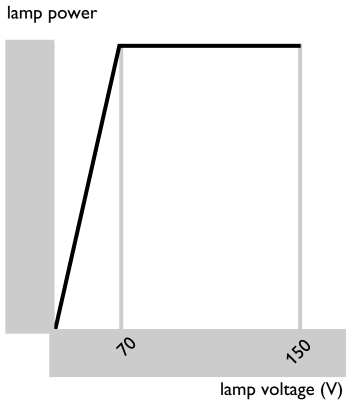


Fig. 114. Lamp power as function of the lamp voltage.

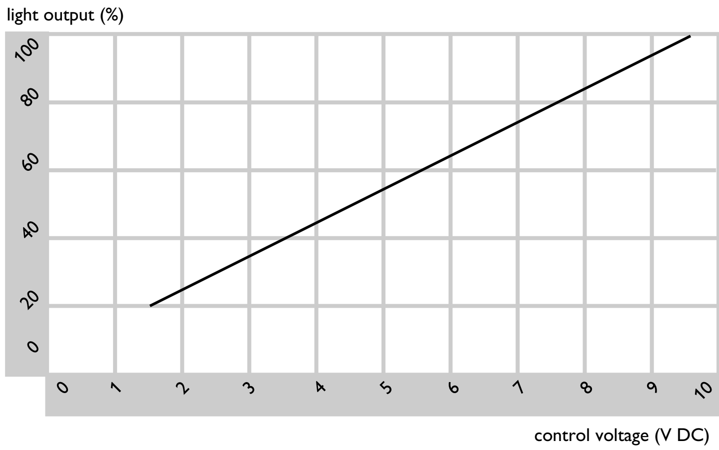


Fig. 115. Light output as function of the control voltage.

The light output as a function of the control voltage is linear, see Fig. 115.

5.8 Control possibilities

There is a wide range of lighting control possibilities for indoor use, especially for fluorescent, halogen and incandescent lamps. There are various systems to realise the switching and dimming functions, see also Section 4.3

of the Application guide to fluorescent control gear. These systems can, in principle, also be used for HID lamps. However, there are only a few dimmable HID ballasts available, and the switching of HID lamps is more complicated, due to aspects such as the high inrush currents, the run-up times and the (hot) restrike times. Also, the customer needs for indoor and outdoor applications are different:

	Comfort	Energy saving	Flexibility	Light pollution	Managing	Safety
Offices/shops	++	+	++	--	-	--
City beautification	+	+	+/-	++	+/-	+/-
Road lighting	-	++	-	+/-	++	++

But the HELIO system, for example, is successfully used to switch the various lighting levels in multi-purpose arenas with 2 kW MHD lamps. Also, for street lighting with SON lamps, the lights can be controlled by the daylight level, a time schedule, and/or traffic intensity by the existing systems.
There is at present a lot of development being devoted to outdoor applications and HID lamps, and so more applications will shortly become available.

5.8.1 Electronic switch EC**

The electronic switch EC** is a dimming switch suitable for use with SON lamps from 70 W to 400 W in combination with the standard and an additional dimming ballast, see Fig. 116.

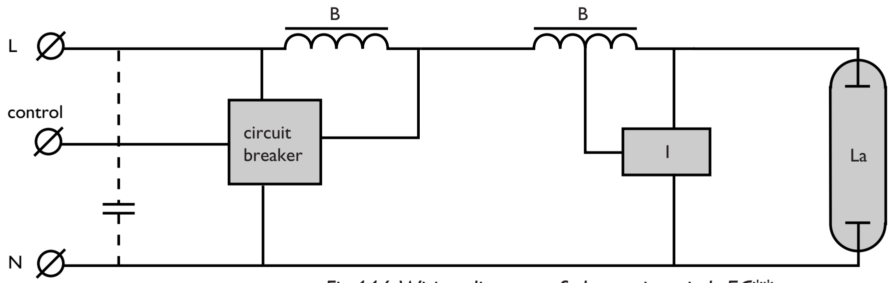


*Fig.116. Wiring diagram of electronic switch EC**.*

The dimming ballast determines the dimming level. The use of three-phase cable is possible.
The range consists of:

Circuit breaker type	Lamp power max. (W)	Control signal	Light output (%)
EC 01	250	On	100
		Off	50
EC 11	250	On	50
		Off	100
EC 03	400	On	100
		Off	50

The control voltage can be 100-250 V DC or 198-264 V AC / 50-60 Hz.

5.8.2 Electronic switching devices

1. HID-SDU

The electronic switch SDU can be used in combination with electronic dimming ballasts with 1-10 V input, see Fig. 117.

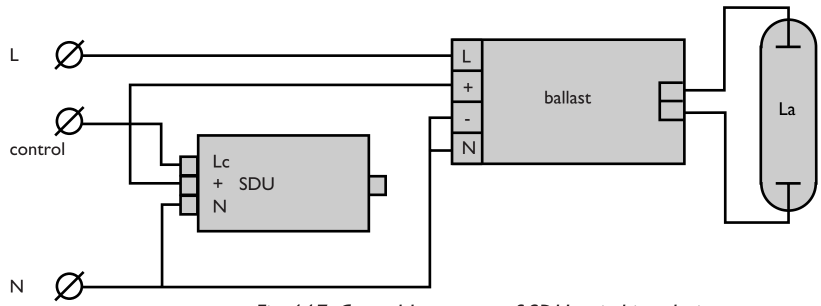


Fig. 117. Control by means of SDU switching device.

The light output can be switched between 100% and 50% by means of the control voltage 198-260 V line signal. The dimming input of the electronic ballast is not galvanically isolated, as the neutral of the mains is connected with the minus of the dimming input.

Controller type	**For lamps**	**Dimming ballast type**	**Control signal (V)**	**Light output (%)**
SDU 01S	TL, PL	HF-R	230	100
			0	50
	SON	HID-DV	230	100
			0	50
SDU 11S	TL, PL	HF-R	230	50
			0	100
	SON	HID-DV	230	50
			0	100

2. Halogen Switch Unit HSU for HID-PrimaVision ballasts

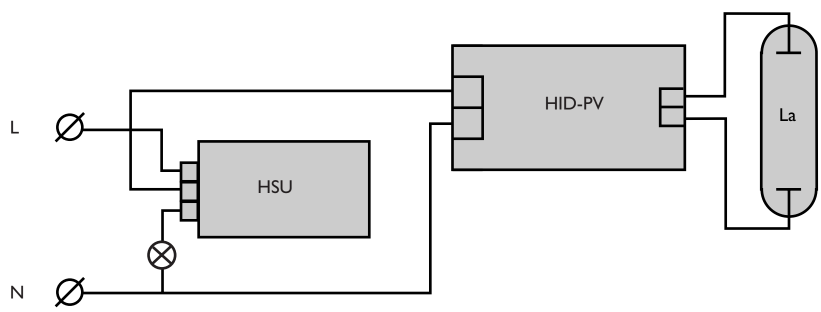


Fig. 118. Circuit for HSU switching device.

The Halogen Switch Unit switches on a Halogen or GLS lamp (230 V, max. 150 W) during ignition, re-ignition, or during end-of-lamp life of HID lamps.
The device checks mains voltage and measures mains current. When the mains voltage is present, and the mains current is below the threshold level, the halogen lamp is switched on. After the lamp has ignited and the mains current has reached the threshold level, the halogen lamp will remain switched on for an extra 2-3 minutes.
Warning: If the halogen lamp is mounted in the luminaire close to the HID-lamp, after mains voltage interruption the halogen lamp can heat the HID lamp so strongly that it will not re-ignite. This has to be checked in the luminaire.

- The Halogen Switch Unit has a standard SN ignitor housing.
- The unit can be mounted in a luminaire or in the installation at some distance of the luminaire. The unit can be used with 1 x HID-PV 150 W or 1 x HID-PV 70 W.
- The unit can also be used with 2 x HID-PV 70 W or with 2, 3 or 4 x HID-PV 35 W.
- The HSU has the additional effect that the inrush current is significantly lower, so that typically 50-100% more ballasts can be mounted in the installation without triggering Mini Circuit Breaker Relays, compared to use without HSU (see application note: Inrush current & maximum number of ballasts for different Mini Circuit Breakers).
- When the unit is used close to the lamp and the ballast, the EMC-conducted interference (EN 55015) behaviour will be improved. When the wiring from the HSU to the halogen lamp must run over a long distance in the luminaire, the interference can increase. This will depend on the specific luminaire and wiring design. EMC then has to be verified per luminaire.

5.8.3 Chronosense

The Chronosense is a stand-alone dimming device intended for integration in an outdoor-type luminaire (street lighting, floodlighting, etc.) or for fitting onto a gear tray that is mounted at the bottom of a lighting pole, see Fig. 119.
It contains a relay to switch a conventional extra dimming ballast or a ballast type with tap for SON-T lamps 70 W to 400 W (see Fig. 120) in order to obtain 50 per cent light level during night-time periods of relatively low traffic density.
Each luminaire can be programmed individually, without pilot cable or any other communication, and the program can be adapted at any time. This saves energy whilst maintaining a homogeneous spread of light over the complete application.
The device contains an intelligent timer with an accuracy of 1 second and has discrete programming steps of 0.5 hour. At switch-on, the power is always at 100% for 10 minutes for smooth run-up of the lamp.
The device must be programmed by means of dip-switches for the time intervals for 100% and 50% operation (see Fig. 121), and it contains a test mode to check the functionality. Power-on is more or less sunset, power-off is more or less sunrise, but the midpoint of the power sequence is not the same as midnight. At the programmed time before the night midpoint it switches

to the dimming level. And at a programmed time after the night midpoint it switches back to 100%. But the Chronosense does not know the absolute time and there is no adaptation to summer/winter time. The lights should be switched on and off by the customer as usual.
The product leaflet for the Chronosense should be followed for correct installation and adjustments.
The Chronosense has a lifetime of 15 years in outdoor applications, based on functioning 4000 hours per year. The power consumption is only 1 –2 watt.
The luminaire operates at 100% in the event of Chronosense failure, and can be combined with a photocell.
The housing is IP20 with extra protection against the ingress of dust and insects. Additional measures have to be taken to protect it from dripping water when mounted in a road lighting column.

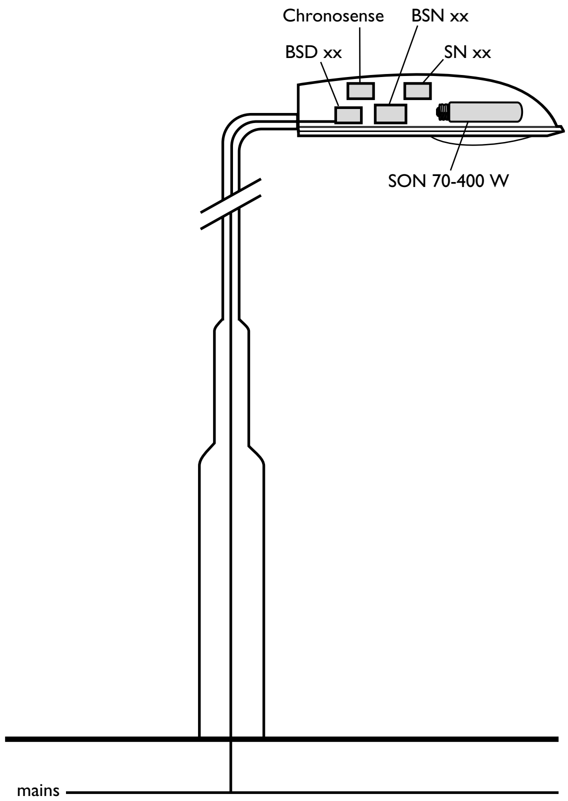


Fig. 119. Chronosense built into luminaire.

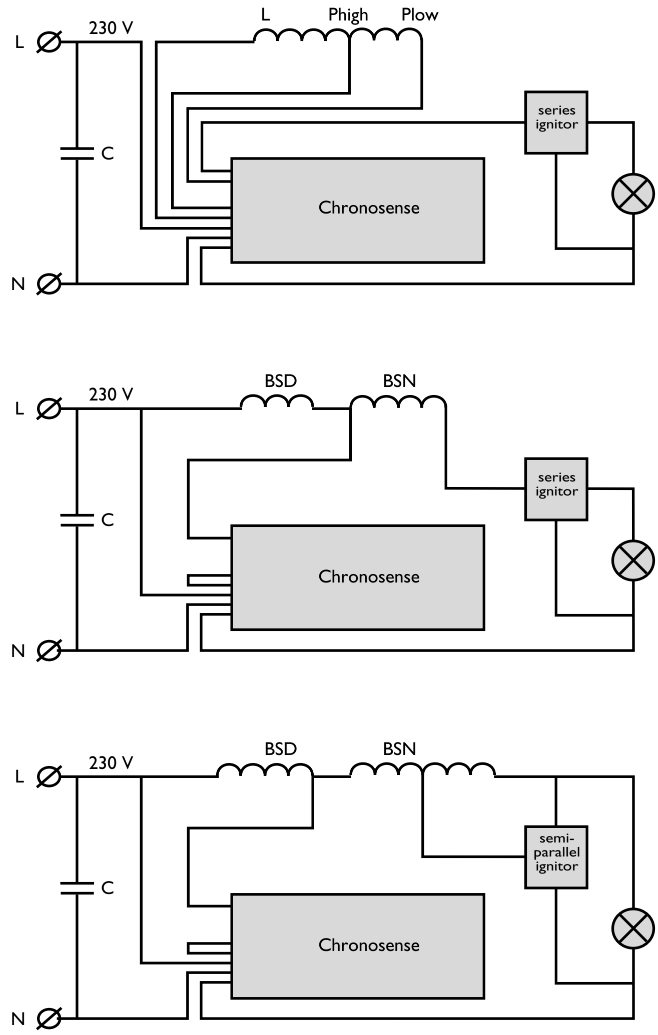


Fig. 120. Wiring diagrams for Chronosense dimming device
1. with tapped ballast and series ignitor
2. with separate dimming ballast and series ignitor
3. with separate dimming ballast and semi-parallel ignitor.

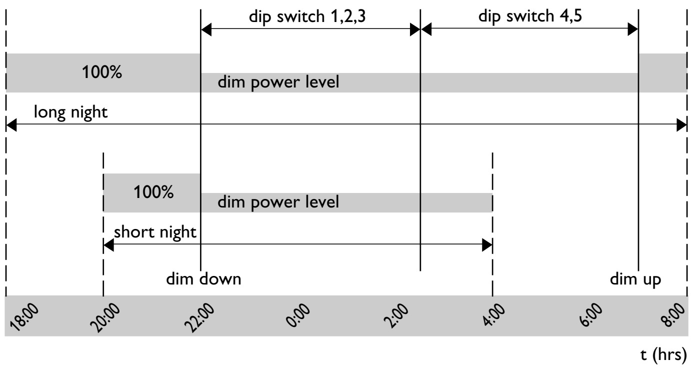


Fig. 121. Example of programmed Chronosense.

5.9 Tele-management systems

There is an increasing demand for the monitoring and sensing of lighting luminaires, especially in street lighting installations, tunnels, stadiums and big area projects such as container terminals and parking lots.
Statistical information can be obtained by monitoring failures and light level, together with burning hours and energy consumption, to make a good choice for group versus individual replacement. Scouting or spotting can be eliminated, which reduces these costs.
Information can be obtained by sensing the lamp for defects or cycling, and an early warning of the end of the lamp life (EOL) can be given. The temperature of ballast or luminaire can be sensed, as well as defects of ballast or compensating capacitor (power factor). Also the quality of the mains supply can be sensed, for example for the average value or dips.
Tele-management also includes switching and/or dimming of individual or groups of luminaires by local or centralised controls. The control signals can be obtained from clocks, traffic density, weather (rain), or light sensors.
Tele-management can help to save energy, the costs of ownership can be reduced, and the overall performance can be improved by better maintenance. Basically, what is needed are intelligent luminaires and a communication protocol.
There are three communication possibilities at present available for communication with Philips luminaires: the phase control line 230 V, the 1 V to 10 V DC, and the DALI protocol, and there are many ways for communication between the interface and the controller, see Fig. 122. But communication can also be realised via the Internet or wireless with Infrared (IR) or Radio-frequency (RF) signals. There are many different standards and networks used in Europe, while the customer demands for a universal open connection or system, which is compatible with existing systems. A system approach for controllers, cabling and luminaires is therefore necessary.

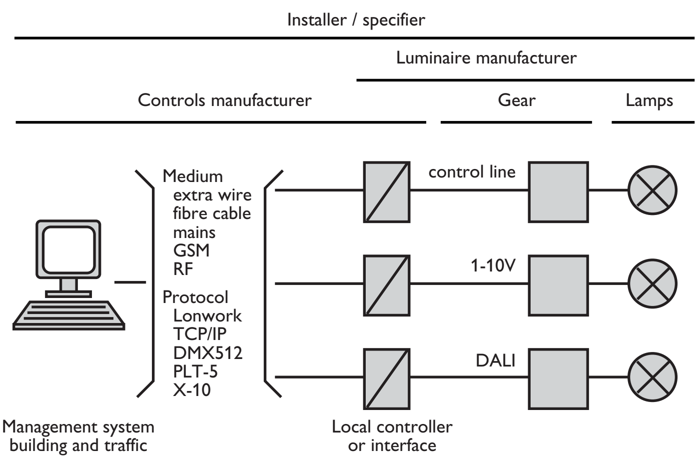


Fig. 122. Various options for communication.

The choice of communication system determines the possibilities offered:

	Simplicity of controller	Dimming	Feedback defect lamp	System reporting	Flexibility
Control line	++	Two levels	No	No	-
1-10 V	+	All	No	No	-
DALI	+/-	All	Yes	Full	++

Information about the DALI (Digital Addressable Lighting Interface) protocol can be found in the Application guide to fluorescent control gear, Section 4.2.10.

It is beyond the purpose of this guide to describe the various tele-management systems such as Telesense (a Mid Range Tele-management System, 3P proprietary protocol based), Starsense (a High Range Tele-management System LON based), and the various OLCs (Outdoor Luminaire Controllers). Information can be obtained from the Lighting Controls group.
A few examples will suffice.

Examples of one-way communication via the control line 230 volt, see Fig. 123.

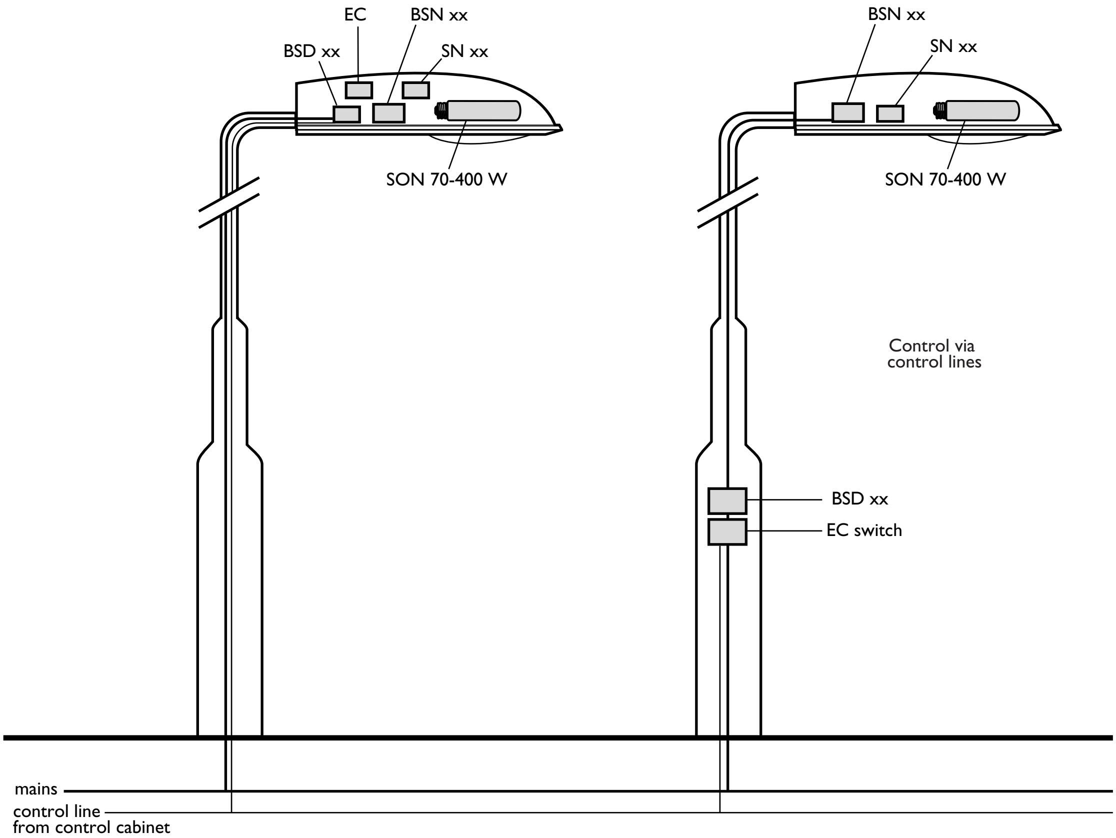


Fig. 123. Example of one-way communication.

Example of simple two-way communication, see Fig. 124.

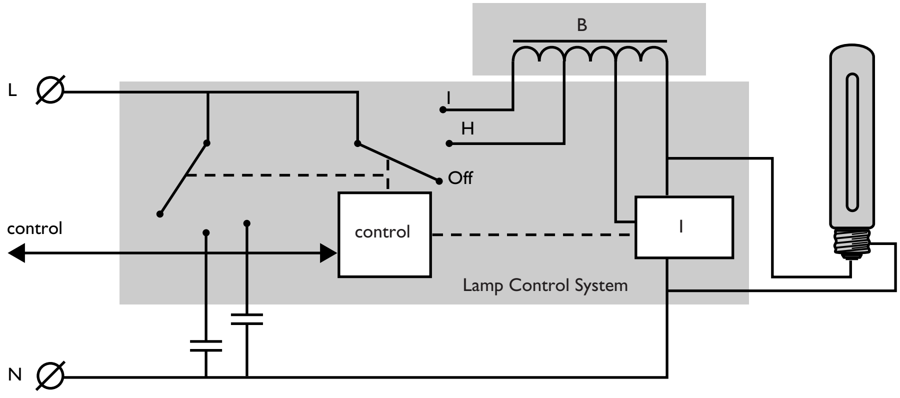


Fig. 124. Lamp control system HID-LCU.

The extended two-way communication with DALI is in project, see Fig. 125.

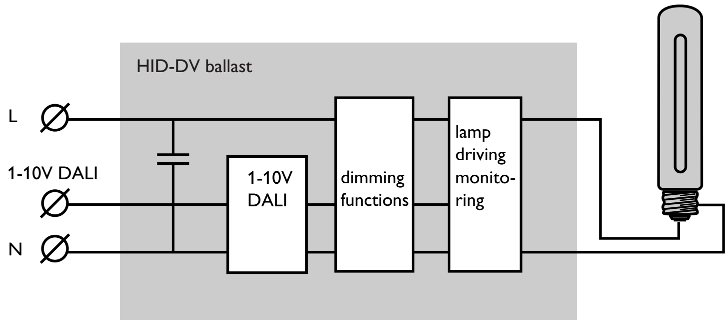


Fig. 125. Extended two-way communication with DALI.

5.10 5.10 Overview of features

	Interface	Minimum light level	On/off	Feed-back defective lamp	System reporting	Power control	Over-voltage regulation	Estimated lamp life
EC **	Control line	50 %	No	No	No	No	No	+5%
LCU **	Control line	40 %	Yes	Yes	No	No	No	+8%
HID-DV 250/400	1-10 V	20 %	No	No	No	Yes	Yes	+15%
HID-DV 150W	1-10 V	20 %	No	No	No	Yes	Yes	+25%
HID-DV 150W	DALI	20 %	Yes	Yes	Full	Yes	Yes	+25%

5.11 Epilogue

The developments in the field of electronic HID application are proceeding at such a pace that it is impossible to keep this Application Guide completely up to date. Since work on the Guide started, new products have already appeared. Examples are the digital versions of the semi-parallel ignitors SN 57 and 58, called SDN 57 and 58, which can replace the standard and the timed SN57/58 ignitors. Also, the electronic EC** switches will be replaced by the more intelligent HID Lamp Control Unit (HID LCU 50/1000 W SON).