Powering UV sources in the most efficient way

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Ultra Violet (UV) low- and medium pressure lamps and LED’s are well known and widely accepted UV sources for disinfection applications for water and other fluids, air and surface. Improving efficiency of UV lamps has reached physical limits and UV LEDs still have a long way to go. Unfortunately the overall efficiency of the energy supply systems for the UV sources are in most cases not getting the right amount of attention and short term costs for initial investment are prevailing over the total cost of ownership.

Most ballasts/lamp drivers act as non-linear loads on power grids, drawing a distorted waveform that contains harmonics and results in electromagnetic compatibility (EMC) problems, including Power Quality issues. When electronic lamp drivers consume power in a pulsed manner, it leads to a lower Power Factor (PF). Remind that our “conventional” power grid was designed for linear loads.

Repeating peak currents at the mains input will contain harmonics and the summation of all harmonics is known as total harmonic distortion (THD) of the current. This again leads to distortion of the voltage, depending on the power line impedance.
The impacts of lower Power Factor and harmonic current and voltage distortion are increased losses in transformers, power lines and overheating and degradation of conductors and insulating material. Last but not least, it could reduce lifetime of components.

Another Power Quality problem for UV systems can be mains surges and transient peak voltages (several kilovolts) at the input of the ballast/lamp driver. With insufficient surge suppression in the ballast, the surges can lead to damage of the driver and also overvoltage can reach the lamp, possibly leading to premature lamp failures.

The impact of Power Factor and THD of electronic lamp drivers was investigated by benchmarking 4 topologies available in the market. A comparison was made with regard to overall efficiency and Power Quality, costs and CO_2 footprint impact.

Power Factor and Harmonics.

The ratio of real power and apparent power defines the Power Factor (optimum PF=1) in an AC electrical power system. The Power Factor is determined by the amount of phase shift between voltage and current and by the amount of harmonic current in relation to the fundamental current. Higher apparent power causes higher currents in the power grid and causes additional copper losses (I^2*R). In addition, distortion of the input current caused by a device like an electronic lamp driver/ballast will lead to more harmonic currents. In this case the copper losses (I^2*R) will increase due to higher currents (I) and the skin effect, where higher frequency currents flow primarily in the outer layer of a conductor, will cause an increase in resistance (R). Also Eddy Currents will add some additional losses as stray electromagnetic fields induce circulating currents in nearby wires and windings of transformers.

The increase in total current (I_{rms}) due to the harmonics can be calculated by multiplying the basic current I_1 (at line frequency 50Hz or 60Hz) by a factor determined by the Total Harmonic Distortion $THD_{(i)}$

$$I_{rms} = I_1 * \sqrt{(1+THD^2)}$$

and is shown in the following graph:

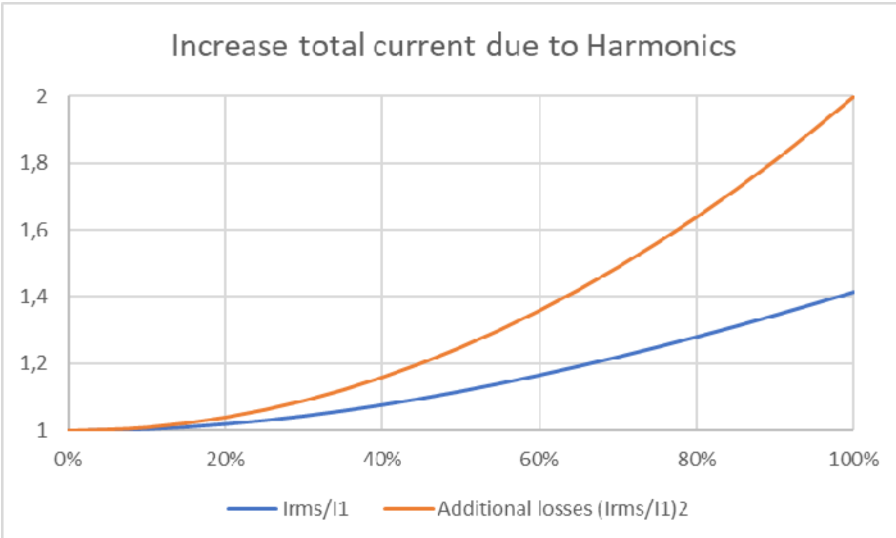


Fig. 1

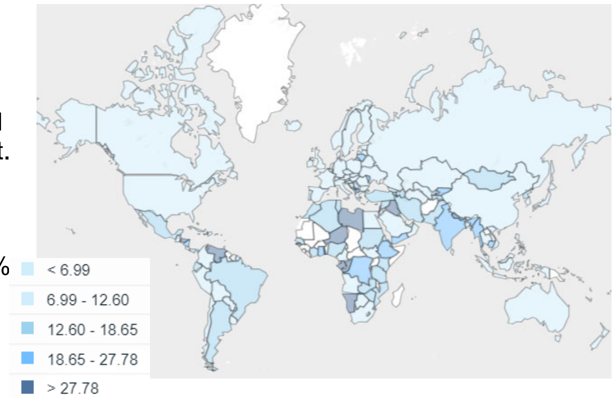
Devices that cause severe $THD_{(i)}$ levels of 60%, will show an increase of total current of 16% leading to additional power losses of **36%.** This is excluding the additional losses due to the skin effect.

<u>Impact of high mains voltage/current distortion (THD):</u>

☆ **More Energy losses**	Harmonics cause additional losses in conductors and equipment.
☆ **Higher subscription costs**	Harmonic currents can cause higher subscribed power level and consequently higher costs. Utilities will be charging customers.
☆ **Oversizing of equipment**	Conductors/equipment must be (over)sized taking into account the flow of harmonic currents. Due to skin effect, resistance increases with frequency. So even more oversizing needed for harmonics. Also neutral conductor needs to be oversized as well.
☆ **Reduced service life equipment**	At THD_u >10%, service life of equipment is significantly reduced. Reduction estimated at: - 32.5% for single-phase machines - 18% for three-phase machines - 5% for transformers To maintain the service lives, equipment must be oversized.
☆ **Overload, tripping and shutdown**	Circuit-breakers are subjected to current peaks caused by harmonics and nuisance tripping could occur resulting in down-time.
☆ **Disturbance of sensitive devices**	Transients can cause failures or damage to sensitive equipment.

In our quest to more reliable and more energy efficient systems it is also important to look into the losses in our power grids, heating up our power cables and transformers. Minimizing these losses will reduce overall costs and will reduce the CO_2 footprint.

On average the power line losses are around 8% but are heavily depending per country, see Fig.2 - Electric power transmission and distribution losses (% of output).



Electric power transmission & distribution losses (% of output). Fig. 2

Benchmark Electronic Lamp Drivers.

To investigate the performance on Power Quality, 4 lamp driver types available in the market were evaluated. As there is a wide range of applicable power levels and type of lamps, 4 drivers for medium pressure lamps were tested and results were normalized to 100% power level. All units were tested with lamps in an air cooled test chamber and at 21°C ambient temperature. Following set-up was used, see Fig. 3.

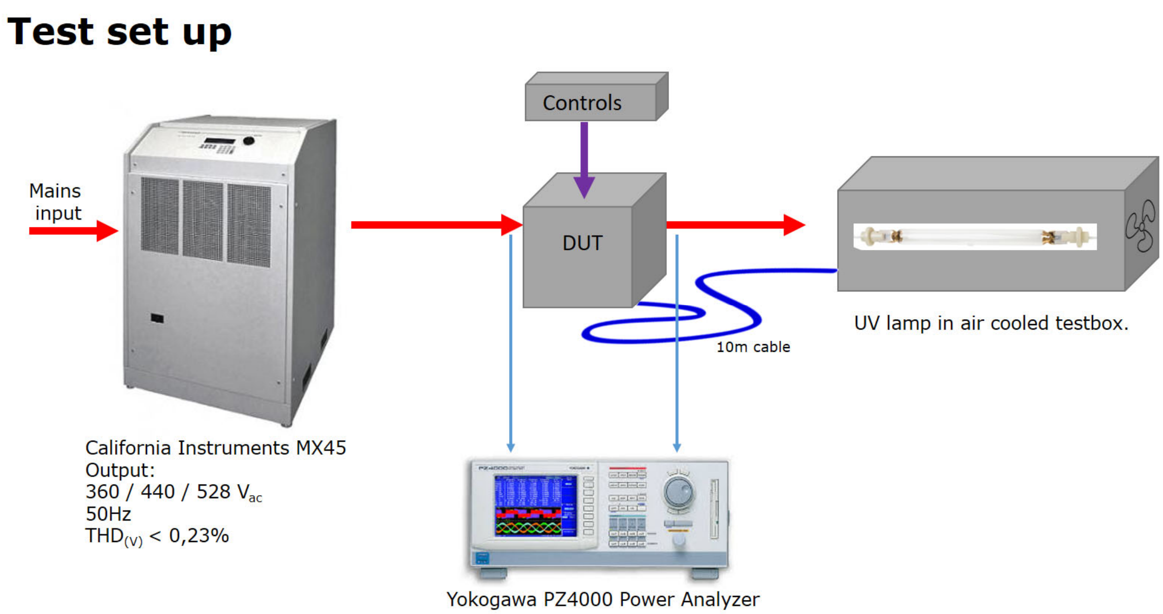


Fig. 3

Besides the Nedap drivers, 3 other topologies were tested, 2 European designs (“A1+A2””and “B”) and 1 Asian design (“C”). A1+A2 are drivers from the same manufacturer but different power levels. Design B is made available in the market at several brands.

Efficiency.

Efficiency of the driver was measured with the Yokogawa PZ4000 Power analyzer at minimum, nominal and maximal specified input voltage and at 100% output power.

Efficiency %

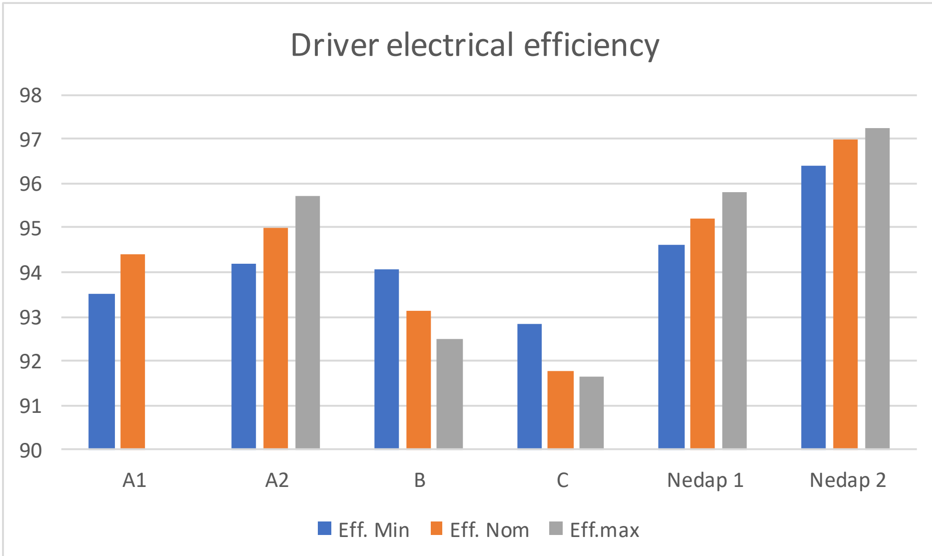


Fig. 4

Note: A1 measurement at Vin max. was not possible due to shut down of driver

It should be noted that for drivers A + B additional power to the cooling fans is not included. In cases C and Nedap the power for the cooling fans and auxiliary voltage for the drivers are included. With state of the art components and designs, an overall efficiency of >95% should be achievable. Be aware that in order to fulfill EMC requirements additional filters are required for A,B and C drivers. This will lower the overall efficiency results.

Power Factor.

Again at 3 input voltage settings the Power Factor was measured, see fig.5.

PF

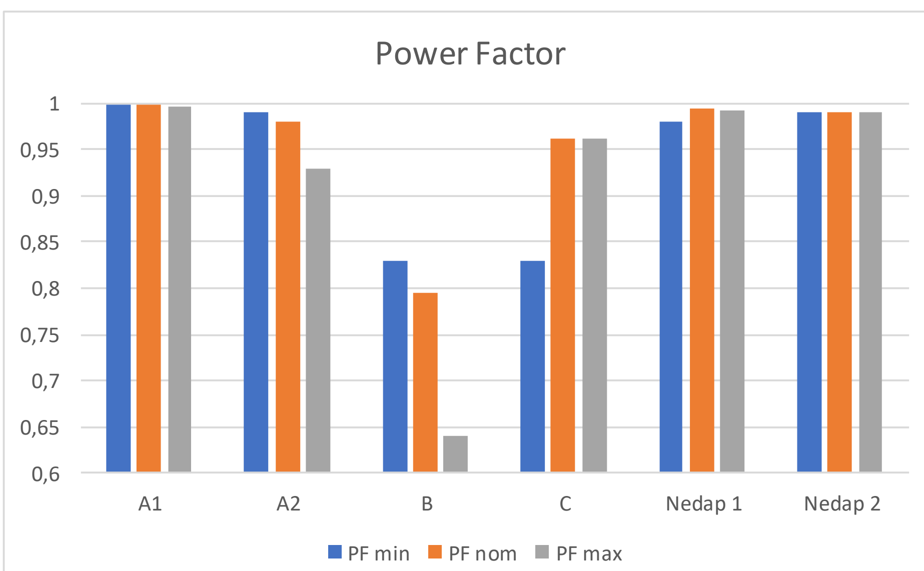


Fig. 5

As indicated the target here is to be close to PF=1. In several cases a good Power factor of well above 0,98 was noticed. In one case (B) a very poor Power Factor (<0.65) was measured at 100% output power and maximal input voltage.

Designs A2 + B showed instability depending on impedance of the power line. In these cases extra attention is needed for additional power line filters to protect the driver for overvoltage, functional instability and to lower the EMC levels, produced by the driver.

Design A showed also a weak point at input line under voltage situations. Output power of the driver in these cases was not automatically dimmed, causing the input current reaching the input fuse rating. This could lead to overheating of components and/or nuisance failures in the field.

During powering up the driver C a current peak of 185A at V_{in}=460V was measured. Nominal value of the input current at 100% output power is around 34A.

Total Harmonic Distortion.

Last but not least the values for the $THD_{(i)}$ were determined at 3 input voltage levels.

THD %

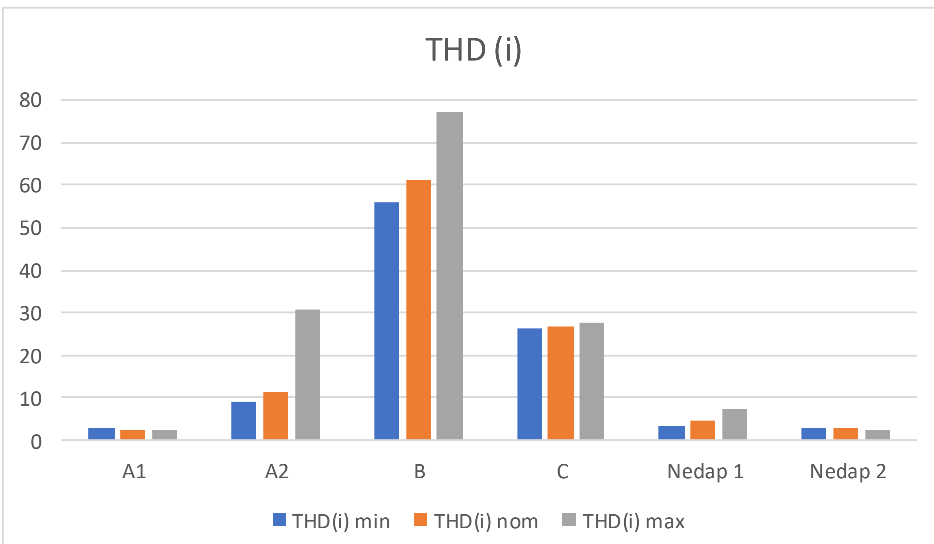


Fig. 6

The target is to be well below 10%. Both Nedap and design A1 show excellent performance here. Design B shows a very high level, even at nominal input voltage, of $THD_{(i)}$=61% leading to a **37%** increase in power losses in the power grid.

In many cases additional filters and protection devices are recommended by the manufacturer in order to fulfill regulations and required performance of the driver. Costs for these additional devices can go up to USD 150,- per lamp driver.

Some lamp driver designs do not offer a hold-up time of 20mses. This means that at a missing input voltage cycle or brown-out, the lamp will extinguish and it requires cool down time before restart is possible. In most cases these designs also show a weak input voltage immunity performance and voltage transients can reach the UV lamp resulting in lower lamp lifetime.

Skin effect.

We de see a trend towards higher power low pressure HO lamps, where currents can go up to 10A at frequencies of up to 60kHz. Besides cable capacitance, inductance and dielectric losses, the skin effect needs to be taken into consideration when designing the lamp cables in order to minimize series resistance of these cables. Specially in some applications where long distances (>50m) are required. See also our publication in IUVA News, Vol. 14, No. 3.
Also connectors and terminals need this attention.

Following picture (Fig.7) shows lamps that have failed after only 300 hrs. of operation with 60-70 on/off cycles.
Very often, initially the lamps and/or drivers are blamed, but in this case this premature lamp failure was caused by wrong ferrules and crimping tool, resulting in excessive additional resistance. This led to too low filament temperatures and excessive wear of the electrodes.

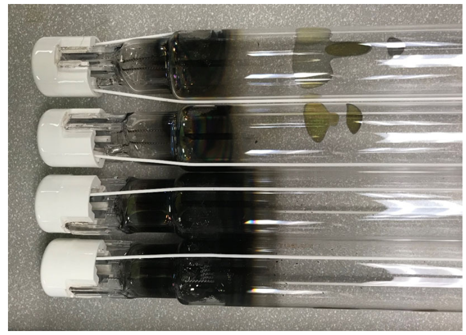


Fig. 7

Conclusion.

Energizing our UV sources can be done more energy efficient. This will save costs over the lifetime of the product, reduce carbon footprint and will improve reliability. Initial low cost systems with limited features with regard to Power Factor, THD, EMC and efficiency will lead to higher operational cost during the lifetime of systems. Looking at the total costs of ownership will help in making the right decision for selecting electronic lamp drivers.

Electronic lamp drivers nowadays are available with excellent performances. For choosing the right solution we advise to select drivers with an efficiency of > 95%, a Power Factor of > 0,98 and THD levels below 5%.

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Sources:
electrical-installation.org / data.worldbank.org

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