

## Power Quality Considerations Related to the banning of Incandescent lamps

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### Outline:

#### Banning of Incandescent lamps

- Background
- The new EUP directive
- Consequences of the new EUP directive

#### Power Quality (PQ) Considerations:

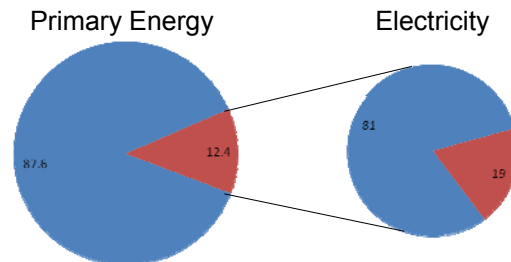
- PQ related requirements of individual Lighting products
- Intermezzo: Relation PF – THD - Harmonics
- Proposals to tighten-up the PF requirements of individual Lighting products
- Motivation for tightening-up the PF requirements of individual Lighting products
- Intermezzo: Mixed-Load conditions
- Motivation for tightening-up the PF requirements under Mixed-Load conditions
- Product consequences of tightening-up the PF requirements of individual Lighting products

#### Conclusions

#### Appendix A & B

## Banning of Incandescent lamps

### Background



Lighting consumes 19% of all electricity in the world (source IEA)

Lighting consumes 2.35% of the primary energy in the world

→ 2700 TWh/year

## Banning of Incandescent lamps

### New EUP directive

By simply switching the incandescent lamps over to other energy saving lighting technologies (and achieving a realistic average saving of 50%) the EU could save:

- 5 - 8 billion Euro in energy costs
- This equates to:
  - 20 million tons of CO<sub>2</sub>
  - Consumption of 74 million barrels of oil per year
  - Annual output of 25 medium sized power stations @ 2TWh/year




In line with the Kyoto / CO<sub>2</sub> objectives of the European Commission

Resulting in a new EUP directive



## Banning of Incandescent lamps

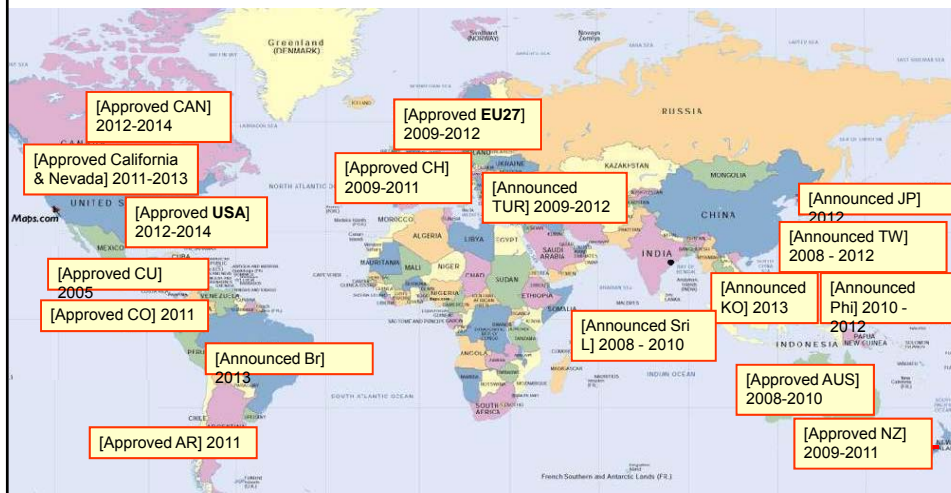
### Consequences of the new EUP directive

	Sep. 2009	Sep. 2010	Sep. 2011	Sep. 2012	Sep. 2013	Sep. 2014	Sep. 2015	Sep. 2016
 Clear	15W	15W	15W	15W	Banning of all incandescent Lamps			
	25W	25W	25W	25W				
	40W	40W	40W	40W				
	60W	60W	60W	60W				
	75W	75W	75W	75W				
 Opal		Banning of all opal Incandescent Lamps						
 Reflector	15W	Directives in preparation						
	25W							
	40W							
	60W							
	75W							
100W								
Special Purpose Lamps								

**Conclusion 1: The majority of the incandescent lamps will be banned in 2013**

## Banning of Incandescent lamps

### Legislation global phase-out Incandescent lamps



Under discussion in RSA, Egypt and many other countries in APR and LATAM.

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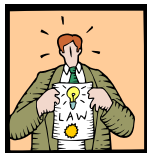
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## Power Quality Considerations

### PQ related requirements of individual Lighting products



#### IEC / EN

- 61000-3-2: Limits for harmonic current emissions ( $\leq 16A$ )
- 61000-3-3: Limitation of voltage fluctuation and flicker in low voltage supply systems for equipment with rated current  $\leq 16A$

#### Directives

- EUP DIM1: Power-factor (PF) requirements
  - $P \leq 25 W: \lambda > 0.5$
  - $P > 25 W: \lambda > 0.9$



#### Market requirements

- UK-EST / EnergyStar: Power-factor (PF) requirements
  - $P \leq 25 W: \lambda > 0.5$
  - $P > 25 W: \lambda > 0.9$

## Power Quality Considerations

### Intermezzo: Relation PF – THD – Harmonics

The Total Harmonic Distortion (THD) is quantified by the injected harmonics. The relation between the individual harmonics and the THD is given by the equation:

$$THD = \sqrt{\sum_{n=2}^{\infty} \left(\frac{i_n}{i_1}\right)^2}$$

Where  $i_n$  is the amplitude of the  $n^{\text{th}}$  harmonic of the mains current

The THD and the displacement -- quantified by the difference in phase ( $\cos \phi_1$ ) between the first harmonic of the mains current and the mains voltage -- are the basis of the Power-factor  $\lambda$ . The relation between  $\lambda$ ,  $\cos \phi_1$  and THD is given by the following equations:

$$\lambda = \frac{\cos \phi_1}{\sqrt{1 + THD^2}}$$

Note: Typical  $\cos \phi_1$  of electronic lighting equipment  $\approx 0.9 - 1$

## Power Quality Considerations

### Intermezzo: Relation PF – THD – Harmonics

#### Summary:

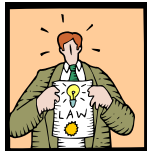
- The “Harmonic current emissions” are defined in the internationally accepted IEC 61000-3-2 “Limits for harmonic current emissions” standard
- The “Power-factor” ( $\lambda$ ) is defined in the regional / local directives and market requirements
- The “THD”, the “Power-factor ( $\lambda$ )” and the “Harmonic current emissions” are interdependent

#### Conclusion 2

The influence of the individual Lighting products on the Power-Quality of the mains is safeguarded by IEC 61000-3-2. There is no need for additional PF requirements of the individual Lighting products.

## Power Quality Considerations

### Proposals to tightening-up the PF requirements of individual Lighting products



IEC:

- 61000-3-2: Limits for harmonic current emissions ( $\leq 16A$ )
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Directives:

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Market requirements:

- UK-EST / EnergyStar: Power-factor requirements
  - $P \leq 25 W: \lambda \rightarrow 0.5 \rightarrow \lambda > 0.7 \rightarrow \lambda > 0.9$
  - $P > 25 W: \lambda > 0.9$

## Power Quality Considerations

### Motivations to tightening-up the PF requirements of individual Lighting products

Increase of the distortion of the mains-voltage

- $THD_i \rightarrow THD_v \rightarrow$  Mal-function of sensitive equipment

Overload of the PEN conductor in 3-phase network

- If non-linear loads with an identical harmonic spectrum are connected to a three-phase "WYE" or "Star" distribution network, the 3<sup>rd</sup> harmonic and its uneven multiples (9<sup>th</sup>, 15<sup>th</sup>, etc.) cumulate in the PEN conductor.

- This can cause an overload of the PEN conductor.

- As the current in the PEN conductor is normally not monitored, there is a potential danger that it will overheat and catch fire.

Increase of the network losses

Are these motivations valid ???

## Power Quality Considerations

### Intermezzo: Mixed-Load conditions

The typical load of a residential network consists of:

Appliance	Watts	Hours/Mo	Avg. \$/Mo
Air Conditioner (Room) 6,000 BTU	750	120	6.75
Refrigerator-Freezer Frost Free	500	150	5.63
Clothes Washer, Automatic	500	7	2.48
Clothes Dryer	5000	6	2.25
Dishwasher	1300	8	1.5
Computer (Monitor & Printer)	200	25	0.38
Clock	5	720	0.3
Coffee Maker	900	4	0.3
Hair Dryer (Portable)	1000	1	0.08
Iron (Hand)	1000	1	0.08
Chandelier (5 Lamp)	300	10	0.23
Ceiling Fixture (3 bulbs)	180	6	0.15
Tri-Light (Table Lamp)	100	10	0.08
Fluorescent (2 Tube 4 ft.)	100	10	0.08
Lighting Single Lamp (60W)	60	17	0.08
Compact Fluorescent (60W Equiv)	18	17	0.02
Microwave Oven	1300	5	0.38
Television	180	60	0.38
Vacuum Cleaner (Portable)	800	2	0.15
DVD Recorder	40	50	0.08
Stereo	30	1	0.01

Source: <http://www.city.ames.ia.us/ElectricWeb/energy/appliances.htm>

## Power Quality Considerations

### Intermezzo: Mixed-Load conditions

“Mixed-Load” workbench investigation:

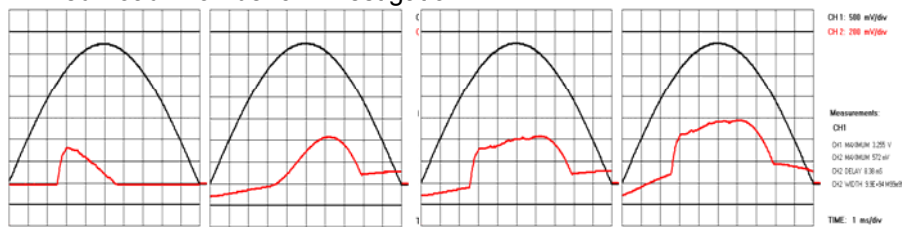


Figure 1 shows the typical current of an electronic lighting equipment of 18.3W.

Figure 2 shows the typical current of a transformer with a rectified load of 35W.

Figure 3 shows the total current of the 18.3W electronic lighting equipment and the transformer with the rectified load of 35 W.

Figure 4 shows the total current of the 18.3W electronic lighting equipment, the transformer with the rectified load of 35 W and a resistive load of 25 W.

Figure	P [W]	$\lambda$	I [mA]	i1 [mA]	i3 [%]	i5 [%]	i7 [%]	i9 [%]
1	18.3	0.63	125	84.5	82	54	28	17
2	35.3	0.72	213	189	47	21	5	5
3	53.6	0.88	265	245	35	10	13	4
4	79	0.94	365	352	24	6	9	3

## Power Quality Considerations

### Intermezzo: Mixed-load conditions

#### Summary:

- The “Mixed-Load” workbench investigation showed significant non-linear loads of the order of 20% to 68% of the total load.
- Given the different current flow angles and phase angles of these different non-linear loads, even high percentages of the individual distorted currents are not detrimental under **Mixed-Load** conditions.

#### Conclusion 3

The proposed tightening-up of the PF requirements and its motivations has to be based on **Mixed-Load** conditions

## Power Quality Considerations

### Motivations to tightening-up the PF requirements under Mixed-Load conditions

#### Increase of the distortion of the mains-voltage

First “Mixed Load” workbench investigations show no negative effects. Further investigations at home, hotel and residential area level are running at the Power-Quality lab of the Lulea University of Technology (Sweden).

#### Overload of the PEN conductor in 3-phase “WYE” network

No problems are expected as long as the wiring systems is designed according traditional (incandescent light bulb based) current ratings. See appendix A.

#### Increase of the network losses

Certainly not true. The rms current of electronic lighting equipment is much lower compared to a “Lumen” equivalent incandescent lamp. See appendix B.

#### Conclusion 4

The motivation to tighten-up the PF requirements seems to be not valid for Mixed Load conditions

## Power Quality Considerations

Product consequences of tightening-up the PF requirements of the individual Lighting products

	Actual (Reference)	No reasonable solution for little PF improvement except "dirty solution" with high losses	Passive PFC	Active PFC
	LPF <sup>1)</sup> 0.5 (0.55)	MPF 0.7	HPF 0.9	VHPF 0.95
Costs:	100%		130%	150%
Dimensions Ø of socket (= ballast-housing):	100%		120%	130%
Performance (Lm/W)	100%		95%	97%
Electronic waste	100%		150%	170%

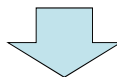
<sup>1)</sup> Typical LPF value is 0.6 for P < 25W circuits developed according IEC 61000-3-2

### Conclusion 5

The proposed tightening-up of the PF requirements of the individual Lighting product has severe disadvantages (and no advantages) for the product.

## Conclusions

1. The majority of the incandescent lamps will be banned in 2013
2. The influence of the individual Lighting products on the Power-Quality of the mains is safeguarded by IEC 61000-3-2. There is no need for additional PF requirements of the individual Lighting products.
3. The proposed tightening-up of the PF requirements and its motivations has to be based on **Mixed-Load** conditions
4. The motivation to tighten-up the PF requirements seems to be not valid for Mixed Load conditions (Further investigations are running)
5. The proposed tightening-up of the PF requirements of the individual Lighting product has severe disadvantages (and no advantages) for the product.



There is no need for PF requirements for individual Lighting products and there is certainly no need to tighten-up these PF requirements



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Appendix A

## Power Quality Considerations

### Overload of the PEN conductor in 3-phase "WYE" network

Example:

A 100 W incandescent light bulb has a current consumption of 435 mA. Consequently, if the system is protected with, e.g., a 16 A fuse, ( $16 \text{ A} / 0.435 \text{ A} = 36.8$ ), approximately 37 incandescent light bulbs can be lit per phase.

If all these light bulbs are now replaced by 18.3W electronic lighting equipments, the PEN conductor currents at the 3rd and 9th harmonics amount to  $3 \cdot 37 \cdot 71 \text{ mA} \leq 7.88 \text{ A}$ . This poses no problem for the PEN conductor which can support loads up to 16 A.

Even if the PEN conductor is only 60% of the cross-section of the outer conductor, and could thus only withstand loads up to 9.6 A, this scenario would still be harmless

Furthermore, in the case of mixed loads, a potential overload of the PEN conductor due to the 3<sup>rd</sup> (and 9<sup>th</sup>, 15<sup>th</sup>, 21<sup>st</sup>, etc.) harmonic is prevented or strongly reduced. This has already been explained in the first discussion point.

## Power Quality Considerations

### Increase of the network losses

The special feature for Energy Saving lamps is that it replaces an inefficient Incandescent lamp (with PF=1) with a 4 - 5 times more efficient CFL (with a PF of 0.5).

Even this low PF CFL draws much less RMS current than the incandescent lamp it replaced

In fact the PF could downgrade to 0.3 and still draw less than RMS current than the Incandescent lamp it replaced.

**CFL Power Factor Implications - an Example**

$$PF = \frac{\text{Power Consumed in Watts}}{\text{Voltage} \times \text{Current}} \quad \left[ P = VI, I = \frac{W}{PF \times V} \right]$$

Compare: P.F. Implication of a 25W CFL, 100W Incandescent Bulb

Voltage (RMS)	Power (Watts)	P.F.	25W CFL Current Draw A (RMS)	100W Inc. Current Draw A (RMS)
120	25	1.0	0.208	0.833
120	25	.9	0.231	
120	25	.8	0.260	
120	25	.7	0.298	
120	25	.6	0.347	
120	25	.5	0.417	
120	25	.4	0.521	
120	25	.3	0.694	
120	25	.2	1.042	
120	25	.1	2.083	

- 25W CFL Draws 0.5A Less Than 1.0 PF 100W Incandescent
- 25W CFL @ 0.6 PF Has Greater "Power Quality" Than 100W A Line

## Power Quality Considerations

### Increase of the network losses

- In real practice (household, office, hotel,..) CFL's are always applied in combination with other loads, thus the effect of PF and harmonics must be considered in such situations.
- Example:
  - Installed capacity: 250.000 MW
  - Distribution losses are assumed to be 10
  - Average power used for lighting is about 19% (not all GLS)
  - Assume GLS consumes 10% of installed capacity
  - Assume all GLS replaced by CFL

## Power Quality Considerations

### Increase of the network losses

- Initial situation: 250000 MW with a PF of 0.85
- 10% of this power is needed for GLS: all to be replaced by
  - CFL with LPF or
  - CFL with HPF

	MW	MVA	PF
Initial situation	250.000	294.118	0.85
- 10% GLS	- 25.000	- 25.000	1
+ LPF CFLi	+ 5.000	+8.333	0.6
+ HPF CFL-i	+ 5.250	+5.833	0.9
Total with LPF	230.000	277.451	0.829
Total with HPF	230.250	274.951	0.837

Difference in PF for the system before and after CFL replacement = **0.021!**  
 If HPF CFL was used instead difference would be **0.013!**  
 The improvement by replacing LPF with HPF is only **0.008!**

## Power Quality Considerations

### Increase of the network losses

- Several studies have indicated that the adding up model as used in previous slide is an over-estimation of reality.
- It turns out that in situations where equipment with a PF not equal to 1 is combined these tend to partly compensate each other due to the **MIXED-LOAD** conditions
- To calculate that is very difficult because it depends on:
  - Impedance of lines & transformer of electricity grid
  - Specific current curves of equipment
  - Internal residential circuit impedances
  - Combinations used
  - .....
- In reality harmonic levels will be 60% - 80% of the addition model.

→ The model calculation impact on total system power factor is always too high!  
 → Real impact LPF CFL on system PF 0.01, difference with HPF 0.00