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Voltage optimisation and lighting technology

Extended Abstract

Martin Braun[1]
University of Sheffield

Goals, Scope and Background

The aim of this paper is to investigate the effects of voltage optimisation of luminaries frequently found in households and retail outlets. As the behaviour of incandescent lighting is well understood (Simpson, 2003, 113 - 117), the experiments concentrated on more modern luminaries to establish the relationship between the voltage (as the input parameter) and power consumption and illuminance (as output variables). In addition to this, the ramification of modern lighting technology and voltage optimisation of the distribution network is also discussed.

At least since shortly after the oil crisis in the seventies, there has been an interest in how voltage optimisation can be used to conserve electric energy. The concept is quite straight-forward as it uses the simple formula: Electric power (P) = voltage (V) · current (I) · power factor (cos φ). This means that for an ideal resister a voltage reduction of 10% results in a reduced power consumption of 19%. The relationship between voltage change and power consumption of an incandescent lamp, the mainstay of household lighting until not so long ago, shows that it cannot be treated as an ideal resistor because for a 10% change in voltage the power consumption drops only by about 15% (whereas the illuminance can drops by up to 38%!).

Materials and Methods

The lamps examined during the experiments included 5 compact fluorescent lamps (CFL) with power ratings of 9W, 11W, 18W, 20W and 21W, linear fluorescent lamps with either an inductive ballast or an electronic ballast, LED tubes and metal halide lamps with either an inductive ballast or an electronic ballast. The voltage was changed with an autotransformer from the maximum voltage to 207V (minimum mains voltage according to BS EN 60038:2011) in about 5-V steps and at each step the power consumption, the illuminance as well as the current and voltage wave forms, were recorded.

Results

The test results were entered into a spreadsheet and then analysed using linear regression. Table 1, which is based on a 10% voltage drop from an initial voltage of 230V, is organized in descending order of potential power savings and also includes an incandescent lamp and a resistor for comparisons. The highest saving potentials are shaded green, medium in yellow and low potential luminaries in pink. Generally speaking, a reduction of power consumption

[1] E-Futures, Dept of Engineering Materials, Sir Robert Hadfield Building, Sheffield, S1 3TD, dtp11mrb@sheffield.ac.uk

is accompanied by a reduction of light output, but this is never as severe as for an incandescent lamp. Lamps with an inductive ballast are more sensitive to voltage changes then their counterparts with an electronic ballast, for which power consumption and illuminance is virtually independent of the input voltage.

No	Devise	Change of power consumption	Change of illuminance	Remarks
1	Linear fluorescent - inductive ballast	-25%	-23%	
2	CFL 20W	-20%	-7%	
3	Metal Halide - inductive ballast	-19%	-18%	
4	CFL 18W	-18%	-11%	
5	CFL 21W	-18%	-14%	
6	LED 10W	-8%	-1%	
7	CFL 11W	-6.5%	-10%	Non linear power behaviour
8	Metal Halide - electronic ballast	-2%	-1%	
9	LED 22W	0%	1%	
10	Linear fluorescent - electronic ballast	0%	0%	
11	**CFL 9W**	**+10.4%**	**-7%**	**Non linear power behaviour**
12	Incandescent lamp	-15%	-30%	For comparison only
13	Ideal resistor	-19%	N/A	For comparison only

Table 1: Summary of results calculated for a 10% voltage drop (100% = nominal voltage)

As the lower power CFLs exhibit a very non-linear relationship between their input voltage and power consumption, Figure 1, which is normalised with respect to their input voltage (230V = 100%), is included to shows this relationship together with a relatively linear graph for the illuminace of these lamps. The graph indicates that, if the input voltage reduced below 230V, then, at some point, a reduction in voltage causes an increase in power consumption.

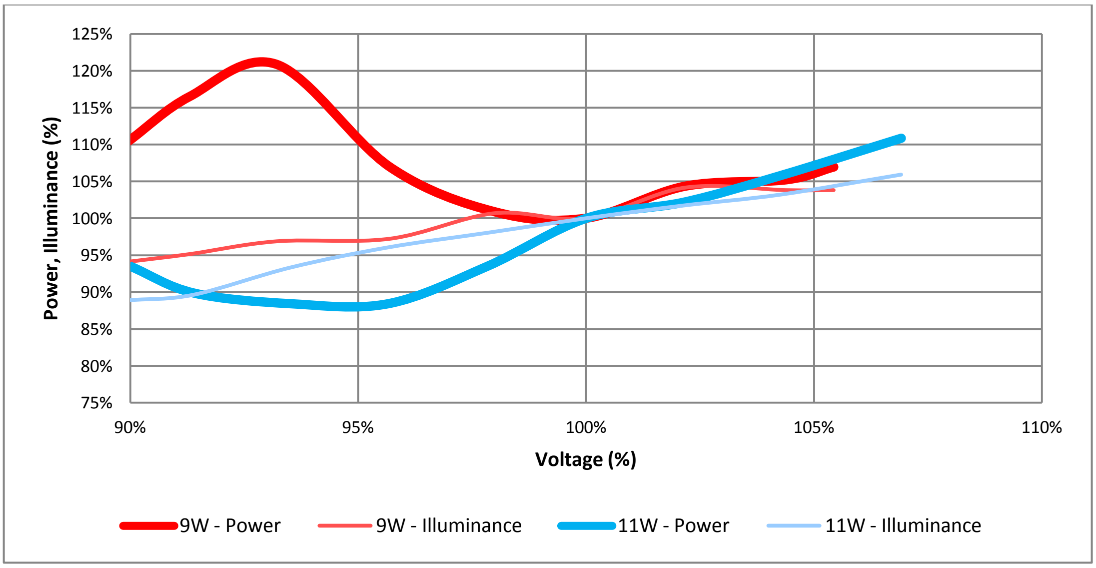

Figure 1: Low power CFLs

With the exception of the light fittings with an electronic ballast all other light fittings drew a highly non-sinusoidal current. A Fourier analysis of their current waveforms showed a high total harmonic distortion (THD).

Discussion

Reducing voltage to lamps listed as Nºs 1 to 5 in Table 1 lowers the power consumption by between 18% to 25%. Although the light output does not reduce as much as with a conventional light bulb, there is a reduction up to 23%. This may lead to an unacceptable lighting level which, in turn, may lead to other lights being turned on or installed, thus nullifying any power reduction. For luminaries Nºs 6 and 8 the energy conservation effort can actually have the very opposite effect as the power consumption may increase when reducing voltage. Even if the power consumption does not change, reducing voltage can be counter productive as the supply current increases, which leads to higher supply losses (for a cable proportional to I^2).

As mentioned earlier, the current drawn by many light fittings (including those with an inductive ballast) has a high total harmonic distortion (THD). Khan and Abas (2011) observe that CFLs with a current THD “squander power rather than conserving energy”. A wide spread adoption of CFLs and other light fittings with a high THD can lead to serious problems in the electricity supply system as current THD cause higher losses in transformers and distribution cables, which can lead to overheating and even failure.

Conclusions

The experiments discussed here showed that power consumption of lighting equipment commonly used in household can be reduced by up to 25% by dropping from the nominal voltage to the minimum voltage permissible. As a reduction in power generally also reduces the light output, the overall effect is not quite clear and may depend on the user. Generally speaking, the evaluation of the effectiveness of modern lighting technology is not straight-forward and may have a negative effect on the overall power consumption and may lead to problems in the distribution network – even to failures.

Recommendation and Perspectives

To establish if voltage optimisation is a valuable tool to curb energy consumption a number of real life scenarios should be investigated to develop a model, which can assist in determining the advantages and pitfalls. In addition, the effect of widespread adoption of CFLs, electronic ballasts and other electronic equipment with a high THD should be studied with emphasis on the effect on the electricity distribution network and its cost implications.

References

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