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EFFECT OF LED LIGHTING IN ELECTRICITY CONSUMPTION OF NORWAY

K. Dursun H. Mordt

Electrical Engineering Department, Ostfold University College, Fredrikstad, Norway
kamil.dursun@hiof.no, helge.mordt@hiof.no

Abstract- This paper discusses advantages and drawbacks of having two supply systems in a household, one conventional and one with low voltage that feeds LED lighting and information flow systems. The technical and economical aspects are discussed. A separate 36 V system can be used for DC distribution. The two systems can be connected via a converter to secure power quality. Merely exchanging incandescent bulbs with LED will not be feasible for such a system. However, it will be easier to integrate local alternative energy sources and trade energy to get a better economy. The advantages of energy trading are not studied in this paper.

Keywords: LED, Household, Energy Consumption.

I. INTRODUCTION

In this paper, a technical and economical study of the electrical wiring system in a house was made. Today only one system (230 V / 50 Hz. or 110 V. / 60 Hz.) is used in households. It is possible to have two separate systems, one existing system for heavy usage and one 36V system for lighting, computers, electronics etc. 36V is chosen because of IEC which defines 42V as the limit for low voltage. In this range, the installations can be done by non-skilled people and will be cheaper.

It was shown that the additional system cannot pay itself back within a reasonable time period if we only consider the savings by changing incandescent light bulbs by LED. However such a system makes it easy to integrate components such as alternative energy sources and have possibility of storing the energy and selling it back to the grid during peak hours. Moreover, the savings in energy mean reduction of the environmental footprint of the households. In a future study, the technical and economical aspects of environmental issues and energy trading should be considered.

II. TECHNICAL ASPECTS

A. Recent Developments in LED Technology

The invention of the bright blue LED by the Japanese Scientist Shuji Nakamura in middle of 1990 was a major breakthrough, because it allowed mixing of the primary colors to make a palette of 16 million colors. The bright blue LED became also a stepping stone to bright light LED which can be used for lighting.

As Moore law has been defined for computer processing power a similar law has been defined for LED, calling Haitz's law. (Roland Haitz, 2006). This law predicts that the luminous output for individual LED devices is increasing at a compound rate of 35 % per year and that the cost pr lumen is decreasing at 20 % per year.

Every day new products are entering the market based on LED technology. According to an EU directive, incandescent lamps should be replaced with more energy efficient light sources like fluorescent lamp and LED lamp. Still fluorescent lamp has a lower cost per lm than LED, but it is assumed that in long term LED will become cheaper and better than every other light source. Remember that LED is a real solid state device, while fluorescent is more like a vacuum tube. A LED has a lifetime that is much longer than an incandescent lamp.

B. Lighting Requirements in a Household

In order to estimate the energy needed for lighting in a household, the E-T curve is considered (Figure 1). The following E-T curve is plotted from periodical measurements of energy consumption in a flat during a period of 3 years. The x-axis is the average daily outside temperature and the y-axis is the energy consumed per day and square meter. The total energy consumption covers heating, lighting and other services such as cooking, TV, computers etc. Hot water consumption is not included in the measurements.

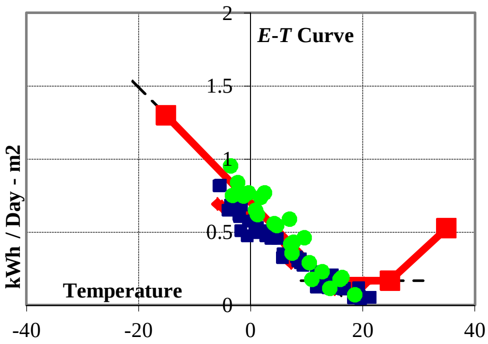

Figure 1. The *E-T* curve

As expected, the energy consumption increases as the average outside temperature drops. In warmer climates, it should be expected that the consumption also increases as the temperature increases over a limit due to the need of air conditioning but this is not a problem in Norway. During the summer months, there is a base consumption that covers everything apart from heating. It can be seen that this specific flat has a base consumption of about 0.2 kWh/day-m^2. Other households with a similar standard of living are expected to have more or less the same consumption.

An average household in Norway is around 80 sq.m so the total daily base consumption is 16 kWh. Norwegian households use electricity for cooking. If we deduce about 5 kWh for cooking, roughly 11 kWh per day is spent for lighting and other services in an average household. For the whole year, this amounts up to roughly 4,000 kWh. There are averages of 2.2 persons living in a household [1] and there are 5 million people in Norway so the total amount of households is 2.23 million. The total energy spent on lighting and services (TV, computers, freezers etc.) in Norway is therefore around 9 TWh.

C. Limitations of LED Spectrum

There are two main parameters that qualify the light from a light source, one is the color temperature, and the second is the color rendering index. The color temperature is expressed in Kelvins, (K) and is the appearance of the color of light to human eye. The higher the color temperature, the cooler the light will be, and the lower the color temperature, the warmer the source will appear to be. Table 1 (ref [5]), gives the color number for different light sources

Table 1. Light table [5]

Temperature	Source
1700 K	Match flame
1850 K	Candle flame
2700-3300 K	Incandescent light bulb
3350 K	Studio "CP" light
3400 K	Studio lamps, photofloods, etc.
4100 K	Moonlight, xenon arc lamp
5000 K	Horizon daylight
5500-6000 K	Typical daylight, electronic flash
6500 K	Daylight, overcast
9300 K	CRT screen

Note: These temperatures are merely approximations; considerable variation may be present.

Color rendering index (CRI) measures the light source's ability to render colors accurately, where 100 represents render completely as sunlight. A CRI on 75 is considered good for lighting, with 85 being very good and 95 excellent. CFL (compact fluorescent light) has a CRI around 80 to 85, for LED CRI has been reported to be in the range 75-80 depending of type of LED used. Using CRI as a reference standard, there is still some limitation for LED as compared with CFL. It should also be noticed that there is a discussion of how adequate CRI number is for classification for white LED lamps [6].

D. Control and Feeding of LV System

The electrical distribution system for a household is either 110 V AC 60 Hz or 230 V AC 50 Hz. This voltage level is based on a compromise between efficiency in power transmission and safety. The first incandescent lamps had a low lm/W ratio, which means that each lamp consumed lot of power.

The light sources today has a lm/W ratio which is at least 100 times better than the first electrical lamps, which means that one gets the same luminance in the house for less power, so the time has come to look at the electrical distribution system in a house. Nowadays electrical power is used for;

Lighting
- Electronic equipments (TV, PC, Ipad, HiFi system)
- Refrigerator and freezer
- Washing machine and drier machine
- Electrical cooking

Internal in electric equipment DC is mainly used, all electronic equipment run on DC, and compare with AC DC can easily be stored in batteries.

It should also be mentioned that nowadays it is more common that hand tools like electrical drill, electrical saw etc also operate on batteries.

12 V DC is used for solar driven electric system for lighting, in small house or a cottage where there is no access to the electrical grid. This LV technology is well known. When less power is needed to give light, why should the distribution system still run on 230 V AC/110 V AC, couldn't it be convenient to run on two different systems?

One high voltage AC system 230 V/110 V for high power equipment like washing machine , stove, heavy duty machines, while lighting, PC, TV etc run on a low voltage system 36 V DC. Using incandescent lamp has a power peak for a household on 1487 W, which means that the current needed in a 230 V system is 6.46 A.

Reducing the peak power needed to 300 W, running on a 36 V system, the current needed is 8,33 A, about 28 % more, but still less than 10 A. This means that the conductor size will approximately be the same. The voltage of 36 volts is chosen because of the IEC standards that define any voltage below 42 as low voltage. In the range of low voltage, installations tend to be simpler and it is not required to be set up by a skilled electrician. Any handy person is allowed to install the electrical system below 42 volts.

Running on DC makes it simple to have a power backup system in case of power cut in the grid, since DC can be fed from local installed batteries. In addition PV panels and a small windmill can directly be connected to the DC system. In connection with smart grid technology and as alternative power sources such as windmills and PV power sources are becoming more common, there will be need for electrical storage system in the grid, which can easily absorb the energy produced, when more energy is produced than consumed.

Conversely, there is a need for energy sources with high speed regulation, for stabilization of the grid e.g. when a cloud is passing over a PV solar plant.

Introducing a low voltage system based on DC, power exchange with the grid will be feasible, and can meet the demand on high regulation speed. It should here be mentioned that a parked electrical car connected to the grid can be used for such purpose. For electrical batteries the figure capacity/price is increasing thanks to the recent developments for electrical cars.

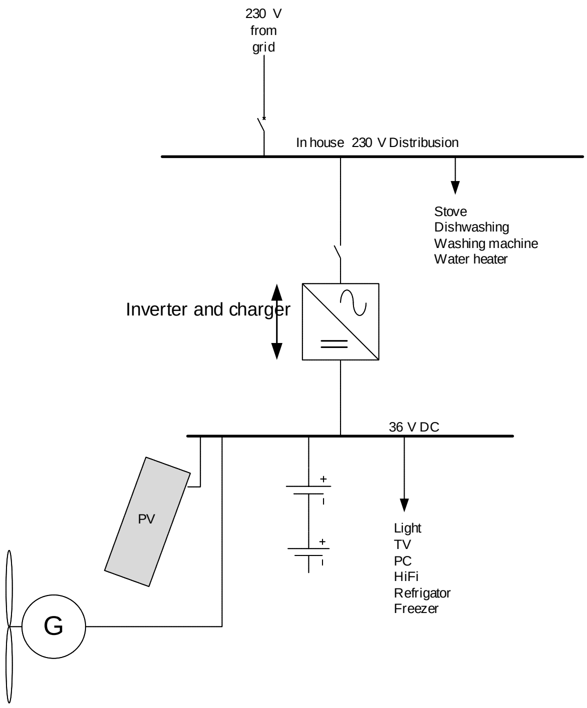

Figure 2. Low voltage distribution system

E. Model of a Typical Flat with Two Separate Electrical Supply Systems

The Flat is assumed to have an area of 80 m^2, with combined kitchen and living room, two bed room, one bath, hall and storage. Figure 3 gives the layout of the flat. The light needed for this flat are in Table 2.

Total peak power for light is 1004 W, for this model flat. These 1004 W, 890 W is connected to incandescent lamp, which easily can be replaced with LED using only 1/7 of the power. The electric power used for light can be reduced from 1004 W to 240 W. Note that if these light bulbs are used 3,900 hours i.e. less than ½ of the 8760 hours in a year, we will get around 9 TWh of consumption for all the 2.3 million households in Norway. This calculation is consistent with the previous calculation in II.B.

The fluorescent lamps have almost the same efficiency as LED, therefore there is no reduction in power consumption by replacing the CFL/TL with LED. Electrical power used in a flat can be summarized in Table 3. The peak electric consumption for the 36 V supply system is 610 W which means a peak current for the 36 V system will be 17 A. For the example flat it means that it will be sufficient to have two or three distribution circuits. With 6 A in each circuit, and a voltage drop on maximum 3%, the maximum length for each distribution will be 12.5 m with a 2.5 mm^2 cable.

Figure 3. The layout of the flat

Table 2. The light information of the flat

Room	Down light	Ordinary	Fluorescents	Total
Hall	4 x 35 W	1 x 40 W		180 W
Bed room 1		2 x 40 W	2 x 11 W CFL	102 W
Bed room 2		1 x 40 W	2 x 11 W CFL	62 W
Bath	4 x 35 W		1 x 15 W	155 W
Store			1 x 11 W CFL	11 W
Kitchen/living room	5 x 10W	5 x 60 W	2 x 22 W TL	494 W

Table 3. The electrical power information of the flat

Description	Used	230 V AC	36 V DC	Total
TV	0.125		130 W	390 Wh
Light LED	0.375		240 W	2100 Wh
Stove	0.0416	1500 W		1497 Wh
PC	0.75		90 W	1620 Wh
HiFi system	0.1		50 W	120 Wh
Refrigerator	0.1		160 W	384 Wh
Washing machine	0.02	2200 W		1056 Wh
Dishwasher	0.0129	2200 W		683 Wh
Aux		200 W	100 W	300 Wh
		6100 W	610 W	8303 Wh

Note: It is assumed that water heating and room heating is supplied from a separate source such as a district heating system.

III. ECONOMICS

A. Macro Economic Considerations of Energy Cost

Norway had a total electricity consumption of 120.6 TWh in 2010 (Figure 4). Of this sum households and farming sector consumed 42 TWh [3]. The total consumption of electricity for on and services (TV, computers, freezers etc.) in Norway was estimated to be around 9 TWh in II.B. It is reasonable that this portion be about 20-25% of total electricity consumed in farms and households. If we deduct 1-1.2 TWh for services, it is assumed that 7.8 TWh is consumed only for lighting.

The cost of electricity is decided by the power stock market (NordPool). Figure 5 shows the variation of electricity price to end users during 2010. The average price was roughly NOK 0.95 / kWh. [2]. As can be seen from the graphics, the energy costs are highest during the winter. This is the time of the year which is darkest and the necessity for lighting is greatest. In this paper, it is assumed that the cost of lighting is distributed uniformly throughout the year, even though this will yield some errors in the calculation because of the seasonal variation.

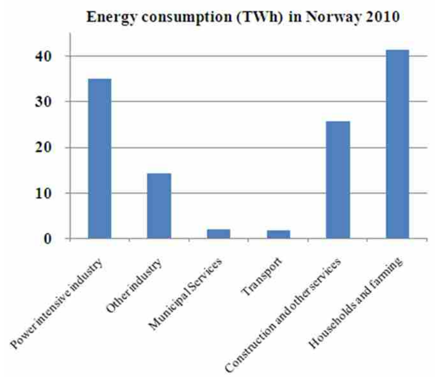

Figure 4. Total electricity consumption in Norway in 2010

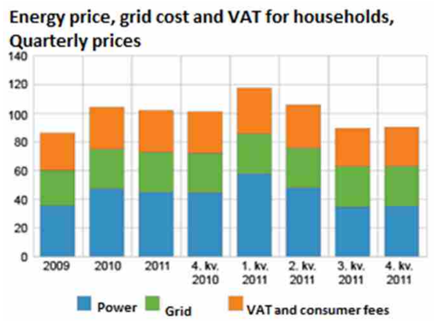

Figure 5. Variation of electricity price to end users during 2010

B. Life Cycle Costs for LED vs. Incandescent Lamps

A normal incandescent light bulb has an average lifetime of 2,500 hours. A LED bulb in comparison has more than 25,000 hours of life. A 2W LED light bulb costs about NOK 80 and the prices are falling rapidly. An incandescent light bulb with corresponding power (15W) costs about NOK 20, i.e. there is a price relation of 1:4. Since the lifetime of the LED bulb is 10 times longer, the price of the incandescent bulb should be multiplied by 10 in order to have a comparison. The difference in purchase price of LED instead of incandescent bulbs for the lifetime of 25,000 hours is NOK 10 x 20–80 = NOK 120; i.e. by installing one LED bulb, it is possible to save NOK 120 on the purchase price for the average lifetime of 25,000 hours.

In addition there is the saving in energy. For a light bulb of 2W (LED) or 15W (incandescent) the difference in energy cost is (15-2) * 25,000 * 0.95 = NOK 308 for 25,000 hours of operation. So one LED bulb of 2 W will save the consumer NOK 308 + 120 = NOK 428 for its lifetime of 25,000 hours.

Assuming 3,900 hours of usage per year, the yearly savings by changing the incandescent bulb with LED would be 428 * 3,900 / 25,000 = NOK 67 per year. In this calculation, the destruction costs are not considered. This may be done at a different study.

From II.B and II.E it was calculated that around 7.8 TWh is spent on lighting for whole of Norway. As of today, more than 99% of all lighting is achieved with incandescent bulbs. A 2W LED bulb gives the same amount of energy as an 15W incandescent bulb. Assuming a ratio of 1:4 shich is a conservative figure; it would be possible to save 6.3 TWh of energy per year by changing all the incandescent light bulbs by LED; which would mean a saving of 6.3 x 0.95 = NOK 6 billion per year.

C. Investment Costs for the Extra System

The investment cost for a two level electrical distribution system is connected mostly to battery and inverter system. The cabling in the house will increase but not dramatically. The peak power consumption for a flat is typically from the example 610W for the 36V system and 6100W for the 230V system.

For one day the total consumption for the flat is 8,9 kWh, which gives an average consumption on 370 W for both systems. Outlets and switches will almost be the same either it is 36V DC or 230V AC, the extra investment cost is connected to the following devices: inverter, battery and charger.

The price for the battery is mainly connected to the power used. From the table, the estimated energy consumption is 4954 Wh for the 36 V system per day. 24 h backup means that minimum battery capacity is 137 Ah. With 40 % spare capacity, the battery capacity should be 228 Ah. Investment cost can be summarized in the Table 4.

Table 4. The investment cost

Item	Description	Estimated price (NOK)
1	3 batteries 12 V of 290 Ah	11,495
2	3 charger 12 V 50 A	8,070
3	Inverter 2000 VA	25,000
4	Aux	10,000
	Total	54,565

Source: www.hyttetorget.no and www.sunwind.no

Depending on type of equipment the extra cost for 36 V systems including a backup time in case of power cut will be approximately 55,000 NOK. In a household with roughly 20 LED lamps, the yearly saving will be 67*20 = NOK 1,350 so the payback period is too long to be feasible. The advantages of storing and selling the energy back to the grid at peak hours will have to be taken into account in this economical calculation. Additionally, the environmental savings have to be reckoned with. This can be a topic for a future study.

IV. CONCLUSIONS

The time has come for validation of the electrical system for households. Until now the electricity used in our homes came from a power station mainly based on hydropower here in Norway, while in the world fossil fuels and nuclear fuels are the common fuel sources.

Changing our lighting system from incandescent to LED will save approximately 7.8 TWh, which can replace electricity produced by fossil fuels in Europe.

Introducing of a two level distribution system in our home (230 V AC/36 V DC), will secure the electric supply and also make it easy to have local micro production of electricity based on renewable energy like PV or/and wind mills. It will also facilitate trading of energy in a micro level.

Securing our electrical supply is important since our dependency on electricity has increased the last years. Reducing our consumption of electricity, and increasing the electricity produced by renewable energy, will reduce the emission from fossil based power plants, and contribute to a green future.

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BIOGRAPHIES

Kamil Dursun was born in Ankara, Turkey, 1954. He received the M.Sc. and the Ph.D. degrees from The Norwegian Technical University, all in Power Electrical Engineering, in 1978 and 1984, respectively. He worked with ABB in several countries. Currently, he is an Associate Professor of Power Engineering at Ostfold University College (Fredrikstad, Norway). He is the secretary of International Conference of ICTPE. His research interests are in the area of efficient power distribution, energy management systems and virtual e-learning educational systems.

Helge Mordt was born in Fredrikstad, Norway, 1954. He received the M.Sc. and Ph.D. degrees from Department of Engineering Cybernetics, Norwegian Technical University, Norway in 1980 and 1991, respectively. From 1979 to 1981 he worked for Institute of Engineering Cybernetics as Assistant Professor. From 1981 to 1985 he worked as Scientist at SINTEF, Division of Automatic Control. From 1985 to 1991 he worked as Process Engineer at Norsk Leca, Norway. From 1991 to 1993 he worked at Aker Engineering with Control System for Troll gas and Troll oil platforms. From 1993 up to now he works as Associate Professor at Ostfold University College, Fredrikstad, Norway. In 1995 he was a co-founder of the company Prediktor AS. His research interests are in the area of industrial control system and energy efficient production.