IMPACT OF STAND-BY ENERGY LOSSES IN ELECTRONIC DEVICES ON SMART NETWORK PERFORMANCE

by

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Limited energy resources and environmental concerns due to ever increasing energy consumption, more and more emphasis is being put on energy savings. Smart networks are promoted worldwide as a powerful tool used to improve the energy efficiency through consumption management, as well as to enable the distributed power generation, primarily based on renewable energy sources, to be optimally explored. To make it possible for the smart networks to function, a large number of electronic devices is needed to operate or to be in their stand-by mode. The consumption of these devices is added to the consumption of many other electronic devices already in use in households and offices, thus giving rise to the overall power consumption and threatening to counteract the primary function of smart networks. This paper addresses the consumption of particular electronic devices, with an emphasis placed on their thermal losses when in stand-by mode and their total share in the overall power consumption in certain countries. The thermal losses of electronic devices in their stand-by mode are usually neglected, but it seems theoretically possible that a massive increase in their number can impact net performance of the future smart networks considerably so that above an optimum level of energy savings achieved by their penetration, total consumption begins to increase. Based on the current stand-by energy losses from the existing electronic devices, we propose that the future penetration of smart networks be optimized taking also into account losses from their own electronic devices, required to operate in stand-by mode.

Key words: *energy efficiency, smart networks, stand-by power, thermal losses*

Introduction

Implementation of smart networks is aimed at enabling remote management, metering and control of numerous devices that have possibilities to receive remote signals over communication network and to respond to these signals. The networks served by these devices within the smart networking include electric power grids, district heating networks, gas supply networks, drinking water supply networks, *etc*., all with an aim to make their operation fully controllable. Such contributions to the overall improvement of efficiency of these infrastructure is anticipated

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from the deployment of smart network technology, in particular including demand-side management. For example, metering of heat energy is necessary on a per-user basis in order to allow appropriate billing according to the level of consumption.

Numerous definitions exist as to what constitutes a smart network. A common element to most definitions is the application of digital processing and communications to a network, making data flow and information management central to the smart network. Various capabilities result from the deeply integrated use of digital technology and integration of information flows into processes and systems is one of the key issues in the design of smart networks. For the electricity networks in particular, a future smart network serving as a dynamic network for two-way energy flows is intended to link widely dispersed micro-level renewable energy sources at the customer level and large scale energy sources providing more dynamic information to customers, thus facilitating greater customer choice about energy source and level of consumption and providing realtime information on the performance of the network and optimising the network operations. Delivery of these objectives will contribute significantly to the objectives of reducing greenhouse gas emissions and enhancing energy security, [1, 2].

The bulk of smart grid technologies are already used in other applications such as manufacturing and telecommunications and are being adapted for use in other smart networks operations. Widely developed are smart-home, smart-office and other services. For example, the amount of data required to perform monitoring and switching home appliances off automatically is very small compared with that already reaching even remote homes to support voice, security, internet, and TV services. Analyses have shown that the average home is equipped with tens of electronic devices working in stand-by mode, particularly those with remote sensing and external supply with AC/DC adapters, so that their stand-by mode consumption reaches 5-10% of the overall residential electricity consumption, [3].

Smart networks technologies include advanced microprocessor meters (smart meter) and meter reading equipment, wide-area monitoring systems, dynamic line rating (typically based on online readings by distributed temperature sensing combined with with real time thermal rating systems), electromagnetic signature measurement/analysis, time-of-use and real-time pricing tools, advanced switches and cables, backscatter radio technology, and digital protective relays, [4]. In general, such devices require a continuous power supply, both in operating and in stand-by mode, in later case with a reduced energy consumption. Nevertheless, due to their very large number, the energy losses in these devices when in stand-by mode are considerable, thus giving rise to the overall power consumption on the national level. In this paper we are addressing the energy losses in particular electronic devices in their stand-by mode, that are usually neglected, but a massive increase in their number can impact net performance of the future smart networks considerably so that above an optimum level of energy savings achieved by their penetration, total consumption begins to increase.

Stand-by power losses

Definition of "stand-by" power

Appliances and equipment with a "stand-by mode" may include any household product that consumes power while not performing its primary function. "Stand-by" is better defined under various modes, as presented in fig. 1, [5]. There are also other definitions that may be used to explain in more detail the term which has recently attracted attention of energy planners in their effort to reduce energy losses in terms of small, but numerous and ever increasing uses of

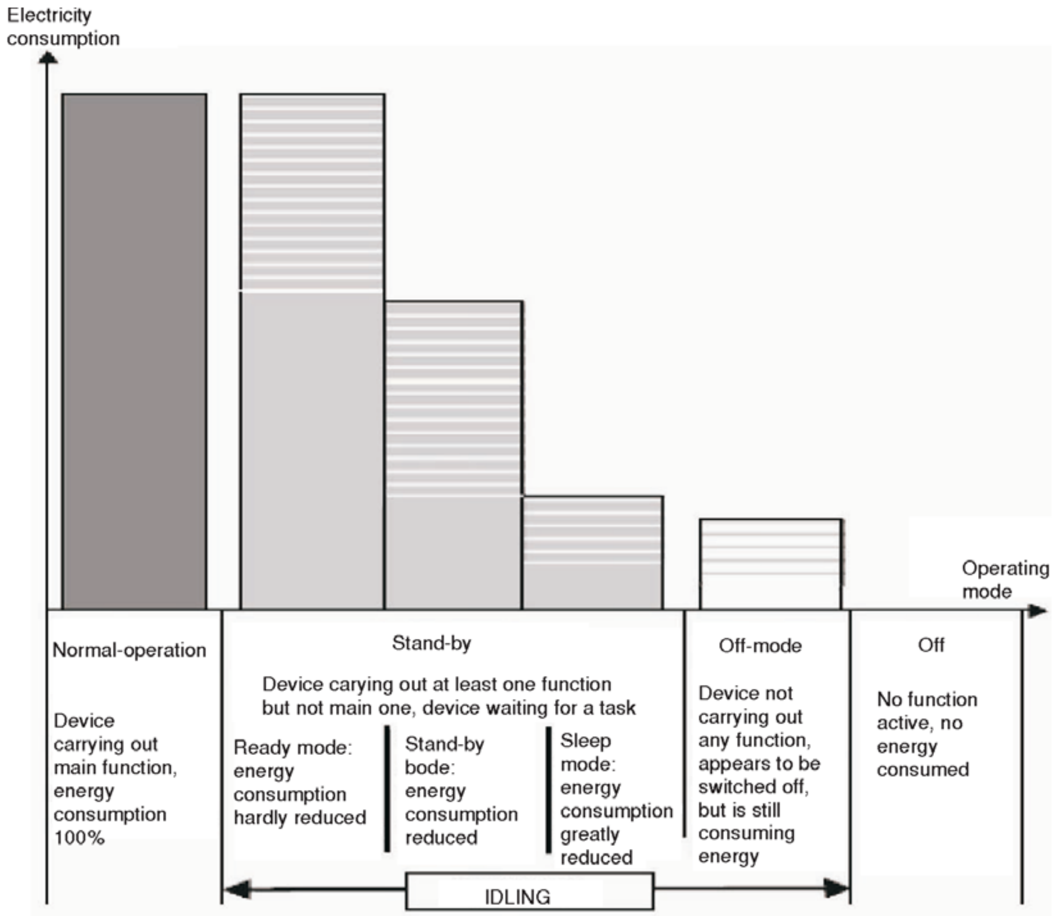

Figure 1. Different operating modes of electronic devices

electronic devices, augmented by the world's move towards smart networking (smart grids, smart homes, smart offices, *etc*.).

– *Off-mode* is when a product or appliance is connected to a power source but does not produce any sound or picture, transmit or receive information or is waiting to be switched "on" by the consumer. If the product has a remote control, it cannot be activated by the remote control from off-mode. While the product may be doing some internal functions in off-mode (*e. g.* memory functions, *etc*.) these are not obvious to the user.
– *Passive stand-by* mode is when a product or appliance is not performing its main function, but it is ready to be switched on (reactivation function, in most cases with a remote control), or is performing some secondary function (*e. g.* has a display or clock, sensor, *etc*.). This mode also applies to power supplies for battery operated equipment (portable appliances which are intended to be used when disconnected from the base station) when the appliance is not being charged.
– *Active stand-by* is mostly applicable to VCR and some stereo equipment where operating involves some mechanical drive (including appliances like DVD and CD players). Active stand-by is when the appliance is on but not performing its main function. For example, a

VCR may be on but not playing or recording. This mode also applies to power supplies for battery operated equipment (portable appliances) when the appliance is being charged (various sub-modes).
– *Delay start* mode is fast becoming common place in many major appliances. Essentially the appliance can be programmed to begin functioning at a later time, in some cases up to 24 hours later. Appliances left in this mode are in neither active nor passive stand-by and therefore it was decided to measure this mode as a separate category, even though this is a short duration mode. The frequency and duration of this mode and its effect on energy consumption will largely be determined by consumer behavior.

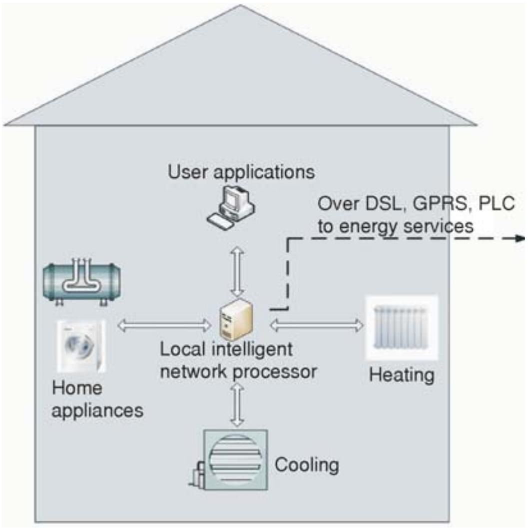

Figure 2. Local smart network

Local smart networks/smart homes

The term "Smart home" includes any residential or office building equipped with electronic devices that enable functioning of smart networks, fig. 2. Electrical appliances used in homes consume some energy when they are left on stand-by mode or even switched off. Different household appliances are considered as dishwashers (maximum power for dishwasher in "delay start" is about 9.4 W [5]), and washing machines. The typical electricity loss for an appliance can range from as little as 1 W to as high as 30 W, [6]. This loss and the associated costs are not high enough to attract the attention of consumers, but when such power losses of all home and office appliances are aggregated at the level of a country, the amount becomes significant and cannot be ignored. According to an estimate of the international energy agency (IEA), the total stand-by power demand of the residential sector in developed countries amounts to 15 GW, [7]. The types of appliances taken into consideration are mostly common in all countries and include audio and video equipment (television, VCR, CD/DVD players, video players/recorders, speakers and sound systems, *etc.*), telephony (cordless telephone, answering machine, as well as interphone, *etc.*), different kitchen appliances (microwave, kitchen oven, bread maker, *etc.*), set-tops

Table 1. Stand-by power of certain home appliances [W]

Appliances	Maximum	Minimum	Average
Television	22	1	7.3
VCR	30	1	9.9
Hertz TV decoders	16	9	11.0
Satellite dish decoders	17	5	8.7
Cable TV decoders	23	3	9.5
Hi-Fi stereo	24	1	7.2
Hi-Fi TV/video	34	4	14.4
Voltage stabiliser	18	14	15.7
Induction cook-top	18	4	13.2
Kitchen oven	18	6	14.5

(analog and digital cable box, television decoder, Internet terminal, satellite system, *etc.*), battery operated devices (cell phones, battery chargers, hand-held power tools and vacuum cleaners, shavers, *etc.*) and other miscellaneous appliances (security system, door openers, timers, motion sensors, *etc.*). All of these units require power supply when in stand-by mode, as presented in tab. 1, [7].

Information and communications technology (ICT) stresses the role of unified communications and the integration of telecommunications, computers as well as necessary enterprise software, middleware, storage, and audio-visual systems, which enable users to access, store, transmit, and manipulate information, [8]. The term ICT is now also used to refer to the convergence of audio-visual and telephone networks with computer networks through a single cabling or link system. There are large economic incentives to merge the audio-visual, building management and telephone network with the computer network system using a single unified system of cabling, signal distribution and management.

Office appliances

Main appliances from the office equipment category are laptops, desktops, monitors, speakers, printers (laser and inkjet) and multifunctional devices. The average metered power of laptops in the off-mode is 1.2 W with maximum of 3 W and minimum 0.4 W, [9]. The average power of the computer monitors LCD type in the off-mode is 0.58 W, with maximum 1.4 W and minimum 0.3 W, and when in passive stand-by (monitor in "sleep mode"), the average power is 0.72 W, with maximum 1.5 W and minimum 0.4 W, [9]. So, there is only very small difference between the power levels in the two modes. The average value of the in-use power of the LCD monitors is 30.1 W, ranging from 25 W to 34.2 W, [9].The average power of the metered computer speakers in active stand-by mode (when switched on, but not producing any sound), is 4.8 W with maximum 15.7 W and minimum 2.1 W. When switched off, 70% of the speakers still draw 2.7 W on average, with maximum 9.2 W and minimum 0 W, [9]. Inkjet printers in off-mode is about 0.7 W on average, with the extreme values of 0 W and 2.4 W, while in active stand-by, these appliances draw 2.7 W on average, with maximum 7.8 W and minimum 1.3 W. Laser printers in active stand-by mode draw the average power of 9.7 W, with a minimum power of 5 W, [9]. In tab. 2 are presented data on stand-by, suspend and off-modes, compared to consumption in active mode, [7].

Table 2. Power consumption of certain office appliances [W]

Equipment	Active	Stand-by	Suspend	Off-mode
PC without monitor	36	27	–	–
Monitor	66	15	–	–
Copier	0.86 Wh/page	206	162	18
Laser printer	0.88 Wh/page	64	21	–
Dot matrix/inkjet printer	26	13	–	–
Laser fax machine	1.10 Wh/page	17	–	–
Thermal/inkjet fax machine	24	14	–	–

Thermal losses in some electronic components

Transformer losses

A transformer is a power converter that transfers electrical energy from one circuit to another through inductively coupled conductors the transformer's coils, fig. 3. A varying current in the first or primary winding creates a varying magnetic flux in the transformer's core and thus a varying magnetic field through the secondary winding. This varying magnetic field induces a varying voltage, in the secondary winding. While new technologies have eliminated the need for transformers in some electronic circuits, transformers are still found in nearly all electronic devices designed for household ("mains") voltage.

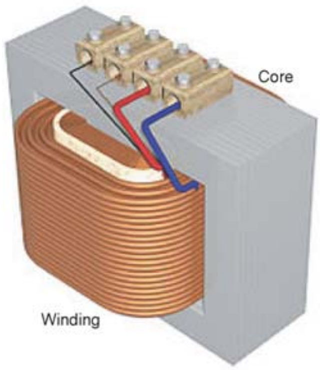

Figure 3. Transformer

An ideal transformer would have no energy losses. In practical transformers, energy is dissipated in the windings, core, and surrounding structures. Losses in transformers (excluding associated circuitry) vary with load current, and may be expressed as "no-load" or "full-load" loss. The no-load loss can be significant, so that even an idle transformer constitutes a drain on the electrical supply.

Transformer losses are divided into losses in the windings, termed copper loss (P_{Cu}), and those in the magnetic circuit, termed iron loss (P_{Fe}). These losses arise from winding resistance, hysteresis losses, eddy currents, magnetostriction, as well as from mechanical losses and stray losses. Winding resistance losses are caused by resistive heating of the conductors due to current flowing through the windings. Resistive losses in the windings represent the main component of the load dependent or the variable losses, designated as copper losses. They vary as square of the current I in the windings and directly with resistance R of winding. The resistance in turn varies with the resistivity ρ, the conductor dimensions; and the temperature. The resistive power losses P_r are calculated as:

$$P_{\mathrm{r}} = RI^2 = \frac{\rho l}{A} I^2 \text{ [W]} \tag{1}$$

where R [Ω] is the winding resistance, I [A] – the current , ρ [Ω mm^{2}m^{-1}] – the resistivity, l [m] – the length of conductor, and A [mm^2] – the area of cross-section of the conductor.

Hysteresis losses are present each time the magnetic field is reversed, when an amount of energy is lost due to hysteresis within the core. Typically, this accounts for 50% of the constant core losses, [10]. For a given core material, the loss is proportional to the frequency, and is a function of the peak flux density to which it is subjected. Hysteresis losses P_h are dependent on the maximum magnetic flux $B_{max.}$, the type of material Θ and frequency f:

$$P_{\mathrm{h}} = \Theta B_{\mathrm{max.}}^{1.6} \left(\frac{f}{100} \right) G_{\mathrm{Fe}} \text{ [W]} \tag{2}$$

where Θ is the hysteresis (Steimetz) constant of core material, f [Hz] – the frequency, $B_{max.}$ [T] – the maximum flux density, and G_{Fe} [kg] – the weight of core.

Eddy currents losses contribute to about 50% of the core losses, [10]. They are due to eddy currents that circulate within the core in a plane normal to the flux, and are responsible for resistive heating of the core material. The alternating flux induces an electromagnetic field in the bulk of the core proportional to flux density and frequency. The losses per unit mass of core material, thus vary with square of the flux density, frequency and thickness of the core laminations. The eddy current losses are calculated from the following expression:

$$P_{\mathrm{v}} = \sigma_{\mathrm{v}} \left(\frac{f}{100} \right)^2 B_{\mathrm{max.}}^2 G_{\mathrm{Fe}} \text{ [W]} \tag{3}$$

where σ_{v} – is the eddy current constant, parameter of losses dependent on thickness of core lamination, f [Hz] – the frequency, $B_{\mathrm{max.}}$[T] – the induction, and G_{Fe} [kg] – the weight of core.

Eddy losses decreases very slightly with increase in temperature, but this variation is very small and is neglected for all practical purposes.

Magnetic flux in a ferromagnetic material, such as the core, causes it to physically expand and contract slightly with each cycle of the magnetic field, an effect known as magnetostriction. This produces the buzzing sound commonly associated with transformers that can cause losses due to frictional heating. In addition to magnetostriction, the alternating magnetic field causes fluctuating forces between the primary and secondary windings. These incite vibrations within nearby metalwork, adding to the buzzing noise and consuming a small amount of power. Stray losses are due to the leakage inductance, that is by itself largely lossless, but any leakage flux that intercepts nearby conductive materials, such as the transformer's support structure, will give rise to eddy currents and be converted to heat. There are also radiative losses due to the oscillating magnetic field, but these are usually small.

Having in mind that almost each of the electronic devices includes transformers which are almost always left to supply DC when in stand-by mode, it is obvious that their losses contribute significantly to the overall stand-by losses. Due to large losses in both their operating mode and stand-by mode, the efficiency of the low voltage transformers in electronic devices much lower than the large power transformers. If their power supply to the device is P, the efficiency of the transformers may be calculated from:

$$\eta = \frac{100P}{P + P_{\mathrm{Fe}} + P_{\mathrm{Cu}}} \text{ [\%]} \tag{4}$$

where P [W] is the power in the secondary windings, $P_{\mathrm{Fe}} = P_{\mathrm{h}} + P_{\mathrm{v}}$ [W] – the iron losses, and $P_{\mathrm{Cu}} = P_{\mathrm{r}}$ [W] – the copper losses.

Typical values of efficiency of low voltage transformers are shown in tab. 3, [10].

Table 3. Energy losses from low voltage tansformers

Power [W]	Efficiency [%]	Losses [%]
3-10	60-70	30-40
10-25	70-80	20-30
25-50	80-85	15-20
50-100	85-90	10-15

Central processing unit losses

Central processing unit (CPU) power dissipation is the process in which the CPU consume and dissipate this energy both by the action of the switching devices contained in the CPU and by the energy lost in the form of heat due to due to the impedance of the electronic circuit. Some implementations of CPU use very little power, for example, the CPU in mobile phones often use just a few hundred milliwatts of electricity. In comparison, CPU in general purpose personal computers such as desktops and laptops dissipate significantly more power because of their higher complexity and speed. These microelectronic CPU may consume power in the order of a few watts to hundreds of watts. CPU for desktop computers typically use a significant portion of the power consumed by the computer. Other major uses include fast video cards, which contain graphic processing units and the power supply. In laptops, the liquid crystal displays (LCD) backlight also uses a significant portion of overall power. While energy saving features have been instituted in personal computers for when they are idle, the overall consumption of today's high-performance CPU is considerable. Figure 4, presents power consumption for Intel Pentium M processor as a function of frequency, as drawn form data in Intel white paper [11].

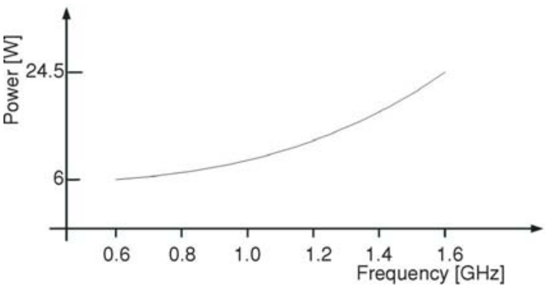

Figure 4. Power consumption *vs.* frequency of CPU

For a given device, operating at a higher frequency (clock rate) always requires more power. Reducing the clock rate of the microprocessor through power management when possible reduces energy consumption. New features generally require more switching circuits, each of which uses power. Processor manufacturers usually release two power consumption numbers for a CPU: typical thermal power, which is measured under normal load, and maximum thermal power, which is measured under a worst-case load. When the CPU is idle, it will draw far less than the typical thermal power.

The dynamic power consumed by a switching circuit is approximately proportional to the square of the voltage. The power consumed by a CPU is approximately proportional to CPU frequency, and to the square of the CPU voltage [11]:

$$P = CfV^2 \text{ [W]} \tag{5}$$

where C = (As/V) [F] is the capacitance, f [s^{-1}] – the frequency, and V [V] – the voltage.

The thermal design power refers to the maximum amount of power for the cooling system in a computer is required to dissipate heat without exceeding the maximum temperature for the computer chip. It can do this using an active cooling method such as a fan or any of the three passive cooling methods, convection, thermal radiation or conduction. Typically, a combination of methods is used.

In many applications, the CPU and other components are idle much of the time, so idle power contributes significantly to overall system power usage. When the CPU uses power management features to reduce energy use, other components, such as the motherboard and chipset take up a larger proportion of the computers energy. In applications where the computer is often heavily loaded, such as scientific computing, performance per watt (how much computing the CPU does per unit of energy) becomes more significant. To manage CPU power dissipation, processor makers favor multi-core chip designs, and software has to be written in a multi-treated or multi-process manner to take full advantage of the hardware.

Heat generated by electronic devices and circuitry must be dissipated to improve reliability and prevent premature failure. Techniques for heat dissipation can include heatsinks and fans for air cooling, and other forms of computer cooling such as liquid cooling. In cases of extreme low environmental temperatures, it may actually be necessary to heat the electronic components to achieve satisfactory operation. In the early 2000s, CPU were produced that emitted more and more heat than earlier, escalating requirements for quality cooling systems. Over-clocking has always meant greater cooling needs, and the inherently hotter chips meant more concerns for the enthusiast. Efficient heat sinks are vital to over-clocked computer systems because the higher a microprocessor's cooling rate, the faster the computer can operate without instability; generally, faster operation leads to higher performance.

Heat sinks are widely used in electronic devices, and have become almost essential to modern CPU. Microprocessors and power handling semiconductors are examples of electronics that need a heat sink to reduce their temperature through an increased thermal mass and heat dissipation (primarily conduction and convection and to a lesser extent by radiation) A heat sink has a metal structure with one or more flat surfaces to ensure good thermal contact with the components to be cooled, and an array of comb or fin like protrusions to increase the surface contact with the air, and thus the rate of heat dissipation. A heat sink is sometimes used in conjunction with a fan to increase the rate of airflow over the heat sink. This maintains a larger temperature gradient by replacing warmed air faster than convection would. This is known as a forced air system, fig. 5.

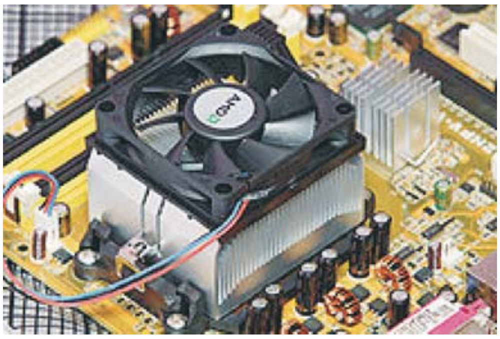

Figure 5. CPU heat sink with fan attached

Impact of stand-by losses on total energy consumption

Total energy consumption in stand-by mode

From the preceding sections of this report it is apparent that stand-by energy consumption in electronic devices cannot be neglected. With their ever groving number in households and offices, this consumption is expected to grow irrespective of the fact that their manufacturers begin to take particular care of energy savings in active and stand-by modes of operation From the measurement and estimates of stand-by energy losses in electronic devices used in residential and office buildings in developed (OECD) countries (which currently have the world largest share in both electricity consumption and stand-by losses) it becomes evident that stand-by power in residential sector alone represents around 1.5% of OECD electricity use. It was found that from an average of 19 appliances per home, about 83% of them have a stand-by power requirement, [9]. Stand-by power requirements in household appliances in particular countries was compared to the overall electricity consumption and presented in tab. 4, [7, 12, 13].

Table 4. Assesment of stand-by power in the residential sectorof some countries

Countries	Number of households [millions]	Average stand-by power [W per home]	Total stand-by power demand [MW]	Total stand-by energy [TWh per year]	Total electricity consumption [TWh per year]	Stand-by as % of total electricity consumption
Australia	7.09	87	617	5.4	171	3.2
Austria	3.38	44	149	1.3	53	2.5
Belgium	3.85	27	104	0.9	78	1.2
Canada	11.70	50	585	5.1	514	1.0
Czech Republic	3.48	20	70	0.6	58	1.1
Denmark	2.35	39	92	0.8	35	2.3
Finland	2.20	39	86	0.8	74	1.0
France	23.14	27	625	5.5	410	1.3
Germany	36.03	44	1585	13.9	527	2.6
Greece	3.65	20	73	0.6	42	1.5
Hungary	3.85	20	77	0.7	33	2.0
Ireland	0.87	32	28	0.2	18	1.4
Italy	22.69	27	613	5.4	273	2.0
Japan	41.37	46	1903	16.7	1001	1.7
Mexico	21.08	20	422	3.7	152	2.4
Netherlands	6.51	37	241	2.1	96	2.2
New Zealand	1.26	87	110	1	33	2.9
Norway	1.93	39	75	0.7	107	0.6
Poland	11.8	20	236	2.1	124	1.7
Portugal	3.66	20	73	0.6	34	1.9
Serbia	2.58	34	88	0.8	37	2.1
South Korea	13.99	20	280	2.5	236	1.0
Spain	14.94	20	299	2.6	167	1.6
Sweden	3.97	39	155	1.4	136	1.0
Switzerland	2.98	27	80	0.7	52	1.4
Turkey	15.09	20	302	2.6	87	3.0
UK	21.93	32	702	6.1	337	1.8
United States	101.04	50	5052	44.3	3503	1.3

There is a lack of data on power losses in the commercial sector. A study revealed that every 2 W of stand-by found in the German residential sector are accompanied with 1 W of stand-by losses in the commercial sector, [14]. When applying this ratio to the estimated residential stand-by consumption, it appears that stand-by power in both residential and commercial sector may account for 2.2% of the total electricity consumption. There is an indication that stand-by power is growing rapidly as more appliances are built with stand-by functions. So, the actual stand-by power consumption is already more important than what this estimation shows. Particular contribution to this rise will come from the smart networks that are becoming widely promoted. Needless to say that the share of total stand-by losses within the overall electricity consumption may be expected to rapidly increase as more and more new home appliances appear on the market alongside with the fast penetration of the smart networks.

Optimum energy consumption and penetration of smart networks

In the previous sections of this paper stand-by power was considered as an inevitable factor to realize the functionality of the smart grids. Having in mind a lot of benefits offered by the deployment of smart networks, it is expected that the current trends related to a rapid increase in corresponding stand-by losses will be a subject of particular concern. Although modern appliances are becoming more efficient with lower stand-by consumption, their number will be growing rapidly and the total power consumption will rise due to increased stand-by losses.

Smart grids have a key role to play in the EU Energy and Climate Package addressing the well known "20-20-20" targets, calling for at least 20% increase in energy efficiency. Using smart meters, that would be the main controller in energy saving processes, different manufacturers declare that 8,5% energy savings is possible, [14]. At the same time, important savings could be done by reducing stand-by power (stand-by power requirements could be cut by 70%). Nevertheless, it may be expected that, due to a continuous increase in number of electronic devices in connection with the deployment of smart networks, their penetration may reach an optimal level corresponding to the minimum of energy consumption achieved and that their further penetration above that level could cause a slight increase in the overall energy consumption, fig. 6.

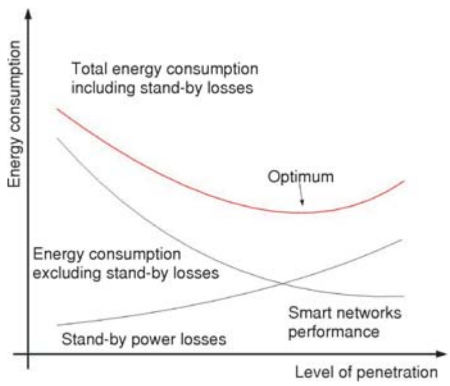

Figure 6. Energy consumption *vs.* level of penetration of smart networks

Smart networks contribute considerably to energy efficiency, operating by the aid of numerous electronic devices with their stand-by power losses. However, an optimum level of penetration of smart networks should be subject of a detailed evaluation, taking also into account other (besides energy) benefits associated with their use.

Conclusions

Smart networks are capable to reduce overall energy consumption, as well as to postpone respective investment otherwise needed for electricity generation. Yet, an ever increasing number of electronic devices involved in their operation, with their stand-by losses superimposed over the existing stand-by losses from other home and office appliances, may contribute to the total stand-by losses to increase considerably. This fact may call for a limit on their level of penetration to be imposed after a minimum in power consumption is achieved. However, the question to what extent their future penetration will be justified should remain open for further studies, because not only energy, but also some other important criteria should be taken into account, if found to be relevant for smart networks deployment.

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