IMPACT OF HOUSEHOLD ELECTRIC ENERGY USAGE TRENDS ON ELECTRICAL POWER SUPPLY NET POWER FACTOR

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Abstract
The article deals with the research results of the household electric energy usage trends impact on the electric power supply grid power factor. The amount of household appliances has increased tremendously during the last 20 to 30 years, substantially raising the electric energy consumption in private sector. As a serious technological development of household appliances took place, for example, LED lamps, inverters for power supply of TV sets and computers, the introduction of microcontrollers and automated systems, as well as efficiency requirements increase for the devices used in household have led to a reduced specific energy consumption per device and increased overall energy consumption. Analytic and experimental research assured that all these changes have a substantial impact on electric grid quality, particularly on the power factor value. Filed research data proved the theoretical analysis results that there is a trend from minor inductive power factor towards considerably high capacitive power factor, thus reducing power supply grid quality. This trend must be considered seriously by the electric grid operators in order to keep high quality of energy supplied to the end users.
Key words: power factor, electric appliances, household electricity use trends, inductive load, capacitive load.

Introduction

Overall energy consumption in household sector is increasing, and electricity accounts for a significant part of overall household energy consumption not only in Latvia but all over Europe (Raudjärv and Kuskova, 2013; Energy in the Residential Sector 2013 Report, 2013), having a fast growth in the EU 28 countries (Electricity Production, Consumption and Market Overview, 2014). Overall energy consumption in the EU 28 countries reached 1.104 Mt of oil equivalent in 2012, and household accounted for 26.2% (Fetie, 2014). Official sources prove that in Latvia in 2011 household accounted for slightly less than average in the EU countries - just 24.2% of all energy consumed (Latvian Energy in Figures, 2013).

At the same time Latvia showed one of the fastest growth rates in household energy consumption between 2002 and 2012 – average annual growth was 4.00% (Fig. 1.) (Mājokļos izmantotās elektroierīces un elektroierīču vidējais vecums, s.a.).

The main reason for consumption increase could be the increasing number of appliances owned by households – data from Latvia Central Statistics Bureau prove that sales of electronic equipment (e.g. TVs, desktop and laptop computers, mobile phones and kitchen appliances) are stable or increasing, and

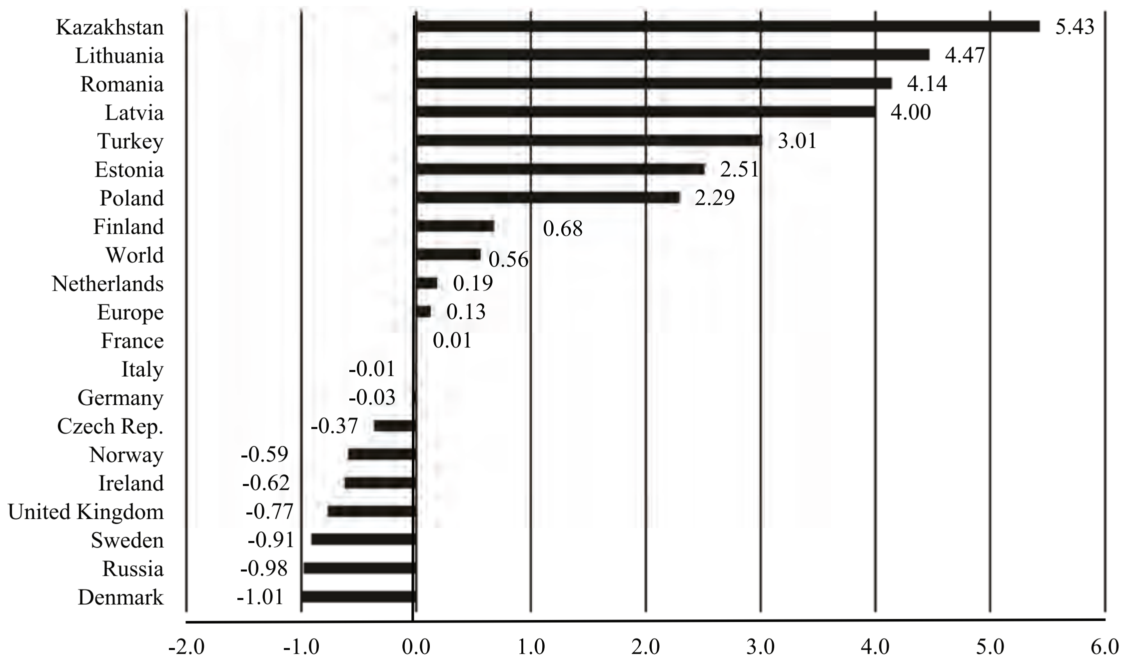

Figure 1. Electricity consumption change per electrified household 2000 - 2012 (% per year).

a large part of households have all basic electric appliances (Mājokļos izmantotās elektroierīces un elektroierīču vidējais vecums, s.a.).

In addition, the rapid technological progress and willingness to live better are the reasons why the appliances are being replaced more frequently than in the past, which also boost electric energy consumption. Increased appliances replacement speed can be caused by shorter newly designed appliances life time and built-in pre-defined product life cycle.

Statistic data show that in Latvia household electric energy consumption increase slowed down during the last three-four years, and showed a drop in consumption (Fig. 2), contrary to Estonia, where the consumption is still growing (Raudjärv and Kuskova, 2013), or the USA, where the overall electricity consumption in household stabilizes although the number of households increases (http://www.eia.gov/consumption/residential).

Although the number of appliances is increasing, due to technology changes energy consumption per appliance has decreased drastically. The sharpest drop took place with the LED technology development – this invention had direct impact on lighting and TV set design, reducing energy consumption on some occasions by more than 5 times (e.g., average electric energy consumption of regular color TV set was 250..300 Wh 30 years ago, but with LED and modern OLED screen technology it dropped below 50 Wh).

Electric energy providers supply energy to end users using electric grid, and current scientific inventions implemented as new devices and products is a challenge for them, because of increasing energy quality requirements and potentially decreasing sales volumes. Technology changes and increased number of household appliances together with changing household lifestyle and daily habits have changed trends in electricity consumption, and also have an impact on electric grid properties.

The power factor is among the main electric grid quality measures. It takes into account the characteristics of the load, and in cases when the load is not only resistance, but also has either inductive or capacitive components, the electric grid is loaded by unnecessary energy, decreasing possibility to deliver enough energy to consumers. The research devoted to the power factor improvement and trends, as well as the control over power factor was provided mainly for industrial grids, as industrial consumers historically were the main electric energy consumers. All Baltic states have established principles of penalties to those industrial consumers, who decrease electric grid power factor - Latvia (MK Noteikumi Nr. 50 Elektroenerģijas Tirdzniecības un Lietošanas Noteikumi, 2014), Lithuania (Цены На Электроэнергию И Тарифные Планы - Для Корпоративных Клиентов - LESTO, s.a.), and Estonia (Типовые Условия Elektrilevi OÜ Сетевого Договора Выше 63 А, s.a.; Прейскурант 0.4 (0.23) кВ - Imatra Elekter, s.a.) have introduced penalties to large industrial users (electric connection current larger than 200 A), who decrease the power factor.

Power suppliers were assuming that power factor in household segment is high (cosφ > 0.95), although due to the recent technological changes it is not true anymore. Observations of the latest research trends in electric grid power factor did not reveal any research results evaluating household electric

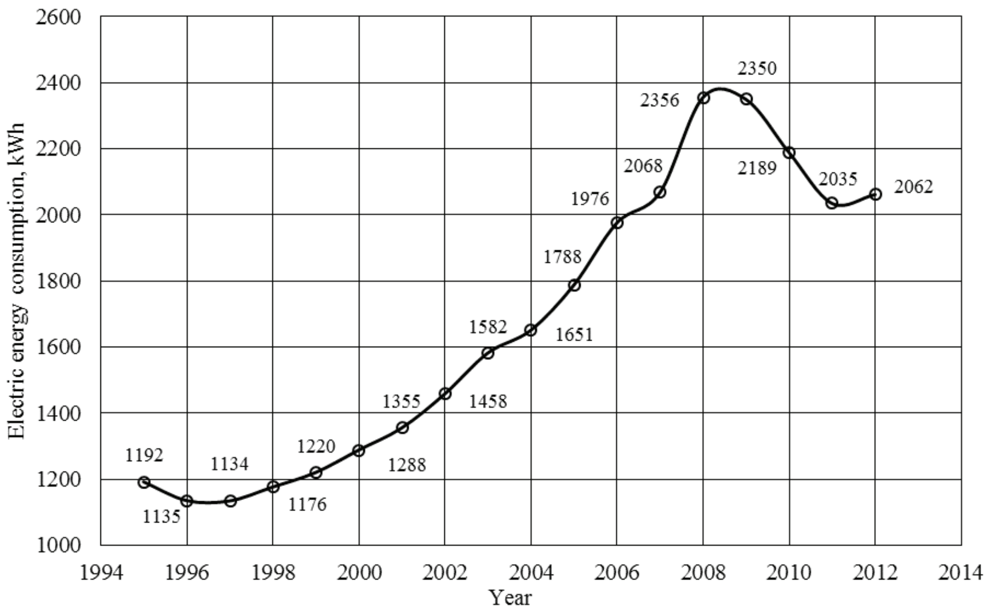

Figure 2. Average annual electric energy consumption in households, Latvia, kWh per household.

energy consumption patterns impact on power factor in the supply grid, although household stake in the electricity consumption is becoming substantial. The necessity to understand the interaction between the household energy consumption patterns, technological changes and electric energy supply grid power factor characteristics has resulted in this research.

Observations prove that households do not care about the power factor and other electricity grid quality issues – they simply consume energy, at the same time requesting more energy and higher quality (stability, availability, etc.). Usually they are not knowledgeable about the electric grid and home appliances interaction. When buying new electrical equipment, they do not care about the grid conditions and the characteristics of the new device load (resistive, inductive or capacitive).

The utility companies - the electricity suppliers, to the contrary, are very cautious about the new reactive energy suppliers into their grid. Their intent always is to establish systems with minimum reactive power.

Industrial electricity users know power factor requirements because of penalties introduced by the electric grid operators. Industrial consumers usually have inductive character of load, because of intensive use of electric motors as mechanical energy suppliers. In order to reduce inductive power factor (to reduce financial penalties), they use capacitive compensation devices – static and dynamic.

The latest trend in the electric grid development is an increased use of insulated cables instead of free air wires because of reduced possibility to break the supply line. Increase in cable lines substantially increase capacitance of electric grid, requesting the utility companies to use additional inductive loads, especially during the off-peak loads and time with low electricity consumption, in order to reduce reactive losses in the grid.

Theoretical research of household electric appliances use in Latvia was done in order to understand the trends in reactive energy changes in household electric energy supply grid. No research results made by other researchers were revealed – currently this is among the first results published in this area.

Materials and Methods

The main research method used in this research was theoretical data analysis about the trends in electric appliances development technologies and consumption trends of households in Latvia. The theoretical analysis results were compared with experimentally acquired long term measurements of the power factor in several household areas of Latvia.

Data about the intensity of electric appliances usage and their power characteristics were collected through on-site observations, technical data from electric appliances producers, and research results from other data sources (state statistics bureaus, etc.), for the time period from 1950 to 2013.

Experimental data collection was provided by using Automated Electric Energy Accounting system (AEEAS), which includes smart energy counters or specialized reactive energy measuring and accounting devices (e.g., PTD 3G, produced by 'Elgama elektronika' (Lithuania)).

The power factor calculation formula used for the analytic calculations is the following:

$$cos\varphi = \frac{P}{S} = \frac{P}{U \cdot I}, (1)$$

where

$cos\varphi$ – power factor;

P – active power, W;

S – apparent power, VA;

U – electric grid voltage, V;

I – current in electric grid, A.

Equation (1) can be used to find the instant power factor. As the households use different household appliances together and individually, power factor is changing all the time. So the best way to find critical values of power factor would be to find out precise daily load schedule of all household appliances, and then to observe which appliances with reactive power component are used in parallel, thus reducing the power factor.

This approach is very difficult to implement, because households usually do not think about electric grid loads, and very often even do not know what equipment is consuming electricity and when this happens. Researchers are trying to collect indirect data (Laicāne et al., 2013), to understand the trends in electricity consumption, but the results are just approximate.

In order to find the household power factor indirectly, and to calculate the critical power factor using the information about the household appliances used and available households in Latvia, the equation (2) was developed by modifying the basic power factor equation for more than one appliance with a different power factor and active power consumption:

$$cos\varphi = \frac{\sum(P_i)}{\sum \frac{P_i}{cos\varphi_i}}, (2)$$

where

$cos\varphi_i$ – power factor of the indexed household appliance;

i – household appliance index;

P_i – active power of the indexed household appliance, W.

Table 1

Power factor of some electrical equipment, used in the household development

Electrical equipment	Load type (R/L/C)*	Active power used P, kW	Power Factor
106 cm LED TV	R/C	0.04	0.80
Color TV set (vacuum tube)	R/L	0.30	0.70
Washing machine (Hazra, 2012)	R/L	1.5	0.57
Water pump	R/L	0.25	0.40
Notebook	R/C	0.05	0.58
Laptop	R/C	0.25	0.56
Wi-Fi rooter	R/C	0.005	0.45
Stationary radio (lamp)	R/L	0.20	0.7
Stationary radio	R/L	0.05	0.80
Refrigerator	R/L	0.1	0.80
Microwave owen	R/L	0.15	0.93
Kitchen ventilation	R/L	0.1	0.53
60 W incandescent bulb	R	0.06	1.00
15 W compact fluorescent bulb	R/L	0.015	0.58
3 W LED bulb	R/C	0.003	0.44
Mobile phone charger	R/C	0.01	0.62
Halogen heater	R	1	1.00
Water kettle	R	2.5	1.00

* R - Active power load, L – Reactive (Inductive) power load, C – Reactive (Capacitative) power load.

Data of active power and the power factor for all major home appliances were collected from their technical specifications for the time period from 1950 to 2013. A sample of the major appliances used in the equation (2) is presented in Table 1, which was developed using (Mājokļos izmantotās elektroierīces un elektroierīču vidējais vecums, s.a.).

Results and Discussion

The results of equation (2) and household appliances power factor and active power data application are presented in Fig. 3 by making power factor measurement simulation of that time electric appliances used.

As no comparable research results were found, the research results can be mentioned as unique in this field.

Trend line describing the simulated power factor changes in household shows stability and high values of power factor (cosφ>0.9) up to 1990ies, still showing a substantial part of inductive load growth (RL). Then (starting with 1990ies) the calculated power factor shows the trend of decrease, with a substantial drop in the last decade. This shows a serious impact of the technological trends in household appliances, and especially the recent capacitative (RC) load growth, which is the result of LED technologies and inverters development and introduction into household.

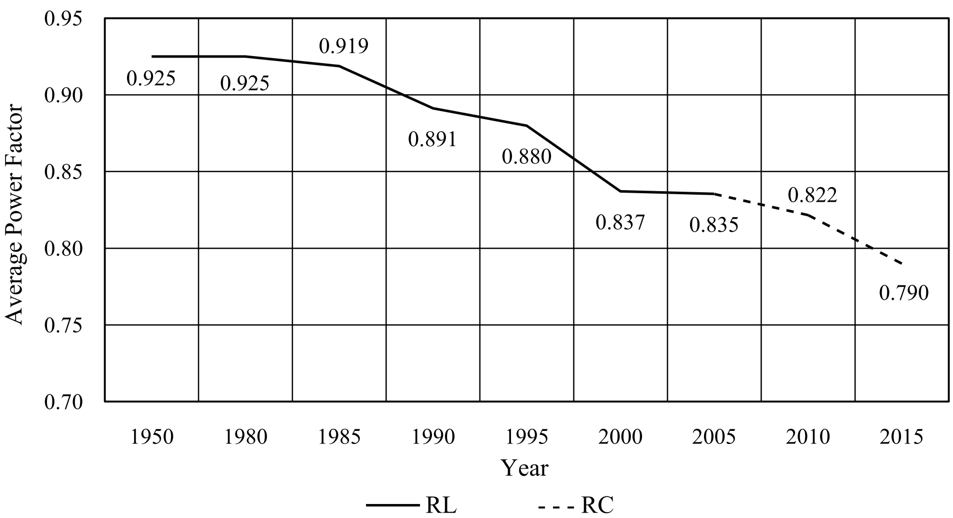

Figure 3. Critical power factor calculation results for household appliances used in Latvia.

As the electricity consumption in Latvia still has a place to grow, this recent trend towards RC reactive load should be taken into account by utility companies, who want to supply high quality electricity to suppliers, and who also want to reduce unnecessary investments in overpowered transformers and electric grid elements, which can only be used for reactive power transfer. Thus, the compensation mechanism of RC load must be developed, or at least considered as a factor to be taken into account in future.

Conclusions

The power factor of household electricity supply grid has changed substantially during the last decade from 2005 to 2015. It not only decreased by number, but also changed the main characteristic – substantial capacitative loads entered the market. Further research is needed to understand the impact of such changes on all electric grid components, including commutation and protection devices, as well as their control principles.

The power factor in households has changed by load type from active-inductive (RL) to active-capacitative (RC) and its value to 0.790 in 2015 (Fig. 3).

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