HOUSEHOLD ELECTRIC POWER SUPPLY GRID POWER FACTOR TRENDS

Arvids Jakusenoks, Aigars Laizans
Latvia University of Agriculture
arvids.jakusenoks@gmail.com, aigars.laizans@gmail.com

Abstract. The article presented is devoted to the research of seasonal trends in household electric grid power factor changes. The power factor (PF) is changing the value and character due to the household electric energy consumption patterns change and different daily/weakly/annual energy needs. Long-term electric energy consumption data collection from the group of individual private houses was organized, and the research revealed that the power factor there has visually recognizable repeated daily (day/night), weakly (working days/weekend) and annual weather based (all seasons - spring/summer/autumn/winter, in Latvia) changes. Data processing allowed developing the equation which with high probability (> 85 %) can predict the power factor changes in the observed household electricity supply grid. Electricity supply utility company to establish appropriate relay protection levels based on the electric load characteristics and to increase the connected loads to the transformer points, which are used to supply energy to particular regions, can use the revealed trend and equation.Development of the power factor compensation system with substantially higher operation quality will take placeusing the microcontrollers with the built-in seasonality equation.

Keywords: power supply grid, seasonality, power factor trend, household energy grid.

Introduction

Energy consumption in the household sector is increasing, and electricity accounts for a significant part of overall household energy consumption all over Europe. Electrical energy is a very important part of the household energy flow because of recent technological developments in home appliances. According to the state officials, householders in Latvia cover 24.1 % of all energy needs using electricity [1], which is a comparable value for households in Europe. At the same time, electric grid development lags behind, especially in the household electric energy supply side because of historically low demands and industrial consumers as the main payers, which requested attention.

In line with tremendous growth of instruments, appliances and technologies, which use electric energy, entering the household market, the electric grid quality is becoming more and more important. People try to change their electrical appliance usages [2] by increasing their comfort of living and appliance technologies, the electricity demand changes, therefore the power factor values in the household sector change. The electrical power demand changes all over the world. It changes by time, by seasons, by appliances used [3]. Utility companies want to increase the power consumption from the household side, but do not want to invest extra money in electricity supply line power increase. One of the solutions, which could require less investment, would be the power factor increase in the electricity supply grid, thus increasing the throughput of electric energy without changing supply wires and transformers.

Analytic research [4] proves that the household electric grid power factor has changed dramatically within the last 65 years. Mean value of power factor dropped to 0.79 on 2013 in Latvia[4], with additional change of the power factor character – from resistive/inductive to resistive/capacitive because of new technologies used in household appliances. Low values of power factor explain impossibility to serve increased electric power demand due to overload of the supply grid with reactive component. Relay protection devices used for electric grid protection also are not properly working if the power factor and its character are not taken into account.

With electric energy use increase in the household sector, resulting in increased electric grid load and power factor change, electric energy supply companies should take into account the electric power use intensity trends, especially daily and annual seasonality, and organize supply and protection system operations in accordance with them.

As no research results devoted to household electricity grid power factor seasonality trends were revealed in the available resources, it was decided to find out the trends in electric energy use and power factor change in household with further theoretical basis development for electric power supply and quality control devices.

Materials and methods

The object chosen for data collection is located the small village Saurieshi near Riga. It comprises the group of individual houses(more than 100 houses) connected to the substation with the transformer point which supplies them with 0.4kV electricity. Each house has its own electricity meter, but summary electricity for the whole house group is being accounted by the electricity meter located in the substation. Data read-out from this electricity meter is provided through the Internet using the Automated Electric Energy Accounting system (AEEAS)developed by the electric energy supplier SC "Latvenergo". The AEES consists of the modem connected to GSM wireless network and a special data reading coil connected to the electricity meter. Based on the tasks established in the control algorithm the AEES system can read the following data from the electricity meter – electric energy consumption – active and reactive, and the load profile (electric energy use intensity during 24-hours). Load profile can be used for the consumer energy use trends analysis, and also tocalculate monthly invoice for the consumers who use multi-tariff (based on two or three time/prices zones) and spot electricity price based electric energy supply agreements.

The electric energy consumption data collected through the AEES system included three sets of data – electric energy active component, reactive (inductive) component, and reactive (capacitive) component, collected by the electricity meter using the four quadrants system [5]. The power factor was calculated using the following equation:

$$\cos\varphi = \frac{W_{P+}}{\sqrt{W_{P+}^2 + \left(W_{Q+} - W_{Q-}\right)^2}} \qquad (1)$$

where $\cos\varphi$ – power factor;
W_{P+} – consumed active energy, Wh;
W_{Q+} – consumed reactive (inductive) energy, varh;
W_{Q-} – consumed reactive (capacitive) energy, varh.

The hourly consumed active energy data are presented in Fig. 1, and the calculated summary reactive energy data – in Fig. 2. The data set comprises measurements during 8784 hours.

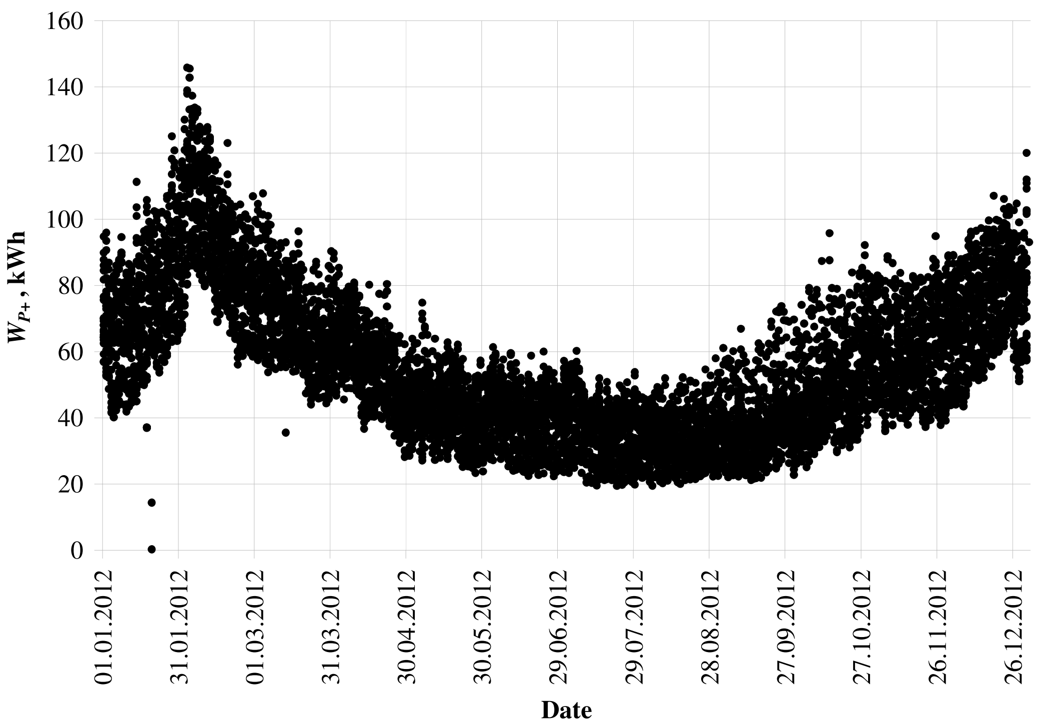

Fig. 1. **Research object consumed active energy data from AEEAS system for 2012**

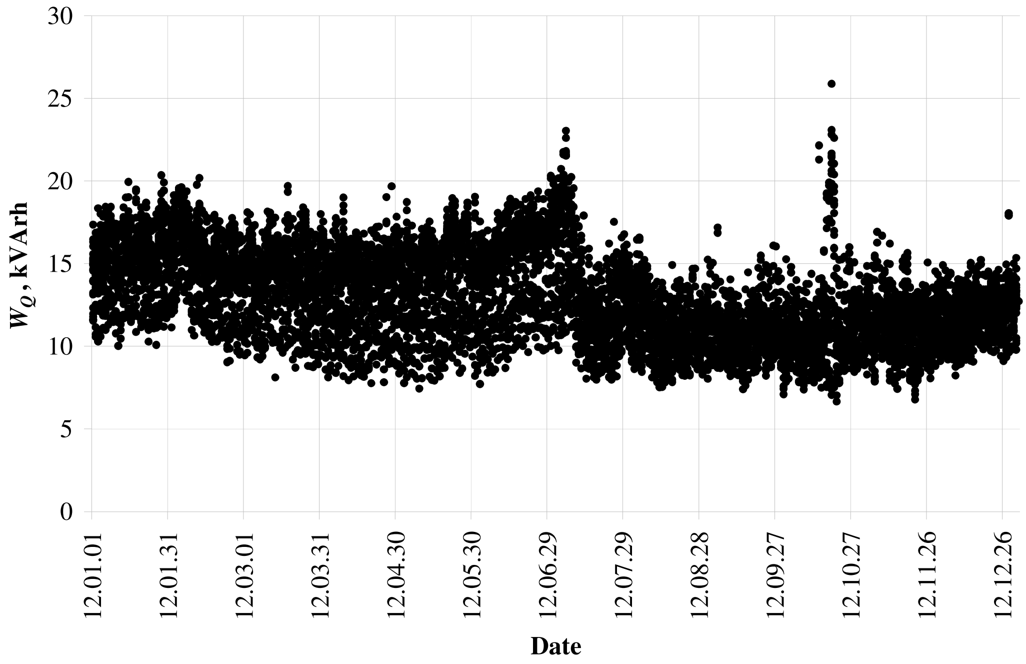

Fig. 2. **Research object consumed reactive energy data for 2012**

Results and discussion

The collected data were used in the equation (1), and the power factor was calculated for each time moment for all data points. The calculation results are presented in Fig.3, revealing yearly power factor trends.

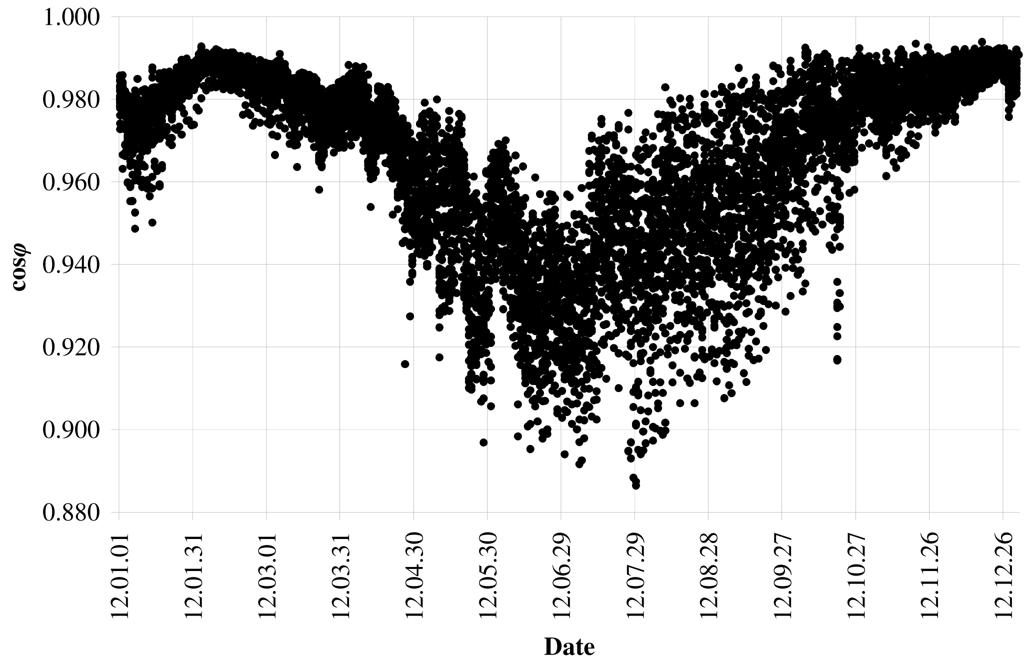

Fig. 3. **Power factor $\cos\varphi = f(t)$ calculated from collected data**

Visual analysis of the calculated power factor data presented in Fig.3 reveal potential sequential trends. Primarily hypothesis stated based on the trends revealed in Fig.3: possible individual consumer electric energy use patterns could be based on daily sequence – sleeping hours – wake-up hours – not-at-home hours, and after-work hours, weekly sequence – working days/Saturday and Sunday, and on weather seasonality – spring/summer and autumn/winter). Extensive research literature observation did not find any support for this hypothesis, so it was decided to do the power factor seasonality analysis.

Power factor calculation formula, which includes seasonality, consists of several components:

$$\cos\varphi = A + B(T_B) + C(T_C) + D(T_D) \quad (2)$$

where A – power factor annual mean value for particular consumer group;
$B(T_B)$ – power factor component taking into account yearly fluctuations, T_B = 8760 hours;
$C(T_C)$ – power factor component taking into account weekly fluctuations, T_C = 168 hours;
$D(T_D)$ – power factor component taking into account daily fluctuations, T_D = 24 hours.

Mean value of power factor states the level around which all seasonal fluctuations take place.

The seasonal fluctuations for each period can be calculated using the following equation (example for yearly fluctuations):

$$B(T_B) = K_1^B \cdot \cos\left(K_2^B \frac{2\pi \cdot t}{T_B} + K_3^B\right) \quad (3)$$

where $B(T_B)$ – observation period (yearly fluctuation in the given example) ;
K_1^B, K_2^B, K_3^B – coefficients calculated for the observation period;
t – time from the year beginning;
T_B – observation period length, in hours (T_B = 8760 hours for the given example).

The cosinusoidal function used in equation (3) allows to introduce regular fluctuations with particular frequency.

Expanded theoretical formula of power factor was developed using equation (2) and equation (3), and has the following shape:

$$\cos\varphi = A + K_1^B \cos\left(K_2^B \frac{2\pi t}{T_B} + K_3^B\right) + K_1^C \cos\left(K_2^C \frac{2\pi t}{T_C} + K_3^C\right) + K_1^D \cos\left(K_2^D \frac{2\pi t}{T_D} + K_3^D\right) \quad (4)$$

Non-linear regression equation coefficient calculation function in data processing software Minitab 16 was used to obtain numeric values of the coefficients for the power factor data presented in Fig. 3. The power factor formula for the given object (group of individual houses in Saurieshi) using the obtained coefficients is the following:

$$\begin{gathered}
\cos\varphi = 0.961 + 0.025 \cdot \cos\left(1.266 \frac{2\pi \cdot t}{8785} - 1.006\right) + \\
+ \left(0.000627 \cdot \cos\left(0.66 \cdot \frac{2\pi \cdot t}{168} - 57.35\right)\right) + \\
+ \left(0.00549 \cdot \cos\left(1.001 \cdot \frac{2\pi \cdot t}{24} - 0.027\right)\right) \\
\cos\varphi = 0.961 + 0.025 \cdot \cos\left(\frac{7{,}955t}{8785} - 1.006\right) + \\
+ \left(0.000627 \cdot \cos\left(\frac{4{,}147t}{168} - 57.35\right)\right) + \\
+ \left(0.00549 \cdot \cos\left(\frac{6.289t}{24} - 0.027\right)\right)
\end{gathered} \quad (5)$$

Equation (5) is the mathematic model of the observation object power factor, which includes all revealed annual, weekly and daily fluctuations. It can be used for power factor prediction during the year. Application of the obtained formula for the given data set is presented in Fig. 4. It can be seen that the trend line drawn using the mathematic model describes the trends in power factor fluctuations.

In order to evaluate the extent, at which the developed mathematic model can explain the real changes in the power factor value during the year, the correlation analysis of the power factor mathematic model data and field research data was provided using MS Excel data analysis tool pack. The correlation was high – the calculated coefficient of determination was $R^2 = 0.864$, meaning, that the developed mathematic model can explain more than 86 % variability of the power factor around its mean.

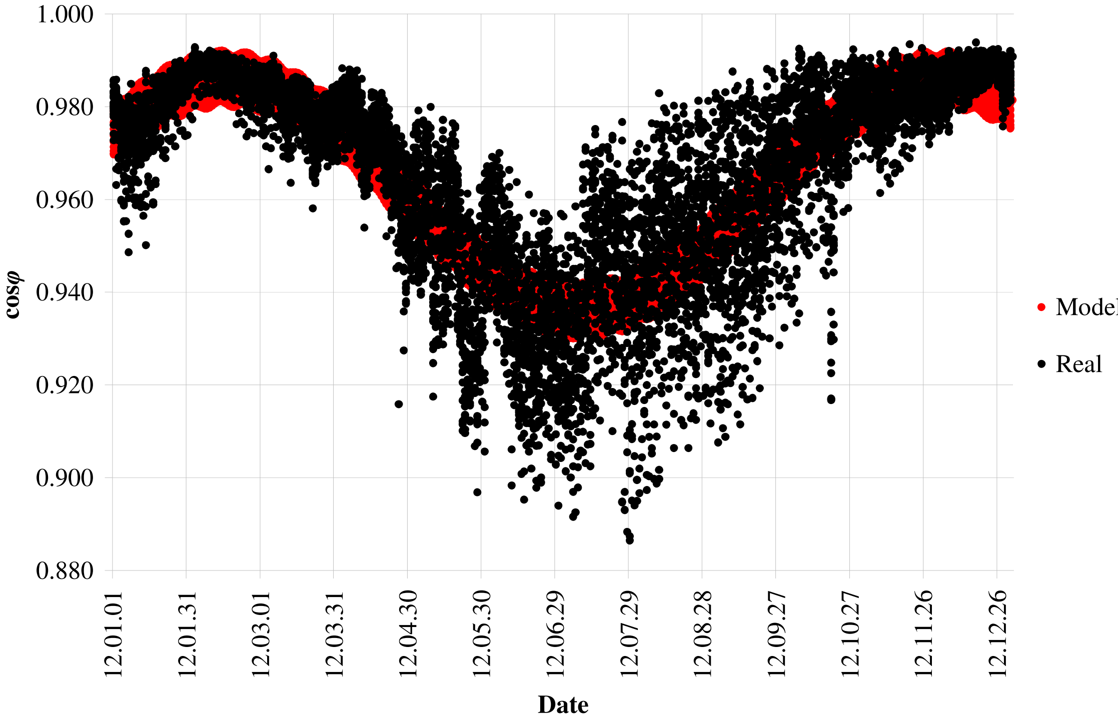

Fig. 4. **Mathematic model cosφ = $f(t)$ application on observed power factor data**

The developed formula can be used in the microcontroller operated power factor control device operation algorithm and substantially improve the power factor regulation quality, because it can predict the power factor change before it occurs.

Major limitation of the research result application is that the calculated coefficients for the formula are obtained from only one year data. Further data collection will allow much more accurate calculation of the coefficients, which will allow for even higher correlation between the mathematic model and real data.

Conclusions

1. The household electric grid power factor varies over the year because of different energy consumption patterns.
2. The energy consumption data analysis revealed strong daily, weekly and season based power factor fluctuation patterns.
3. The power factor calculation mathematic model was developed. Comparison of theoretic and field data revealed high correlation – the mathematic model can explain more than 86 % of the power factor annual variation.
4. Further research should be done in order to collect more data and to develop even a more accurate model, which then could be used for power factor compensation device algorithm development.

References

1. Ministry of Economics of the Republic of Latvia. Latvian energy in figures. Ministry of Economics of the Republic of Latvia, Rīga, 2013.
2. Cabeza L.F., Urge-Vorsatz D., McNeil M.A. Camila Barreneche, Susana Serrano. Investigating greenhouse challenge from growing trends of electricity consumption through home appliances in buildings.Renewable and Sustainable Energy Reviews 36, 2014. pp. 188-193.
3. Powells G., Bulkeley H., Bell S., Judson E. "Peak electricity demand and the flexibility of everyday life," Geoforum 55, 2014. pp. 43-52.
4. Jakušenoks A., Laizāns A. Impact of household electric energy usage trends on electrical power supply net power factor. Research for Rural Development 2015, 2015, p. 6.
5. "ELGAMA-ELEKTRONIKA" Ltd., "EPQS Multifunction Meter of Active, Reactive and Apparent Electric Energy," Vilnius, 2007, p. 36.