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An Analysis of Variability in Demand for Natural Gas at Rural Households

Małgorzata Trojanowska, Dorota Lipczyńska

Department of Power Engineering and Agricultural Processes Automation, Agricultural University of Cracow
Balicka Str. 116B, 30-149 Kraków, Poland, e-mail: malgorzata.trojanowska@ur.krakow.pl

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Summary. The variability in hourly demand for natural gas in rural households was analyzed at various time intervals. The results enabled the determination of typical daily courses of gas consumption by this group of consumers, separately for workdays and weekends, divided into two periods i.e. high and low gas demand. For the purpose of drawing typical curves of the loads of rural gas networks, the courses of gas consumption were classified with the use of variance analysis, cluster analysis, and based on the principal indicators describing the variability in gas consumption.
Key words: gas market, typical profiles of natural gas consumption.

INTRODUCTION

Despite great efforts being made to open up the natural gas market in Poland, it has not been fully liberalised yet. At the end of December 2012, the gas exchange was launched at the Polish Power Exchange, and a partial deregulation of gas prices for industry occurred in 2013, whilst on 1 August 2014, a new entity, PGNiG Retail LLC was spun-off from the existing structure of the Polish Oil and Gas Company Joint Stock Company (PGNiG SA). All the trade services in the area of natural gas sales to retail clients were spun off to this new company. At present there is no possibility to liberalise natural gas prices for retail consumers, but according to experts it will happen within the next couple of years.

For business entities involved in sales of natural gas, this near perspective of the liberalisation of gas market means the increasing importance of developed forecasts of demand for this fuel, particularly short-term forecasts [2, 6, 11, 14, 16, 17, 19, 20].

In the energy industry, the most demanding market in terms of the quality of forecasts is the electricity market. One of the ways to predict the demand in the electricity industry is to determine the demand for electricity on the basis of typical load profiles of customers [1, 7, 8, 15]. By analogy, this method can also be used to forecast the demand for natural gas [5].

The aim of the presented study was to analyse the variability of demand for natural gas in rural households at different time intervals for the purpose of determining the typical daily courses of gas consumption by this group of consumers. This study focused on the daily and weekly variability in gas consumption within the periods of high and low demand for this fuel.

MATERIALS AND METHODS

In this study, a statistical analysis of the consumption of natural gas by rural households, which are a specific customer group of natural gas distribution companies, was carried out. In order to obtain typical profiles of daily gas usage, the courses of gas consumption were categorised with the use of variance analysis, cluster analysis, particularly the agglomeration and k-means methods, as well as using principal indicators describing gas consumption.

Calculations were made on the basis of data of a gas company, pertaining to gas consumption by rural customers supplied via a low-pressure network from a selected grade I gas pressure reduction station located in the province of Lower Silesia.

In the study area, the density of the natural gas distribution network is 10.5 km per 100 km^2, and the consumption of gas per resident is ca. 42 m^3.

RESULTS

Individual consumers use natural gas for heating buildings, providing domestic hot water and cooking meals. The amount of consumption depends on a number of factors [3, 4, 12, 13, 15, 17, 18], among which air temperature is

particularly important. The correlation coefficient between the mean daily demand for gas in a given month and the mean temperature is -0.97. Examples of the changes of the two correlated values are presented in Fig. 1.

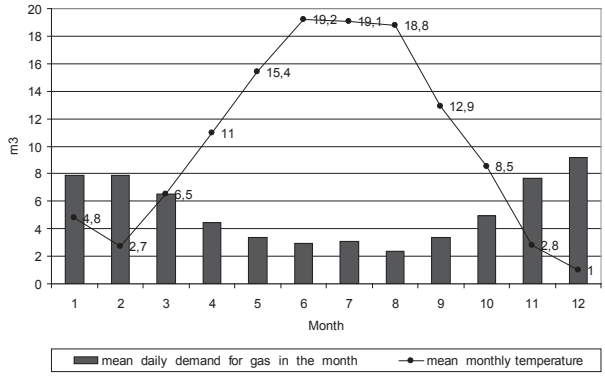

Fig. 1. The mean daily demand for natural gas in particular months of the year vis-à-vis mean monthly air temperature

The variance analysis completed in this study showed that the values of average daily gas consumption by rural households over a month-long period did not differ significantly from one another from November to March, and from April to October. These two periods are considered separately later in the paper and are referred to as periods of high and low consumption of natural gas, respectively.

When a large number of consumers are supplied at the same time, certain regularities can be seen in the timing of gas consumption. These changes are illustrated in Fig. 2 where the courses of demand for gas are presented in particular hours of July and December.

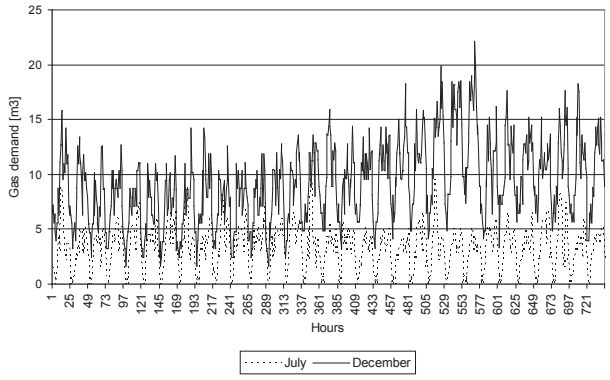

Fig. 2. The courses of demand for gas in particular hours of July and December

A similarity analysis of daily loads of gas networks was performed in order to identify the regularity in the courses of changes. For the purposes of the similarity analysis of gas consumption in particular days of the week, normalized vectors of daily courses, called normalized daily profiles, were determined and classified using the *Cluster analysis* module in the Statistica software package, in particular the agglomeration and k-means methods.

The normalized profiles of daily loads of gas networks containing information on the shape of the course were determined according to the following formula [9]:

$$g_i = \frac{G_i - G_{dsr}}{\sum_{j=1}^{24}\left(G_j - G_{dsr}\right)^2}, \qquad i = 1, 2, \ldots, 24 \qquad (1)$$

where:
Gi, Gj – load in ith (jth) hour,
Gdsr – mean load in 24 hours.

Both methods produced the same results for the period of high and low consumption alike, which permitted two characteristic days of the week i.e.: workday and weekend day, with respect to the daily variability of demand for gas (Fig. 3).

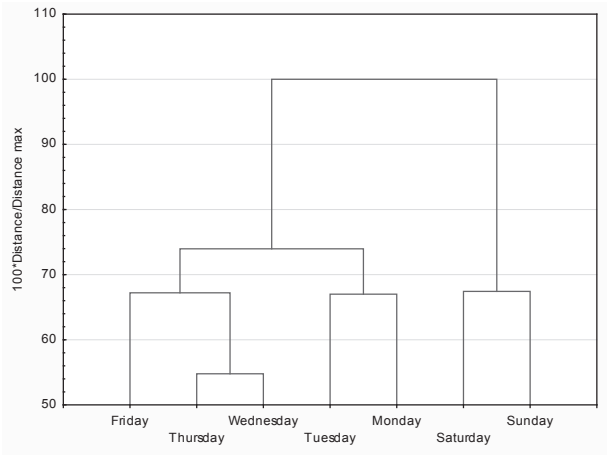

Fig. 3. Diagram of agglomeration of similarities of daily profiles of gas consumption on particular days of week

Sets of various indicators characterising the variability in loads are often used to classify the daily courses of demand [1, 10, 15]. Among the indicators most often used to describe the variability in demand for electricity are the medium and base level of load [1, 15]. These were defined for natural gas in the following way:

– medium level of gas load

$$m = \frac{G_{sr}}{G_{\max}}, \qquad (2)$$

– base level of gas load

$$m_o = \frac{G_{\min}}{G_{\max}}, \qquad (3)$$

where:
Gsr, Gmax, Gmin are medium, maximum, and minimum levels of gas consumption, respectively.

The values of these indicators for daily and weekly periods were compiled in Table 1.

Table 1 shows that the courses of demand for gas in the low-consumption-period are characterized by greater unevenness and lesser balanced than in the high-consumption period. The differences are so great that there was a need to develop standard daily load graphs separately for each of these periods.

Table 1. Indicators of daily and weekly load of gas network

Value	Period of low gas consumption				Period of high gas consumption			
	m_d	m_{do}	m_t	m_{to}	m_d	m_{do}	m_t	m_{to}
Mean	0.48	0.01	0.37	0.00	0.60	0.21	0.52	0.13
Minimum	0.31	0.00	0.28	0.00	0.41	0.07	0.43	0.05
Maximum	0.75	0.33	0.50	0.00	0.71	0.43	0.63	0.22

As a result of the analysis performed four typical reduced profiles of daily gas consumption by rural consumers i.e. for a workday and a weekend day during the low-consumption-period, and for a workday and a weekend day during the high-consumption-period, in the form of averaged courses, and corrected, at the same time. The reference value was the respective maximum hourly demand for gas in the low- or high-consumption-periods. The profiles are presented in Figs 4 and 5.

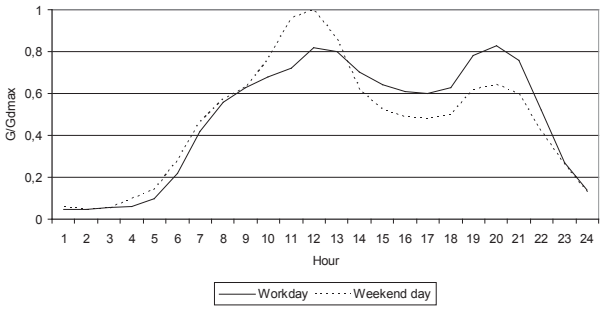

Fig. 4. Typical profiles of daily gas demand in low gas consumption period

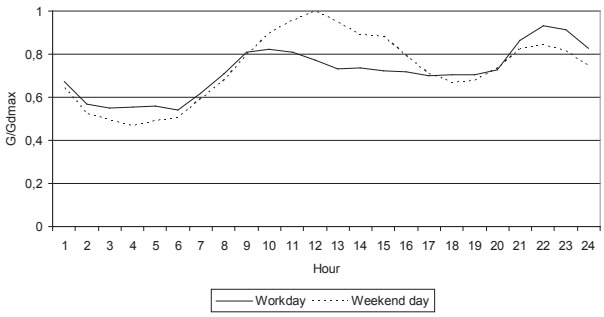

Fig. 5. Typical profiles of daily gas demand in high gas consumption period

The studies demonstrated that gas consumption by rural households on weekend days is slightly higher than on workdays (in the last two years – by ca. 1%), though it is much more uneven, with clearly marked peaks of consumption in the midday hours.

CONCLUSIONS

The demand for gas in rural households shows periodic daily, weekly, and monthly fluctuations.

Considering the shapes of gas usage curves, four standard profiles were distinguished representing the consumption, i.e. for a workday and a weekend day, respectively for periods of high and low demand for gas. These curves can be used both for the purpose of operating gas distribution networks and in short-term forecasts of gas demand by households in rural areas. At present, gas traders usually use the simplest, naive method to predict demand.

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ANALIZA ZMIENNOŚCI ZAPOTRZEBOWANIA WIEJSKICH GOSPODARSTW NA GAZ ZIEMNY

Streszczenie. Przeanalizowano zmienność godzinowego poboru gazu ziemnego przez wiejskie gospodarstwa domowe w różnych interwałach czasowych i na tej podstawie opracowano typowe dobowe przebiegi zużycia gazu przez tę grupę odbiorców, oddzielnie dla dni roboczych i weekendowych, w rozbiciu na dwa okresy tj. dużego i małego zapotrzebowania na gaz. Dla potrzeb opracowania typowych krzywych obciążenia wiejskich sieci gazowych, przebiegi poboru gazu klasyfikowano z wykorzystaniem analizy wariancji, analizy skupień, a także w oparciu o podstawowe wskaźniki opisujące zmienność zużycia gazu.
Słowa kluczowe: rynek gazu, typowe profile zużycia gazu ziemnego.