Comparative Analysis of The Variability of Daily Electric Power Loads

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Received December 02.2014; accepted December 17.2014

Summary. This publication analyses the variability of loads in rural medium and low voltage distribution networks compared to the variability of energy demand in the national power grid. Values of standard indicators used to characterise power demand, such as load factors and balancing factors, have been identified and compared. This analysis was carried out based on data recorded at 6 main supply stations and 37 15/0.4 kV transformer stations.
Key words: power grid, distribution networks, load variability.

INTRODUCTION

One of the important problems of power system engineering is to optimise the time curves of electrical loads, which practically boils down to balancing them and reducing peak power. This is why it is so important to correctly analyse power demand curves. In order to characterise their variability, various measures (functions and coefficients) are used, whose examples can be found in the literature of the subject [2, 3, 4, 7, 8, 9, 11, 12, 13, 14]. The majority of these measures come from classical methods of analysing power system loads [1, 6, 10]. These make it possible to characterise loads during 24 hours, a week, a month and a year, at various supply voltages, caused by individual consumers, groups of consumers or all consumers in total. The total of loads of all consumers constitutes the load on the national power grid ("national grid"). In practice, it is not only analyses of the curves themselves that are important, but also their comparisons.

This publication presents the results of a comparative analysis of the variability of loads in rural medium (MV) and low voltage (LV) distribution networks compared to the variability of energy demand in the national power grid. Since it is only the variability of load over 24 hours that is significant for power system management, this publication is limited to analysing the 24h variability of power demand, which has been described using standard indicators characterising electrical power loads.

MATERIALS AND METHODS

This analysis is based on the results of power measurements taken at the main supply stations on the medium voltage side and in MV/LV transformer-distribution stations on the low voltage side. In total, research work covered 6 main supply stations over at least 1 year and 37 MV/LV stations. Figures on national grid loads were taken from *Monthly reports on the operation of the National Power Grid and the Balancing Mechanism.*

RESULTS

For the purpose of this comparative analysis, reduced load graphs were drawn, with mainly relative indicators used to characterise load curves. The reference value was either peak load P_s and indicators thus calculated are referred to as load factors *m*, or the average load P_{sr}, with balancing factors *l* being calculated. Detailed definitions of load and balancing factors can be found, *inter alia*, in the collective publication [1971] and in Góra's publication [1975].

The 24h variability of loads is most frequently presented graphically, usually as a calendar graph. The comparison of individual power values to the peak power produces the reduced graph of loads. These were the graphs plotted for the analysed systems. Internal analyses confirmed other authors' observations that the 24h curve of power consumption is mainly driven by the rhythm and intensity of human activities and the season of the year (Fig. 1). Consequently, when presenting the variability of power demand, averaged profiles of loads contrasted with the annual peak power P_{sr} were presented separately for different seasons, split into business days and holidays (Fig. 2-3). Figures 2a and 3a present graphs of national grid loads in the form of averaged load curves for 9 years, thus significantly reducing the random factor. The remaining illustrations are 24h schedules of loads on systems supplying rural consumers. A characteristic feature of these curves is the smooth, low load during the morning peak starting around 6 a.m. regardless of the season and type of day, and a general lack of an afternoon trough. Changes in the shape of load curves are mainly caused by the changing length of the day, influencing the time at which the evening peak load materialises. In winter, the evening peak starts around 4 p.m., but in summer as late as at 7 p.m. and lasts almost till 11 p.m. The season also influences the level of power demand, which is much greater in winter than in summer.

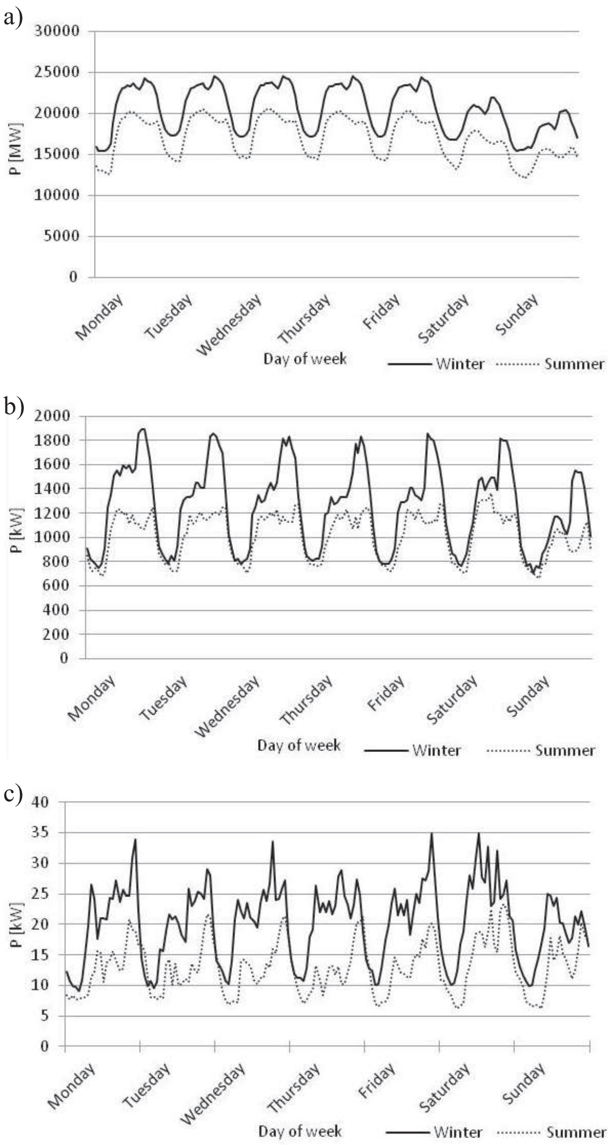

Fig. 1. Example curves of the power demand variability in selected periods of the year: a) national grid, b) MV, c) LV

To characterise loads over 24 hours, mean values of daily load and balancing factors were determined for the analysed systems. In particular, the following were calculated [1, 6, 12]:

– average load factor:

$$m = \frac{P_{sr}}{P_s} \quad , \tag{1}$$

– base load factor:

$$m_o = \frac{P_o}{P_s} \, , \tag{2}$$

– balancing factor of the base load:

$$l_o = \frac{P_o}{P_{sr}} \quad , \tag{3}$$

where: P_o, P_{sr}, P_s represent the base (lowest), mean and peak power, respectively.

Mean values of these indicators for business days and holidays, split by season, are presented in Table 1, while their values for a selected winter and summer week for exemplary transformer-distribution stations and the national grid are shown in Figure 4.

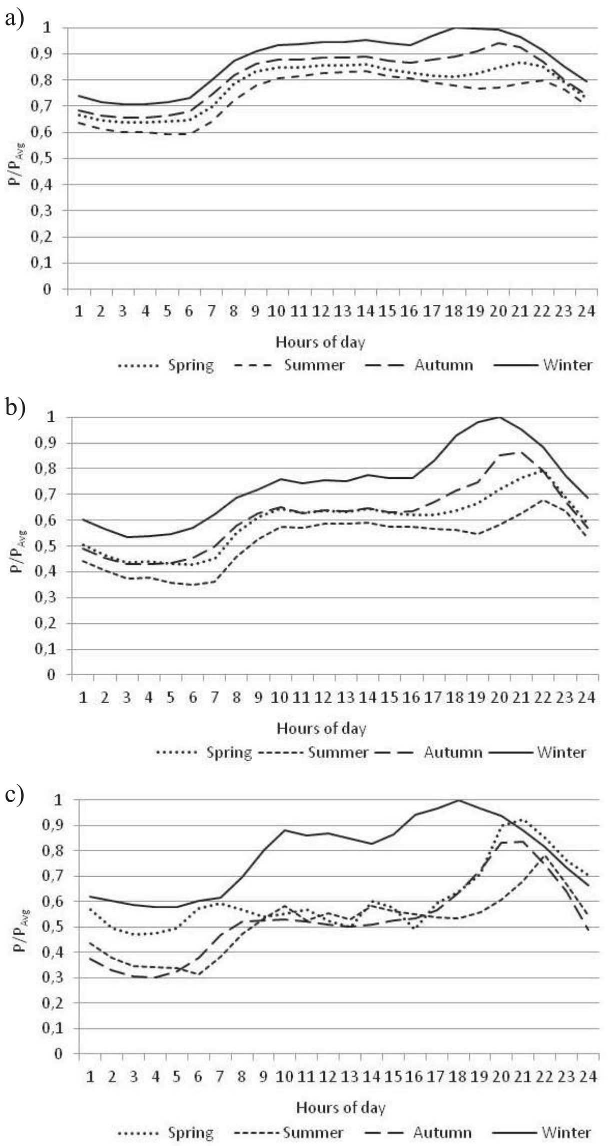

Fig. 2. Averaged load profiles during a business 24h period: a) national grid, b) MV, c) LV

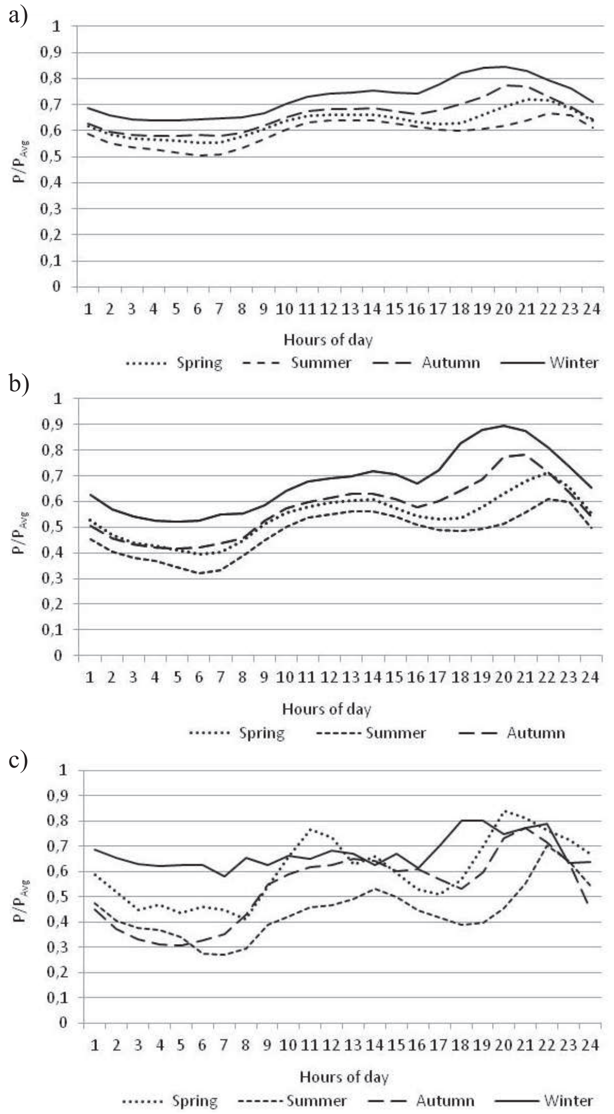

Fig. 3. Averaged load profiles for a 24h holiday period: a) national grid, b) MV, c) LV

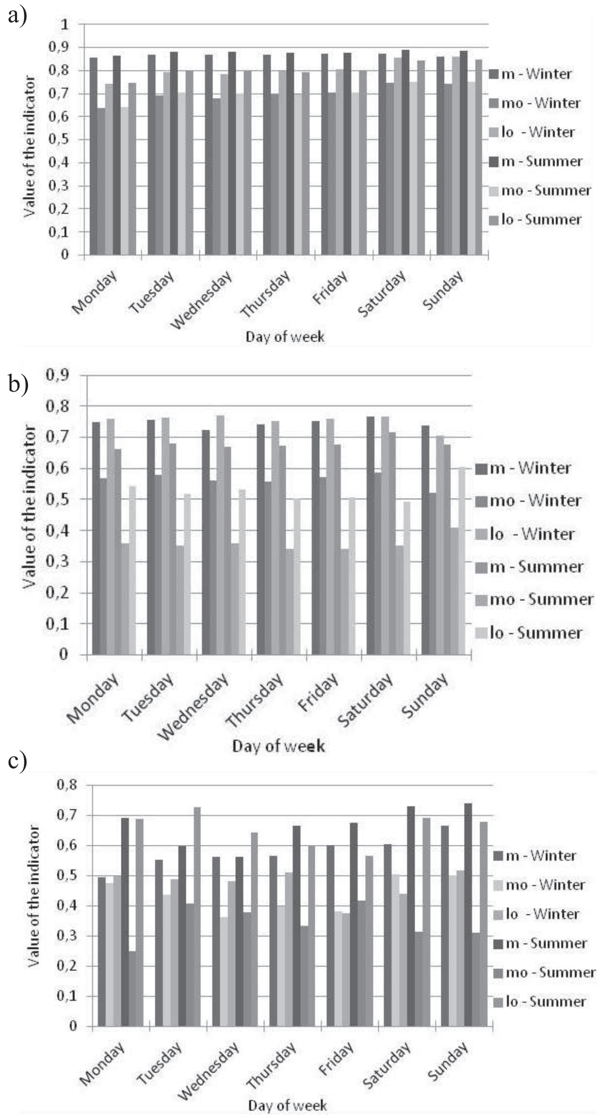

Fig. 4. Daily load and balancing factor values in a selected winter and summer week for the national power grid and for exemplary transformer-distribution stations: a) national grid, b) MV, c) LV

Table 1. Mean values of daily load and balancing factors

Period		National Grid			MV			LV		
		m	m_o	l_o	m	m_o	l_o	m	m_o	l_o
Business day	spring	0,88	0,70	0,80	0,70	0,46	0,65	0,50	0,19	0,34
	summer	0,87	0,69	0,78	0,69	0,40	0,58	0,65	0,37	0,55
	autumn	0,85	0,66	0,77	0,68	0,46	0,67	0,57	0,29	0,48
	winter	0,86	0,68	0,78	0,75	0,54	0,72	0,63	0,35	0,54
Holiday	spring	0,86	0,74	0,86	0,72	0,49	0,67	0,54	0,20	0,32
	summer	0,89	0,74	0,83	0,71	0,43	0,60	0,66	0,39	0,58
	autumn	0,84	0,72	0,85	0,68	0,46	0,68	0,62	0,31	0,48
	winter	0,86	0,73	0,85	0,75	0,56	0,74	0,67	0,43	0,62
average		0,87	0,72	0,82	0,73	0,49	0,68	0,60	0,31	0,48
coefficient of variation [%]		2,3	6,7	5,6	7,1	13,7	9,4	20,3	55,6	42,7

The lowest values of the analysed indicators, and their greatest variabilities, characterise the curves of power demand recorded on the low voltage of a MV/LV transformer station and confirm a significant inequality of power demand. The m_o indicator is best suited for assessing the load inequality. Its lowest values for 24h loads caused by consumers supplied at low voltage are observed in the spring, on Mondays, Saturdays and Sundays. Load inequality assessed by the value of m_o on medium voltage is, on average, one third lower than on the low voltage, and approx. one third greater than in the national grid.

The indicator most frequently used for analysing the variability of loads in Poland and abroad is the average load factor *m* [5]. It is also used to classify consumer load schedules and predict the electrical capacity and energy demand. Figures 5 and 6 show the values of this indicator for individual days of the week and individual months of the year.

As graphs for the entire power grid and medium voltage grids show, neither the season of the year nor the type of day influences the average values of the *m* indicator. The impact of the season is observable only for the low voltage grid, in which the mean value of *m* changed in the studied period from 0.46 in November to 0.68 in July.

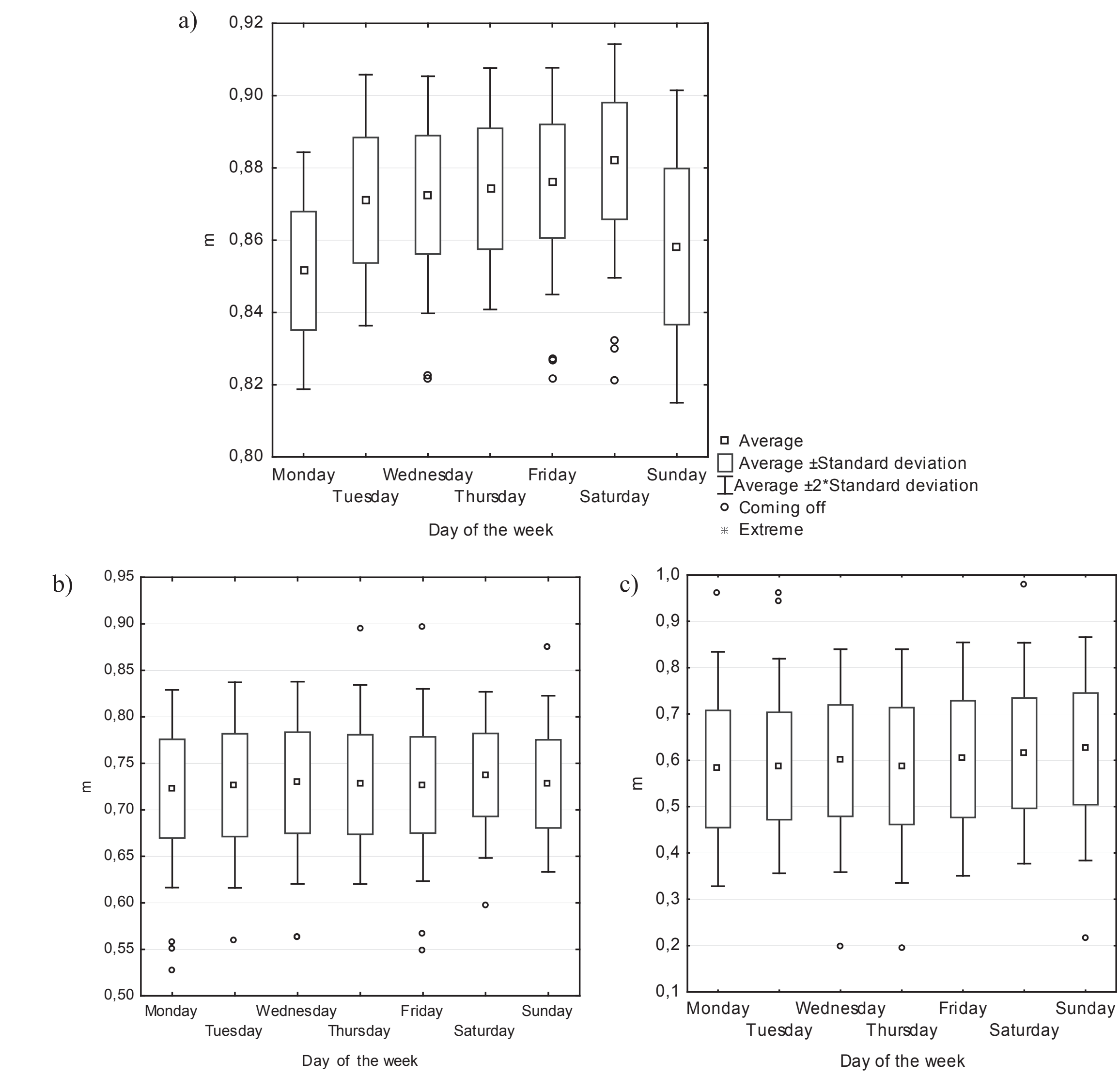

Fig. 5. Weekly variability of the *m* indicator: a) national grid, b) MV, c) LV

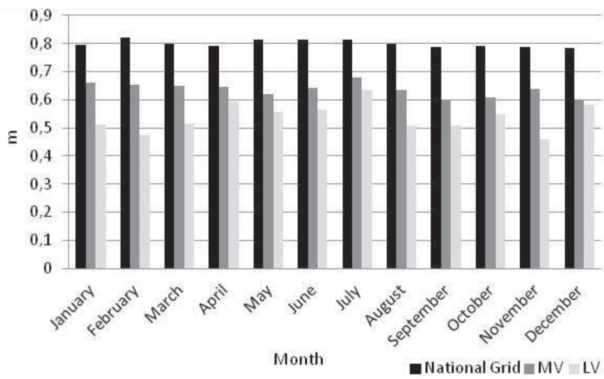

Fig. 6. Monthly variability of the *m* indicator

The greatest inequality is noted in loads of consumers recorded on low voltage. Their variability is significant regardless of the type of day and the season. The variability of rural consumer loads recorded at main supply stations is 30% lower on average.

Characterising the variability of electrical power loads using indicators such as load and balancing factors makes the comparative analysis easier and can be used by distribution companies when defining typical load schedules of consumers and modelling the demand for electrical power and energy.

CONCLUSIONS

Daily schedules of rural consumer loads recorded on the low and medium voltage are characterised by a low load during the morning peak, which is good for the national grid, but the evening peak load in rural areas coincides with the peak load on the entire power grid.

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ANALIZA PORÓWNAWCZA ZMIENNOŚCI

DOBOWYCH OBCIĄŻEŃ ELEKTROENERGETYCZNYCH

Streszczenie. Przedstawiono analizę zmienności obciążeń w wiejskich sieciach dystrybucyjnych średniego i niskiego napięcia na tle zmienności zapotrzebowania na energię w krajowym systemie elektroenergetycznym. Wyznaczono i porównano wartości standardowych wskaźników wykorzystywanych do charakteryzowania zapotrzebowania na moc, takich jak stopnie obciążenia i stopnie wyrównania. Analiza została przeprowadzona w oparciu o dane zarejestrowane w 6 głównych punktach zasilających i w 37 stacjach transformatorowych 15/0,4 kV.

Słowa kluczowe: system elektroenergetyczny, sieci dystrybucyjne, zmienność obciążeń