The Analysis of Typical Seasonal Load Duration Curves of Low Voltage Consumers

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Abstract – **The paper presents typical load duration curves of months belonging to winter and summer season. Typical load duration curves of different load classes at low voltage are mutually compared. The influence of different number of working days, Saturdays and Sundays on monthly load duration curves is discussed and corresponding load factors and loss factors for winter and summer months are statistically analysed.**

Keywords – **Load Duration Curve, Low Voltage Consumer, Load factor, Loss factor.**

I. INTRODUCTION

Load data are necessary for exploitation and planning of electric power system. Thus, load curves are very important for power plant operation, electric power system control, the analysis of operation conditions in the future, calculation of electric power and energy losses in distribution networks etc.

Many factors such are: load composition, influence of seasons, life habits, economic standard of living, usage of central heating, tariffs and other factors, influence on load curves. Therefore, load curve determining is pretty difficult job and the subject of many research papers. For example, one of the very first researches regarding load curves in electric power system of this region is published in [1]. The results of one comprehensive study that regard determining of loss factor in distribution network of PD "Jugoistok" Nis are presented in [2]. The necessary data for this study are obtained from load curves recorded during ten years at the buses where utility buys electric energy.

However, small number of papers deals with analysis of load curves on low voltage level. The reasons are the larger influence of stochastic load variation on the shape of load curves and the lack of measurements at large number of low voltage consumers. One of the papers presents the load curves obtained on the basis of questionnaires completed by low voltage consumers [3]. More recent research [4] presents typical curves of real and reactive power in four seasons. These are obtained by measurements at low voltage in town Novi Sad during three years. These curves are used for reactive power and energy compensation in distribution network. Typical daily load curves in low voltage distribution network in the area of town Nis are presented in [5]. These curves are the result of procession of data collected by the system for remote energy meter reading in time period longer than two years. Since data regarding nearly 7000 consumers are processed, statistically reliable daily load curves of seven load classes are obtained and implemented in the software for energy loss calculation in low voltage distribution network. In [6] the results of another comprehensive research of load curves on the basis of measurements during two years at low voltage consumers that belong to residential, commercial and industrial load class are presented.

As mentioned before, the shape of load curves depends of lot of factors that can be climate, social and economic. This factors are so important that the load curves of the same load class and the same season can be significantly different in different countries, as can be noticed by comparison of load curves presented in [5] and [6]. Also, load curves in two regions of one country can be pretty different that is the case of load curves published in [4] and [5].

This paper presents typical seasonal load duration curves of different load classes in the area of town Nis on the basis of typical winter and summer daily load curves for working day, Saturday and Sunday taken from [5]. Seasonal load duration curves are actually load duration curves of winter and summer month. These load duration curves are devoted on those that relate to load classes of households and other load classes, analysed and mutually compared. Afterwards, the influence of number of days in winter and summer month and the number of working days, Saturdays and Sundays in the month on monthly load duration curves is investigated. This influence has not been treated by now, but in the paper it is quantified as well as the influence on corresponding load factor and loss factor values. The values of load factor and loss factor of individual load classes are statistically analysed.

II. LOAD FACTOR AND LOSS FACTOR CALCULATION

Variable losses of energy in the line can be calculated [2, 7] as

$$\Delta W = R\frac{P_m^2}{U_n^2\cos^2\varphi}T\vartheta, \qquad (1)$$

where: R - line resistance, P_m - maximum (peak) power known in most cases, U_n - nominal voltage, $\cos\varphi$ - power factor of the load that regard to be constant since varies in narrow ranges, T - time period in which the losses of energy are calculated (mainly year or month) and ϑ - loss factor. Loss factor depend on the shape of load curve and it is calculated on the basis of normalized load duration curve

$$\vartheta = \int_0^1 \left(y(x)\right)^2 \cdot dx\,. \qquad (2)$$

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In this equation x and $y(x)$ denote normalized time and normalized load power, respectively. Also, loss factor can be calculated from load factor using one the formulae from the literature [7]. The selection of the formula depends on the load curve of considered load. Load factor is calculated on the basis of normalized load duration curve using formula

$$m = \int_0^1 y(x) \cdot dx \,. \tag{3}$$

In concrete cases when discrete measurements of real power are performed and the values are memorized, formulae (2) and (3) are in the form

$$\vartheta = \frac{1}{N} \sum_{i=1}^{N} p_i^2 \,, \tag{4}$$

$$m = \frac{1}{N} \sum_{i=1}^{N} p_i \,, \tag{5}$$

where N and p_i denote number of measurements and normalized real power value from i^{th} measurement, respectively. If load and loss factors are calculated for the month which has 30 days and the measurements are performed every 15 minutes, N is calculated as $N = 4 \times 24 \times 30 = 2\,880$.

III. Seasonal Load Duration Curves

Typical seasonal load duration curves are formed on the basis of averaged (typical) daily load curves for winter and summer season and working day, Saturday and Sunday that are presented in [5]. Table I summarizes maximum power of different load classes obtained from these typical daily load curves in winter and summers season. For all investigated load classes at low voltage, the maximum power in winter is larger than corresponding power in summer season. The ratio of maximum power in winter and maximum power in summer season belongs to the range from 0.473 for load class 2 - households in buildings without central heating to 0.884 for class 3 - households in buildings with central heating.

Typical seasonal load duration curves presented in this section are actually monthly load duration curves for winter and summer season. It is taken that the month in both seasons has 30 days and starts with Monday, Tuesday, Wednesday or Thursday, i.e. each has 22 working days, four Saturdays and four Sundays. Normalization of the curves is performed by maximum load of the load class in considered season given in Table I.

The curves from Fig. 1 regard to winter month for three load classes of households. These are clearly different. The curve corresponding to class 1 - individually built households without central heating, is the one with highest normalized power values along whole length. This curve has the values larger than 0.8p.u. even 21.6% of time during typical winter month.

TABLE I
MAXIMUM POWER OF DIFFERENT LOAD CLASSES

Load Class	Season	P_{max} [kW]
Class 1 - individually built households without central heating	Winter	1.477
	Summer	0.973
Class 2 - households in buildings without central heating	Winter	1.723
	Summer	0.814
Class 3 - households in buildings with central heating	Winter	1.054
	Summer	0.932
Class 4 - commercial load excluding craft stores and shops	Winter	2.049
	Summer	1.469
Class 5 - common equipment and installations in residential buildings	Winter	0.832
	Summer	0.429
Class 6 - craft stores	Winter	1.970
	Summer	1.289
Class 7 - shops	Winter	1.721
	Summer	1.432

The smallest power values for load class 1 in winter season is 0.5568 indicating that the ratio maximum to minimum power is pretty small for this load class. It is 1.796, while other load classes of households have larger ratios, close to 3 since their minimum power values are around 0.34. The curve corresponding to class 2 - households in buildings without central heating has larger slope in the first part of the curve and after 0.2p.u. of time reaches 0.59p.u. power value.

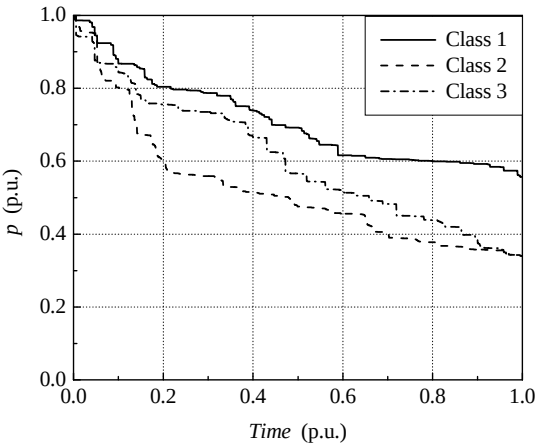

Fig. 1. Typical load duration curves of winter month for three load classes of households

Characteristic of all typical load curves of winter month, for load classes 4-7 which are not households (Fig. 2), is that duration of high power values, greater than 0.8, is longer than the duration in the case of load classes of households. It belongs to the range from 0.3p.u. for class 6 - craft stores, to 0.517p.u. for class 4 - commercial load excluding craft stores and shops.

Typical load duration curve for class 4 in winter season has almost constant slope and its smallest value is 0.6232. Load curve of class 6 also has approximately constant slope, but it is lower and its smallest power value is 0.256. The curve of class 5 (common equipment and installations in residential buildings) has even smaller minimum power value, 0.241. Thus, maximum to minimum power ratio of four investigated

load classes that are not households, belongs to the range from 1.605 for class 4 to 4.149 for class 5.

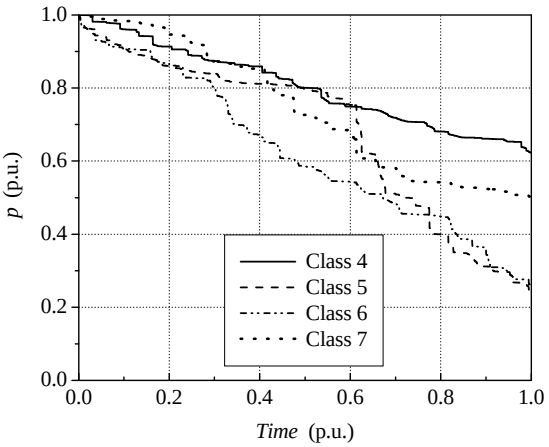

Fig. 2. Typical load duration curves of winter month for load classes other than households

Fig. 3 presents typical load duration curves of summer month for load classes of households. The curve of class 1 can be roughly separated into three parts: almost linear drop with the increase of normalized time up to 0.386p.u., region of approximately constant power from 0.386p.u. to 0.478p.u. of normalized time and after that drop up to 0.4354p.u. power value. The curves of class 2 and 3 decrease continuously with time, have similar shape and finish at 0.2601p.u. and 0.3545p.u. power value, respectively. Maximum to minimum power ratios vary in relatively narrow range in comparison with ratios obtained in winter season. They change from 2.297 for class 1 (individually built households without central heating) to 3.845 for class 2 (households in buildings without central heating).

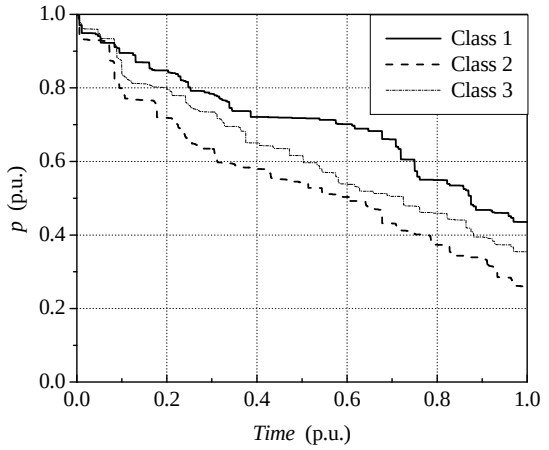

Fig. 3. Typical load duration curves of summer month for three load classes of households

Narrower range of maximum to minimum power ratios in summer in comparison with corresponding range in winter season is also obtained for load classes other than households. The smallest ratio is 1.816 in the case of class 4 (commercial load excluding craft stores and shops) and the largest is 2.867 for class 5 (common equipment and installations in residential buildings). For load classes 4-7 the time periods when the power values are larger than 0.8p.u., are quite long, similarly to those found in winter season. In summer season these periods belong to the range from 0.191p.u. for class 5 to 0.478p.u. for class 4.

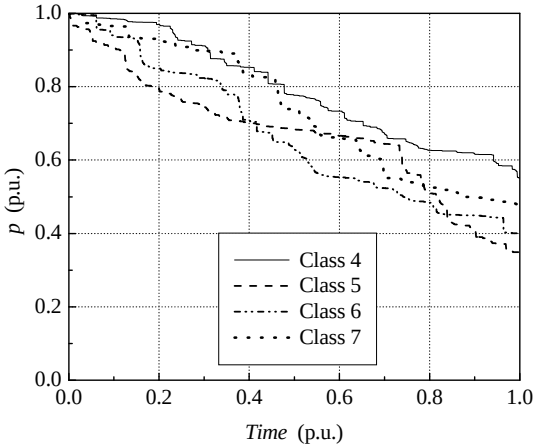

Fig. 4. Typical load duration curves of summer month for load classes other than households

IV. The Effect of Number of Days

Since seasonal load duration curves are obtained by using typical daily load curves of working day, Saturday and Sunday in winter or summer season, their shape depends on the number of days in winter or summer month. As mentioned in previous section, the curves from Figs. 1-4 correspond to winter and summer months that have 30 days - 22 working days, four Saturdays and four Sundays.

However, the month in winter season can also have 31 days, 28 days or 29 days in leap year. The month in summer season can have 30 or 31 days. Furthermore, the number of working days, Saturdays and Sundays in particular month can be different. For example, the month that has 30 days can consist of:

- 22 working days, 4 Saturdays and 4 Sundays (if the month begins with Monday, Tuesday, Wednesday or Thursday),
- 21 working days, 5 Saturdays and 4 Sundays (if the month begins with Friday),
- 20 working days, 5 Saturdays and 5 Sundays (if the month begins with Saturday) and
- 21 working days, 4 Saturdays and 5 Sundays (if the month begins with Sunday.

For every load class and winter and summer season, monthly load duration curves are created for all possible number of days in the month and all possible combinations of number of working days, Saturdays and Sundays. Thus, for winter season even 12 curves are plotted on the same figure for every load class. Similarly, 8 load duration curves are plotted for summer season.

It is found that these individual curves belonging to the same season and the same load class are very close to each other. For example, in the case of class 5 the curves are almost identical. Maximum difference between individual curves is obtained for the curves of class 7 in summer season (Fig. 5),

and the difference is 0.0825p.u. For the same load class, but winter season, maximum difference between individual load curves is 0.06p.u., while for other load classes the difference is smaller, up to 0.05p.u.

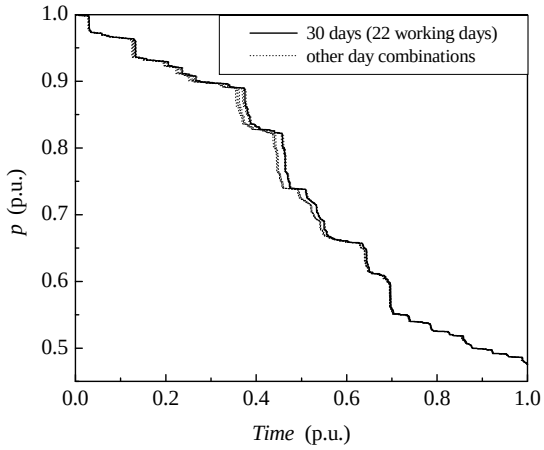

Fig. 5. Individual load duration curves of summer month for class 7

V. Load Factor and Loss Factor Analysis

Regarding the fact that load duration curves slightly differ with number of days in the month and the number of working days, Saturdays and Sundays, load factor and loss factor are calculated for all 12 and 8 possible combinations of days in winter and summer month, respectively. Table II presents only extreme values of these factors for every load class. It can be noticed that minimum and maximum values of corresponding factor differ from each other at third decimal place. The analysis of the ranges the factors belong to, showed that these are less than 1% of the mean value of corresponding factor.

Therefore, mean values of load factor and loss factor should be used. Mean values of load factor in winter season are: 0.7128, 0.5230, 0.6057, 0.8019, 0.6798, 0.6200 and 0.7416 for classes 1-7, respectively. In summer season mean values of this factor in the same order are: 0.7051, 0.5532, 0.6233, 0.7889, 0.6705, 0.6640 and 0.7352.

TABLE II
EXTREME VALUES OF LOAD FACTOR AND LOSS FACTOR

Season	Load class	m_{min}	m_{max}	ϑ_{min}	ϑ_{max}
Winter	Class 1	0.7108	0.7149	0.5194	0.5253
	Class 2	0.5201	0.5260	0.2974	0.3039
	Class 3	0.6030	0.6086	0.3932	0.4010
	Class 4	0.7990	0.8047	0.6504	0.6597
	Class 5	0.6792	0.6804	0.5120	0.5147
	Class 6	0.6164	0.6233	0.4227	0.4320
	Class 7	0.7387	0.7442	0.5772	0.5861
Summer	Class 1	0.7037	0.7065	0.5162	0.5205
	Class 2	0.5515	0.5549	0.3371	0.3412
	Class 3	0.6207	0.6259	0.4150	0.4222
	Class 4	0.7853	0.7923	0.6366	0.6480
	Class 5	0.6693	0.6716	0.4745	0.4778
	Class 6	0.6601	0.6678	0.4697	0.4814
	Class 7	0.7320	0.7382	0.5675	0.5772

Statistical analysis of loss factor values yields that mean values in winter season are: 0.5223, 0.3006, 0.3971, 0.6551, 0.5133, 0.4274 and 0.5817, while in summer season these are: 0.5183, 0.3391, 0.4186, 0.6424, 0.4761, 0.4756 and 0.5724 for load classes 1-7, respectively.

VI. Conclusion

Typical load duration curves of months belonging to winter and summer season for seven load classes at low voltage are presented in the paper. The curves that correspond to three load classes of households are clearly different from each other in both winter and summer season. There is increase of maximum to minimum power ratio in summer season for all three load classes. Load duration curves for investigated load classes other than households have pretty long period of the load greater than 0.8p.u. This period for commercial load excluding craft stores and shops reaches approximately 0.5p.u. of normalized time in both winter and summer season.

It is shown that different number of days in winter or summer month, as well as different number of working days, Saturdays and Sundays does not influence on significantly the shape of seasonal load duration curves. Consequently, load factor and loss factor calculated from these curves differ from each other at third decimal place.

Acknowledgement

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