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ANALYSIS OF ENERGY SAVING EFFECTS IN ELECTRICAL NETWORKS

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ABSTRACT

The growth of energy costs necessitates the search of efficient measures for energy saving. A row of LV networks in Germany were investigated by authors with the purpose to develop and to verify practical measures for the reduction of power consumption without affecting the production processes in the networks under study. One of the possible measures for the energy saving is an optimization of voltage levels in electrical distribution networks. The practical results of the carried out voltage optimization are discussed in the paper.

Index Terms – Energy saving, voltage optimization, electrical distribution networks

1. INTRODUCTION

There are a row of typical measures in electrical networks for an energy saving. Many measures are based on capital inputs, for example, investments in a network reconstruction, in buying new equipment, in implementation of new technologies, etc. The effect from introduction of such measures, as a rule, is high. But the investments are also high. On the other hand there are a lot of measures providing a reduction of an energy consumption in the enterprise and, first of all, of a payment for consumed energy without attracting of additional investments.

One of the possible measures for energy saving is an optimization of the voltage levels in electrical distribution networks. The authors' investigations have shown that such measure can be realized in a lot of industry enterprises and can reduce of annual energy consumption (and, respectively, payments) by several percents. The practical investigation results of low-cost measures of reducing of the energy consumption are discussed in the paper.

2. THEORETICAL CONSIDERATIONS

It is known that the reduction of voltage level causes a reduction of power consumption for many kinds of consumers in electrical networks [1 – 7]. The dependences of load power consumption from the supplied voltage are static load characteristics. The power consumption, as a rule, is increasing for main load types (industrial, commercial, residential) with the increasing of the actual supply voltage and can be approximately represented as follows:

$$P(U) = P_0 \cdot \left(\frac{U}{U_0}\right)^{k_P} \qquad Q(U) = Q_0 \cdot \left(\frac{U}{U_0}\right)^{k_Q} \quad (1)$$

where P, Q - active and reactive power consumption by actual voltage U,
P_0, Q_0 - active and reactive power consumption by the voltage U_0,
k_P, k_Q - factors characterizing the voltage dependences

For an idealized RL-load the factors are $k_P = 2$, $k_Q = 2$. According to [5] the typical values corresponding to real loads in electrical networks for k_P, k_Q are:

$$0{,}6 < k_P < 1{,}8 \qquad 1{,}8 < k_Q < 4{,}0 \quad (2)$$

Other forms of the static load characteristics representation can be founded in [6]. The static load characteristics for a row of concrete types of consumers are given in [7].

Taking into account the typical behaviour of static load characteristics tap changing of step-down transformers can be advised for the reduction of the voltage level in LV networks. The effect of the power consumption decrease must be expected after the tap changing mentioned above.

3. PRACTICAL REALIZATION

For the decision about the permissibility of the tap changing the estimation of the RMS voltage values distribution at the busbar under study is required.

The limits of the permissible changes of voltage levels for LV networks are given in [8 – 10]. 95% of the values measured during one week must be between (90 – 110) % of the network rated voltage. For a LV network with a rated voltage 230 V it means that the 95% of the measured values must be between 207 V and 253 V.

The Figure 1 shows the voltage levels at the LV busbar of an enterprise before and after the tap changing for reduction of the voltage level.

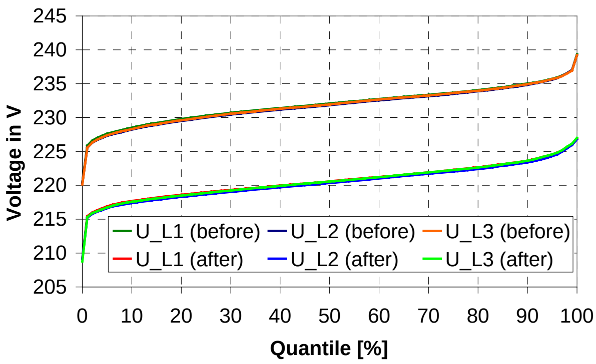


Figure 1 Voltage levels at the LV busbar before and after the tap changing

It can be seen from Figure 1 that all measured voltage values are within the limits mentioned above. It means that the carried out tap changing did not violate the power quality requirements.

Figure 2 shows the active power consumption in the enterprise mentioned above for the week before the tap changing and for the week after the tap changing. These weeks can be considered as reference weeks for the fast-analysis of the effect of the voltage level reducing.

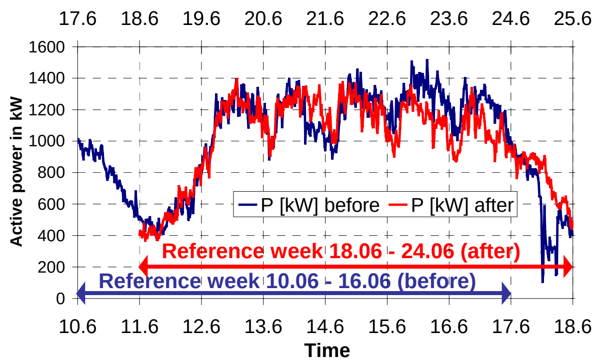


Figure 2 Active power consumption (15-min average values) before and after the tap changing

It is important for the estimation of the effect caused by the reducing of the voltage level considered over a relative short time (for instance one week) and has to be made sure that the same consumers are in operation under comparable condition during both reference time periods. For many enterprises, especially for the enterprises making small series of various products the production conditions and, respectively, the power consumption by different consumers can be significantly different from day to day. Using the correlation analysis the estimation of the power reduction effect caused by the reducing of the voltage level can be carried out more correctly.

Table 1 characterizes the measured energy consumption in the enterprise under consideration for each day of both reference weeks. On the base of the analysis of the active power consumption (30-min values) the correlation coefficients r_{AB} for each day of the week were determined and represented in Table 1. From Table 1 can be seen that the total energy consumption was reduced by 4,07 % after the tap changing.

Table 1. Energy consumption before and after tap changing

before		after				
Date	W_P [kWh]	Date	W_P [kWh]	ΔW_P [%]	r_{AB}	Day
10.6	19041,0	24.6	18407,1	3,33	0,95	Sa.
11.6	13215,3	18.6.	13209,0	0,05	0,90	Su.
12.6	30934,8	19.6	27270,6	1,25	0,93	Mo.
13.6	28729,5	20.6	25309,5	-3,94	0,60	Tu.
14.6	28939,2	21.6	28736,7	0,70	0,70	We.
15.6	27719,4	22.6	28811,4	11,84	0,71	Th.
16.6	27877,8	23.6	27528,6	11,90	0,62	Fr.
	Total 176457,0		**Total 169272,9**	**Total 4,07**		

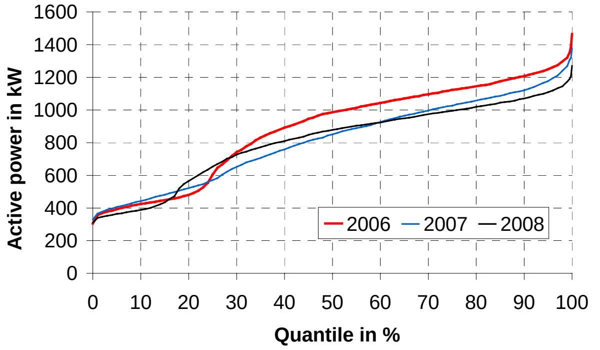
The correlation between two data rows can be characterized as follows:

$$\begin{aligned} &0{,}2 < r_{AB} \le 0{,}5 - \text{weak correlation} \\ &0{,}5 < r_{AB} \le 0{,}7 - \text{medium correlation} \\ &0{,}7 < r_{AB} \le 0{,}9 - \text{strong correlation} \\ &0{,}9 < r_{AB} \le 1{,}0 - \text{very strong correlation} \end{aligned} \quad (3)$$

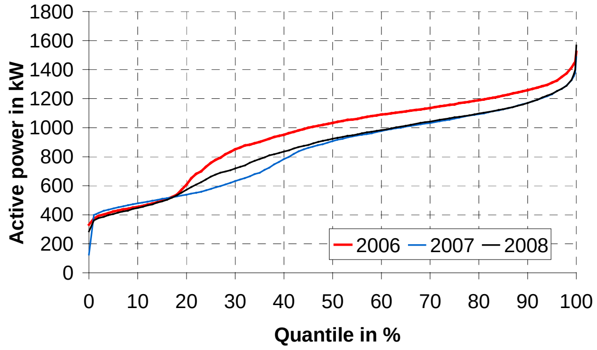
For the pairs of days characterized by correlation coefficients r_{AB} > 0,7 (strong and very strong correlation) can be concluded that the consumers operation at these days was similar. It can be seen from Table 1 that the reduction of the energy consumption were registered for all these days. For the pairs of days characterized by medium correlation the changes of the energy consumption have different signs. Both an increase and a decrease of the energy consumption were registered for these days. It can be explained by different consumer operation states at the days mentioned above.

A complete estimation of an energy saving effect after the tap changing can be carried out only after a long time of operation under changed conditions.

Figure 3 a) and b) show cumulative frequency distributions of 15-min values of the active power consumption during two months which were chosen as a case in point. The distributions are shown for April (Figure 3 a)) and Mai (Figure 3 b)) for three years (2006, 2007 and 2008). The values measured in the year 2006 characterize the power consumption in the enterprise before the tap changing was made. The values for the years 2007 and 2008 represent the power consumption by operation under changed conditions.



a)



b)

Figure 3 Monthly active power consumption (15-min average values) before (year 2006) and after(years 2007, 2008) the tap changing

a) April 2006, 2007, 2008

b) Mai 2006, 2007, 2008

It can be clearly seen from Figure 3 that the power consumption was decreased after the tap changing.

The achieved reduction of the monthly power consumption for the months mentioned above is between 8 and 11 percents.

These results correspond with the power consumption reduction of 10 percent achieved due to the voltage optimization mentioned in [4].

Figure 4 explaines the changes of the power consumption.

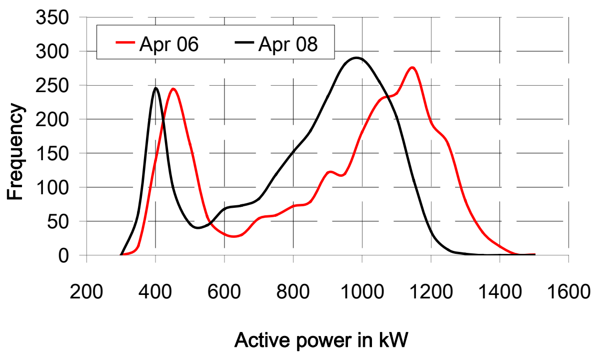


Figure 4 Distribution of monthly active power consumption values (15-min average values) before (year 2006) and after (year 2008) the tap changing

It can be seen from Figure 4 that the monthly frequency distribution can be characterized by two typical peaks. The left peak in Figure 4 corresponds to a low-load period, i.e. loads at weekends and at the nights, the right peak in Figure 4 corresponds to the load at work days.

It can be seen from Figure 4 that both load peaks mentioned above are shifted in direction of smaller loads after the tap changing.

It can be seen from Figure 4 that the reduction of power consumption is more significant for the workdays in comparison with the low-load period.

This reduction is about 15 % for the workdays peak in comparison with the reduction by 11 % for the low-load time.

4. POSSIBLE CONSTRAINTS

It must be noted that the reduction of the voltage level at the busbar leads to an increase of the depth of short-term voltage drops (dips) caused by transients, for example, during the start of a motor load connected to the busbar. Sometimes it can cause non-permissible voltage dips in the electrical network.

Figure 5 shows the measured voltage dips at the LV busbar of the enterprise considered above before and after the tap changing. The measured minimal voltage RMS values during the time in which voltage dips occurred and their durations are presented in Figure 5. The limiting curve for permissible voltage dips levels is the ITIC-curve presented in Figure 5 [10]. The measurements were carried out during the reference weeks.

It can be seen from the Figure 5 that more significant voltage dips occurred after the tap changing in comparison with the voltage dips quantity before the tap changing was made. It can be seen from the Figure 5 also that the limiting values are not violated.

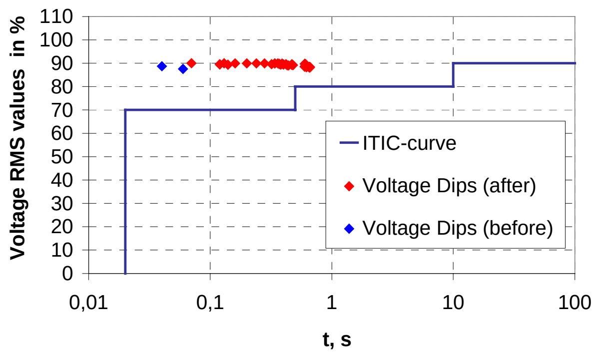


Figure 5 Voltage dips before and after the tap changing during the reference weeks

Another problem after the realization of the voltage level reduction can be the reduction of the luminous flux from the installed lighting.

In [11] is noted that an incandescent lamp supplied by the voltage of 90 % of the rated value has a luminous flux of only 75 % of its rated value.

Generally the luminous flux Φ from a lamp depends on the voltage as follows [12]:

$$\Phi = U^{\gamma} \quad (4)$$

where γ is a factor characterizing the lamp type.

For conventional incandescent lamps is $\gamma \approx 3{,}6$, for fluorescent lamps is $\gamma \approx 1{,}5$, for modern energy-saving lamps is $\gamma \approx 0{,}17$ [12].

It means that the effect of the luminous flux reduction is not so important for fluorescent lamps and can be neglected for energy-saving lamps.

Taking into consideration the decision of the European Community to prohibit a production of incandescent lamps and the increase in the number of energy-saving lamps in electrical networks, it can be concluded that the reduction of the voltage level for an energy saving can be recommended for many enterprises.

Last but not least: A voltage level reduction increases significantly the lifetime of an incandescent lamp.

The equation for the lifetime estimation can be written as follows:

$$\text{Lifetime} = \left(\frac{U_{\text{rated}}}{U}\right)^{13} \quad (5)$$

where U is the actual voltage supplying an incandescent lamp.

It means that after the reducing of the supply voltage to 90% of its rated value the lifetime of the incandescent lamps is increased up to 393 % or practically by 4 times.

In the case considered above the voltage reduction was about 5 % (s. Figure 1). The decrease of the luminous flux of incandescent lamps is about 15 %. But the increase of the lifetime for incandescent lamps in the enterprise is 188 %.

It means that the carried out voltage reduction has mainly positive influence on the consumer operation in the enterprise under study.

5. SUMMARY

On the base of the carried out analysis can be concluded that the reducing of voltage level in an electrical network is an efficient measure for the reduction of power consumption.

The authors' investigations have shown that the voltage reducing in the enterprise under study caused a reduction of the monthly energy consumption of up to 11 percents.

6. ACKNOWLEDGMENT

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