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DIAGNOSTICS OF ELECTRICAL POWER NETWORK AND ITS UTILIZATION EFFICIENCY

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Abstract: This paper discusses problems of the electrical energy utilization of industrial and institutional consumers. Nowadays difficult economic circumstances make more and more companies waking up to use energy as efficient as possible. Today all companies are interested in lowering their energy consumption, because even a relatively low percentage of energy savings may have a significant effect to the budget balance. This increased interest in energy efficiency increases number of offers on the market promising 5-30% electrical energy saving. In this paper diagnostic of one of energy saving equipment is analysed.

Keywords: electrical energy saving, electrical power diagnostic, electrical energy efficiency

1. INTRODUCTION

As it is well known energy cost is a significant part of the full budget at most of consumers, independently from the measure of it, e.g. small household consumer, institutional or large industrial consumer. As we also know electrical energy is the most expensive type of energy, and its price is continuously increasing (Figure 1.). Therefore even a small saving has significant effect to the electricity bill of consumers.

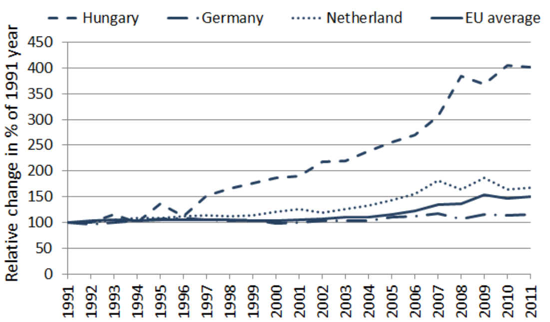


Figure 1. Change of electricity price in Europe in percentage relative to the price of 1991 year (made by data of Eurostat) [1]

This fact forces more and more consumers to deal with energy saving problems, to study available saving methods and equipment. Obviously market answers to this increased demand offering wide range of services and equipment of electrical energy saving. Most of these offers are based on real and valid professional considerations, and these can be really useful especially for those consumers having out of date technical installations. Besides of the professionally correct offers we also can find some advertisements with imprecise and sometimes false drafting and definitions. In few cases we have found power saving equipment using objectionable methods which may have a bad effect to the operation of machines; hence such equipment can decrease even the lifetime of the electrical apparatus connected to the network. This is the reason why the author coming from Department of Electrical and Electronic Engineering at the University of Miskolc decided to summarise possible energy saving methods and the team of the department, working in the field of power network diagnostics for many decades, decided to analyse a particular power saving equipment.

2. EXAMPLES OF ENERGY SAVING METHODS

First of all offers of the enterprises providing different energy saving methods was analysed. The question is, what kind of offers can be found on the market by those professionals/leaders of companies, who decide to improve their energy efficiency, how they can find and choose the best method for their purpose. The offers can be divided into three parts: In the first part we will find methods of classical and/or modern energy management, in the second we count those offers, which aim to modernize technical solutions in the company, and the third part includes equipment installed into the network, offering direct energy level decrease.

In the first group economy expert oriented companies offer solutions and help to find the best contract possibilities. In the time of market opening in electricity industry, economical evaluation of the regional and local circumstances is important, as well as these energy management experts can help to find the best supplier offer.

In this first group we also can find some technical solutions of the energy management. Uncountable number of network monitoring equipment can be found on the market, offering high level regulation of contracted and consumed energy ratio, they also can help in producing accurate load characteristics of the company or in optimization of the load distribution on the network. These energy monitoring and/or control systems may have important role in decision making process of time schedules, consumption limitations, supplier contract, tariff selection, etc.

Besides of all these really nice results we know the truth is in the details, which means here that efficiency of these monitoring systems depends very much on its technical parameters. For example the sampling frequency, the used synchronisation methods, or averaging methods all has important effect to the operation and reliability of the monitoring results. As the subject of this paper is not economical, this first part of the energy saving methods is not discussed.

In the second group we classify those methods offering modernization of the network's or consumer's equipment. Numerous of companies offer lighting modernisation, mostly with sophisticated control system. Others offer modernisation of cabling and wiring; using copper wires, having very good electrical conductivity. These offers usually recommend also use of larger than necessary cable section sizes. The payback interval of course is a critical question in this case, and should be calculated in detail, as the complex cable and wire replacing in an existing house needs a relatively high investment. As the copper price is continuously increasing (see figure 2.) this investment needs longer and longer payback time.

Figure 2. Change of copper price in the last 11 years by information of Global InfoMine [2]

Thing worth mentioning that losses in transformers and motors can be also relatively high especially in case of using them on lower load level. In many cases replacing older motors with high efficient motors will payback less than 1 year or around [7]. Each of these modernisation methods is a huge area of the energy saving science. All of them can be studied individually, but they are out of this paper frame.

Finally subject of this papers is the third part including equipment installed into the network and offering direct energy saving. The main question is how these savers work, which methods they use, and how is their reliability and efficiency?

3. ANALYSIS OF DIRECT SAVING METHODS

In order to achieve energy saving, several well-known methods should be applied in the power saver equipment. Which parameters of the network should be controlled to increase the utilization efficiency?

1. Voltage level should be kept on optimal level;
2. Reactive power should be kept at minimal level and suggested to compensate it as closer to the cosφ lowering equipment as possible;
3. Network disturbances and distortions should be minimized;
4. Network asymmetry also should be minimized.

All equipment offering optimization of the above listed parameters may have positive effect to the electricity bill of the company. Some offers include optimization of two or three parameters from the above listed four. Phase compensation is a really old and well applied method at most of industrial consumers, so this will not bring any novelty in the field, it just a compulsory task of consumers. Other offers concentrate to the disturbance compensation and harmonic filtering. Why harmonic disturbances increase energy costs? There are several kickbacks of harmonics and interharmonics. They

- produce harmonic power which increase heat of consuming equipment, produce parasite torques in rotating electrical machines, so lifetime of the machines will be shorter;
- highly increase current in neutral wire, harmonic currents flow on neutral cable, spreading out disturbances in all three phases;
- overheat transformers & rotating equipment;
- increase Hysteresis losses;
- decrease kVA capacity;
- cause unacceptable neutral-to-ground voltages;
- cause breakers and fuses tripping;
- cause interference on phone and communications systems;

- cause unreliable operation of electronic equipment;
- cause erroneous register of electric meters;
- increase maintenance of equipment and machinery. [8]

One of energy saver equipment is advertised by the following text in Hungary: "*In case of frequent and drastic current fluctuation on the network, the fluctuating voltage is connected to our machines, the XX (name of the saver equipment) prevents direct connection of the fluctuating current into our network. The XX stabilizes and filters the incoming current, than pass it to the electrical equipment connected into the network, saving our equipment from the current fluctuation. The XX keeps the current level stable by a special electronic controlled capacitance, resulting increased efficiency of consuming equipment's operation on the network. Self-consumption of the XX saver is zero.*"

Maybe the XX equipment works properly and efficiently, but the description includes huge professional mistakes. The first is the confusion of voltage and current meanings. Secondly the advertiser forgot about the fact that at normal network operation "the drastic current fluctuation" is caused by load change, and the zero self-consumption is also doubtful.

There is an other energy saver equipment, offering result by decreasing the voltage level of the network, as follows:

„Electrical energy consumption can be dramatically reduced if the voltage is decreased and stabilized in the range of standard limitations. Our practice proved that general saving is between 10 and 15%, if the voltage level is reduced to 207 V, which is absolutely suitable for all consuming electrical equipment on the network."

The nominal level of the voltage in this country is 230V, the standard range is ±10%, so the lower permitted limit is 207 V. The above cited offer lowers the supply voltage to the lower limit. As we know electrical loads can be resistive, inductive or capacitive, but they can be also classified from aspect of controllability, e.g. some loads can be controlled by voltage, others by current. In the first group loads operate by ohm law, so if the voltage level is decreased, the current also decreases, so the power decreases in quadratic measure. Operating these loads on lower supply voltage can result energy saving. In the second group mostly rotating machines are included, which try to keep their own power on a defined level, so if the voltage is decreased, they will increase current consumption according to their characteristics in order to keep voltage and current product at the relatively same level. So the energy consumption will not have drastic change, but the network and heat losses will increase, so the lifetime of the motors probably will be shorter.

Our Department had a possibility to test an energy saver equipment offering optimization of all four parameters listed at the begin of this section. The equipment was tested in a hospital for 8 days, in first part of which the equipment was installed and switched on and in the second part of the test time it was switched off. Results of the tests are summarised in the next section.

4. DIAGNOSTIC OF A PARTICULAR DIRECT POWER SAVING EQUIPMENT

The **a**nalysed **p**ower **s**aver **e**quipment (APSE) advertised also on the Internet operates on the basis of phase correction, harmonic filtering and load asymmetry improving. According to its description tests included analysis of the above listed parameters, as well as analysis of voltage and current RMS, active and reactive power and energy consumption.

Tests were performed on a hospital's power network. The APSE was installed directly to the incoming supply, i.e. between the transformer's secondary side and the loads. Tests were run for 8 days, in the first half of which the APSE were operated and in the second half it was switched off. As the two test periods cannot be run parallel, we had to face problem of slightly different load characteristics in the two serial 4-4 days periods. As this difference was compensated, results could be compared with relatively high reliability.

4.1. Analysis of voltage and current RMS

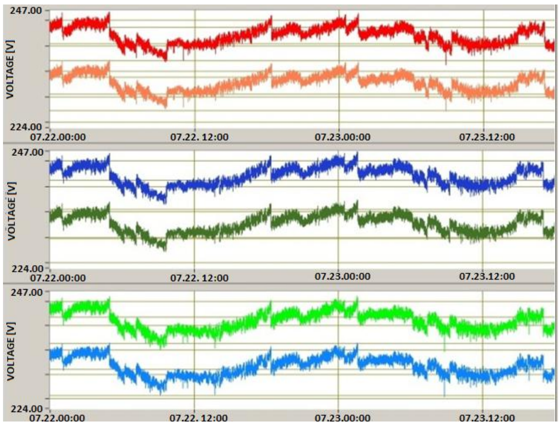
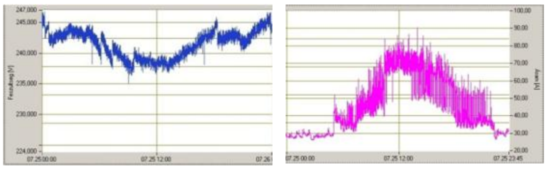


Figure 3. Graphs of the three phase voltages on the input and output sides of the APSE

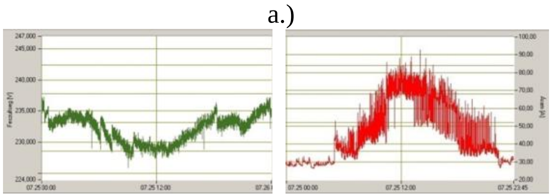
Voltage and current levels on the input and output sides of the APSE were registered. Average level of the voltages is 241V without the equipment and 232V with the equipment. It means that decrease of the voltage level near to the optimal 230V is definitely a good solution from the efficiency point of view, as it can result energy saving on the ohmic loads and also provide optimal circumstances for all types of loads from the heat loss side. Figure 3. shows graphs of the three phase voltages on the input and output side of APSE. The higher level graphs are measured on the input side and lower level graphs on the output side.

As the voltage level decrease is ~4%, it can theoretically provide ~7.8% energy savings, but only if clear resistive loads are connected to the network, which is not a case.

Analysing current levels in the two test periods, we have found 2.4% current decrease, over against the theoretical 4%, but it can still result ~6.3% energy saving. In this point we should note, that in an industrial or bigger institutional consumers, having an individual transformer on the field, method of the voltage level regulation is an easy task, not requiring any additional equipment.



a.)



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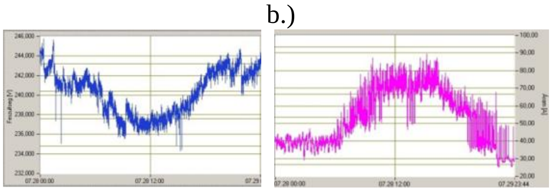


c.)

Figure 4. One phase RMS graphs of voltages (left) and currents (right)

a.) APSE primary side APSE in operation

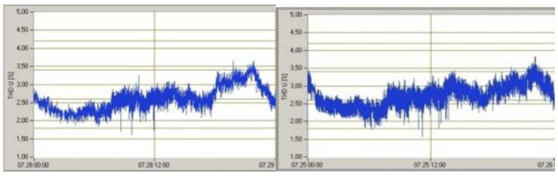
b.) APSE secondary side APSE in operation

c.) APSE in no-operation

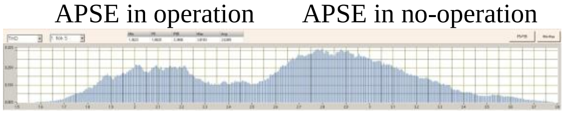
Figure 4. shows one day, one phase RMS graphs of voltage and current, on the input (a) and output (b) side of the operating ASPE, and without ASPE. We can see that load characteristics are very similar in the two test days, but there is no noticeable difference between current levels. It means that most of the loads connected to the network are current driven, and only voltage level causes some power decrease in the system.

4.2. Network disturbances and distortions

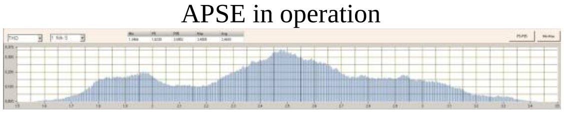
Voltage total harmonic distortion was ~ 2.7% in both test periods, the difference is in the range of measuring errors and load differences, nevertheless the maximum values of THD_U on all phases were a slightly lower (<l%) in the second periods, when the APSE was switched off. Same observation could be experienced with current signals, but the differences are more significant, average THD_I was less in the second period by 4.9% and the maximum values by 7.3%, which means that in spite of the load differences we can state with high probability, that APSE has no positive effect to the harmonic distortion, hence it doesn't use this parameter for energy consumption optimisation. We know that harmonics may disturb operation of other consumers on the network, may increase heat losses, arise parasite torques, decrease lifetime of equipment, summarised, they increase the energy cost. Figure 4. shows statistical distribution of THD_U in the two test periods, we can see, that no practical differences between them.



APSE in operation APSE in no-operation



APSE in operation



APSE in no-operation

Figure 5. Time graph (above) and statistical distribution of voltage's total harmonic distortion, with APSE operation, and no-operation

4.3. Reactive power and phase shifting

Cosine of the phase between the voltage and current signal was in average 0.8560 in APSE operation period and 0.8385 at switched off period. Both values are unacceptable for an industrial/institutional network. Improvement with APSE is 2%, which is very close to the rate of measuring error. Nevertheless from statistical and time analysis we could define a small positive effect of APSE to the reactive power compensation. Figure 5. shows statistical distribution of cosφ.

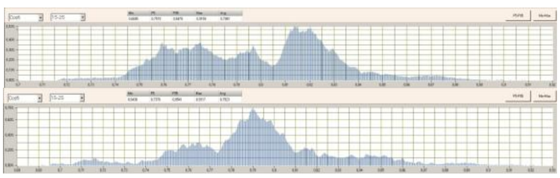


Figure 6. Statistical distribution of cosφ on one phase, above with APSE operation, below when APSE is switched off.

This small compensation difference resulted 10% decrease in reactive power consumption, but even this was much higher, than the supplier company's charge limit. As the internal length of the cabling is relatively high, more than 1 km, the internal reactive power transmission causes high energy losses.

Energy consumption is summarised in the table 1.

Energy consumption	APSE in		Difference in %
	operation	no-operation	
Active, phase R, kWh	563,28	604,29	
Active, phase S, kWh	742,90	761,86	
Active, phase T, kWh	697,02	711,40	
Reactive, phase R, kvarh	359,68	391,56	
Reactive, phase S, kvarh	560,87	595,74	
Reactive, phase T, kvarh	300,71	360,25	
Total active energy consumption, kWh	**2 003,20**	**2 077,55**	**3,71**
Total reactive energy consumption, kvarh	**1 221,27**	**1 347,55**	**10,34**

Table 1. Energy consumption

4.4. Voltage and load asymmetry

As we know asymmetry of three phase voltage causes additional heat losses, and other problems in the equipment operation, therefore standards limit the asymmetry level to 2%. Asymmetry of the network was very good in both periods, its average level was ~0.3%. Analysis results show slight improvement in voltage asymmetry's maximum levels, which was 1.1% in first test period and 3.2% in the second period.

Load asymmetry was not compensated by APSE as promised in its description, it was ~30% in both test periods. Figure 7 shows three phase current signal while ASPE in operation. Distortion and asymmetry level of the signals are very high.

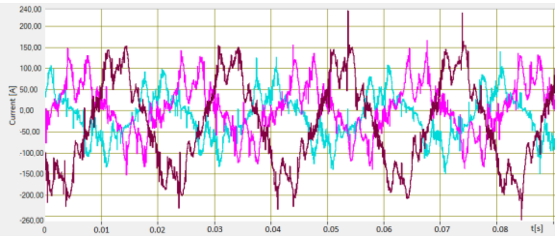


Figure 7. Three phase current signal in ASPE operation test period

5. SUMMARY

Diagnostics of the analysed power saver equipment proved its positive effect to the energy consumption, but it was resulted mostly by decreased level of the supply voltage, and in fewer ratio by phase shifting correction. Unfortunately there was no possibility to study APSE behaviour in case of the supply voltage is close or below of the nominal 230V, which is an important question from the point of consuming equipment lifetime, as studied in section 3. All other parameters were not efficiently optimized.

Finally we can state that total active energy consumption was decreased by 3.8% and the reactive energy consumption by 10% by APSE, which could be also achieved by adequate setting of supplier transformer's secondary voltage.

6. ACKNOWLEDGEMENT

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