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REACTIVE POWER COMPENSATION AND ENERGY SAVING

KOMPENSACJA MOCY BIERNEJ A OSZCZĘDNOŚĆ ENERGII

A b s t r a c t

The issue of energy saving in workplaces where multiple machines are in use, and consequently there is high energy consumption, is discussed in this paper.

Keywords: *compensation*, *reactive power*, *active power*, *energy efficiency*

S t r e s z c z e n i e

W niniejszym artykule podjęto temat energooszczędności w zakładach pracy, w których wykorzystywane są maszyny, aco za tym idzie, bardzo duże zużycie energii

Słowa kluczowe: *kompensacja*, *moc bierna*, *moc czynna*, *kondensator*, *energooszczędność*

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1. Introduction

Issues surrounding energy-saving, passive, or even zero-energy construction techniques, are commonly debated these days, particularly when we consider the use of new technology in house-building. The practice is regulated in law, which describes in precise terms how walls of buildings should be constructed so that: thermal heat loss is as low as possible; and energy requirements are at the minimum required to heat the building. However, the question of how to save energy in factories with higher machinery and lighting energy demands is discussed less frequently. Practically speaking, it is possible to limit electrical energy consumption in any business, factory and office block without any harm being done to the normal operation and function of the building. Rising prices in electrical energy, further legislation and regulations, and increasing fuel costs will not affect this situation, which explains why we need to consider all feasible means of reducing the amount of electrical energy used and the associated costs. This is why an analysis of reactive power compensation is necessary.

2. Reactive power compensation

Power, or more specifically induction reactive power, occurs only in alternating current circuits. The flow is between the source and the recipient/customer. This energy is required to generate alternating magnetic fields for engines, for magnetizing core convertors and for charging supplies carried in overhead and cable transmission lines to capacity levels. Reactive power does not readily convert into work energy, but it is often necessary to do so and all machines must utilize reactive power.

All induction machines run on reactive power, however, a-synchronic engines (especially idle engines), low-demand convertors, welding machines, low-demand transmission lines and long cable lines absorb the most reactive power. Electrical devices supplied with alternating current may also require reactive power, except where these require real/actual power. Reactive power must be used to create magnetic fields in engines, convertors, gland/shell-cased seals or electrical fields in capacitors. Additionally, reactive power is used in other capacities such as cables and non-linear devices such as fluorescent compact lamps, in which the current shifts in a time-frame to generate voltage, or devices that are not sinusoid.

Unfortunately, the energy flow of reactive power also has disadvantages. The flow from the source to the recipient/customer places a burden on electrical cables and lines, lowering the flow capacity and resulting in additional voltage levels, falls and losses of actual electrical power.

That is why electrical energy suppliers require consumption of reactive power to be limited. The suppliers make money from the amount of actual power delivered to the user, so wish to supply as much energy as possible, but with minimum losses and within the required parameters. As far as the measurement of losses is concerned, the value of the current flowing through the net elements depends upon the parameter of what is known as the apparent power – referred to as *S*.

$$S = \sqrt{3} \cdot U \cdot I \tag{1}$$

where:

U – root mean square of strain,

I – root mean square of current intensity.

The apparent power is the geometric sum of real/actual power P and reactive power Q:

$$S = \sqrt{P^2 + Q^2} \tag{2}$$

where:

Q – reactive power,

P – real power.

Figure 1 shows a graphic interpretation of the dependence between powers, depicting the ‘so called’ triangle of powers.

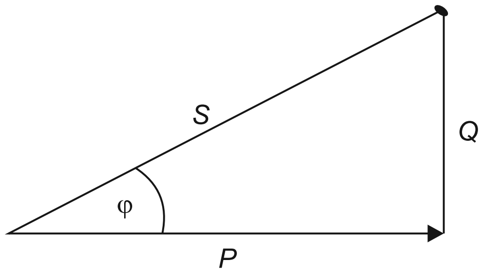

Fig. 1. The triangle of powers [3]: Q – reactive power, S – apparent power, P – real power, φ – the angle of difference (in degrees) between current and voltage

It would be ideal if the apparent power S was equal to real/actual power P, so that reactive power Q would be worth 0. In order to get such a result, the following is applied: reactive power compensation is represented as the relations hip between the reactive power consumed by the recipient/customer and the reactive power of an identical or approximate value but with an opposite sign. Figure 2 presents a graphic illustration of reactive power compensation.

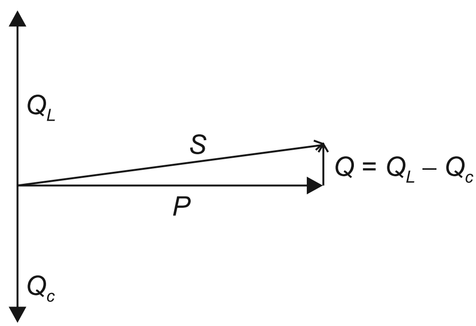

Fig. 2. Reactive power compensation [3]: Q – reactive power, Q_L – induction reactive power consumed e.g. by engines, Q_c – capacity reactive power absorbed by capacitor, S – apparent power, P – real power

After compensating, the amount of power absorbed from the network is much lower than would otherwise be the case.

Practically, there is no need to compensate to an extent that reactive power is zeroed out. The reason is that the increase in current is not significant when only real/actual power is consumed, and is also within a low value in terms of the difference in angle between the current and the voltage. The bigger the angle, then the faster is the current generated. As a result, fixed limits are established and losses are relatively slight and acceptable. The limits are described in terms of the tangent of the angle of difference between the current and the voltage, which is given as 0.4.

It is important to limit reactive power consumption by an appropriate choice of (work) load for converters in order to limit the energy expended by idle engines, to limit welding work on idle engines and for the maintenance of engines.

Reactive power compensation also plays an important role. It is generated by means of a synchronic capacitor. Therefore, there is no need for it to be sent from the supplier to the receiver, which explains why a greater amount of actual power can be carried along the same electrical power lines.

3. Capacitor batteries

A capacitor battery is a device used to compensate induction reactive power. It usually consists of a few capacitors, a regulator and various accessories. The regulator automatically switches on the appropriate number of devices, depending on the reactive power needs, to maintain a power factor cosine φ at the required level. The capacitor module consists of an electrical capacitor, a contactor, protection and glands/shells (in some types of batteries).

Fig. 3. Capacitor models (with various capacities) which set the 'heart' of each battery used for reactive power compensation

Capacitor batteries create capacitive reactive power (compensating induction reactive power) whose unit is expressed as a kilowar (kVAr).

Capacitor battery applications area commonplace, but relatively recent solution, mostly popular in medium and large-scale factories, as only these receivers can be charged to provide additional reactive power consumption. As a result of the fact that modern electrical power meters became more commonly used, so smaller induction reactive power receivers must be taken into consideration for setting induction reactive power. Battery effectiveness is considered to be100%; the only preconditions for success being the appropriate choice of device and correct installation. Therefore each recipient, who is billed on the basis of their usage of induction reactive energy according to their contract terms, is free to fit a capacitor battery. This should only be considered if the investment is economically profitable, and a decision is taken on the basis of when it will pay for itself.

Kinds of capacitors

In view of the fact that networks and receivers have various characteristics in particular factories, four basic kinds of capacitors are considered here:

- Common batteries – batteries of the simplest construction, which may be applied only in places where the current and voltage are not adversely affected to a large extent and where the phenomenon of resonance with the network does not occur. If these requirements are not satisfied, then the battery will deteriorate and expire rapidly.
- Amplified batteries – these batteries are constructed in a similar way to common ones. However, they contain more durable capacitors. Such batteries may be applied in an environment where there is a higher level of deterioration, but cannot be used where there is resonance between the battery and the network.
- Batteries with thriystor linkages – batteries in which a thriystor is used instead of a contraction device. Therefore these react very quickly to any change in the power burden. These batteries are very expensive and are used only where large changes of reactive power occur in short periods and where traditional batteries would not provide the required results.
- Protective shell (glands) batteries – batteries with additional shells which protect capacitors from decay caused by current and voltage fluctuations. These batteries may be used wherever significant current and voltage fluctuations are observed and where there is a risk of resonance with the network.

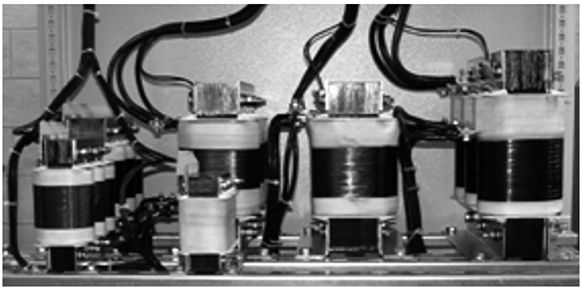

Fig. 4. Batteries with additional shells which protect capacitors from decay due to current and voltage fluctuations

Appropriate choice of batteries

When purchasing batteries, it is important to know which to choose. There are many kinds of batteries, which may be used for various purposes. All brands of batteries differ in both construction and price. If an inappropriate choice is made, the battery will deteriorate very quickly and may also pose a risk. Therefore, people with specialist knowledge should be responsible for selecting the batteries. In order to make an appropriate choice, the power profile and any rate of deterioration must first be taken into account. Once this is done, the power of the device and its other parameters must betaken into consideration. Only such an approach will guarantee that the device will be of good quality with along life span. On the basis of the demands for electrical power, it is possible to make an approximate calculation of the cost of the device. However, this approach will not give us any information about the fluctuations of the current and voltage, the risk posed by resonance or degradation.

There is no obligation for the electricity supplier to agree on the choice and use of a battery, and there is no requirement to inform the supplier about the fittings. It is perfectly within the rules to use batteries, and they do not interfere with instruments designed to measure the amount of electrical power supplied.

Batteries are self-contained and fully functional and they do not require continual maintenance. An operator monitoring the readings will control the amount of power to the capacitor modules so that the required power factor (cosine φ)is maintained (the battery operator is guided by the cosine – but on the print-out the tangene φ is shown because it allows for easier and clearer calculations to be made). It is necessary to carry out regular maintenance such as changing the filters.

The installation of a battery will not lead to an increased consumption of actual power. The battery only generates reactive power, at the same time compensating for induction reactive power absorbed by the receiver. The battery does not take much real power, at the same time reducing the amount of loss of electrical energy in power lines and convertors. It is expected that actual power consumption will be unchanged, or will decrease to a slight degree.

Usually applying capacitor batteries completely eliminates reactive power induction costs. Generally, prices are reduced by about 90%.

The cost of installing such a battery usually pays for itself after a few months. Considering the fact that the life span of an appropriately-selected device extends to 12 or so years, it is an excellent investment which should return on its investment cost as many as 20 times over, throughoutits useful working span.

4. Penalties for higher reactive power consumption [1, 2]

If excessive reactive power induction consumption occurs, then the additional levy is calculated on the basis of the value of the actual factor tgφ (tangene φ). This is calculated as a quotient of the reactive power to the actual power consumed within the chargeable billing period. If the power factor is higher than the required factor tgφ (usually 0.4), then the cost for the additional reactive power induction consumption is calculated on the basis of the following formula:

$$O_b = k \times C_{rk} \times \sqrt{\frac{1+\mathrm{tg}^2\varphi}{1+\mathrm{tg}^2\varphi_0} - 1} \times A \tag{3}$$

where:

O_b – the fee for additional reactive power consumption in PLN,

k – the price factor C_{rk} as set out in the scale of charges. For the customers supplied atthe low voltage level, factor k usually amounts to 3 and for customers supplied at the medium voltage level, factor k is set at 1,

C_{rk} – average price of electrical power on the open competition market set on the day that the tariff was approved,

$\text{tg}\,\varphi_0$ – power factor under the contract (usually 0.4),

$\text{tg}\,\varphi$ – the power factor arising from the reactive power consumption,

A – actual power consumed on a 24 hour basis or for the time period during which the consumption of reactive power took place.

Fees for additional consumption of reactive power:

– Increase the distribution service costs of electrical power leading to an increase in the average price;
– Should encourage the customers to take up compensation measures for the reactive power induction levels consumed;
– Reflect on the high prices charged to customers using the *nN* network, and the lower prices of electricity meters measuring the consumption of reactive power induction; reactive power prices to be paid by small-scale customers, who mainly use induction, single-phase devices, refrigerated units, ventilators, air conditioners etc.

5. Real savings

Capacitor batteries are deployed in almost all kinds of situations. In the past, these devices were almost solely used in industry, but nowadays are in common usage in shops, municipal buildings, office blocks, hotels, sewage treatment plants etc. Generally speaking, capacitor batteries are in place where energy distributors provide for the additional consumption of reactive power, and the recipient/customer possesses a significant number of machines, pumps, old types of lighting units etc. Examples include companies producing furniture pots, soles for shoes, and engaged in metalworking. In each case, once the device has been installed, the customer is in a postion to control the effects. In around 90% of cases, the costs associated with reactive power are eliminated. In the remaining 10% of cases, the additional amount to be paid does not exceed 10% of the total amount billed for reactive power – prior to the installation of the device. The majority of batteries pay for themselves after 6–10 months. Information was gleaned from one company, in relation to the choice and fitting of batteries. To take the example of the town swimming pool in Silesia, the monthly net costs prior to the battery being fitted into position were about 1800 PLN. Excess costs were completely offset once capacitor batteries were fitted (shell-protected batteries in this instance because measurements showed resonance with pumps supplied occurring). The entire cost of the device and its fittings amounted to approximately 9600 PLN net. The investment cost paid for itselfwithinnearly6 months.

As mentioned earlier, a good choice of batteries eliminates the costs associated with reactive energy. As far as the excess fees are concerned much depends on the power factor – which is between 10% and 60% of the distribution bill. In turn, this may account for between 5% and 30% of the entire chargeable energy bill.

6. Conclusions

– The customer is not required to obtain the agreement of the electricity power supplier to fit the battery.
– The amount of actual energy consumed does not increase.
– The application of batteries to supply capacitors either completely off-sets the financial cost of induction reactive power, or at least significantly decreases it by at least 90%.
– Batteries are fully automated and do not require ongoing service. It is necessary to change the filters.
– Installing a battery does not carry any financial penalty in terms of any additional consumption of reactive energy.

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References

[1] A Minister of Economy decree of 18 August 2011 Dz.U. (legal daily record) no. 189 in relation to detailed rules of development and calculations of the scale of charges and settlements of accounts for electrical energy.
[2] A Minister of Economy decree of 27 April 2012 Dz.U. (legal daily record) no. 535 amending the existing decree in relation to detailed rules concerning the development of and calculations for the scale of charges for electrical power.
[3] http://www.korporacjasystem.pl/
[4] http://www.elektroinstalacje.info/