

## Research of the features of reactive power compensation in the combined system of food industry

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### ABSTRACT

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The ways of increasing operation efficiency of reactive power compensation on the plants are considered. Small capacitor units may be connected at the individual loads. Greater power – factor corrective effect for a given total capacitor kilovolt – ampere will result with the capacitors located directly at each individual load, since the current is thereby reduced all the way from the load to the source. The first cost of an installation of individual capacitors will be greater, however, than that for one unit of the same total kilovolt – amperes located at a central point. The greater saving in operating expense due to individual capacitors must be weighed against their increased first cost. The locking circuit against high voltage is presented. The problems of its engineering implementation are considered. The expediency of the use of each synchronous motor for reactive power compensation. If the load factor of a synchronous motor is less than unity, economically expedient to use fully expected reactive power output. The need to apply the power of higher harmonics filters with a distortion factor is more than 8%, which is typical for plants with thyristor converters. Recent calculated from the calculated values of the distortion factor is based on the composition and level of harmonics.

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### Introduction

Almost all factories of food industry in Ukraine have a combined system of electricity supply and receive electricity from their own thermal power stations and are connected to the supply system. In the repair period thermal power station is not working and electricity is received from the general electrical networks.

### Material and methods

Power-stations have limited possibilities to generate reactive power. At thermal power station generators with power factor of 0.8 are installed. Much of the generated reactive power has consumed by transformers and power lines. Distribution of reactive power consumption is: induction engines - 70%, transformers - 20%, lighting and other electrical consumers - 10% [1].

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It is not enough to use the generators reactive power of the own thermal power station for the normal plant operation, and many factories are equipped with high condensing apparatus. But it is not reasonable because during the transmission of reactive power to consumers there are significant losses of active power due to resistance of conductors  $r$

$$\Delta P = \frac{Q^2}{U^2} \cdot r \quad \text{or} \quad \Delta P = P^2 \cdot (1 + tg^2 \varphi)$$

The crosscut of conductors is increased, because crosscut is selected according to the load current, and the current depends on the reactive power

$$I = \frac{P}{\sqrt{3} \cdot U \cdot \cos \varphi}$$

Thus, there is the overrun of conductor material.

The power of transformers ST is used irrationally

$$S_T = P \cdot \sqrt{(1 + tg^2 \varphi)}$$

There are additional losses of voltage [1]

$$\Delta U = \frac{Q_x}{10 \cdot U_{\text{НОМ}}^2},$$

$x$  – the reactance of the power supply system's elements.

Thus, the reactive power which is transmitted to electrical consumers is to be reduced (to compensate) to economic levels.

### **Results and discussions**

During the process of compensation it is necessary to consider the following general requirements [2,3]:

- 1) the reactive power can be generated at any point of the network (unlike the active power);
- 2) the network unloading depends on the distance between sources of reactive power and consumers facilitates;
- 3) the balance of reactive power must be the same for all power supply system components.

A small weight, no rotating parts, slight loss of energy, ease of maintenance, safety and reliability allow the using of the capacitors for reactive power compensation at all levels of electricity supply.

The synchronous engines are widely used by enterprises to drive devices that do not require the speed control (compressors, pumps, ventilators, etc.). The engines can work with outstripping power-factor and reactive power to compensate other electrical consumers. The compensating engine capacity is determined by the load on its shaft, voltage and current excitation.

When placing capacitors in the enterprise network be aware that there are individual and centralized reactive power compensation [1].

In case of individual compensation the capacitor unit is connected to the clamp of electrical consumer without commutation apparatuses. This type of compensation should only be used only in relatively large electrical consumers by the quantity of annual working hours. Individual compensation allows relieving of all production network from the reactive currents. However, this method demands significant investments. In addition, time of compensating

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devices work depends on the time of turning on of electro-transceiver because when you turn off the electric network you turn off the capacitor battery, too.

With centralized compensation the capacitor unit is to be connected to the tire of 0.4 kV transformer substations or to the tire of 6... 10 kV distribution units [4].

In the first case the all high-voltage network, transformer of transformer substation and thermal power station generators are relieved because of reactive power; in the second - only part of the high-voltage network and generators thermal power station.

The criterion of rational decision of a reactive power compensation problem is the reducing of losses. They consist of the costs for compensating, regulatory and related devices, the costs for reactive-power control and its transmission to the elements of network. These costs include the components that do not depend on the value of reactive power. That's why the methods of the compensating devices power determination were developed. They does not require taking into account the absolute value costs of the electrical system elements [2,3,4].

According to this methodology for an acting factory during the reconstruction of the electricity supply system:

$$Q_{KV} = Q_M - Q_{TEH},$$

where:  $Q_M$  - the maximum consumption of reactive power on the daily chart speed plant,  $Q_{TEH}$  - reactive power of the thermal power station generators.

As a rule:

$$Q_{KV} = Q_{HK} - Q_{BK},$$

$Q_{HK}$  - power of compensating devices (voltage up to 1000 V),

$Q_{BK}$  - the same but for voltage of 6... 10 kV.

In turn:

$$Q_{HK} = Q_{HK1} + Q_{HK2},$$

where:  $Q_{HK1}$  - the total power of CD based on the optimal number of transformers TS and acceptable their downloading  $\beta$  ;

$Q_{HK2}$  - the power of compensating devices based on the optimal value of losses in transformers and network with voltage of 6... 10 kV that nourishes of these transformers.

The maximum reactive power is determined. It is reasonable to pass it through the transformers in transformer substation network voltage up to 1000 V

$$Q_T = \sqrt{(N_{TE} \cdot \beta_T \cdot S_T)^2 - P_P^2},$$

where:  $N_{TE}$  - the number of transformers in the group (workshop, corps),

$\beta_T$  - the expected load factor of transformers,

$S_T$  - the nominal power of transformer in a group, kV · A,

$P_P$  - the calculation of the active power of electrical consumer with voltages up to 1000 V.

The total capacity of compensating devices for this group of transformers is

$$Q_{HK1} = Q_P - Q_T,$$

where:  $Q_T$  - the calculation of the reactive power of electrical consumer with voltages up to 1000 V.

If you find that  $Q_{HK1} < Q_T$ , then it should be accepted  $Q_{HK1} = 0$ .

At the second stage an additional total capacity of compensating devices for this group of transformers of transformer substation is determined:

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$$Q_{HK2} = Q_p - Q_{HK1} - \gamma \cdot N_{TE} \cdot S_T ;$$

where  $\gamma$  - the calculation coefficient which depends on the power scheme and is determined by the formula.

For one substation:

$$\gamma = \frac{49,5}{100 + \frac{r \cdot l \cdot S_T}{F}} ;$$

here:  $l$  - the length of the supply line (with radial circuit) or the distance to the first transformer (in the main circuit), km,  $F$  - crosscut of power lines conductors, mm<sup>2</sup>,  $r$  - coefficient which depends on the supply voltage:  $r = 8(27)$  in radial circuits for 6 and 10 kV,  $r = 15(5)$  according to the backbone networks.

Each synchronous engine can be a source of reactive power, the nominal value of which is [1,2,3]:

$$Q_{CD} = P_{CD\text{HOM}} \cdot \text{tg}\varphi_{\text{HOM}} ,$$

where:  $P_{CD\text{HOM}}$  - the nominal active power of SM,

$\text{tg}\varphi_{\text{HOM}}$  - the nominal power factor.

If the load factor of synchronous engine is less than 1 (one), economically reasonable to use fully expected reactive power of synchronous engine

$$Q_{CD} = \alpha_M \cdot S_{CD\text{HOM}} ,$$

where:  $\alpha_M$  - the factor of the synchronous engine's allowable overload, which depends on its loading with active power.

$$\alpha_M = \sin \varphi_{\text{HOM}} + (1 - K_3) \cdot \left( \frac{\sin \varphi_{\text{HOM}}}{48 \cdot \sin \varphi_{\text{HOM}} - 32} + 0,4 \right) ,$$

where  $K_3$  - the load factor active power synchronous engine.

If the distortion factor is  $k_{HC}$  to 5-8% (it is typical for plants with thyristor converters), it is recommended to use the capacitor batteries together with protective reactor or filter for compensation [2, 3]. The power of capacitor battery is determined by the balance of reactive power.

Voltage of the power capacitor is

$$U_{BK} = \frac{v_{\text{MIH}}^2 \cdot U_{\text{HOM}}}{(v_{\text{MIH}}^2 - 1)}$$

where  $U_{\text{HOM}}$  - the nominal network voltage, where the protected by reactor condenser is set;  $v_{\text{min}}$  - the minimum number of harmonic.

It is necessary to provide an inductive character of the circle for the harmonic with the lowest frequency of the harmonics which are generated by nonlinear loading total. The inductive resistance of protective reactor at 50 Hz is

$$x_p \geq \frac{1,1 \cdot U_{BK.HOM}}{(v^2 Q_{BK.HOM})}$$

where  $Q_{BK.HOM}$  - reactive total power of power capacitor according to the data of a manufacturer.

If the distortion factor is more than 8% (it is typical for plants with thyristor converters) it is recommended to use the power filters of higher harmonics (hereinafter - just filters). They are calculated from the computed value  $k_{HC}$  which is based on the composition and level of harmonics. The calculation of filters should be started from the smallest harmonic filter. It is necessary to check the admissibility of filters loading with the current of proper harmonics. The total reactive power generating filters should be chosen from the condition of reactive power balance.

Let's considered the calculation of the filter which is tuned to the same frequency [2,3,4]. The voltage at the filter elements is

$$U_c = U_L + U_{\text{ж}},$$

where  $U_c, U_L$  - the voltage on the capacitor and the coil inductance,

$U_{\text{ж}}$  - supply voltage.

The power of the filter is

$$S = \frac{U_{\text{ж}}^2}{x_c - x_L},$$

where  $X_c, X_L$  - the reactance of capacitor and inductor at the basic frequency.

The characteristics of the filter which is tuned to harmonic  $v$  are

$$x_o = vL = \frac{x_c}{v}; \quad x_L = \frac{x_c}{v^2}; \quad U_L = \frac{U_c}{v^2}$$

Then

$$S = \frac{U_{\text{ж}}^2}{x_c \left(1 - \frac{1}{v^2}\right)}; \quad U_c - U_L = U_c \left(1 - \frac{1}{v^2}\right) = U_{\text{ж}}; \quad U_c = U_{\text{ж}} \frac{v^2}{v^2 - 1}.$$

The capacitors for the filters should have a low temperature coefficient of capacitance. It is needed to avoid the filter damaging due to changes in ambient temperature or capacitors self-heating. That's why we are to avoid the prolonged work with overvoltage, because it can cause a dielectric thermal destruction or its destructive ionization.

The load of the first harmonic capacitor is

$$\frac{U_c}{x_c} = \left(\frac{U_{\text{ж}}}{x_c}\right) \cdot \left[\frac{v^2}{v^2 - 1}\right]^2 = S \cdot \left[\frac{v^2}{v^2 - 1}\right]$$

Load from the higher harmonics is

$$I^2 \cdot \left(\frac{x_c}{v}\right) = \left[\left(\frac{I_v^2 \cdot U_{\text{ж}}^2}{S_v}\right) \cdot \left(\frac{v^2}{v^2 - 1}\right)\right]$$

The power losses in the capacitor are

$$S \cdot \kappa_c = \kappa_c \cdot \left[ S + \frac{I_v^2 \cdot U_{\mathcal{K}}^2}{S_v} \right] \cdot \left[ \frac{v^2}{v^2 - 1} \right],$$

where  $S$  - total load kvar;

$\kappa_c$  - factor of loss, kW / kvar.

The inductance of the filter is calculated as follows.

Load from the first harmonic is

$$\frac{U_L}{x_L} = \left( \frac{U_C}{v^2} \right) \cdot \left( \frac{v^2}{x_C} \right) = \frac{U_C}{v^2 \cdot x_C} = \frac{S}{v^2} \cdot \left( \frac{v^2}{v^2 - 1} \right)$$

Load from the higher harmonics is equal to load on the condenser.

The energy losses in inductance grow due to the surface effects or hysteresis. Besides, the magnetic nonlinearity can derange the filter. You are to keep the low magnetic flux density in the presence of magnetic core. It is better to use reactors without a magnetic core. The significant switching overvoltage can appear in the reactor coil.

It is convenient to found the power losses in the joint equivalent resistance

$$r = \frac{x_O}{Q} = \frac{x_C}{v \cdot Q}$$

The current of the first harmonic is

$$I_1 = \frac{S}{U_{\mathcal{K}}}$$

The total power losses are

$$\begin{aligned} (I_1^2 + I_v^2) \cdot r &= \frac{S^2}{U_{\mathcal{K}}^2} \cdot \frac{x_C}{v \cdot Q} + \frac{I_v^2 \cdot x_C}{v \cdot Q} = \\ &= \left( \frac{S^2}{v \cdot Q} \right) \cdot \frac{1}{S} \cdot \frac{v^2}{v^2 - 1} + \frac{I_v^2 \cdot U_{\mathcal{K}}^2}{v \cdot S \cdot Q} \cdot \frac{v^2}{v^2 - 1} = \\ &= \left[ \frac{S}{v \cdot Q} + \frac{I_v^2 \cdot U_{\mathcal{K}}^2}{v \cdot S \cdot Q} \right] \cdot \frac{v^2}{v^2 - 1}. \end{aligned}$$

## Conclusions

The cost of electric energy losses increases much faster than the cost of capacitors. It allows supplying of all induction engines with the capacitors of individual compensation. It will help to reduce the losses in electric networks of voltage up to  $Q_I$ .

The use of individual compensation capacitor allows refusing from complicated and expensive devices for power capacitors control which are used as the necessary parts of a centralized compensation on the transformer substations.

Each synchronous engine of the sugar refinery can be a source of reactive power. If the load factor of a synchronous engine is less than 1 (one), it is more reasonable to use fully expected reactive power output.

It is shown that if the distortion factor is KHC to 5-8% (it is typical for plants with thyristor converters), it is recommended to use the capacitor batteries together with protective

reactor or filter for compensation. The power of capacitor battery is determined by the balance of reactive power.

When your distortion factor is more than 8% (which is typical for plants with thyristor converters) there is the necessity to apply the power higher harmonics filters. They are calculated from the computed value of the distortion factor which is based on the composition and level of harmonics. The calculation of filters should be started from the smallest harmonic filter. It is necessary to check the admissibility of filters loading with the current of proper harmonics. The total reactive power generating filters should be chosen from the condition of reactive power balance.

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