Reactive power compensation in the combined system of sugar refinery electricity

Volodymyr Shesterenko, Iryna Sydorchuk

National University of food technologies, Kyiv, Ukraine

Keywords:
Reactive power
Compensation
Induction engine
Supply system

Article history:
Received 03.09.2012
Received in revised form 04.10.2012
Accepted 17.10.2012

Corresponding author:
Iryna Sydorchuk
E-mail:
wolis@nline.net.ua

ABSTRACT

We consider the ways of increasing operation efficiency of reactive power compensation on the plants. The basic aspects of standardized methods of power compensating devices choice, depending on the voltage and configuration of its individual elements are noticed. The expediency of each synchronous engine usage for reactive power compensation is shown. If the load factor of a synchronous engine is less than 1 (one), it is reasonable to use fully expected reactive power output. It is proved the necessity to apply the power higher harmonics filters with the distortion factor of more than 8%, which is typical for plants with thyristor converters. 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.

УДК 621.316

Introduction

The problem of reactive power compensation on the plant facilities of Ukraine began to be interesting only in the 30th of the last century. Before that both active and reactive powers were received from the generators of power-stations.

Almost all sugar factories 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.

Research methods

Power-stations of sugar refineries 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].

As the cos φ of sugar factory's thermal power station generators and of the main consumers (induction engines) coincided and were equal to 0.8, for a long time it was considered that it is not necessary to compensate the reactive power at sugar factories. But in the real conditions the load of engines often doesn't coincide with the nominal capacity. If the engine is running at full load,

$$\beta = 1, \quad \cos\varphi = \cos\varphi_{ном} \approx 0.8$$

If the load is reduced the power factor decreases:

$$\beta = 0.5, \quad \cos\varphi \approx 0.6$$

$$\beta = 0.25, \quad \cos\varphi \approx 0.4$$

In the idle run $\cos\varphi \approx 0.1....0.3$.

That's why 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

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

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 S_T is used irrationally

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

There are additional losses of voltage [1]

$$\Delta U = \frac{Qx}{10 \cdot U^2_{ном}},$$

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 discussion

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 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:

$$Q_{КУ} = Q_{М} - Q_{ГЕН} ,$$

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

As a rule:

$$Q_{КУ} = Q_{НК} - Q_{ВК} ,$$

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

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

In turn:

$$Q_{НК} = Q_{НК1} + Q_{НК2} ,$$

where: $Q_{НК1}$ - the total power of CD based on the optimal number of transformers TS and acceptable their downloading β ;

$Q_{НК2}$ - 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

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

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

β_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

$$Q_{НК1} = Q_P - Q_T \,,$$

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

If you find that $Q_{НК1} < Q_T$, then it should be accepted $Q_{НК1} = 0$.

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

$$Q_{НК2} = Q_P - Q_{НК1} - \gamma \cdot N_{TE} \cdot S_T \,;$$

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

For one substation:

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

where: 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^2, 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]:

$$Q_{СД} = P_{СД\ НОМ} \cdot tg\varphi_{НОМ} \,,$$

where: $P_{СДНОМ}$ - the nominal active power of SM, $tg\varphi_{ном}$ - 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

$$Q_{СД} = \alpha_M \cdot S_{СД\ НОМ} \,,$$

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

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

where $K_З$ - 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

$$U_{БК} = \frac{\nu^2_{мін} U_{ном}}{(\nu^2_{мін} - 1)}$$

where $U_{ном}$ - the nominal network voltage, where the protected by reactor condenser is set;

$\nu_{мін}$ - 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

$$x_p \geq \frac{1{,}1 \cdot U_{БК.ном}}{(\nu^2 Q_{БК.ном})}$$

where $Q_{БК.ном}$ - 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

$$U_C = U_L + U_Ж,$$

Where U_C, U_L - the voltage on the capacitor and the coil inductance, $U_Ж$ - supply voltage.

The power of the filter is

$$S = \frac{U_Ж^2}{x_C - x_L},$$

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 ν are

$$x_o = \nu L = \frac{x_C}{\nu}; \quad x_L = \frac{x_C}{\nu^2}; \quad U_L = \frac{U_C}{\nu^2}$$

Then

$$S = \frac{U_Ж^2}{x_C\left(1 - \frac{1}{\nu^2}\right)}; \; U_C - U_L = U_C\left(1 - \frac{1}{\nu^2}\right) = U_Ж; \; U_C = U_Ж \frac{\nu^2}{\nu^2 - 1}.$$

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 selfheating. 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

$$\frac{U_c}{x_c}=\left(\frac{U_ж^2}{x_c}\right)\cdot\left[\frac{\nu^2}{\nu^2-1}\right]^2=S\cdot\left[\frac{\nu^2}{\nu^2-1}\right]$$

Load from the higher harmonics is

$$I^2\cdot\left(\frac{x_c}{\nu}\right)=\left[\left(\frac{I_\nu^2\cdot U_{жс}^2}{S_\nu}\right)\cdot\left(\frac{\nu^2}{\nu^2-1}\right)\right]$$

The power losses in the capacitor are

$$S\cdot к_c=к_c\cdot\left[S+\frac{I_\nu^2\cdot U_ж^2}{S_\nu}\right]\cdot\left[\frac{\nu^2}{\nu^2-1}\right],$$

where *S* - total load kvar;

$к_c$ - factor of loss, kW / kvar.

The inductance of the filter is calculated as follows.

Load from the first harmonic is

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

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

$$r=\frac{x_O}{Q}=\frac{x_C}{\nu Q}$$

The current of the first harmonic is

$$I_1=\frac{S}{U_Ж}$$

The total power losses are

$$\left(I_1^2+I_\nu^2\right)\cdot r=\frac{S^2}{U_Ж^2}\cdot\frac{x_C}{\nu\cdot Q}+\frac{I_\nu^2\cdot x_C}{\nu\cdot Q}=\left(\frac{S^2}{\nu\ Q}\right)\cdot\frac{1}{S}\cdot\frac{\nu^2}{\nu^2-1}+\frac{I_\nu^2\cdot U_Ж^2}{\nu\cdot S\cdot Q}\cdot\frac{\nu^2}{\nu^2-1}=$$

$$=\left[\frac{S}{\nu\cdot Q}+\frac{I_\nu^2\cdot U_Ж^2}{\nu\cdot S\cdot Q}\right]\cdot\frac{\nu^2}{\nu^2-1}.$$

Conclusions

1. As the cosφ of sugar factory's thermal power station generators and of the main consumers (induction engines) coincided and were equal to 0.8, for a long time it was

considered that it is not necessary to compensate the reactive power at sugar factories. But in the real conditions the load of engines often doesn't coincide with the nominal capacity. If the load of engine is reduced the power factor decreases.

2. 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_1.

3. 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.

4. 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.

5. It is shown that 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. The power of capacitor battery is determined by the balance of reactive power.

6. 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.

References

1. *Шестеренко В.Є.* Системи електроспоживання та електропостачання промислових підприємств. Підручник. – Вінниця: Нова Книга, 2011. – 656 с.

2. Правила технічної експлуатації електроустановок споживачів. Затверджено наказом Міністерства палива та енергетики України від 25.10.2006.

3. Правила користування електричною енергією. Затверджено постановою НКРЕ 31.07.2005 № 910. Зареєстровано в міністерстві юстиції України 18.11.2005 № 1399/11679.

4. Патент України на корисну модель №27126, H02J 3/12. – Спосіб керування джерелами реактивної потужності промислового підприємства./ Шестеренко В.Є., Шестеренко О.В., –Опубл.25.10.2007. Бюл.№16.

5. *Mahesh K. Mishra, Avinash Joshi, Arindam Ghosh*. A new compensation algorithm for balanced and unbalanced distribution systems using generalized instantaneous reactive power theory. – Electric Power Systems Research, Volume 60, Issue 1, 30 November 2001, Pages 29-37.