Optimization of power supply system at food production enterprises

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Keywords:

Reactive power
Powersupply
Compensation

Article history:

Received 31.03.2014
Received in revised form 13.05.2014
Accepted 30.06.2014

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Abstract

Introduction. Improve the efficiency of reactive power compensation in food factories advisable by applying a two-level system control sources of reactive power.

Materials and methods. It is research developed a comprehensive compensation system, provides a shift in the emphasis of reactive power sources capacity management: from decentralizing to ensuring the system commitment in solving problem that is conceptually related to the optimization of power consumption mode at the industrial enterprises.

Results and discussion. Reactive power consumption during the day is uneven.

Hierarchical structure and high complexity is inherent to the system of reactive power compensation at the enterprises. During the day the generated power should overlap not less than for 80-90% with schedule of consumed reactive power. It should be noted that due to this principle of control static source of reactive power with combined regulation has the same performance as the smooth and stepped source of reactive power, but unlike the stepped source of reactive power, reactive power allows you to regulate smoothly, and unlike smoothly regulated sources of reactive power do not cause significant distortions of voltage waveform in the power supply system. Operation mode of all reactive power sources must meet schedule of reactive power consumption. The proposed systematic approach to compensation allows improving the economic performance of all reactive power sources significantly. To improve the power factor condenser units are used.

Conclusions. The results recommended for use in the food industry to improve the efficiency of electricity.

Introduction

The main production of food industry enterprises occupies small territory (excluding pumping stations). They have power voltage of 35 ... 10 kV and high-voltage distribution network of 6 ... 10 kV. Power transformers at these plants usually exceed 750 kV·A, thus reactive power compensation needs to be provided.

Power supply organization sets the mode of company's compensating devices work. Capacity of unregulated power batteries is taken as the least reactive load network. Typically, multi-stage regulation should be used. Reactive power adjustment is an ideal method from many points of view. The controller turns on in the power network node. Condensing unit can be multisection and regulation can be maintained with sufficient accuracy according to schedule of reactive load.

The criterion of rational solution to the problem of reactive power compensation is the minimum of stated expenses. They include costs of compensating, regulatory and related devices, as well as expenses on reactive power regulation and its transfer through the power supply system elements. These expenses include components that do not depend on the value of reactive power, thus there was developed a methodology of determining compensating devices capacity that does not require considering the absolute costs of power supply system elements [1,2,3].

Reactive power consumption during the day is uneven. Operation mode of all reactive power sources must meet schedule of reactive power consumption. Power of compensating devices should be changed according to schedule of reactive power consumption. The use of individual compensation capacitor helps to eliminate the use of complex and expensive devices of capacitor installations power control that are needed to complete the centralized compensation installations in transmission substations [1,2,3].

Materials and methods

Hierarchical structure and high complexity is inherent to the system of reactive power compensation at the enterprises. At the industrial enterprises capacitors and synchronous engines are used to compensate reactive load [2,3]. The most widely spread are capacitors. Small mass, absence of rotating parts, minor loss of energy, simplicity of maintenance, safety and reliability in exploitation allow the use of capacitors for reactive power compensation at all levels of power supply [Patent of Ukaine № 34943, Method of connecting individual capacitor condensators having reactive power compensation of induction motor. Shesterenko V.Y., Siryj O.M., Baluta S.M., Maschenko O.A. Published on 26.08.2008]. Synchronous engines are widely used at the enterprises to drive devices that do not require speed control. Engines can run with advanced power factor and compensate reactive power of other power receivers. Compensating ability of engine is determined by the load on its shaft, voltage and excitation current.

In shops with lots of low-power engines individual compensation is not always effective. In such cases, a centralized compensation with capacitors installation near the transformer substation plant is used.

Reactive power of j station network

$$Q(t)=\sum_{j=1}^{n}\left[Q_j(t)-Q_{KY\,i}\right], \tag{1}$$

where $Q(t)$ - reactive power of load, Q_{KY} - power capisity of condensing units.

For chosing condensing units their function should be studied.

$$f=\sum_{i=1}^{n} r_i\left[\sum_{j=1}^{i}(Q_j - Q_{KY\,j})\right]^2+\sum_{j=1}^{i}\sum_{e=1}^{i}K_{je}, \tag{2}$$

where Q_j - mathematical expectation of reactive power of load in j–station, K_{je} - correlation moment of random values $Q_j(t)$ and $Q_e(t)$.

Losses of electrical power

$$\Delta W_i=\frac{r_i}{U_{nom}^2}\cdot\sum_{k=1}^{\omega}T_k\left[M_k(P_i^2)+M_k(Q_i^2)\right], \tag{3}$$

where $M_k(P_i^2)$ - mathematical expectation of active power, $M_k(Q_i^2)$ - mathematical expectation of square reactive power, ω - number of intervals of stationarity and ergodicity, T_k - duration of these intervals.

If there are few condensing units at the enterprise, multi-stage regulation of total reactive power is applied by means of different time enabling or disabling individual cells according to the load schedule. Total capacity of unregulated sources should not exceed the consumption power in the hours of low load, because reactive power should not be transferred from the enterprise power network into power supply system.

The analysis of modern Ukrainian and foreign scientific papers on the subject of reactive power compensation is conducted and existing regulatory systems of reactive power are summerised and evaluated.

Results and discussion

Regulation of reactive power sources capacity may be conducted by: voltage, load current, reactive power load, time of day and external signal [2,3].

Let us consider these methods in detail. Adjustable voltage is very effective way if the supply lines have high inductive reactance. This applies mainly to rural power supply systems, where overhead power lines dominated. The method can improve the quality of voltage for power receivers.

Regulation by full power is implemented very simply. Capacitors are disabled while reducing load. If compensation is done at substation power leads, the efficiency of the method decreases as line's load may be different. In addition, the decrease in the load of industry equipment leads to cos φ fall. The method can be recommended for common customers.

Regulation by reactive power is an ideal method from many points of view. The controller turns on in the network power node. Capacitor unit can be multisection and regulation may be maintained with sufficient accuracy according to reactive load schedule.

Regulation by time of day is a simple and effective way of control. The signal for compensating device sections switching is sent by a timer with appropriate program. The program is developed on the basis of retrospective analysis of load schedule. If the actual schedule will be different from the developed model, the method can give significant errors in regulation.

Regulation by external signals and reactive power is provided by the system of reactive power complex compensation. The system allows you to maintain the optimal flows of reactive power in the electrical power supply system elements, to optimize the flows in real time, to use company compensating devices with maximum effectiveness, since disabling of compensating devices in the times of reactive power shortage is not allowed in the node of power supply system.

The power of unregulated capacitor batteries is taken by the least reactive load of power supply system. It is usually necessary to apply multi-stage regulation.

The basic principle of smooth regulation is laid down in the change of conduction angle or time during which the thyristor remains open and passes current. As the conduction angle decreases, there is also a decrease in the effective value of the first harmonic of current, flowing through the capacitor, and so does the capacity that is given by capacitor battery to the power supply system. Change of thyristors conduction angle in a circle with a capacitor battery cannot be conducted by the change of control angle, that is, by the change in the time of their discovery. This regulation is known to be accompanied by significant current free throws and provides almost no effect on the regulation. Smooth regulation of capacitor battery, equipped with a thyristor switch, is achieved by artificial disabling thyristors. Terms of thyristor disabling are formed when the voltage is negative or cathode potential is greater than anode potential. To perform the specified correlation of value potentials special device is used - the source of current pulses for force close of thyristors. The following technical indicators of capacitor battery that is controlled by thyristors are considered to be the most significant:

1) the range of reactive power or the capacity of reactive power source to change this power gradually from minimum to maximum;

2) performance or the time during which the reactive power source is able to change generated capacity from one value to another;

3) harmonic components of total current that characterize the quality of compensation and filtering harmonic power of generated reactive power source.

The listed characteristics of above discussed reactive power sources are interrelated and depend on the network in which the reactive power source is turned on. Thus, expanding the range of regulation causes the deterioration of the harmonic composition of reactive power source current. This effect is also reached by the growing correlation between installed capacity of reactive power sources and output of short circuit at the point of its installation, which can contribute to creation of resonance events. For smooth regulation, there is practically reasonable limited range, which has as its capacity upper and lower limit [2,3,4].

Synchronous engines are used to drive mechanisms with long operating hours, including pumps, fans, etc. National electrical industry enterprises produce synchronous engines with the rated advancing power factor equal to 0.9 and can be used as a source of reactive power. In this respect technical possibility to use synchronous engines is limited to the greater reactive power that it can generate without breaching the conditions of acceptable stator and rotor heating. Synchronous engines allow both to vary infinitely reactive power that is generated by changing excitation current and to keep it constant. The use of synchronous engines as sources of reactive power can reduce the amount of other compensating devices. When conducting technical and economical comparison of synchronous engines with other sources of reactive power, defining active power is required. The bulk of the costs will be determined by the cost of active power losses (which is the disadvantage of synchronous engines).

Consumer of electricity is obliged to maintain the level of reactive power in accordance with the power supply system requirements. With this reactive power is set and controlled between maximum and minimum in the power supply system, Q_{e1} and Q_{e2} respectively [2,3]. Intermediate modes are not controlled, and the consumer can exploit the compensating devices to his liking during 60-80 % of the day time. Thus, the total power of compensating devices in industrial enterprise is defined by power supply system, and the way of distributing reactive power sources in the nodes of enterprise power supply system, their operation time and control options can be selected according to the adopted optimization criteria.

In modern schemes the methods of distributing compensating devices in power supply system nodes are used: in proportion to the reactive load of nodes, with a minimum of aggregate costs and minimum of energy loss [2,3]. Due to the high degree of reactive power compensation at the projected enterprises, and the use of multisection capacitor units that are usually installed on the transformer substations, the latter two methods do not provide large benefits, while labor costs for their calculations are one level higher. Method of capacitor batteries power control according to their voltage is justified only in nodes where there is a shortage of reactive power. Due to the fact that there is the tendency to full compensation of reactive power at the nodes of its consumption, the method of regulation by reactive current should be considered progressive.

Local regulation through individual regulators allows minimizing energy losses in consumer power supply systems that are caused by reactive power overflows. However, this type of regulation does not allow taking into account working hours of the power supply system and consumer's capacity units may be disabled during periods of reactive power shortage in power supply system.

During the day the generated power should overlap not less than for 80-90% with schedule of consumed reactive power. It is always necessary to provide disabling unregulated compensating devices at weekends and during non-working hours. Disabling can be done manually or automatically. The number of capacitor sections should be chosen depending on the nature of the reactive power schedule.

Step-adjustable capacitor units are made with different number of adjustable sections. These units of stepped adjustment allow you to maintain the value of the parameter that is set to the measuring body of control unit within set limits. It is their added advantage in comparison to unfixed shunt capacitor batteries. The disadvantage of such devices is the inability for accurate setting regulation, because battery power changes discretely, increasing or decreasing at once in value of one section capacity.

Step-adjustable source of reactive power is a capacitor unit, consisting of a number of capacitors, connected to total power leads over contactors or semiconductor keys (counter-parallel turned on thyristors). Power supply organization sets working mode for company compensating devices. For enterprises with more uneven load demand automatic regulation should be provided: excitation of synchronous engines, the power of the capacitor batteries.

Combined regulation of capacitor batteries is based on a combination of the two methods of regulation, namely stepped and smoothly. This combination allows the use their best qualities and get new top features of regulated static source of reactive power [2,3]. On the basis of this lies the combination of several degrees of capacitor batteries that are controlled by thyristors, with a degree within which reactive power varies smoothly. The method of reactive power smooth change varies, it is either a capacitor battery that is enabled by thyristor switch and disabled with a help of special source of controlled current pulses, or it is permanently switched capacitor battery, the power of which is equal to single capacity of degree, parallel to which the same power reactor controlled by thyristors is enabled. This enabling allows you to gain power smoothly from zero to the boundary equal to the degree of power, and then using the appropriate system control and synchronization allows you to enter the first degree, at the same time reducing to zero power of smoothly regulated degree. In between degrees the power of static compensator is equal to power of lower degrees and power of smoothly regulated degree. Reduction of power is implemented in the same way. In case of forcing, all degrees are enabled and smoothly regulated degree reaches its maximum value. If you need a full reset of received power, control and synchronization system disables both static compensator degree and planned-regulated section.

It should be noted that due to this principle of control static source of reactive power with combined regulation has the same performance as the smooth and stepped source of reactive power, but unlike the stepped source of reactive power, reactive power allows you to regulate smoothly, and unlike smoothly regulated sources of reactive power do not cause significant distortions of voltage waveform in the power supply system. Among the disadvantages of this regulation method the need for carefully organized systems of control and synchronization may be noted.

Great hopes are now set on centralized regulation, which is performed by connecting condenser units to automated systems of supervisory control in power supply system. But the system requires a considerable amount of sensors and connecting channels that is a challenging task. In addition, centralized regulation takes into account primarily the interests of power supply system and can lead to an overestimation of energy losses in the individual consumers' power supply systems.

Optimality criterion in efficient management of compensation is minimum power losses. A significant reserve of efficiency increase may be a system of complex reactive power compensation that is created on the basis of modern technical and computational tools [2,3]. The system allows you to change the emphasis in management of compensating devices capacities from decentralization to ensuring systematic commitment of solving problem that is conceptually related to the optimization of power consumption mode at the industrial enterprise.

System of reactive power complex compensation takes into consideration the requirements of power supply system at the interface of power supply systems and consumers' ones, and simultaneously considers power regulation of high-voltage capacity units, batteries for voltage lower than 1000 V, the level of reactive power, which is produced by synchronous engines. To improve the power factor condenser units are used. By means of the reactive power controller we change the reactive power of capacitor batteries, compensating devices (or synchronous engines) [1, 2, 3].

For minimizing losses and accurate fulfillment of power supply system requirements with respect to reactive power, signal that comes to the regulators in the lines of power supply system grows faster over time. Thus here occurs switching of low-power capacitor installations, causing changes in the power factor. If the new factor meets the requirements of power supply system as to the amount of consumed reactive power, power at the output of voltage regulator drops to zero and the signals are also reduced.

Efficiency ratio of compensatory devices use:

$$\Psi = \frac{\sum_{1}^{n} Q_i t_i}{T\sum_{1}^{n} Q_i}, \qquad (4)$$

where Q_i - reactive power of compensating devices, quarter;

t - the duration of the compensating device work during the year, hours;

T - the duration of the company work during the year, hours.

By changing the efficiency ratio of reactive power sources use it is possible to increase performance of low efficiency devices.

To choose compensating devices it is enough to minimize the function

$$f = \sum_{i=1}^{n} r_i \left[M^2(Q_i) + D(Q_i) \right] \qquad (5)$$

where $M(Q_i)$ - mathematical expectation of Q on i-site of power supply system, $D(Q_i)$ - dispersion of this power value.

Maximum capacity of compensating devices

$$Q_M = M(Q_\Sigma) + \beta\delta_2 \ , \qquad (6)$$

where $M(Q_\Sigma)$ - mathematical expectation of reactive power, consumed in power supply system, δ_x - the standard deviation of power, β - multiplicity of dispersion extent.

By reducing the transmitted reactive power, losses of active power are reduced to 0.12 kW / kVAr and depend on the distance to a power source. During compensation it is necessary to consider the following general requirements: unlike active power reactive one can be generated at any point in power supply system; approximation of reactive power sources to consumers facilitates unloading of the system; reactive power balance must be maintained for all nodes of electric power supply.

When switches in the power lines are not enough, in some time the signal will reach the level that will cause switching in the degree of capacitor installation on the main site (or changes in the operating mode of synchronous engines). After such a switch commutation of low-power installations becomes possible in the lines of power supply system for more accurate support of reactive power required value. If the signal meets the requirements to connect additional section of battery and $tg\varphi$ in line is close to zero, connection will not happen. Additional sections will be connected only in those lines where own reactive power is not completely offset. Thus, close to optimal power factor will be hold up in lines of power supply system. Only when all the capacitor installation power on the main site is used, the growth of signal will be possible to such a level that the condenser units in lines will switch regardless of signal of local deliverer [2, 3].

A significant advantage of two-level method of reactive power sources regulation is complex control of reactive power flow and simultaneous regulation of all sources of reactive power at the enterprise. However, in contrast to the remote control, where according to the signal from control point switching is done, regardless of $tg\varphi$ in branch, this method proposes to take into account the level of two signals - from the local sensor and from starting regulator. Switching of capacitor batteries sections occurs selectively, in some branches, and only under certain signal levels. Reactive power consumption during the day is uneven. Operation mode of all reactive power sources must correspond to the schedule of reactive power consumption. The smallest specific losses are typical for condenser battery with voltage above 1000 V. The greatest occur in low power synchronous engines. The smaller are losses in compensating devices, the better it is to use them in continuous working mode and vice versa, compensating devices with larger losses should be connected transitorily. For example, to cover reactive loads in the hours of maximum power, and also to cover peaks in the graph [5-14].

Thus, in the long-term, baseline mode it is better to use high-voltage compensating devices. Regulated compensating devices with voltage of 0.4 kV and synchronous engines with low losses (high power, speed) - to cover the main graphic, synchronous engines with high specific losses - only to offset short-term peaks in the graph.

The system is done on the basis of the NOVAR type controller, Czech made. The work is introduced in Dnipropetrovsk Dairy. Result of implementation is to reduce energy losses by 23% and the amount of reactive power payment by 78%.

Conclusions

1. Reactive power consumption during the day is uneven. Operation mode of all reactive power sources should correspond to the schedule of reactive power consumption. Compensating devices power should be changed according to schedule of reactive power consumption.
2. Hierarchical structure and high complexity is inherent to the systems of reactive power compensation at the enterprises. Optimality criterion in efficient management of compensation is minimum power losses.
3. Significant potential for raising the efficiency of the system can be the system of complex compensation of reactive power that is created on the basis of modern technical and computational tools. The system allows you to change the emphasis in management of compensating devices capacities from decentralization to ensuring systematic commitment of solving problem that is conceptually related to the optimization of power consumption mode at the industrial enterprise.
4. The system of complex compensation allows you to maintain the flow of reactive power in the elements of power supply system at the optimum level, with maximum effect to use set sources of reactive power, as far as disabling of compensating devices is not allowed in times of reactive power shortage in the power supply system node.

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