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ACHIEVING ENERGY SAVING BY COVERING THE REACTIVE POWER IN THE OPERATION OF ASYNCHRONOUS MOTORS USED IN AGRICULTURAL ENTERPRISES

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Abstract:

This article provides information on the series and nominal values of short-circuited rotor three-phase asynchronous motors used in agricultural enterprises. Also, the amount of active and reactive power consumed by the agricultural enterprise in 2022-2023 was analyzed, and an offer was made for compensation of reactive power.

Keywords asynchronous motor, active, reactive and apparent power, power factor, load, power factor, line losses, motor efficiency, power quality.

INTRODUCTION. Currently, the agricultural sector in our Republic is improving and developing more and more. Three-phase asynchronous motors are the main consumers of electric energy used in agricultural enterprises. 70-80% of the produced electricity is used in electric motors[1].

Nevertheless, the main part of the main reactive power consumption in electric motors occurs in asynchronous motors. Taking this into account, compensating the reactive value exceeding the norm in the asynchronous motor used in agricultural equipment and $\cos\varphi$ increasing is considered one of the main problems [2].Therefore, during the operation of electrical devices used in agriculture, a number of measures should be taken to start the asynchronous motor of the devices, as well as to stabilize the supply voltage [3]. A lot of reactive power is consumed during the operation of the asynchronous motor of electrical devices used in agricultural enterprises. In this case, the following measures are taken in order to increase the power coefficient of the asynchronous motor and reduce the power loss in electrical equipment during the operation of the asynchronous motor, which is mainly used in devices [4]:

METHODS. The dynamics of reactive power change is expressed by the reactive power coefficient [5]:

$$tg\varphi = \frac{Q}{P}, \tag{1}$$

here $Q = U \cdot I \cdot \sin\varphi -$ reactive power, $P = U \cdot I \cdot \cos\varphi -$ active power, $\varphi -$ the angle between the voltage and current vectors. Although $tg\varphi$ A more power factor is used to fully describe the production modes of electric consumers:

$$\cos\varphi = \frac{P}{U \cdot I}, \tag{2}$$

here $S = U \cdot I$ – full power.

Power factor is a coefficient describing how much of the full power is used for useful work. If the power factor of the consumer decreases, the full power in the network increases, i.e.[5,6]:

$$S_T = \frac{P_P}{\cos\varphi}, \tag{3}$$

here P_p – the asset power of the consumer and U in unchanged values of indicators

$$I_P = \frac{P_P}{\sqrt{3} \cdot U \cdot \cos\varphi} \tag{4}$$

the value of the reactive current increases, which leads to an increase in operating costs, that is, an increase in the loss of electrical energy in the network:

$$\Delta P = 3 \cdot R \cdot I_P^2 = \frac{R \cdot P_P^2}{U^2 \cdot \cos^2 \varphi}, \qquad (5)$$

here $R -$ active resistance of one phase of a three-phase device.
To determine the power factor of AD.
The power factor of AD is determined by the following expression[3]:

$$\cos \varphi = P / S = P / \sqrt{P^2 + Q^2} \qquad (6)$$

From this $P = M \cdot \omega_0 + 3 \cdot I_1^2 \cdot R_1$ - active power;

$Q = 3 \cdot I_\mu^2 \cdot x_\mu + 3 \cdot I_1^2 \cdot x_1 + 3 \cdot I_2^2 \cdot x_2$ -reactive power;

$$S = \sqrt{P^2 + Q^2} \text{ - full power.} \qquad (7)$$

$\cos \varphi$ = 1.0, it is usually necessary to connect a battery of additional capacitors. Calculation of the capacity of the capacitors required for reactive power compensation is carried out by the following formula:

$$C = \frac{P}{\omega \cdot U^2} \cdot (tg\varphi_1 - tg\varphi_2), \qquad (8)$$

Here $\mathrm{P} = I_a \cdot U -$ active power of the electric consumer, $\omega = 2\pi f -$ angular frequency, $U -$ mains voltage, $\varphi_1, \varphi_2 -$current vector before and after reactive power compensation $\dot{I}$ with mains voltage U the angles between The capacity of capacitor batteries is determined by the following formula [7]:

$$Q = \mathrm{P} \cdot (tg\varphi_1 - tg\varphi_2). \qquad (9)$$

In industrial plants, the main consumers of reactive power are three-phase asynchronous motors, transformers, power transmission lines and fluorescent lamps. Asynchronous motors consume 65-70% of reactive power, three-phase transformers in the power supply system consume 15-25%, power transmission lines, reactors, fluorescent lamps and other consumers consume 5-40%. The dynamics of reactive power change is expressed by the reactive power coefficient:

$$tg\varphi = \frac{Q}{P}, \qquad (10)$$

here $Q = UI \sin \varphi -$ reactive power, $P = UI \cos \varphi -$active power, $\varphi -$ the angle between the voltage and current vectors.
Although $tg\varphi$ A more power factor is used to fully describe the production modes of electric consumers:

$$\cos \varphi = \frac{P}{UI}, \qquad (11)$$

here $S = UI$ – full power.

The power factor is a coefficient describing how much of the full power is used for useful work. If the power factor of the consumer decreases, the total power in the network increases, that is:

$$S_{\mathrm{T}} = \frac{P_{\mathrm{P}}}{\cos \varphi}, \qquad (12)$$

where PP is the active power of the consumer and U is in the unchanged values of the indicators

$$I_P = \frac{P_p}{\sqrt{3} \cdot U \cdot \cos \varphi}, \qquad (13)$$

the value of the reactive current increases, which leads to an increase in operational costs, that is, an increase in the waste of electrical energy in the network:

$$\Delta P = 3RI_P^2 = \frac{RP_P^2}{U^2 \cos^2 \varphi}, \qquad (14)$$

where R is the active resistance of one phase of a three-phase device.
Asynchronous motorsto determine the power factor of .
Asynchronous motorsThe power factor of is determined by the following expression.

$$\cos \varphi = P / S = P / \sqrt{P^2 + Q^2} \qquad (15)$$

from which P = Mω0+ 3 $I_1^2 R_1$ - active power; (16)

$$Q = 3I_\mu^2 x_\mu + 3I_1^2 x_1 + 3I_2^2 x_2$$ -reactive power; (17)

$$S = \sqrt{P^2 + Q^2}$$ - full power. (18)

If the power coefficient is sosφthe smaller it is, the more reactive power AD takes from the network and loads it with additional current and creates additional losses in it. Power factor largely depends on the load of asynchronous motors. In the mode of pure operation of asynchronous motors, the power factor is not very large, because the proportion of reactive power is greater than the active power at full power. With an increase in the load of asynchronous motors, its sosφsi also increases and reaches its maximum value in the nominal load area of asynchronous motors.

Asynchronous motors are the main consumer of reactive power in the power supply system (its consumption is equal to 70-80% of the total volume), so increasing their power factor is an important technical and economic task. Methods of increasing the power factor of asynchronous motors. Currently, the following main measures have been developed and used to increase the power factor of asynchronous motors:

In addition, compensation of the power factor by artificial means is carried out by capacitors, synchronous motors, compensators, transverse filters and semiconductor static reactive energy sources.

Calculation of the capacity of capacitors required for reactive power compensation is carried out by the following formula:

$$C = \frac{P}{\omega U^2}(tg\varphi_1 - tg\varphi_2), \tag{19}$$

Here $P = I_a U$ − active power of the electric consumer, $\omega = 2\pi f$ − angular frequency, U − mains voltage, φ_1, φ_2 − current vector before and after reactive power compensation $\dot{I}$ and the angles between the network voltage U. The capacity of capacitor batteries is determined by the following formula:

$$Q = P(tg\varphi_1 - tg\varphi_2). \tag{20}$$

The installation of its own calculated reactive power compensating devices for each individual consumer frees the power supply networks from excessive reactive power loading and provides maximum economic efficiency.

RESULTS. Comparative descriptions of the energy performance of standard and new series induction motors with a power of 0.75 kW and 18.7 kW are given. This is achieved due to the increase in fig in asynchronous motors to reduce Chuck resistance and power losses in the magnetic system. Stator and rotor cores are made of high quality steel; stator and rotor cores have increased copper and aluminum content; the dimensions of the lamellas and the dimensions of the air groove between the stator and the rotor are given to optimal values.

Table 1. An analysis of power losses in standard and new series asynchronous motors used in agriculture is presented

No	Basic energy waste	Standard asynchronous motor (%)AIR71A2,AIR160M4	New series asynchronous motors (%) M2AA, EFF3, EFF2, EFF1
1	Stator and rotor losses	50	47
2	Waste in the magnetic field	30	25
3	Mechanical power losses	5	5
4	Additional power consumption	15	8
5	Full power consumption	100	85

Table 2. Comparative characteristics of the energy indicators of standard and new series asynchronous motors used in agricultural enterprises are shown

Nominal power of the motor, kW	Standard asynchronous motor AIR71A2,AIR160M4		New series of asynchronous motors M2AA, EFF3, EFF2, EFF1	
	FIC, %	cos φ	FIC, %	cos φ
0.75	75	0.76	81.5	0.84
18.7	89	0.86	91.0	0.865

In addition to the high energy performance of these engines, it heats up less (which extends the life of the engine), makes less noise during operation, and the power factor does not depend on the quality indicators of the voltage. True, the price will be higher than standard engines, but it will pay for itself in two years of electricity saved.

Currently, the French Jeumont-Schneider company produces FNBB, TNBB, RNBB, ISTAND, TNCB, PNCB series asynchronous motors, as well as DSOR, DKOK and other series asynchronous motors manufactured by Helmke and Brown. The German company Boveri, as well as dozens of leading companies in the field of electromechanical production, for example, Companysal Electric (USA), have 7-8% and 18-21% higher than the standard coefficient motors.

Table 3. Reactive power in asynchronous motors of agricultural enterprises statement of measures for compensation

Results	**Q. kVar 1st month**	**soph 1st month %**
Reactive power when the compensation device is not installed results	49920	0.85
Reactive power results after installation of the compensation device	32 777	0.93

The rated power factor for most induction motors is sosφ_n ≈0.8÷is equal to 0.9. For these values Q = (0.1÷0.75)R, that is, asynchronous motors 0.1 from the network for each kilowatt of active power÷Takes 0.75 kilovar of reactive power.

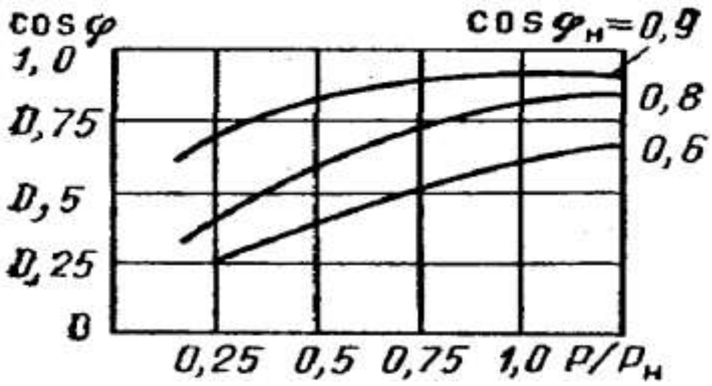

Figure 1.Agricultural enterprises4A series asynchronous motors power factor dependence graph

During the operation of asynchronous motors used in agricultural enterprises, the power coefficient of the motor (sosφ) is smaller, the more reactive power the asynchronous motor takes from the network and loads it with additional current and creates additional losses in it. The power factor depends mainly on the load of the asynchronous motor. In the idle mode of an induction motor, the power factor will not be very large, since the proportion of reactive power compared to active power at full power is greater. As the asynchronous motor load increases, its power coefficient (sosφ) also increases and reaches its maximum value in the nominal load area of the asynchronous motor. Power coefficient for asynchronous motors used in agriculture (cosφ) is shown in Figure 1.

The next figure, Figure 2, shows the relationship between different rated powers and the number of pairs of poles, R, and the rated power factor. It can be seen from the figure that as the nominal power of asynchronous motors used in agricultural enterprises increases, the nominal power coefficient (sosφ_n) also increases. Also, asynchronous motors with a small pair of poles, that is, high speeds, will have a larger nominal power factor. Asynchronous motors used in agricultural enterprises are the main consumer of reactive power in the power supply system, i.e. (its consumption is equal to 70-80% of the total volume), therefore, increasing their power factor is one of the important technical and economic tasks. consists of The methods of increasing the power factor of asynchronous motors used in agricultural enterprises are as follows.

1. Replacement of low-load asynchronous motors used in agriculture with small power motors. When replaced by small-power induction motors, the motor operates at (or close to) rated power at its shaft, where cosφwill also be higher. It can be added that the efficiency of the asynchronous motor will also be greater.

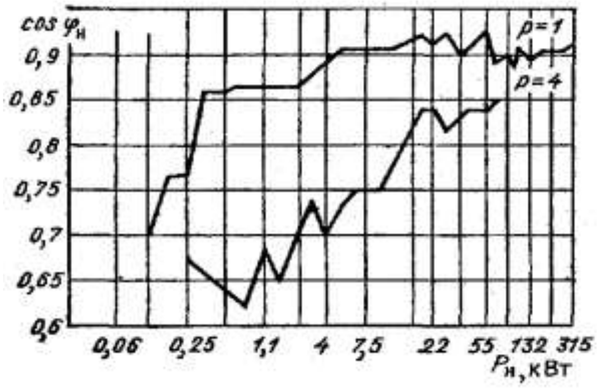

Figure 2. Used in agricultural enterprises graph of values of nominal power coefficients of series 4A asynchronous motors at different speeds and nominal powers

Calculations show that if the average load of asynchronous motors used in agricultural enterprises is less than 45% of its nominal power, then it is advisable to replace it with smaller power asynchronous motors. If the loading of asynchronous motors is more than 70%, it is not advisable to replace it, if the loading of asynchronous motors is in the range of 45-70%, it is necessary to prove the desirability of replacing them using additional technical and economic calculations [8,9].

2. Limiting the time of operation of asynchronous motors used in agricultural enterprises in the idle mode. In this mode, the small power coefficient of asynchronous motors (cosφ), if this mode lasts for a long time, then it is advisable to disconnect the asynchronous motors from the network.

3. Voltage reduction of asynchronous motors working with a small load of asynchronous motors used in agricultural enterprises. When the voltage supplying asynchronous motors is reduced, the reactive power it receives also decreases, and the power coefficient (cosφ) increases. The possibility of implementing this method is related to the reconnection of the stator windings of the asynchronous motor from the "delta" scheme to the "star" scheme. This causes the voltage in each phase winding to decrease three times.

4. Replacement of asynchronous motors used in agricultural enterprises with a synchronous motor (SM) (when the conditions of the technological process of the working machine allow it). SM, as you know, has a very valuable property: it is the power coefficient (cosφ) can work in the =1 mode (that is, it does not receive reactive power from the network) and when necessary, it generates reactive power to the network [10,11,12].

In addition, compensation of the power factor by artificial means is carried out by capacitors, synchronous motors, compensators, transverse filters and semiconductor static reactive energy sources. It is recommended to install capacitors near asynchronous motors, which act as reactive power generators.

Figure 1.3, a shows the equivalent electrical circuit of one phase of an asynchronous motor used in agricultural enterprises. 1.3, b is the inductive component of the load current in the vector diagram constructed for this equivalent electrical circuit in Fig. $\dot{I}_1$ capacitance current generated by capacitor batteries $\dot{I}_C$ is shown to be compensated with As can be seen from the vector diagram, the angle after connecting the capacitor bank φ the value of decreases ($\varphi_2 < \varphi_1$), power coefficient $\cos\varphi$ and increases.

In most cases, it is not necessary to fully compensate the reactive power, because the power coefficient is cos φ = 0.95 is sufficient, and the creation of a small reactive current does not cause additional power loss. Power factor cos φ = 1.0, it is usually necessary to connect a battery of additional capacitors. Calculation of the capacity of capacitors required for reactive power compensation is carried out by the following formula:

$$C = \frac{P}{\omega U^2}(tg\varphi_1 - tg\varphi_2),$$

Here $\mathrm{P} = I_a U$ – active power of the electric consumer, $\omega = 2\pi f$ – angular frequency, U – mains voltage, φ_1, φ_2 – current vector before and after reactive power compensation $\dot{I}$ and the angles between the network voltage U. The capacity of capacitor batteries is determined by the following formula:

$$Q = \mathrm{P}(tg\varphi_1 - tg\varphi_2).$$

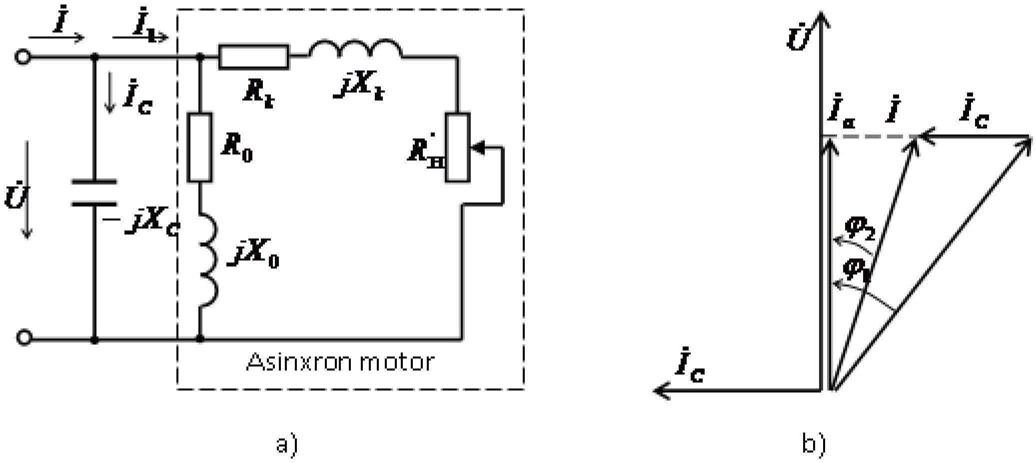

Figure 3. Asynchronous motors of agricultural enterprisesphase equivalent switching scheme (a) and vector diagram (b) [4]

An example. Asynchronous motors used in agricultural enterprisespower factor cos φ Cos φ = 0.93, it is necessary to determine the power of the compensating device consisting of capacitors. Network voltage 380/220V active energy consumption during the year Wy = 1300 000 kWh, tY = 4100 s.

The solution.The average active power during the year is P = Wy /ty =1300000/ 4100 = 317.1kW. The power of the reactive power compensating device $Q = P(tg\varphi_1 - tg\varphi_2) = 31701(0{,}85 - 0{,}39) = 145{,}9k\ \mathrm{var}$. A 150 kvar complete condenser device is selected from the catalog [4].

Installation of its calculated 1 reactive power compensating devices for each individual consumer (Fig. 1.4) relieves power supply networks from excessive reactive power loading and provides maximum economic efficiency [4].

Installation of batteries of capacitors calculated for several groups of consumers leads to effective use of these capacitors.

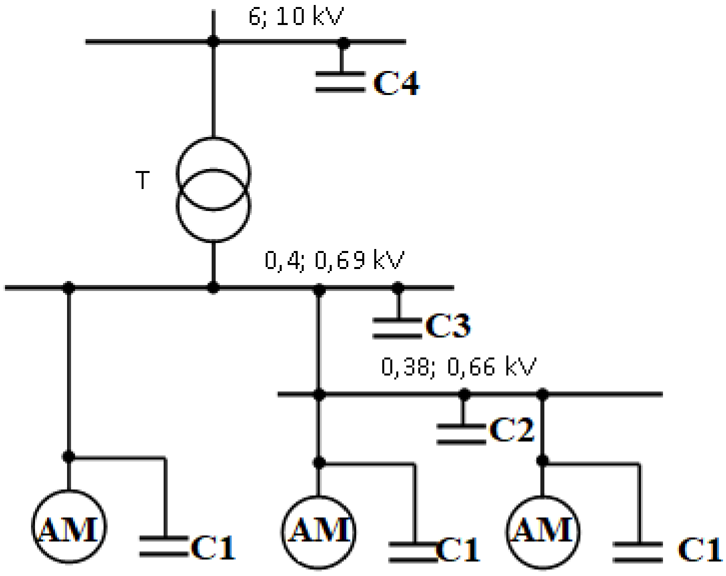

Figure 4. In asynchronous motors of agricultural enterprisesoptions for installing static capacitors:1– 4 – capacitor batteries

If the start capacitor is not accidentally disconnected after the motor reaches rated speed, the phase shift in the windings will decrease, it will no longer be optimal, and the stator magnetic field will become elliptical, which will degrade the performance of the motor. It is extremely important to choose the right starting and operating capacities in order for the engine to work efficiently.

The figure shows typical circuits for switching on capacitor motors used in practice. For example, consider a two-phase squirrel-cage motor whose stator has two windings to power two phases A and B.

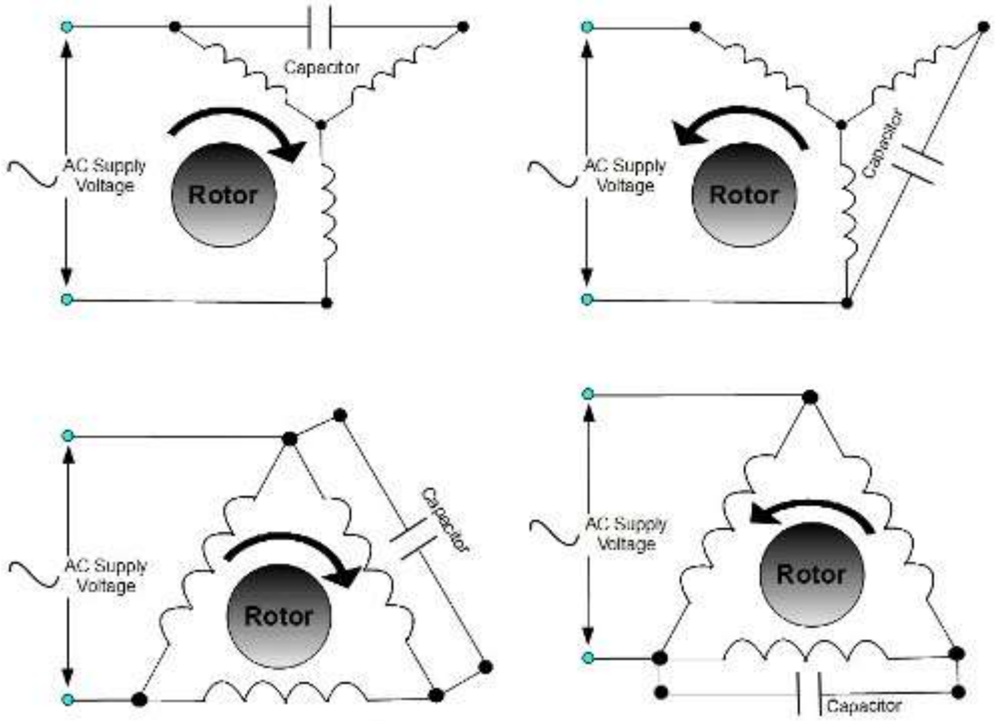

Figure 5. Two-phase motor with squirrel-cage rotor, whose stator has two windings to supply two phases A and B.

A capacitor C is included in the circuit of the additional stator phase, so the currents IA and IB flow in both stator windings in two phases. By the presence of a capacitance, a phase shift of the currents IA and IB of 90 ° is achieved.

The vector diagram shows that the total current of the network is formed by the geometric sum of the currents of both phases IA and IB. By selecting the capacitance C, such a combination with the inductances of the windings is achieved so that the phase shift of the currents is exactly 90 °.

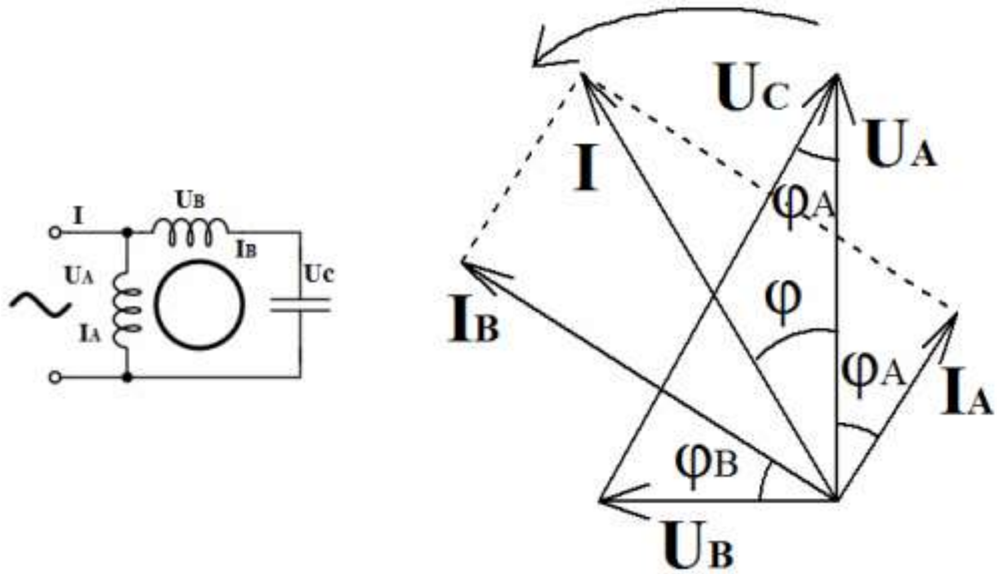

Figure 6. Vector diagram

The current IA lags relative to the applied mains voltage UA by an angle φA, and the current IB lags by an angle φB relative to the voltage UB applied to the terminals of the second winding at the current moment. The angle between the mains voltage and the voltage applied to the second winding is 90°. The voltage across the capacitor UC forms an angle of 90° with the current IB.

The diagram shows that full compensation of the phase shift at φ = 0 is achieved when the reactive power consumed by the motor from the network is equal to the reactive power of the capacitor C. The figure next to it shows typical circuits for switching on three-phase motors with capacitors in the stator winding circuits.

The industry today produces capacitor motors based on two-phase motors. Three-phase are easily modified manually for power supply from a single-phase network. There are also small-scale three-phase modifications already optimized with a capacitor for a single-phase network.

Often such solutions can be found in household appliances such as dishwashers and room fans. Industrial circulation pumps, blowers and smoke exhausters also often use capacitor motors in their work. If it is required to turn on a three-phase motor in a single-phase network, a phase-shifting capacitor is used, that is, again, the motor is converted into a capacitor.

$$C_{\Delta} = 4800\frac{I}{U}$$

$$C_{\curlywedge} = 2800\frac{I}{U}$$

$$I = \frac{P}{1{,}73\, U\, \eta\, \cos\varphi}$$

For an approximate calculation of the capacitance of the capacitor, well-known formulas are used, in which it is enough to substitute the supply voltage and the operating current of the motor, and it is easy to calculate the required capacitance for winding connections in star or delta.

To find the operating current of the motor, it is enough to read the data on its nameplate (power, efficiency, cosine phi), and also substitute it into the formula. As a starting capacitor, it is customary to install a capacitor twice as large as the working one.

Figure 7. Capacitor motor

The advantages of capacitor motors, in fact, asynchronous ones, mainly include one thing - the ability to turn on a three-phase motor in a single-phase network. Among the disadvantages are the need for optimal capacity for a specific load, and the inadmissibility of power supply from inverters with a modified sine wave.

DISSCUSION & CONCLUSION. The purpose of using controlled capacitor batteries is not only to compensate the reactive power, but also to maintain the set value of the voltage transmitted from the network without changing during maximum and minimum loads [13].

Summary so it can be said that in the asynchronous motors of the devices used in agricultural enterprises bThe purpose of using expandable capacitor batteries is not only to compensate the reactive power, but also to maintain the set value of the voltage transmitted from the network during maximum and minimum loads without changing..

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