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METHODS AND MEANS OF ACCELERATING THE PROCESS OF AUTOMATIC SYNCHRONIZATION OF THE SYNCHRONOUS GENERATORS

Methods and means of accelerating the process of automatic precision synchronization, which ensure successful switching on simultaneous operation of synchronous generators, while ensuring the maintenance of the quality of electric energy is required by consumers are considered. Recommendations regarding using synchronization devices are outlined.

Keywords: *synchronization of the synchronous generators, accelerating the process of synchronization, quality of electric energy.*

Introduction

To enable the simultaneous operation of synchronous generators, methods of exact synchronization and coarse synchronization (synchronization with the current-limiting impedance, as used by the reactor), are usually used [1–2; 5; 7; 11–13]. During performing precise synchronization as conditions (parameters) that ensure its perfect completion, the following correlations [6; 8–9; 19] are required.

$$\begin{aligned} &U_1 - U_2 = \Delta U = 0; \\ &\omega_1 - \omega_2 = \omega_S = 0; \\ &\delta = 0, \end{aligned} \quad (1)$$

where U_1, U_2 – active values of the working 1 та the one that turns on 2 generators;

ΔU – unequality of the voltage;

ω_1, ω_2 – angular rotational speeds of the shaft of the first and second generators;

ω_s – angular frequency of the slip;

δ – angle between synchronized voltages.

When performing a self-synchronization operation, the generator that is activated is not tense, $U_2 \approx 0$, therefore, only the condition $\omega_s \approx 0$ must be fulfilled, but the angle value δ can be unlimited. During the self-synchronization in the power supply system there are disturbances associated with the inevitable voltage drops and throttling currents, that is unacceptable for consumers who require compliance with the quality indices of electrical energy for their work.

During performing coarse synchronization operation, only the conditions for limiting the kinetic energy reserve are required, $w_s \approx 0$, but the scheme of the electricity supply system is significantly complicated due to the need of using the reactor and an additional generator switch, the small-scale characteristics of the power supply system are increased and the management of this system becomes more complicated. In the context of the foregoing, the methods and means for implementing the exact synchronization, the operations of which are being constructed to be performed automatically, are considered in the following. It should be noted that when performing the automatic exact synchronization the ideal synchronization conditions are virtually impossible, since at zero angular slip frequency $\omega_s = 0$ it is impossible to obtain a zero angle of phase shift δ, due to ω_s the fact that the vectors U_1 and U_2 rotate with the same angular frequency and the angle between them is unchanged.

Analysis of literature. In the well-known literature [4; 17–18] the concept of real initial parameters of exact synchronization, according to which $\Delta U \le \Delta U_{доп}$, $\omega_S \le \omega_{доп}$ and $\delta < \delta_{доп}$, and valid values of synchronization parameters $\Delta U_{доп}, \omega_{Sдоп}$ and $\delta_{доп}$ is introduced. It is recommended to determine from the condition of holding a stable synchronization, which is understood as the implementation of the synchronization operation in the first cycle of oscillations of the rotor of the generator, which is activated, without its rotation and occurrence of asynchronous stroke. The conditions for implementing the stable synchronization operation proposed in [4] are less stringent in comparison with the conditions proposed in [7], and which in the future will be called the conditions of successful precise synchronization. Under the conditions of successful synchronization, the process of activating generators for parallel work is completed without unacceptable disturbances, that is, without the dangerous currents for generators and without voltage failures that are inadmissible to consumers from the conditions of the quality of electric energy. In case of use for the synchronization operation, automatic circuit-breakers of generators, the timing of which is equal $t_{вмк}$, in addition to observing the conditions of successful precise synchronization, it is necessary to take into account the inertia of the generator switch [7].

The purpose of the article is teaching of technical solutions, the implementation of which will accelerate the process of synchronizing synchronous generators, increase the accuracy of the moment of determining the command to switch on the generator switch and increase the reliability of automatic precision synchronization devices.

The main material

The automatic exact synchronization device should determine the moment when the command is started to turn on the generator switch in the case when the first and second conditions of successful exact synchronization are fulfilled, but not at the time when the angle is zero, and in advance with some outrunnings, so that this angle is minimal at the moment of closing of the generator's switch contacts. Depending on which values of angles δ and slider frequencies w_s should be observed when performing a synchronization operation, synchronization devices with a constant forward angle $\delta_{вип}$ will be distinguished, in which turning angle is $\delta_{вик} = \delta_{вип} = \omega_{Sp} t_{вмк}$, where ω_{Sp} – calculated angular slip frequency and synchronization devices with constant advance time $t_{вип} = t_{вмк}$, where turning angle $\delta_{вмк} = \omega_{S\phi} t_{вмк}$, where $\omega_{S\phi}$ – the actual angular frequency of the slip and the device of the zone synchronization, where the process of activating the generators is carried out in the calculated zone of the angles of phase shift and slip rates [7]. During the constructing of the device for automatic precise synchronization, the measurement of the performed synchronization parameters should be considered: using a straight-line beat or by using the instantaneous values of the angles between the synchronous voltages. Synchronizers [3; 10–11], in which the voltage of the beats is used to determine the slip rates and the angles of phase displacement, does not allow obtaining the required accuracy of determining the moment when the command is started to switch on the generator switch and are used only for low power generators with small moments of inertia.

In synchronizers with the measurement of instantaneous values of angles of phase shift between the voltages for determining the moment of the command to switch on the generator switch uses a pulse method to obtain a constant forward angle [4; 7; 14–15]. In this way, at the beginning of the period of the sinusoidal stresses of the working and switching generators form rectangular pulses, the duration of which is constant and equal $\tau_1 = \tau_2 = \tau_0$. Due to the fact that the frequency of the generators is different, the pulsed sequences are shifted relative to each other. In this case, pulses of greater frequency $\omega_1 > \omega_2$, with their front approaching as "steps" for impulses of lower frequency, and the distance between the fronts of impulses $A_1, A_2, ...A_n, A_{n+1}$ decreases with each step assigned to a period of lower frequency T_2, from the maximum value to zero $A_{max} \le T_2$.

After that, the distance between the front lines of the pulses increases to A_{max} and the cycle is repeated. The value of each "step" A_n is equal to the difference between periods of lower and higher frequencies $T_2 - T_1$ and is permanent provided that ω_s is constant. This condition is fulfilled when there is no need for alignment of synchronized scratches during synchronization. If, at the moment of the front edge of the pulse of a higher frequency with a rear edge of the pulse of a lower frequency to give the order to turn on the generator switch, then at this moment of time the angle between the voltages will be constant and equal to the angle of advance:

$$\delta_{вип} = \frac{2\pi}{T_2} \tau_0 . \qquad (2)$$

Angle $\delta_{вип}$ (2) will be constant, since it does not change the time allocated to the synchronization frequency, and if it changes, then it is negligible. It should be noted that the command for switching on the generator should only be submitted if $\omega_S < \omega_{Sдоп}$. Control of the size $\omega_{Sдоп}$ is advisable to calculate the number of steps in a pulsed way N, which need to make the front edge of pulses of greater frequency in order to pass a path whose length is determined by the duration of the generated momentum τ_0:

$$N = \frac{\tau_0}{A} = \frac{\tau_0}{T_2 - T_1} = \frac{\tau_0 f_2 f_1}{f_1 - f_2} = \tau_0 \frac{f_2 f_1}{f_S}, \qquad (3)$$

where f_1, f_2 – frequency of the first and second generators;

f_S – slip frequency.

As the difference $T_2 - T_1$ increases and f_S increases as well, then in order to fulfill the condition $f_S \le f_{Sдоп}$ it is necessary to $N \ge N_{доп}$, where $N_{доп}$ – the minimum allowed number of steps, the corresponding magnitude $f_{Sдоп}$. However, the command for switching on the switch of the synchronous generator is formed before determination of the slip frequency and it is necessary to wait almost the period of beating to get the possibility of a command to turn on the generator for parallel work. In order to increase the speed of the synchronizer τ_0, in addition to the duration of the main pulses $\tau_д$, it is necessary to form auxiliary pulses that are rigidly tied to the back front of the main pulses. It is obvious that before the front of the main pulse frequency with the rear edge of the main pulse of less frequency will coincide, the front edge of the main pulse of the higher frequency will coincide with the reverse of the auxiliary impulse of less frequency. The introduction of auxiliary impulses will allow, at the time of working out a constant forward angle, to complete counting the number of "steps" of the main pulse of a higher frequency on the auxiliary impulse of a smaller frequency, that is, determine the slip frequency and determine the angle of advance in the same period of the beating. This is especially important at low slip rates, when the beating periods are very large. Synchronization devices in which the command for switching on the generator switch is fed at a constant forward angle allows a zero angle between the synchronous voltages to be obtained at the moment of switching the contacts of the switch only when the actual value of the slip frequency is equal to the calculated value. In other cases, the synchronization is carried out at an angle δ other than zero, with the angle errors more, than bigger actual value of the slip frequency, which differs from the calculated value of this frequency. In this connection, it is expedient to use synchronizers with a constant angle of advance only for high-speed switches of the generator.

Significantly bigger accuracy of working out the moment of a command to switch on the generator switch can be obtained by using synchronizers with a constant advance time. A constant lead time can be obtained by:

– phase shift in the direction of lowering the voltage of a lower frequency;

– shift of the phase of both synchronized tensions;

– comparison of the value of current and settlement angles.

In the synchronization device [7], the command to turn on the generator switch gives the moment of correlation over the phase of the voltage of a higher frequency, with a lower frequency voltage, which is shifted towards the lag in an angle $\delta_{\text{вип}}$ equal to the

$$\delta_{\text{вип}} = \omega_{S\phi} t_{\text{ср}} . \qquad (4)$$

In the synchronizer [7], which implements the relation (4), to extend the range of using in the angle of displacement by the phase of limited inequality

$$f_{S\text{доп}} t_{\text{вмк}} \le \frac{\delta_{\text{вмкмакс}}}{360^\circ} \le 1 , \qquad (5)$$

where $f_{S\text{доп}}$ – acceptable, under conditions of synchronization of the slip frequency;

$\delta_{\text{вмкмакс}}$ – the maximum possible angle of advance which can not be bigger than 360°. It is proposed to make the transition from frequencies f_1 and f_2 to frequencies $f_{1n} = \frac{f_1}{n}$ and $f_{2n} = \frac{f_2}{n}$, which makes it possible to reduce the slip frequency by n times $f'_{S\,\text{доп}} = \frac{f_{S\text{доп}}}{n}$, which in the end is equivalent to an increase of n times the maximum advance angle $\delta_{\text{випмакс}}$. Thus, the proposed solution extends the range of using the synchronization device both by the slip frequency $f_{S\,\text{доп}}$ and by the time the generator's switch is switched on $t_{\text{вмк}}$.

The disadvantages of this synchronizer include its inability to accurately work out the angle of advance in the range of low-frequency slip. In order to overcome this shortcoming, it is proposed to phase off each phase of synchronization [7]. The accuracy of working out a constant advance time over the entire range of admissible values of slip frequency is achieved due to the fact that each synchronized voltage shifts over the phase towards the lagging angle, which is proportional to the slip of each voltage relative to a certain fixed frequency, which is common to both voltages and knowingly greater voltages than any synchronized voltage. In this case, the constant time of advance is fixed at the moment of phase coincidence of phases displaced by the voltage. Since the phase shift angle of the operating generator is proportional to the frequency difference between this oscillator and a certain fixed frequency, and the angle of displacement of the phase of the voltage of the alternator, which is activated, is proportional to the frequency difference of this generator and the same fixed frequency, and the required pre-angle is proportional to the slip of the generator frequency, which is activated relative to the frequency of the generator that operates, then the difference between the first of these angles is proportional to the slip frequency of the alternating generator, in relation to the frequency of the generator that operates. Improvement of the accuracy of the synchronization device is achieved due to the use of aperiodic links of the first order of the general type for the phase shift of each voltage [16, 20], the transfer functions of which are determined by the expression

$$W(P) = \frac{K}{TP + 1}, \qquad (6)$$

where K – gain factor;

T – constant time;

P – operator of differentiation.

The logarithmic phase characteristic of such units is approximated in the range of angular frequencies $\omega < \frac{0,1}{T_{\theta(\omega)=0^\circ}}$ by low frequency asymptote $\theta(\omega) = 0^\circ$ but in the interval $\omega > \frac{10}{T}$ by high-frequency asymptote, but in the interval $\frac{0,1}{T} < \omega < \frac{10}{T}$ straight line with an angle of inclination equal to 45°. In addition, the fixed frequency must be substantially higher than each of the synchronized voltage frequencies. The choice of the parameters of the aperiodic units should be made in such a way that the range of possible values of the angular frequency of the slip is on the linear phase of the phase characteristic of the link, which corresponds to expression (6). An interesting variant of the practical realization of the phase shift mode of the synchronous voltages is proposed in [7]. In this synchronizer, for phase shifting of each voltage, systems of phase automated frequency modulation are used, which includes RS-triggers, low-pass filters, and pulse generator controls. To the S-input of the RS-trigger, the output of the impulse generator is connected to the input of which the sinusoidal voltage of the working (the switching generator) is fed, and a pulsed sequence appears on the pulse shaper output, the pulses of which are formed at the beginning of each period of synchronous voltages. To the R-input of the RS-trigger, the output of a controllable pulse generator is connected, the input through the low-pass filter is connected to the output of the RS-trigger. The angular frequency of the pulse sequence from the output of the controlled pulse generator is determined from the expression

$$\omega_y = \omega_0 - K_п U_ф , \qquad (7)$$

where ω_0 – the angular frequency of following pulses from the output of a controlled pulse generator in the absence of voltage at its input;

$K_п$ – the gain of the controlled pulsed generator;

$U_ф$ – voltage at the output of the low-pass filter, determined by the dependence $U_ф = K_ф U_T$;

$K_Ф$ – low frequency filter gain;

U_T – the average value of the voltage at the output of the RS-trigger.

The choice of coefficients $K_п$ and $K_Ф$ is carried out in such a way that, in a definite possible working frequency range ω_1 та ω_2 and operating and activating synchronous generators, the frequency capture ω_y of the controlled pulse generator and its frequency substitution $\omega_1 (\omega_2)$ respectively occurs. Generators of pulses that are controllable begin to generate pulse sequences with a frequency $\omega_1 (\omega_2)$, shifted by phase to the lagging angle $\beta_1(\beta_2)$ with respect to pulse sequences that follow from the output of pulse shapers. The magnitude of the phase shift angle $\beta_1(\beta_2)$ is proportional to the required control voltage applied to adjust the frequency of the controllable pulse generator to the frequency $\omega_1 (\omega_2)$, that is $U_{T_1} = K_T \beta_1$, $U_{T_2} = K_T \beta_2$. It is clear that the angles β_1 and β_2 are proportional to the sliding of the frequency of the working (switching) generator ω_0 relative to the fixed frequency of the controlled pulsed generator, $\beta_1 = \frac{\omega_0 - \omega_1}{K_п K_ф K_T}$, $\beta_2 = \frac{\omega_0 - \omega_2}{K_п K_ф K_T}$, and, at the moment of phase coincidence, the angular momentum in the direction of the backward voltage is ahead $\delta_{вип} = \beta_1 - \beta_2 = \frac{\omega_2 - \omega_1}{K_п K_ф K_T} = \frac{\omega_s}{K_п K_ф K_T}$. If it is ensured that the coefficients $K_п, K_ф, K_T$ are selected in such a way that $\frac{1}{K_п K_ф K_T} = t_{вмк}$, at the time of the matching of the voltage phase, which moves towards the lag, a constant advance of time is obtained. The using of RS-trigger, controllable pulse generator and low-pass filter in the synchronizer [7], which form a closed system of automatic frequency tracking, allows to significantly expand the range of possible synchronization of angular slip frequencies and synchronize when the sliding frequency is very small. At the same time, the essential disadvantage of such systems of the phase automated frequency pivot is a large inertia, which can result in changes in the frequency of at least one of the generators before the occurrence of dynamic errors in determining the constant time of advance, which inevitably leads to a deterioration of the parameters of the transient process during synchronization due to the appearance of perturbations.

In order to eliminate dynamic errors when changing the frequency of synchronous voltages, it is proposed to make shift in device [11] to the side of the lag of pulse sequences tightly tied to zero phases of the voltage of the working and switching generators. The displacement of pulse sequences is carried out with the help of single-impeders, which allow to hold pulse sequences at the time of delay τ_3 equal to the difference between the synchronized voltage period $T_1(T_2)$ and the transition time of a single-ion beam to a stable state τ. The synchronizer transitions time slices $\tau_{31} = T_1 - \tau$ and $\tau_{32} = T_2 - \tau$ into corresponding phase angles $\alpha_1 = \frac{360}{T_1}\tau_{31}$ and $\alpha_2 = \frac{360}{T_2}\tau_{32}$. The differences between these angles are equal $\alpha_1 - \alpha_2 = 360\tau f_S$, that is, when $360\tau = t_{вмк}$, $\alpha_1 - \alpha_2 = \delta_{вмк} = t_{вмк} f_S$, which means that at the moment of coincidence shifts in the direction of the lag of pulse sequences a team is formed to switch on the generator switch with constant advance time. A constant forward time is also obtained by comparing the current and the calculated angles between the synchronous voltages. To do this, in the synchronization device [15], the constant lead time is processed when the levels are equal in two counters, one of which is filled with frequency f, and the second after half the period of a lower frequency – with frequency $f+\frac{f}{a}$. Comparing the number $N_i=\tau_i f$ with the number $N_{i+1}=\tau_{i+1}(f+\frac{f}{a})$, we obtain at the moment of their equality that $\tau_1-\tau_{i+1}=\frac{N_i}{f(1+a)}$. Since the difference between the duration of two adjacent impulse pulses of pulsed sequences obtained at pulses forming outputs included in the voltages of the working and turning generators, is equal to the difference in periods, that is $\tau_1-\tau_{i+1}=\frac{1}{f_1}-\frac{1}{f_2}=\frac{f_S}{f_1 f_2}$, at the moment of coincidence of the numbers recorded in the counter

$$N_i=\frac{f_S f(1+a)}{f_1 f_2}=t_{\text{вмк}} f_S, \qquad (8)$$

where $f(1+a)=K=t_{\text{вмк}}$ – practically constant coefficient, the value of which is chosen equal to the time of advance, obtains a constant time of advance.

The high accuracy of determining the moment when the command is given to turn on the generator switch in synchronizers with a constant advance time can be obtained when the current value of the phase shift angle becomes equal to the calculated value, that is, when the equality holds

$$\delta+t_{\text{вмк}}\frac{d\delta}{dt}=0. \qquad (9)$$

Let's prove this statement. To do this, a transition from the differential equation (9) to the finite-difference equation

$$\delta+\frac{\delta_1-\delta_2}{T_{\text{м}}}t_{\text{вмк}}=0, \qquad (10)$$

should be made, where δ_1,δ_2 two consecutive values of the angle between the tensions that are synchronized, measured over a period equal to the period of a lower frequency. Entering the notation $\frac{t_{\text{вмк}}}{T_{\text{м}}}=K$, from (10) follows that at the time when the current value of the angle δ_2 is equal to the calculated, determined from the ratio $\delta_2=\delta_1\frac{1+K}{K}$, $\tau_{31}=T_1-\tau$, will receive a constant advance time. The same result can be obtained by comparing the duration and the two consecutive time segments τ_1 and τ_2 between the pulses formed at the beginning of the period of the sinusoidal voltages of the working and the switching generators. In the system of calculating impulses of bigger frequency $T_{\text{Б}}$, the magnitudes of the angles δ_1,δ_2 corresponding to the segments of time τ_1 and τ_2, are equal to $\delta_1=2\pi\frac{\tau_1}{T_{\text{Б}}}$, $\delta_2=2\pi\frac{\tau_2}{T_{\text{Б}}}$, and the angular slip frequency $\omega_S=\frac{\delta_1-\delta_2}{T_{\text{Б}}}=2\pi\frac{\tau_1-\tau_2}{T_{\text{Б}}^2}$, with the time of advance $t_{\text{вмк}}=\frac{\delta_2}{\omega_S}=\frac{\tau_2}{\tau_1-\tau_2}T_{\text{Б}}$. To form a command with time ahead, equal to the time of switching off the generator switch $t_{\text{вмк}}$, it is necessary that the value τ_2 is determined from the ratio

$$\tau_2=\frac{\tau_1}{t_{\text{вмк}}+T_{\text{Б}}}t_{\text{вмк}}. \qquad (11)$$

According to the condition (11), in order to obtain a constant advance time, it is necessary to consistently determine the length of the segments τ_1 and τ_2 and compare them with each other, recording, for example, while the number N_1 in the reverse counter is proportional τ_1, read the number N_1 in the interval of time τ_2 with the frequency of passage of pulses in times $\frac{t_{\text{г}}+T_{\text{Б}}}{t_{\text{вмк}}}$ larger , than recording frequency. The technical implementation of these operations is described in [7]. It is possible to accelerate the synchronization process with the use of zone synchronizers [7], in which the gain in time is directly proportional to the width of the inclusion zone and inversely proportional to the slip frequency at which synchronization is performed. The inclusion zone is limited to the extreme phase trajectory in the coordinates of the angular frequency of sliding ω_s – the angle δ. Switching on the generator with values and those ω_s and δ, that are inside the switching zone ensures the successful completion of the synchronization process, which supports the required quality of electric power consumers. Fig. 1 shows how the command for switching on the generator switch is constructed.

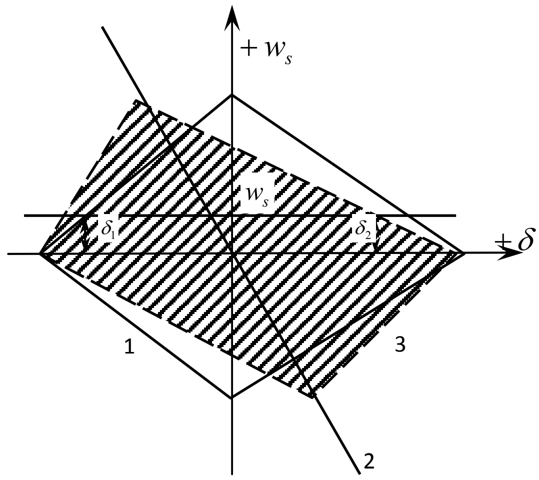

Fig. 1. Building a command to turn on the generator switch

In this figure, the boundary phase path (separatrix) is selected to simplify construction in the form of a broken line, restricting the area of successful synchronization. The straight line passing through the origin is a line of inclusion 2 that corresponds to the expression $\delta_{роз} = \omega_S t_{вмк}$. Absciss boundaries of the zone of switching 3 by the compilation of the abscissa of the separatrix 1 and the inclusion line 2 corresponding to a certain value of the coordinates w_s. Arrows indicate the possible directions of the phase trajectories.

In devices for bandwidth synchronization, the possibility of transmitting a command to turn on the generator switch is almost eliminated, since this command at a given slip frequency is served not at one point, but on the segments, which significantly increases the failure of the synchronizer.

The command for switching on the generator switch is given when the point reflecting the motion of the phase trajectory is the zone of switching on

$$\delta(\omega_S) - \omega_s t_{вмк} > \delta\text{-}\delta(\omega_s) + w_s t_{вмк}, \qquad (12)$$

where $t\delta(\omega_s)$ is the phase shift angle between the synchronous voltages, which is determined from the boundary phase trajectory (1).

Unlike [18] in the synchronization device [19], in addition to the angular slip frequency ω_s, the angular acceleration of the slide is taken into account, and the angles $\delta(\omega_s)$ are on for the current angular slip frequency, and for its expected the acceleration value taking into account. The using of this double-differentiation operation with the help of differentiating operational amplifiers inevitably causes the formation of a high level of interference signals on the front and rear fronts of pulse sequences. In order to obtain the angular frequency ω_s and accelerate the slip ε_S in [21] and [22], it is suggested to use a rice filter 2, consisting of three consecutive integrated integrating amplifiers 2, 3 and 4, covered by feedback bundles such that their resulting transfer function corresponds to the transfer function of the third-order line of the form

$$W(p) = \frac{K_1}{ap^3 + bp^2 + cp + 1}, \qquad (13)$$

where K_1 – the gain factor;

a, b, c – coefficients for derivatives;

$p = \frac{d}{dt}$ – operator of differentiation.

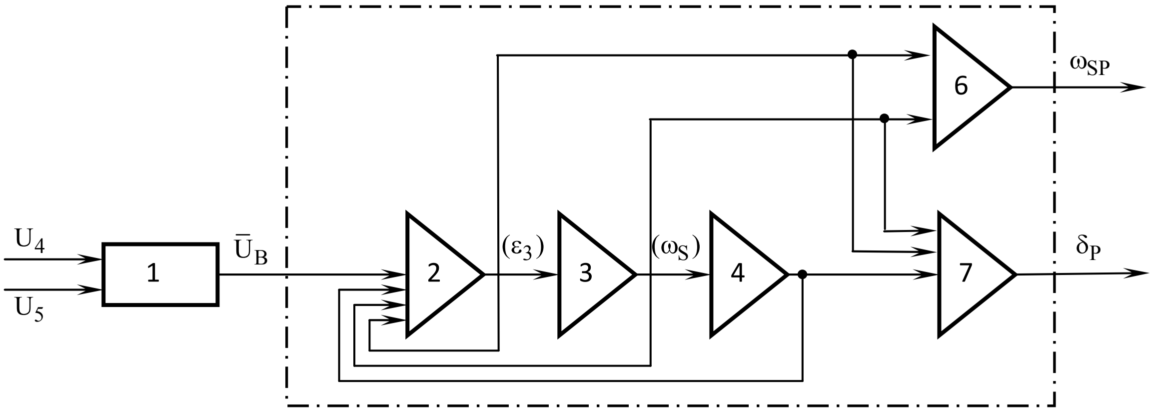

Fig. 2. A filter consisting of three series integrating integrating amplifiers

The voltage at the input of the integrating amplifier 2 is proportional to the current angle between the voltages U_1 and U_2. The voltage at the output of the filter U_δ is simultaneously the output voltage of the integrating amplifier 4, which means that the input of this amplifier receives voltage $U(\omega_s)$, is proportional to the angular frequency of slipping ω_s, and the input of the integrating amplifier 3 enters a voltage $U(\varepsilon_S)$ proportional to acceleration of slip ε_S.

Discussion of the results

1. To implement the process of switching synchronous generators into parallel operation, the device of automatic exact synchronization should be able to measure and compare the amplitude or operating values of the voltage of the working and switching oscillator and the value of their frequencies or the value of the angular frequency of slip. In addition, automatic precision synchronization devices should be able to measure the angle of displacement by the synchronous voltage phase, and to take into account its inertia when forming a command to turn on the generator.

2. In determining the method of measuring angular slip rates and angles of phase shift of the synchronous voltages, it is possible to use devices in which straightened bout voltage is used to determine the synchronization parameters or the instantaneous values of the angles between the synchronous voltages is used and in terms of reduction the influence of negative perturbations on the process of synchronization should be given to syn-

chronization devices in which the instantaneous values of the angle are measured the values of slip rates ω_s and angles δ between the voltages.

3. In devices, the automatic synchronization point of the commands for switching on the generator switch can be supplied with a constant advance angle, constant advance time or in the zone of allowable values of angles and slip rates.

4. Synchronizers with a constant angle of advance usually used for generators of low power (up to 1000 kw), which have insignificant moments of inertia and equipped with high-speed switches. In this case, to obtain a constant advance angle, pulsed sequences of constant duration formed at the beginning of the period of each of the synchronous voltages should be used. And to accelerate the process of synchronization, in addition to the main pulses, it is necessary to form auxiliary impulses, rigidly tied to the main pulses.

5. Significantly greater accuracy of forming a command to turn on the generator switch can be obtained from synchronizers with a constant advance time. In which a phase shift of the two synchronous voltages is used or comparing the current and the calculated angles between the voltage of the working and the alternating generators. Pulse and digital devices should be used to perform voltage-phase shift operations and to compare angles between voltages.

6. To increase the range of determining the possible angles of advance in synchronizers with a constant advance time in the case of using switches with a significant switching time in synchronization devices it is expedient to determine the moment of forming the command to switch the generator's switch from the real values of the frequencies of the synchronized voltages to reduced in n -times values.

7. To eliminate the dynamic errors that occur when changing the synchronized voltage frequencies, which occurs when it is necessary to align the frequencies in the synchronization devices, it is expedient to convert the time intervals between the pulse sequences at the corresponding angular intervals.

8. In order to accelerate the synchronization process and improve the reliability of the synchronization devices, bandwidth synchronizers should be used, in which, for the elimination of interferences occurring during the differentiation operations, links with serially connected integrating operational amplifiers covered by feedback should be used.

9. Synchronization devices should also be used in emergency automatics systems, in particular, in systems for automatic re-activation and in systems for automatically switching the reserve, if in these systems among electric power consumers there are electric motors which, when the voltage from the power supply disappears, goes into the generator mode work with a gradual decrease of frequency when the kinetic energy of rotors of electric motors decreases.

10. Tabl. 1 provides recommendations about automatic precision synchronization devices.

Table 1

Recommendations for using the automatic exact synchronization devices

Factors what influenced by	Type of synchronizer	With constant advance angle	With constant advance ahead						Bandwidths synchronization	
			1	2	3	4	5	6	ω_s	ω_s ε_S
Power generator	under 1000 kW	+	+	-	-	-	+	-	-	-
	above 1000 kW	-	-	+	-	-	-	+	-	-
Speed switch generator	great	+	-	-	+	+	+	+	-	-
	low	-	-	+	-	-	+	+	-	-
Range frequencies slip	great	+	+	-	-	+	+	-	-	-
	low	+	-	-	-	-	-	-	-	-
Way frequency measurement slip and the angle between voltage	High-voltage beating	+	-	-	-	-	-	-	-	-
	Instant value angles	+	+	+	+	+	+	+	+	+
With the need to align the corners		-	-	-	-	+	+	+	-	+
With increased requirements for the failure of the device		-	-	-	-	-	-	-	+	+
When used in the system of emergency automatics		-	-	-	-	+	-	-	+	+

Table 1 accepts the following notation:

1 – shifting synchronization device in the direction of lower frequency voltage lag;

2 – synchronization device using a reduction in n - times frequencies;

3 – synchronization device using phase automatic frequency substitution systems;

4 – synchronization device using shift in the direction of pulse sequence lag;

5 – synchronization device with digital comparison of current and calculation angles;

6 – synchronization device with pulse comparison of current and calculation angles.

Conclusion: The technical solutions described in the article explain the ways of increasing the speed and reliability of synchronization devices, and substantiate ways to improve the accuracy of determining the moment of giving the order to switch on the synchronous generator switch when performing automatic exact synchronization.

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МЕТОДИ ТА ЗАСОБИ ПРИСКОРЕННЯ ПРОЦЕСУ АВТОМАТИЧНОЇ СИНХРОНІЗАЦІЇ СИНХРОННИХ ГЕНЕРАТОРІВ

Б.Т. Кононов, В.Б. Кононов, О.А. Кононова, В.В. Кірвас

Розглядаються методи та засоби прискорення процесу автоматичної точної синхронізації, що забезпечують успішне включення одночасної роботи синхронних генераторів, що забезпечують необхідну якість електроенергії, що подається споживачам. Описано рекомендації по використанню пристроїв синхронізації.

Ключові слова: *синхронізація синхронних генераторів, прискорення процесу синхронізації, якість електричної енергії.*

МЕТОДЫ И СРЕДСТВА УСКОРЕНИЯ ПРОЦЕССА АВТОМАТИЧЕСКОЙ СИНХРОНИЗАЦИИ СИНХРОННЫХ ГЕНЕРАТОРОВ

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Рассматриваются методы и средства ускорения процесса автоматической точной синхронизации, обеспечивающие успешное включение одновременной работы синхронных генераторов, обеспечивающих требуемое качество электроэнергии, подаваемой потребителям. Описаны рекомендации по использованию устройств синхронизации.

Ключевые слова: *синхронизация синхронных генераторов, ускорение процесса синхронизации, качество электрической энергии.*