Controls of the modes of operation of the pumping station with application of frequency-controlled electric drive

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Abstract. The article describes the developed system of automatic control of technological process of water supply of a pumping station, providing mainly for potable, technical and circulating water supply stable maintaining constant the required pressure in their main delivery pipe when the probabilistic nature of water consumption through a smooth frequency start and further regulation of productivity and pressure develop any of the parallel pump units on the steps for power regulation.

In the current conditions of increasing scarcity of water and energy resources, the urgency of the task of reducing electricity consumption for the needs of systems of consuming, technical and circulating water supply by pumping stations (PS) is moving to one of the first places. In this regard, the provision of energy - and resource-saving modes of functioning of the PS is an important task, the solution of which will allow achieving a significant amount of electricity (E) during the technological process of water supply, which in the country can make about 18 - 20% of the energy consumed by PS. However, it is quite obvious that adjusting the rotational speed of the motor drive of the pump unit (PU) will significantly increase its energy performance [1, 2, 3], obtain significant electrical energy savings, and reduce water losses by eliminating excess pressure in the pipeline hydraulic network.

Nowadays in most operating pumping stations of systems for drinking, technical and circulating water supply and their hydraulic networks, the excess pressure is almost up to 35% exceeds the objectively required level, which causes the excess pressure to be extinguished by hydraulic means. This is mainly due to the fact that the pumping stations, in the process of designing them, were selected from the standard row with an over-pressured supply and designed for the maximum flow rate, where the operating zone of the actual pump mode does not always coincide with the zone of optimum efficiency of the PU.

It should be pointed out that in the detailed development of such control systems for automated drives should combine the advantages of step-by-step control of the pumping stations with the control of the speed of the pumping unit between the stages in a given range of changes in the required flow rate of water supplied by the pumping power which can avoid unnecessary costs of electric energy. One of the main benefits of using a controlled electric drive of the pumping unit is the ability to adapt its characteristics to the characteristics of the hydraulic pressure network by providing a rational speed of rotation of the impeller of the pump, which corresponds to the basic mode of operation of the pumping unit (PU).
Moreover, the use of an automated electric drive will also allow making it possible for a more rational use of water resources by reducing unproductive costs [4].

A theoretical prerequisite can be the following method of graph-analytical calculation of the joint operation of the “pump – pressure network” system for the development of the principle of automatic control of the PS that justifies the mode of parallel operation of the PU as part of the PI with a random probabilistic nature of the water consumption mode figure 1.

Figure 1. Characteristics of joint parallel work on the main pressure - In the network of pumping stations at rated modes of operation of 3 identical pumps.

Figure 2. Characteristics of joint parallel operation of 3 identical pumps in the mode of regulating the rotation frequency of the third pumping unit when changing the characteristics of the main pressure network by pumping stations.

Figure 3. Characteristics of joint parallel operation of 2 identical pumps in the mode of regulating the rotation frequency of the second pump unit with further changes in the characteristics of the main pressure network by pumping stations.

Figure 4. Characteristics of operation of a pumping unit in the mode of regulation of its speed of rotation at a further significant change of the characteristic of the main pressure network by pumping stations.

Figure 5 presents, respectively, a functional diagram of the PS, a schematic diagram of the main power part of the automatic control system (ACS) of the PU operating in the common main pressure network (MPN), block diagram of the device of automatic control of the PS.

ACS for the technological process of water supply by PS operates as follows [5, 6, 7]. The setting device (Set Dev) sets the required pressure (Hrp) value, which must be constantly maintained in the MPN with a randomly probabilistic nature of the changing water consumption by the PS, which, in accordance with the accepted design scheme of the PS under consideration figure 5, can actually be determined in accordance with the conditions of joint parallel operation three pump units operating in
nominal modes in accordance with the maximum water consumption equal to the $Q_{\sum 3}$ of the system they serve figure 1, where the fourth PU is allocated in reserve.

**Figure 5.** Functional diagram of the pumping station of water supply systems.

**Figure 6.** The electric circuit of the power unit of the ACS of pumping units.
Figure 7. Block diagram of the device for the ACS of the pumping station of water supply systems.

From the moment of commissioning of the memory, a command is received to start the inverter (circuit breaker QF) of the frequency converter (FC), to which through the reactor L1, which protects the inverter from switching overcurrent, an appropriate signal connects it to work. Simultaneously, one of the outputs of the PU by means of a frequency sensor (FS), and the other through the output reactor L2, which limits the capacitive output currents of the converter and the peaks of voltages on the actuators, are connected to the corresponding inputs of the block of choice of the startup priority sequence unit (SPSU) of the pumping units. When this is connected, to the frequency control starter PU1 (magnetic contactor MC1), one of the outputs of the SPSU gives a signal to the beginning of a smooth frequency start \( f = \text{var Hz} \). As a result of the operation of PU1, the electric motor M1 is turned on and starts to accelerate the pump N1 in the mode of smooth frequency start. In order to ensure its lightweight starting mode and equalization of pressure in communication with discharge line pressure in MPN, with some time delay, to the input of gate valves VGIR1 that are in the open state in the communication pipe network CPIR idle discharge of water from the control unit gate valve CUVG1r, receives the command to close VGIR1. At the same time, the input to the pressure gate PG1 through the control unit CUPG1 receives a signal to open the pressure gate PG1, which starts, the water is pumped by the pump P1 through the supply communication pipeline HCP1 in the mainline PS1.

The signal proportional to the magnitude of the developing pressure pump P1 from the pressure sensor PS1 through the switched closing contact \( K_{SD1} \) enters the intermediate unit of comparison IUC1, from which at the end of the process of comparison with the incoming signal from the pressure sensor PS2 mounted on the main pressure unit of the result of the general comparison unit GCU and further from it to the input of the control device, which continues to change the frequency \( f \) of the FC converter and, as a consequence, the speed of rotation of the motor M1 of the pump P1, seeks to provide the maintenance of a desired constant pressure value equal to the water pressure in the MPN pumping station at a given stage of its aggregate regulation performance.

However, with the completion of the start-up mode and the output of the P1 pump to the rated operating mode, the maximum pressure they develop remains still below the set value figure 1. Thus, at this first stage of regulation, the corresponding signal from one of the outputs of the general comparison
unit (GCU), entering the startup priority selection unit, leads to a state of readiness for the implementation of the starting mode of one of the pumps P2-P4. At the same time, the signal is equal to the signal of the task from the other output of the general comparison unit, coming through the control device (CD) to the inverter of the IF frequency, brings it to the ready state for smooth start of the next pump unit, as well as the signal from the sensor, fixing the achievement of the frequency. Equal the frequency of the power supply network (f = 50 Hz), contributes to the shutdown of the starting device (SD1) (magnetic contactor MC1) through the startup priority selection unit and thereby switching off its closing contact KSD1, as well as the simultaneous subsequent activation of the network starting device SD2 (The circuit breaker QF1) directly connects the M1 motor drive, which continues to operate at rated power, to the power supply.

The frequency converter from the moment of the next operation of the control unit of the valve latch of the pumping unit and switching on the starting device of the frequency control of the starting device (magnetic contactor MC2), changing the frequency (f = var Hz) begins to smooth start the motor M2 of the pump P2. In this case, from the corresponding starting device of the smooth frequency control of the starting device with a certain time delay, to the input of the valve gate VGR1, which is in the open state in the communication pipeline network CP1r idle water discharge, from the control unit of the valve gate CUVG2, comes the command to close VGR2. At the same time, the input to the pressure gate PG1 through the valve control unit CUPG1 from the starting device SD2 also receives a signal on its opening, which is carried out water supply pump P2 through the supply communication pump pipeline HCP2 in the MPN pumping station. Furthermore, the signal proportional to the magnitude of the developing pressure pump P1 from the pressure sensor PS1 through the switched closing contact KSD1 enters the intermediate unit of comparison IUC1, from which at the end of the process of comparison with the incoming signal from the pressure sensor PS2 mounted on the main pressure unit of the result of the general comparison unit GCU and further from it to the input of the control device, which continues to change the frequency (f) of the FC converter and, as a consequence, the speed of rotation of the motor M2 of the pump P2, seeks to provide the maintenance of a desired constant pressure value equal to the water pressure in the MPN pumping station at a given stage of its aggregate regulation performance.

As before, with the completion of the start-up mode and the output of the P2 pump to its nominal operating mode, the maximum head (pressure) developed by it remains below the set value H2 < HBP by the setting device (Set Dev) figure 1. At the same time, the corresponding signal generated at the second stage of regulation from one of the outputs of the general comparison block, entering the block for selecting the start-up sequence, leads to the state of readiness for the start-up mode of one of the pumps P3 – P4. Meanwhile, a signal equal to the reference signal from the other output of the common comparison unit, supplied through the control unit to the frequency converter, puts it in a state of readiness for the smooth start-up of the next pump unit, and also the signal from the sensor (S), fixing the achievement of a frequency value equal to the frequency of the mains (f = 50 Hz), it contributes to the shutdown of both the starting device for the frequency regulation of SD2 and it makes contact KSD2 through the selection block of the startup sequence, as well as the simultaneous subsequent switching on of the networks SD5 of starting devices (automatic circuit breaker QF2) is directly connected to the mains electric motor M2 figure 6, which then continues to operate with nominal power indicators.

The frequency converter from the moment of the next operation of the control unit of the valve latch of the pumping unit and switching on the starting device of the frequency control of the starting device (magnetic contactor MC3), changing the frequency (f = var Hz) begins to smooth start the motor M3 of the pump P3. In this case, from the corresponding starting device of the smooth frequency control of the starting device with a certain time delay, to the input of the valve gate VGR1, which is in the open state in the communication pipeline network CP1r idle water discharge, from the control unit of the valve gate CUVG3, comes the command to close VGR3. At the same time, the inlet of the PG1 pressure valve through the CUPG1 control unit from the starting device SD3 also receives a signal to open the PG1 pressure valve which starts the water is pumped by the P3 pump through the HCP3 supply communication pressure pipe to the main pressure network by pumping stations. The proportional signal, the magnitude of the developing head pump P3, from the pressure sensor PS3 through the included closure contact.
$K_{SD3}$ enters the intermediate unit of comparison IUC3, and its other input receives a signal from the pressure sensor ($f$) backbone network and then the resulting signal goes to the common block comparison from it to the input of the controlling device, the latter changes the frequency of the converter and thus the speed of rotation of the motor M3 of the pump P3, seeks to ensure the sustainability of the required value of pressure is equal and water pressure in the pressure network at the final third of the degree of aggregate regulation of its productivity. At the same time, the signal from the FS frequency sensor, recording the attainment of the frequency equal to the frequency of the power supply network ($f = 50$ Hz), facilitates by means of the SPSU pumping units to disable both the starting device of frequency control SD3 and its closing contact $K_{SD3}$, as well as the simultaneous subsequent activation of the network the SD7 starting device (QF3 circuit breaker) directly connects the M3 motor to the power supply figure 6. In this case, the pump P3 together with the pumps P1 and P2 continues to function in parallel with the nominal values, which ultimately provides the sustainability of the required value of the developing pressure (H$_{RP}$ equal pressure) and the corresponding maximum water supply, at this third of the degree of regulation of the performance of the pumping station. In this case, the frequency converter is in idle mode when the soft starters of the smooth frequency control SD1 – SD4 (magnetic contactors MC1-MC4) are switched off figure 6.

Due to the fact that at a pumping station with parallel work of the pumping unit in the common backbone network of systems of drinking, technical, circulating water supply, in which the modes of their water consumption, as a rule, have a random - probabilistic nature of change, then to maintain the constant pressure in the backbone pressure network, pumping stations should monitor these changes by continuously controlling the modes of operation of the pumping unit by adjusting their rotational speed and adjusting the working pairs of the pumping units in accordance with the operating mode they are served by the water system. Thus, the decrease in water consumption figure 2 to the $Q_{23}^1$ value is accompanied by an increase in hydraulic resistance in the main pressure network, which in turn leads to an increase in the slope of the $H_{MPN3}$ pressure pipeline of the main network and thus to an increase in the magnitude of the pressure above the set $H_1 > H_{RP}$ value that specifies the driver (Set Dev) figure 2 In this case, the increased signal from the pressure sensor PS2 of the main pressure network of the pumping station through the intermediate comparison unit IUC3 enters the outputs of the general comparison unit. As a result of the interaction of the increasing signal with the incoming signal from the master device, their resulting signal, entering the lock for selecting the start sequence, contributes to disconnecting the network starting device SD7 (automatic switch QF3) from the supply network and connecting the starting device frequency control SD5 (magnetic contactor MC3), which provides the process of frequency control of the drive motor M3 of the pump P3.

Furthermore, the signal is proportional to the value of the developing pressure of the pump P3, from the pressure sensor PS1 through the included closing contact $K_{SD3}$ enters one of the inputs of the intermediate unit of comparison IUC3, and its other input comes from the pressure sensor $PS_3$ growing signal. At the end of the process of comparison in the intermediate unit of comparison IUC3 its resultant signal is received in the common comparison unit, and then from it to the input of the control device, where the latter contributes to the change of frequency ($f$) of the converter (FC) and thereby equalizes the values of pressure $H_1 = H_{RP}$ figure 2.

In case of further reduction of the water consumption to $Q_{23}^2$, which leads to a more significant increase in hydraulic resistance in the main pressure network and as a consequence contributes to the steepness of the $H_{MPN2}$ characteristic of the main line mains pipeline, and thus increases the magnitude of the pressure $H_2 > H_{RP}$ above the set value device figure 3. In this regard, an increased signal from the pressure sensor $PS_2$ main pressure network of the pumping station through the intermediate unit of comparison IUC3 enters the GCU and then the resulting signal from one of its outputs, coming to the SPSU, contributes to the shutdown of network starting devices SD1 and SD6 (circuit breakers QF3 and QF2) from the supply network and the starting device of the frequency control SD1 (magnetic contactor MC3), which is implemented with a certain time delay, which allows to close the pressure gate PG3 and further open the valve shutter VG$_{IR3}$ just dumping water. At the same time, the starting device is connected to the frequency regulator SD2 (magnetic contactor MC4), where the resulting signal from the
output of the GCU goes to the input of the control device CD and further into the frequency converter, which provides the process of frequency control of the motor M2 of the pump P2. In this matter, only two pumping units will be involved in the operation of the pumping station figure 3. So, the proportional signal developing pressure pump P2, from the pressure sensor PS2 through the switching contact closes $K_{SD2}$ enters one of the inputs of the intermediate comparison unit IUC2, and its other input receives an increased signal from the pressure sensor PS2 backbone pressure network of PS. At the same time, this result signal goes to the GCU and then from it to the input of the CD, the latter changes the frequency (f) of the converter and thereby equalizes the $H_2 = H_{RP}$ figure 3.

The control unit of the pumping station, similar to the above, with a further greater increase in hydraulic resistance in the main pressure network MPN and a significant increase in the steepness of its characteristics $H_{MPN1'}$ due to a deeper decrease in water consumption by the serviced system less than the $Q_1$ supply goes into sub-holding mode constant pressure by frequency control of supply with only one the pump P1 figure 4.

At the considered PS, one, two or three pumping units may be permanently in operation, where the fourth pumping unit is a spare unit.

As a consequence of this, the proposed device for automatic control of the pumping station provides stable support for the constancy of the required value of the set pressure in the main pressure pipeline pumping stations at the probable nature of water consumption, by smoothly adjusting the flow and pressure of any of the pumping unit combined in a common parallel register pressure network, as well as through the smooth frequency start of the actuator of each of the connected, in the work of the pumping station and achieve effective values of the main technical parameters of centrifugal pumps at aggregate levels by regulation.

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