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O.Y. Nurmatov
Tashkent State Technical University

S. K. Matkarimov
Tashkent State Technical University

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ANALYSIS OF TRANSITION PROCESSES IN POWER SYSTEMS WITH HYDROENERGETIC ISTALLATIONS

O.Y.Nurmatov[1] , S. K. Matkarimov[1]
[1]*Tashkent State Technical University*

Abstract
This article is presented an overview of hydro mechanical and electromechanical processes. Little attention was paid to the study of these two areas at the same time. The two directions above are the results of a simultaneous study. A joint study of these components of a single process received little attention. In conclusion, conclusions are drawn on the effect of AER (automatic excitation regulator) on the damped operational parameters and ensuring the stable operation of hydropower plants. The results can be used in the reconstruction of existing and designing new pumping stations, so transients are considered for a certain range of variation of these parameters. One of the difficult modes is to reduce the voltage on the tare of the station, especially on the system buses. The analysis shows that a decrease in voltage on the system buses by more than 8% leads to the output of the LED out of synchronism, if during this period for some reason the ARV of the machine is turned off. The characteristics of transients with a decrease in voltage on the system tires by 2% are given.

Key words: *transitional processes, hydromachine, hydroenergy device, automatic field control.*

The operational experience of hydropower installations (GEM) shows that the largest number of accidents of the main and auxiliary equipment occurs during maneuvering, starts and stops of units, i.e. during transients. The duration of the transitional processes is determined by the parameters of equipment and facilities, the layout features of the aggregate unit, the working conditions in energy and water management systems.

Transients are characterized by a significant increase in dynamic loads on equipment elements and building structures. The increase in dynamic loads in transient modes of operation with high-quality assembled and serviceable equipment is primarily due to the increased intensity of pressure pulsations on the walls of the flow part of hydraulic structures.

Until recently, the development of transient studies in hydropower plants was carried out in two main directions, namely, the study of hydro mechanical processes in water pipes and a hydraulic machine, the study of electromechanical processes in a hydro generator and in a power system. Little attention was paid to the joint study of these components in a single process, with the exception of [1, 3], in which the above transients are significantly affected.

In cases where it is necessary to more accurately calculate the modes (synchronization or self-synchronization of a synchronous motor, the influence of the type of short circuit, etc.), you should use the equations of the full model of the first accuracy class. For example, the starting mode of a synchronous motor can be investigated on the basis of complete equations reduced to the form:

$$\frac{d\psi_d}{dt} = ri_d - \left(1 + \frac{d\delta}{dt}\right)\psi_q + u_d,$$

$$\frac{d\psi_q}{dt} = -ri_q + \left(1 + \frac{d\delta}{dt}\right)\psi_d - u_q,$$

$$\frac{d\psi_f}{dt} = \frac{1}{T_{d0}} u_f - \frac{1}{T_{d0} x_f}\left(x_f \psi_f + x_{ad} e_{id}\right), \quad (1)$$

$$\frac{d\psi_{rd}}{dt} = \frac{1}{T_{rd} x_{rd}}\left(x_{ad} e_{id} - x_{rd} \psi_{rd}\right),$$

$$\frac{d\psi_{rq}}{dt} = \frac{1}{T_{rq} x_{rq}}\left(x_{aq} e_{iq} - x_{rq} \psi_{rq}\right),$$

$$\frac{d^2\delta}{dt^2} = \frac{1}{T_{JA}}\left(M_{ДВ} - M_{НАС}\right),$$

$$i_f = \frac{x_f}{x_{fs}} \psi_f - \frac{x_{ad}}{x_{fs}} e_{id}, \quad i_d = -\frac{1}{x_s} \psi_d + \frac{1}{x_s} e_{id},$$

$$i_q = \frac{1}{x_s} \psi_q - \frac{1}{x_s} e_{id}, \qquad e_{id} = \frac{1}{\alpha}\left(\frac{x_{ad}}{x_s} \psi_d + \frac{x_f}{x_{fs}} \psi_f + \frac{x_{rd}}{x_{rds}} \psi_{rd}\right),$$

$$e_{iq} = \frac{1}{\beta}\left(\frac{x_{aq}}{x_s} \psi_q + \frac{x_{rq}}{x_{rqs}} \psi_{rq}\right), \quad \alpha = 1 + x_{ad}\left(\frac{1}{x_s} + \frac{1}{x_{fs}} + \frac{1}{x_{rds}}\right),$$

$$\beta = 1 + x_{aq}\left(\frac{1}{x_s} + \frac{1}{x_{rqs}}\right).$$

$$M = \Psi_q I_d - \Psi_d I_q. \quad (2)$$

The electromagnetic moments of the engines can be determined by the following formulas:
- for a synchronous motor;

$$M_C = x_{ad}[i_{qC}(i_f + i_{1d}) - i_{dC} i_{1q}](1 + s_k); \quad (3)$$

- for asynchronous

$$M_A = x_m(i_{qA} i_{dr} - i_{dA} i_{qr})((1 + s_k). \quad (4)$$

A simplified Kloss formula is also used for an induction motor [1]

$$M_{АД} = M_{Д}^{м} \frac{2(1 + s_{kp})}{\frac{s}{s_{kp}} + \frac{s_{kp}}{s} + 2 s_{kp}}$$

Where $M_{Д}^{м}$ is the maximum moment of the induction motor, and s_{kr} is the critical slip of the machine.

In the calculations for the sake of simplification, as a rule, the electromagnetic and hydro mechanical moments are replaced by the corresponding powers, i.e., $M_{DV} = P_{DV}$ and $M_{NAC} = P_{NAC}$.

Finally, a generalized system of equations of the electro- and hydro mechanical system, taking into account the previously given relations, we can write in the form:

- flow equation:

$$\frac{dQ}{dt} = (H_{i-1} - H_i - r_0 L_{уч} Q|Q|)/Ll_{уч} \ , \tag{6}$$

- pressure equation:

$$\frac{dH}{dt} = -c_0 \frac{1}{L_{уч}} (Q_i - Q_{i-1}) \ , \tag{7}$$

- equations of the synchronous motor:

$$\frac{ds}{dt} = \left(\frac{1}{T_{JA}} \right) \left(P_{DVA} - P_{N\,AC} \right)$$

- equation of an induction motor:

$$\frac{d\delta}{dt} = s \ , \tag{8}$$

$$\frac{ds}{dt} = \left(\frac{314}{T_{JC}} \right) \left(P_{DVC} P_{N\,AC} \right) \tag{9}$$

- equations of the excitation controller of the synchronous motor, respectively:
  - transitional emf:

$$\frac{dE'_q}{dt} = \left(\frac{1}{T_{d0}} \right) \left(E_{qe} - E_q \right), \tag{10}$$

- voltage on the rotor rings:

$$\frac{dE_{qe}}{dt} = \left(\frac{1}{T_e} \right) \left(E_{eq0} - E_{qe} + v \right), \tag{11}$$

- voltage at the input of the pathogen:

$$\frac{dv}{dt} = \left(\frac{1}{T_P} \right) (e - v). \tag{12}$$

In the above equations, the notation is the same as previously used in the previous chapters.

Changes in the parameters of the regime of the electrical system and the elements of the pumping station significantly affect transients and determine the reliability and stability of the pump unit as an element of the electrical system. The results can be used in the reconstruction of existing and designing new pumping stations, so transients are considered for a certain range of variation of these parameters. The processes with a sharp change in the voltage of the tires of the electrical system and the generator, variations of such parameters as time constants, damping coefficient of a synchronous motor, etc.

The results of calculation and experimental studies below correspond to the main conditions of the Khamza-2 pumping station and have the following values [1, 2,3]:

- a synchronous motor of the type ВДС-375-130-24: rated power P = 12.5 MW, rated voltage U = 10 kV, rated power factor $\cos\varphi$=0,8, fly mass GD^2=87 $тм^2$. The electromagnetic parameters of the machine are taken equal to: synchronous inductive resistance along the longitudinal axis x_d = 1.2; synchronous inductive resistance along the transverse axis x_q = 0.9, transient inductive resistance x'_d = 0.3, damping coefficient of the machine P_d = -0.5 + 0.5.;

- pathogen BBC-99-24-8: rated voltage U_f = 130 V, rated current I_f = 960 A;

- automatic excitation regulator: excitation time constant T_e = 0.5 s., regulator time constant T_r = 0.1 s, time constants of measuring, converting and differentiating elements are not taken into account – $T_I = T_P = T_D = T_{DD} = 0$, gain ARV along the voltage channel K_{0U} = 1-50 units of excitation, gain factors along the channels of the derivative of voltage $K_{1U} = K_{2U}$ = 0-5 units of excitation / s.

- pump ОПВ10-260: flow Q=40 м^3/с head H = (37-55) m, rotation speed n = 250 rpm, coefficient of performance η = 0.86;

- pipeline: length L = 1500 m, diameter D = 4.24 m, wall thickness ε = 20 mm, wave propagation velocity c = 1000 m / s;

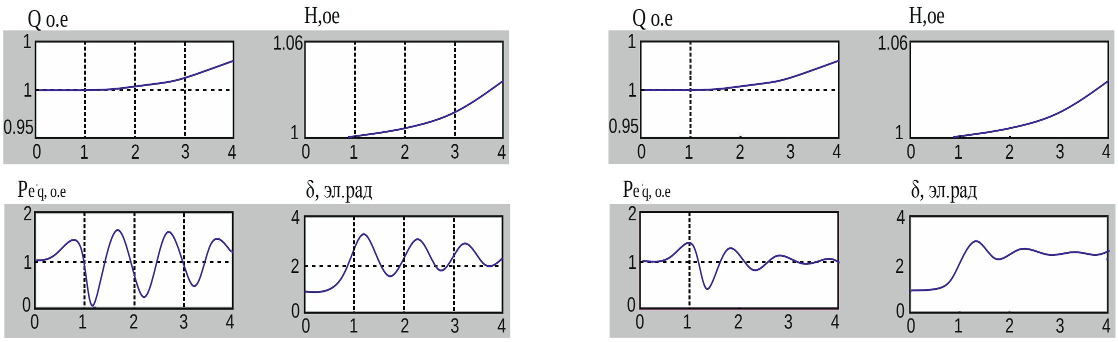
- electrical system: inductance of the line to the bus bars of the system $x_л$ = 0.2 pu, inductive resistance of the communication transformer x_T = 0.1 pu, rated voltage on the higher side U_l = 1 pu (in absolute units it is equal to 110 kV). In the nominal mode, the active power consumption of the P_{DB} = 1 p.u., the reactive power Q = ± 0.3 p.u.

The calculations were carried out in relative units, in which the nominal values of the mode parameters were taken as the base.

The voltage change mode can occur frequently, especially during the passage of the peak mode of the electrical system.

In fig. Figure 1 shows the characteristics of the transition mode with an increase of 5% in the voltage on the buses of the receiving system with respect to the normal mode, obtained based on the solution of the system of equations (8-10). It can be seen from them that the flow rate and pressure of the pump unit increase slightly, and the parameters of the electromagnetic transient change significantly. Deviations of the electromagnetic rotation power can occur from + 30% to -90%, and the load angle up to 3 radians. The process is generally stable, since the automatic excitation controller works in the right direction and reduces the electromotive force by acting on the magnetic flux of the machine. Fluctuations in the load angle and its derivative occur in concert.

One of the difficult modes is to reduce the voltage on the bus bars of the station, especially on the system buses. The analysis shows that a decrease in voltage on the system buses by more than 8% leads to the output of the LED out of synchronism, if during this period for some reason the ARV of the machine is turned off. The characteristics of transients with a decrease in voltage on the system tires by 2% are given.



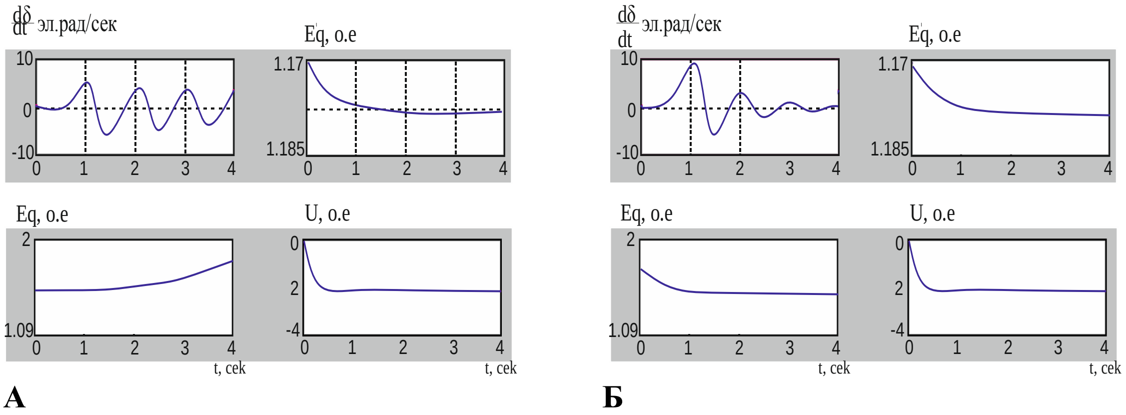


Fig. 1. Transient electro-and hydromechanical processes with an increase in voltage on the system buses by 5%: A) ARV is turned on with a coefficient gain by voltage deviation $К_{0U}$ = 1 ed., Б) $К_{0U}$ = 5 ed.

From the above curves it is seen that the nature of the flow of hydromechanical transients varies somewhat, namely, the flow rate decreases, while the pressure increases. This is because the driving force - the torque of the machine is reduced, and the increase in pressure is associated with the inertia of the flow.

As for electromagnetic transients in diabetes, ARV plays an important role. The included ARV not only ensures the stable operation of the machine, but also significantly damps the fluctuations of the operating parameters.

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