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LARGE PUMPING STATIONS AS REGULATORS OF POWER SYSTEMS MODES

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Abstract. The article discusses the issues of the effective use of synchronous motors installed in irrigation pumping stations. The necessary capacities for water delivery to waterless territories are given. It is shown that synchronous motors can generate reactive power and thus actively participate in the control of the system mode.

Introduction

Synchronous motors of pumping units can become regulators of the parameters of the electrical system mode. This is due to the fact that the existing and successfully operated SM (synchronous motor) of pumping units have power factors in the range of cosφ = 0.8-0.85 and one unit in the nominal mode can produce up to 6 MVAr of reactive power (P_{nom} = 12.5 MWt). Considering that the number of SM at large pumping stations in Uzbekistan is several dozen, then we are talking about a solid reserve of reactive power regulation. The output of reactive power from pumping stations improves the voltage mode of the electrical system, reduces losses in the network, therefore, the energy efficiency of both pumping stations and the electrical system as a whole increases.

On the other hand, the output of reactive power from the pumping station increases the e.m.f. motor, therefore increases the safety factor of the static and dynamic stability of the unit. Unfortunately, pumping stations are usually presented only as consumers to electrical system dispatchers. This situation has its own explanation - in them automatic excitation regulators do not work in coordination with the dispatching service of the EPS for various reasons (technical, organizational). Therefore, they belong to the category of consumers both in terms of active and reactive power. In other words, the regulatory capabilities of pumping stations are practically not used, but they must operate in the mode of consumer-regulators, meaning. at least reactive power regulation.

A synchronous machine can work not only as a source of active power, but also as a source of reactive power [1,2,3]. This can be seen from the diagram below (Fig. 1), showing the capabilities of a synchronous motor in a wide range to change the reactive power (within the limits allowed by technical conditions). This diagram is constructed under the condition of the constancy of the active power consumed by the machine P = const.

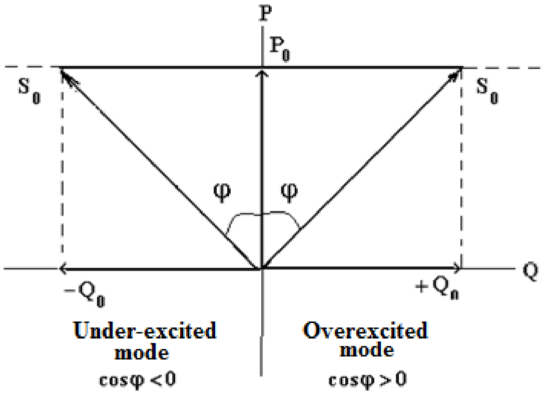

Fig. 1 Output (cosφ > 0) and consumption (cosφ < 0) modes reactive power synchronous motor.

1.1 Regulation of the SM operation modes

As you know, the total engine power is determined by the expression:

$$S = P + jQ \quad \text{or} \quad S = \sqrt{P^2 + Q^2} \qquad (1)$$

where P, Q - active and reactive power consumed by a synchronous motor. The degree of workload of the machine with active power is determined by the ratio - the power factor.

$$\cos\varphi = \frac{P}{S} = \frac{P}{\sqrt{P^2+Q^2}}.$$

In case of overexcitation, the synchronous motor delivers reactive power to the electrical system (cosφ>0, Q>0), in case of under-excitation it consumes (cosφ < 0, Q<0).

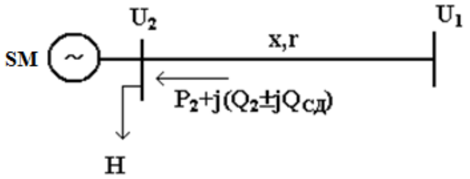

Fig. 2. Scheme of a network with a synchronous motor, as reactive power regulator

The essence of voltage regulation by influencing the reactive power flows through the elements of the electrical network lies in the fact that when reactive power changes, voltage losses in reactances change. So, for the network diagram shown in Fig. 2, the relationship between the voltages of the beginning of U_1 and the end of U_2 can be written as:

$$U_2 = U_1 - \Delta U = U_1 - \frac{P_2 r + (Q_2 \pm Q_{SM})x}{U_2} \quad (2)$$

Unlike active power, reactive power at network nodes can be changed by installing lateral compensation devices in them, i.e. compensating devices [4,5]. Such devices can be synchronous compensators, shunt and controlled reactors, static thyristor compensators, as well as generators of local power plants connected to the power transmission and distribution system, synchronous electric motors, etc. Some compensating devices can only supply reactive power to the network, some can only consume reactive power from the network (shunt and controlled reactors). The most acceptable for voltage regulation are devices that, depending on the network mode, both generate and absorb reactive power (synchronous motors, compensators, static thyristor compensators) [6].

Compensating devices can be non-adjustable and adjustable. When an unregulated compensating device is switched on, a constant value compensation for the voltage loss (negative or positive) is created in the network. If the compensating device allows you to change the direction of reactive power depending on the network mode, then the value of compensation for voltage loss, as follows from formula (2), turns out to be variable, as a result of which it becomes possible to regulate the voltage. So, in the network diagram shown in Fig. 2, when the compensating device changes reactive power from generation (minus sign in formula (2) before Q_{SM}) to consumption (plus sign in front of Q_{SM}), the amount of voltage loss will change, which, with a constant voltage U_1 = const, will also lead to a change voltage U_2 at the end of the network, i.e. voltage regulation will be provided.

As follows from formula (2), the efficiency of voltage regulation with the help of transverse compensating devices increases in networks with relatively large reactances compared to active ones, for example, in overhead networks compared to cable ones. In this case, the greatest effect is achieved when installing compensating devices in the load nodes that are most distant from the power supply centers, which are pumping stations with synchronous motors.

With the help of a transverse compensating device, it is possible to create a mode in which the voltage value at the end of the network is greater than the voltage value at the beginning ($U_2 > U_1$). This will happen when the magnitude of the voltage loss in formula (2) becomes negative:

$$\frac{P_2 r}{U_2} + \frac{Q_2 x}{U_2} - \frac{Q_{SM} x}{U_2} < 0 \ . \quad (3)$$

Hence the power of the compensating device for such a mode,

$$Q_{SM} > P\frac{r}{x} + Q_2 \quad (4)$$

The physical essence of voltage regulation using synchronous motors is additionally explained by the vector diagram (Fig. 3).

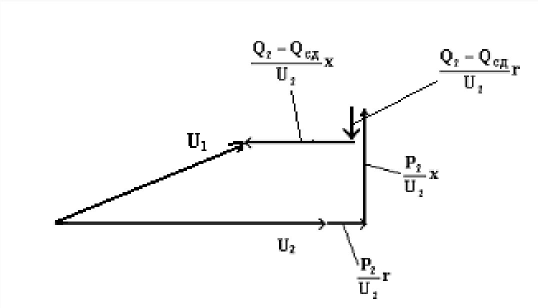

Fig. 3. Vector diagram of a synchronous motor, overexcitation mode (Q_{SM} >0, cosφ>0)

To do this, we write the relationship between the voltage U_1 and U_2 through the voltage drop:

$$U_1 = U_2 + \frac{P_2 r + Q_2 x}{U_2} + j\frac{P_2 x - Q_2 r}{U_2} = \\ = U_2 + \frac{P_2}{U_2} r + j\frac{P_2}{U_2} x - j\frac{Q_2}{U_2} r + \frac{Q_2}{U_2} \quad (5)$$

When installing a synchronous motor delivering reactive power, equation (6) takes the form:

$$U_1 = U_2 + \frac{P_2}{U_2} r + j\frac{P_2}{U_2} x - \\ -j\frac{Q_2 - Q_{SM}}{U_2} r + \frac{Q_2 - Q_{SM}}{U_2} x \quad (6)$$

Because $\frac{Q_2-Q_{SM}}{U_2}x > \frac{P_2}{U_2}r$, therefore

$$.|U_2| > |U_1|$$

For the case when the generated reactive power of the synchronous motor fully compensates the reactive load of consumers

($Q_{SM} = Q_2$):

$$U_1 = U_2 + \frac{P_2}{U_2}r + j\frac{P_2}{U_2}x. \qquad (7)$$

Compensating devices for lateral compensation have a complex positive effect on the mode of electrical networks. In addition to the possibility of voltage regulation, they allow to reduce the losses of active power and electricity by unloading the network elements from reactive power and, accordingly, reducing the operating currents. In some cases, when the transmitted active power is limited by the permissible current for heating the conductors or by the permissible voltage loss, due to the unloading of the network from reactive power, it is possible to increase the throughput active power. Therefore, the issues of choosing the power and installation locations of compensating devices should be resolved in a complex manner. Let us consider the features of the choice of the power of the compensating device according to the voltage regulation condition [7,8].

Suppose that at U_1 = const, the voltage U_2 for some reason does not satisfy the consumers (Fig. 2), and it must be increased to U_2 by choosing the appropriate power of the compensating device installed at the end of the network. When calculating, it should be taken into account that when the voltage U_2 rises to U_2, the consumed loads P_2 and Q_2 will change to P_2z and Q_2z in accordance with their static characteristics P_2 = f (U_2) and Q_2 = f (U_2). This factor may not be taken into account if the load is connected to the secondary side of a transformer with a control device, which allows the voltage on the secondary busbars to remain unchanged.

Before and after the installation of a synchronous motor with power Q_{SM}, the relationship between the voltages of the beginning and end of the network, respectively, is represented as:

$$U_1 = U_2 + \frac{P_2r+Q_2x}{U_2},$$
$$U_1 = U_{2j} + \frac{P_{2j}r+(Q_{2j}-Q_{SM})x}{U_2} \qquad (8)$$

Equating the right-hand sides of these equations by the condition U1 = const, we find the power of the compensating device:

$$Q_{SM} = \frac{(U_{2j}-U_2)U_{2j}}{x} +$$
$$+(P_2 - P_{2j}\frac{U_{2j}}{U_2})\frac{r}{x} + (Q_2 - Q_{2j}\frac{U_{2j}}{U_2}) \qquad (9)$$

Here the powers P_2, Q_2, P_2j, Q_2j are found according to the corresponding static characteristics.

Calculated part

Let us consider the influence of the direction of reactive power on the transient regime of the electric power system. The results of the computational and experimental studies given below correspond to the basic conditions of the pumping station Khamza-2 in Uzbekistan and have the following values [9]:

- synchronous motor VDS-375-130-24: rated power P = 12.5 MW, rated voltage U = 10 kV, rated power factor cos = 0.8, flywheel mass GM^2 = 87 tm^2. The electromagnetic parameters of the machine are taken equal: synchronous inductive resistance along the longitudinal axis x_d = 1,2,; synchronous inductive reactance along the transverse axis x_q = 0.9, transient inductive reactance = 0.3, machine damping coefficient Pd = -0.5 + 0.5 .;

-exciter VVS-99-24-8: rated voltage U_f = 130 V., rated current I_f = 960 A;

- automatic excitation regulator: excitation time constant Te = 0.5 s., regulator time constant Tr = 0.1 s., time constants of the measuring, conversion and differentiating elements are not taken into account - TI = T_P=T_D=T_{DD} =0, gain AEC (automatic excitation control) on the voltage channel K_{0U} = 1-50 exc. Units, amplification factors on the voltage derivative channels K_{1U} = K_{2U} = 0-5 exc. Units / sec.

- pump OPV 10-260: flow rate Q = 40 m3 / s, head H = (37-55) m, rotation frequency b n = 250 rpm, efficiency η = 0.86;

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

- electrical system: inductive resistance of the line to the buses of the system xl = 0.2 p.u., inductive resistance of the coupling transformer xT = 0.1 p.u., rated voltage on the upper side U_l = 1 p.u. (in named units equal to 110 kV). In the nominal mode, the consumed active power of the R_{FE} = 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 parameters of the pumping station mode were taken as the basic ones.

Fig. 4. shows the angular characteristic of a synchronous motor of the VDS-375-130-24 type,

$$M_M = \frac{E_q U_c}{X_{d\Sigma}} \sin\delta + \frac{U^2}{2}\frac{(X_d - X_q)}{X_{d\Sigma} X_{q\Sigma}} \sin 2\delta \qquad (10)$$

built according to the formula (10) and characterizing the parameters of the normal mode of the machine (P_0 = 1 p.u.): load angle δ_0 = 40.50, maximum power P_m = 1.42 p.u., limiting angle δ_m = 820. Safety factor static stability equal

$$K_{ST} = \frac{P_m - P_0}{P_0} * 100\% = 42\% \qquad (11)$$

low enough for the accepted baseline. These data show the importance of studying the temporary voltage deviation on the mode and stability of a synchronous motor [10,11].

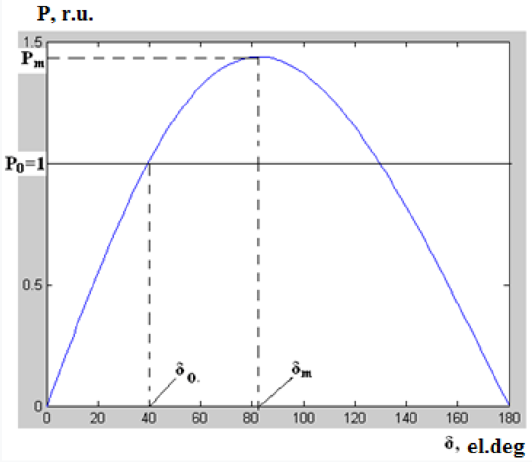

Fig. 4. Angular characteristic of a synchronous motor type VDS-375-130-24

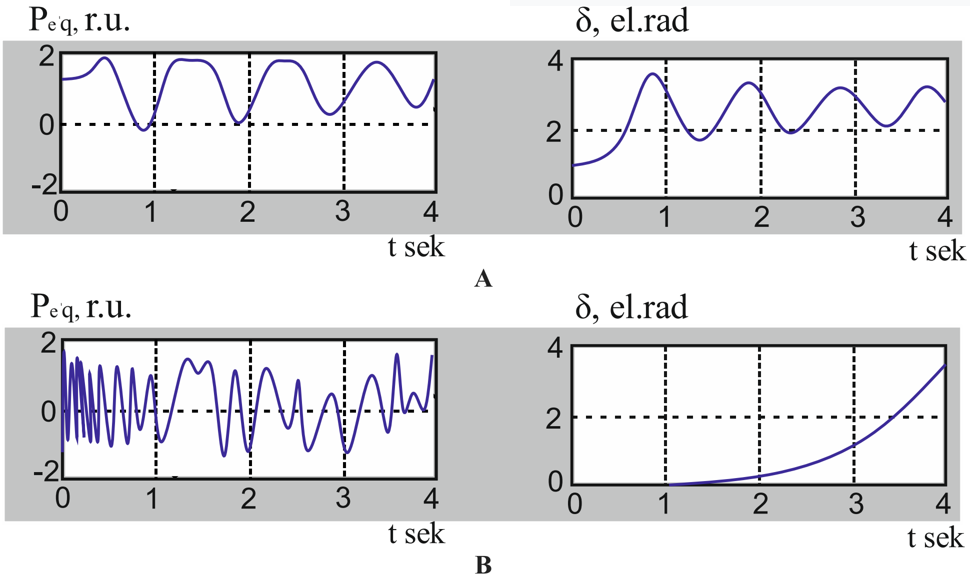

Fig: 5. The influence of the direction of reactive power on the transient regime. A - delivery mode, B - production limitation modereactive power by a synchronous motor.

In fig. 5, the characteristics of the transient process are presented with a jump-like surge of reactive power on the buses of the EPS station by a value of ± 0.1 p.u. from the local load side (it is assumed that the reactive power comes only from this station). Before the thrust, the machine produced the rated reactive power and the static stability safety factor was 70%. If this reactive power is supplied by synchronous motors (A → +0.1 pu), after a series of oscillations, the stability of the machine

remains, and the safety factor becomes equal to 92%. If the machine does not deliver this reactive power (B → -0.1 p.u.), then the engine goes out of synchrocheck. The reason lies in the decrease in the

voltage on the station buses by more than 8%, which leads to a decrease in the safety factors for static and dynamic stability. In the second case, the automatic excitation regulator does not help either.

Conclusion

The curves show that the nature of the hydromechanical transient processes changes somewhat, namely, the flow rate decreases, while the pressure increases. This is due to the fact that the driving force - the torque of the machine decreases, and the increase in pressure is associated with the inertia of the flow.

With regard to electromagnetic transients in synchronous motors, AEC (automatic excitation control) plays an important role. The presence of AEC not only ensures stable operation of the machine, but also significantly dampens fluctuations in operating parameters.

Thus, synchronous motors of pumping stations can successfully perform the role of consumers-regulators of reactive power and voltage, especially when they are equipped with (AEC).

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