Calculation methodology for determining the number of simultaneous self-starting pumping units

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Abstract. The paper considers the methodology of calculating the number of self-starting pump units depending on the network voltage landing and the basic calculation dependencies of the process of self-starting of electric motors supplied from three-phase three-winding transformer; the substitution scheme for one phase of the circuit is made. Technical solutions for upgrading pump units, which allow applying the self-start mode at ameliorative pumping stations, are proposed.

Keywords. Self-start, transient, reclamation pumping stations, pump unit, electrical equipment, starts, emergency shutdowns, pipeline, free-running, shutdown, power equipment, electric drive, induction motor, power system, power line, self-start device.

1 Introduction

One of the main factors influencing the yield of agricultural crops, in particular cotton, is timely irrigation. Therefore, uninterrupted operation of pumping units during the irrigation season to ensure the specified water delivery schedule of pumping stations is of great importance for the economy of the republic.

During planned shutdowns of pump units in pumping stations the gate valve in the discharge line is closed beforehand [1]. In this case the speed of the pump unit is reduced to zero. In addition, water remains in the discharge line (manifold). At present, both in case of an emergency as well as in case of a successful automatic reclosure (reclosure) of the power grid there is a complete abrupt shutdown of the pump units of the pumping stations. Due to the loss of drive by the pump, the flow is reduced to zero and the unit will rotate in the same direction. The water flow through the pump initially slows the pump down, the speed reaches zero, then the direction of rotation changes to turbine mode and accelerates to a steady angular speed, as the pipeline is emptied it slows down and stops. As a consequence, no water remains in the manifold, the pump glands burn and fail, fasteners are loosened and the entire pump unit fails [2].

Pump plugs must be removed, damaged glands removed, new gland packings stuffed and plugs reassembled in order to start the pump unit after repainting. The rear gate valve must be closed tightly to create a vacuum before the pump is started. Therefore, in such cases it is necessary to fill the manifold with water in order to create a vacuum in the pump before start-up. An emergency situation is created at the pumping station after each repowering. Start-up of pumping units requires qualified personnel and scarce materials (gland packing, turbine oil). It takes a long time (2-3 days) to carry out start-up and bring the pumping unit to its normal operating condition, which leads to disruption of water supply for irrigation. Therefore, the problem of self-starting of pumping units is urgent [3].

2 Methods

The number of pump units installed in reclamation pumping stations varies widely (2-16). The drive motors of the pumps are supplied by the step-down substation of the pump station. Two-winding and three-winding transformers are used in these substations.
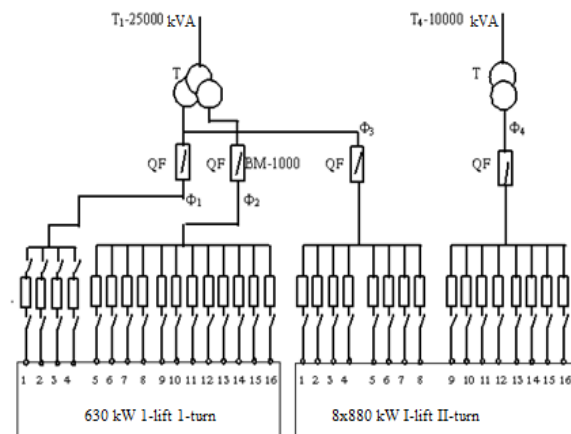
Fig. 1. Electrical scheme of the Amu-Zang-I, I and II stage pumping station

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The number of simultaneous self-starting motors in a pumping station is determined on the basis of the permissible mains voltage drop at the time of self-starting. Knowing the mains voltage and the power supply resistance, the value that restores the voltage to the motors is determined. If the torque of the motor at this voltage is greater than the pumps' resistance torque, the motor can be restarted.

A calculation procedure for determining the number of self-starting pumping units depending on the mains voltage landing is given. Fig.1 shows the power supply scheme of typical pumping stations of the first lift. The main calculated dependencies of the self-starting process of electric motors supplied from a 3-phase three-winding transformer are derived.

Primary rated line voltage: U_{vl}

Primary phase voltage:

$$U_{1pv} = \frac{U_{vl_1}}{\sqrt{3}}; \qquad U_{2pv} = U_{2vl}. \tag{1}$$

Transformer transformation ratio:

$$K_{t_{12}} = K_{t_{13}} = \frac{U_{1pv}}{U_{2pv}} = \frac{U_{1pv}}{U_{3pv}}; \tag{2}$$

Determine the rated winding currents of the three-winding transformer:

$$I_{1pv} = I_{1vl} = \frac{S_{vI} \cdot 10^3}{\sqrt{3} \cdot U_{1_{vl}}}; \tag{3}$$

$$I_{2нл} = I_{3нл} = \frac{S_{vII} \cdot 10^3}{\sqrt{3} \cdot U_{2vl}} = \frac{S_{vII} \cdot 10^3}{\sqrt{3} \cdot U_{3vl}}; \tag{4}$$

$$I_{2pv} = I_{3pv} = \frac{I_{2nl}}{\sqrt{3}} = \frac{I_{3nl}}{\sqrt{3}} \tag{5}$$

From the short-circuit voltage values, find the total short-circuit resistance relating to one phase when the supply transformer is three-winding:

$$Z_{к23} = \frac{U_{к23}}{100} \cdot \frac{U_{1pv}}{I_{1pv}}; \tag{6}$$

$$Z_{к12} = \frac{U_{к12}}{100} \cdot \frac{U_{1pv}}{I_{1pv}}; \tag{7}$$

$$Z_{к13} = \frac{U_{к13}}{100} \cdot \frac{U_{1pv}}{I_{1pv}} \tag{8}$$

Bring these resistances to the secondary and tertiary windings:

$$Z'_{к23} = Z_{к23} \cdot \frac{1}{K_m^2}; \tag{9}$$

$$Z'_{к12} = Z_{к12} \cdot \frac{1}{K_m^2}; \tag{10}$$

$$Z'_{к13} = Z_{к13} \cdot \frac{1}{K_m^2}. \tag{11}$$

Ignore the active components of the short-circuit resistances. Then the inductive short-circuit resistances reduced to the secondary and tertiary windings:

$$X'_{к23}; \qquad X'_{к12}; \qquad X'_{к13}. \tag{12}$$

Inductive resistance of the primary winding dissipation reduced to the secondary and tertiary windings:

$$X'_{\delta_1} = \frac{X'_{к12} + X'_{к13} + X'_{к23}}{2}; \tag{13}$$

Inductive resistance of the secondary and tertiary windings:

$$X'_{\delta_2} = \frac{X'_{к12} + X'_{к23} + X'_{к13}}{2}; \tag{14}$$

$$X'_{\delta_3} = \frac{X'_{к13} + X'_{к23} + X'_{к12}}{2}. \tag{15}$$

Convert the secondary and tertiary windings of a delta-connected transformer to equivalent stars:

$$X'_{\delta_{1э}} = \frac{X'_{\delta_1}}{3}; \tag{16}$$

$$X'_{\delta_{2э}} = \frac{X'_{\delta_2}}{3}; \tag{17}$$

$$X'_{\delta_{3э}} = \frac{X'_{\delta_3}}{3}. \tag{18}$$

Assume that the network supplying the transformer has infinite capacity. To calculate the self-start of the transformer-fed motors, make a substitution diagram (Fig. 2) for one phase of the circuit. Ignore the transmission line resistances.

The calculation formulas for the substitution diagram and self-starting of electric motors from a 3-winding transformer are given below:

On the basis of the obtained expressions a calculation is made at parametrically given motor slip values S=1; 0,5; 0,06; current values in individual feeders F_1; F_2; F_3; and voltage at the end of these feeders, i.e. at the terminals of individual groups of electric motors fed from these feeders and the voltage landing in the transformer windings (without considering the loss in the connecting cables), when the number of electric motors starting at S=1 and self-starting at S=0,5; 0,06 varies from one to four. Based on the calculated dependencies obtained, the number of self-starting electric motors of the operating pumping stations "Amu-Zang -I" is determined.

$$Z_{f_I} = \left(\frac{R_{1_I}}{n_1} + \frac{R'_{2_{II}}}{n_1 S}\right) + j\frac{X_{к_I}}{n_1}; \tag{19}$$

$$Z_{f_{II}} = \left(\frac{R_{1_{II}}}{n_2} + \frac{R'_{2_{II}}}{n_2 S}\right) + j\frac{X_{к_{II}}}{n_2}; \tag{20}$$

$$Z_{f_{III}} = \left(\frac{R_{1_{III}}}{n_3} + \frac{R'_{2_{III}}}{n_3 S}\right) + j\frac{X_{кIII}}{n_3} + jX_{\delta 3э}; \quad (21)$$

$$Z_{f_I} - F_{II} = jX_{\delta 2э} + \frac{Z_f \cdot Z_{f_{II}}}{Z_{f_I} + Z_{f_{II}}}; \quad (22)$$

$$Z_e = jX'_{\delta 2e} + \frac{Z_{f_{III}}Z_{f_I} - \Phi_{II}}{Z_{f_{III}} + Z_{f_I} - Z_{f_{II}}}; \quad (23)$$

$$I_e = \frac{U_{2f}}{Z_e}; \quad (24)$$

$$U_{AB} = U_{2f} - I_e \cdot X'_{\delta 1e} \cdot \varepsilon^{j90^o}; \quad (25)$$

$$I_{f_{III}} = \frac{U_{AB}}{Z_{F_{III}}}; \quad I_f - I_{F_{II}} = I_e - I_{f_{III}}; \quad (26)$$

$$U_{qIII_l} = \sqrt{3}I_{f_{III}}\left(\frac{R_{III}}{n_3} + \frac{R'_{2III}}{n_3 S} + j\frac{X_{кIII}}{n_3}\right); \quad (27)$$

$$U_{qI_l} = U_{qII_l} = \sqrt{3}\big(U_{AB} - U_{f_I} - I_{F_{II}} \cdot X_{\delta 2э} \cdot \varepsilon^{j90^o}\big); \quad (28)$$

$$I_{f_I} = \frac{U_{qII_l}}{\sqrt{3}Z_{f_I}}; \quad I_{f_{II}} = \frac{U_{qII_l}}{\sqrt{3}Z_{f_{II}}}. \quad (29)$$

Parameters of transformer
TDTN-25000/110/6/6.
Scheme and winding connection group
Y/Δ/Δ/-II-II.
Short circuit voltage:
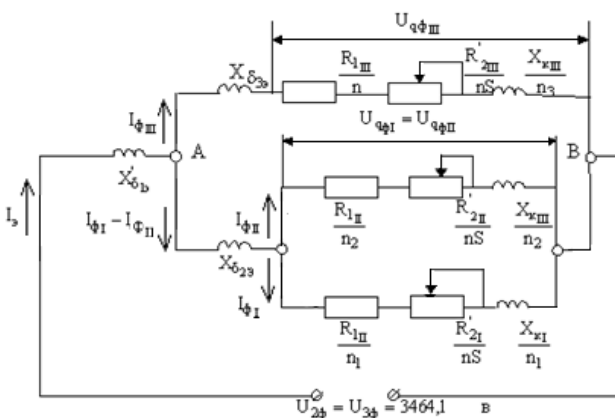HV-HV at 2500 kVA 10.7%,
HH-HH at 12500 kVA 16.5%,
HV-HV at 12500 kVA 9.87%,
HH-HH at 12500 kVA 9.48%.

3-phase asynchronous motor type
DAZO 15-59-10U1:
U_{dl} = 6 kV, η=93%, P_{2H}=630kWt,

Fig. 2. Schematic diagram of one phase of a circuit supplied from a three-winding transformer

$$M_{п_{kr}} = \frac{M_п}{M_н} = 1,3,$$

n=595 rpm, $I_{п_{kr}} = \frac{I_п}{I_н} = 6,6,$ I_H=80A,

$$M_{maxkr} = \frac{M_к}{M_н} = 3,26;$$

Cos φ$_n$ =0,81. Pump type: 24 VAT, DRC = 875 mm.
RESULTS. The results of the calculations are shown in summary table 1 and in figure 3. 3.
Calculation of self-starting electric motors from TDTN-25000/110/6/6 transformer.

Table 1

S	n	U_{qII} = U_{qIII}	U_{qIIII}	I_{FI}	I_{FII}	I_{FIII}	ΔU_{qII}= ΔU_{qIII}	ΔU_{qIII}
	pc	B	B	A	A	A	%	%
1,0	1	5680	5832	540	675	560	5,3	2,8
	2	5393,64	5660,6	1046	1277	1098	10,1	5,8
	3	5130	5495	5495	1500	1840	16,10	8,4
	4	4894,7	5344,6	1899	2314	2073	18,4	10,9
0,5	1	690	5838	535	668	553	5,1	2,7
	2	3406,1	5668,4	1035	1266	1085	9,9	5,5
	3	5150	5520	1488	1828	1599	14,1	8
	4	4914,09	5377,1	1881	2301	2058	18,01	10,4
0,06	1	5880	6940	343	430	342	1,5	1,0
	2	5755,94	5869,3	664	843	677	4,05	2,2
	3	5633	5810	973	1235	1006	6,1	3,2
	4	5516,86	5743,12	1273	1616	1325	8,05	4,3
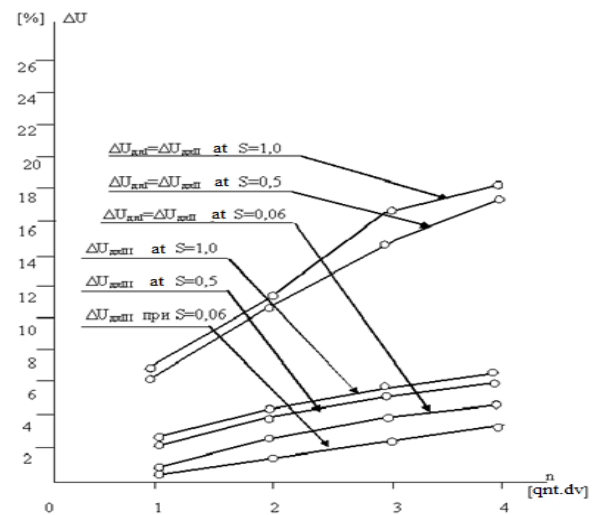
Fig. 3. Number of self-starting pump units

Conclusion

As a result of the conducted research of pump unit's operation at the first lift pump station it was found out that self-starting of asynchronous motors can be performed. The number of self-starting asynchronous motors at the existing scheme of electric equipment of the pump station depends on the time of short-circuit failure in the network. The maximum number of self-launching induction motors in pumping stations is 8 for a start-up time of 0.8 s and 4 for a start-up time of 2.5-3 s. The mains voltage drop under these conditions is within the permissible limits.

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