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A simulation model of electric actuator unit of electric centrifugal pump with a submersible individual compensation installation

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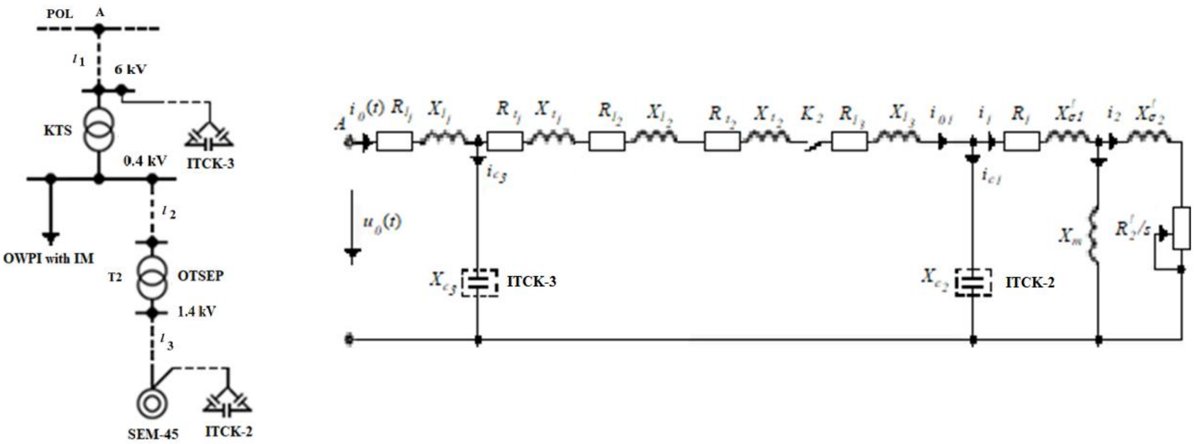
Abstract. The substitution scheme and the system of differential equations for electrotechnical complex of producing well are given. The mathematical and simulation models of electric drive of electric centrifugal pump installation with submersible individual compensating installation are developed. The scheme of inclusion and practical realization of individual compensating installation consisting of the static capacitor battery with non-standard nominal voltage which is connected directly to the stator clips of submersible electric motor in a well is proposed. The simulation model of electric actuator of the electric centrifugal pump allows one to simulate the operation mode of electric actuator in steady-state and transient modes, as well as the group start of electric drives of electrical complex of the producing well. The optimal level of outgoing line voltage, energy parameters and the optimal parameters of individual, node and centralized compensating installations, as well as the rational voltage level of the main substation were determined from simulation.

1 Introduction

Exploitation of high flow rate wells with high water content is carried out using intensive oil production technology, at this electrical complexes of producing well (ECofPW) are operated with electric centrifugal pump installations (CPI) with submersible electric motors (SEM). According to statistically averaged data their amount is about 20% of total base of electrotechnical complexes of producing wells of oil and gas enterprises, and they produce up to 70% of total produced volume of oil. Share of electrical energy costs is a large part of the total amount of electricity spent on mechanized oil production, so the question of reducing power losses in supply cable of ECofPW equipped with SEM [1] is relevant [2-4].

Submersible motors are specific electric equipment and reactive power consumption of these installation depends on their rated power and demand factor. Dependence between reactive power and voltage on SEM contact terminals is cubic, at this voltage is non-standard and can be in the range of 500-3400 [5]. In fact capacity factor takes into account strengthened watering of operated well and is ~ 0.7 OE [6-10].

As an object of research we have chosen the electrical complex of producing well with a power line, a step-down oil transformer (OT), a step-up oil transformer for submersible electric motor (OTSEM)



a) b)

Fig. 1. Principal diagram of electrical power supply of electrical complex of producing well (a) and its equivalent circuit (b).

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with an off-standard voltage on secondary winding, the installation of an electric centrifugal pump (ECP) and SEM, supplemented by individual submersible compensating installation.

Non-standard voltage level at SEM terminals when connected to power supply system requires an additional stage of transformation (Fig. 1). A special step-up transformer OTSEM-0.4 kV with non-standard voltage on the secondary side is used for this purpose. The considered electrical complex consists of the following elements: plot overhead lines (POL) of 6(10) kV; nodal compensating installation, i.e. traversal compensating installation ITCK-3; complete transformer substation (KTS) of 6(10)/0.4 kV; control station, i.e. oil-well pump installation (OWPI) with a chain drive induction motor (IM); OTSEM transformer; control station pumping system (ESPI); cable line (CL) with voltage of 1400 V, descending into well to a depth of 1.5 km; SEM with submersible individual compensation installation, i.e. traversal compensating installation ITCK-2.

Currently, static capacitor banks with non-standard rated voltage are used to compensate reactive power in electrical complexes of producing wells with ESPI [11], which are connected directly to terminals of stator and submersible motor in well. This installation allows compensating reactive component of linear motor current in cable line and in OTSEM transformer and reducing the active power loss up to 6% [8, 12-15].

2 Methods

According to equivalent circuit shown in Fig.1, we developed a mathematical model of the complex under consideration. Total active resistance and inductance of the equivalent circuit branch are:

$$R = R_{t_1} + R_{l_2} + R_{t_2} + R_{l_3},$$
$$L = L_{t_1} + L_{l_2} + L_{t_2} + L_{l_3}.$$

The equivalent circuit of the object under study is represented by a system of differential equations:

$$u(t)_0 = i(t)_0 R_{l_1} + L_{l_1} \frac{di(t)_0}{dt} + u(t)_{c_3},$$

$$u(t)_{c_3} = i(t)_{01} \mathrm{R} + L \frac{di(t)_{01}}{dt} + u(t)_{c_2},$$

$$i(t)_1 = \frac{di(t)_{01}}{dt} - C_2 \frac{du(t)_{c_2}}{dt},$$

$$u(t)_{c_2} = i(t)_1 R_1 + \frac{d\psi_1}{dt},$$

$$0 = i_2 R_2 + \frac{d\psi_2}{dt},$$

where u_0 is the input voltage in ECofPW; R_{l_1} and L_{l_1} is the active resistance and inductance of supply line of step-down transformer; i_0 is the input current of ECofPW; i_{C_2} is the current through capacitor C_2; u_{C_2} and u_{C_3} are voltage at capacitors terminals; i_1 is stator current; i_2 is rotor current; $\psi_1 = i_1 L_1 + i_2 L_m$, $\psi_2 = i_2 L_2 + i_1 L_m$ is the flux linkage of stator and rotor windings, respectively; R_1 is active resistance of stator winding; R_2' is active resistance of rotor winding, connected to stator winding; $L_1 = L_{6_1} + L_m$, $L_2 = L_{6_2} + L_m$ is full inductance of stator and rotor windings, respectively.

The system of differential equations are reduced to the Cauchy form, supplemented by equation of motion, consisting of two components of electromagnetic moment, moment of resistance and input voltage, which is presented as a single step function [7], taking into account time of reduction and recovery of voltage level and coefficient characterizing degree of failure of voltage level.

Energy parameters, rational parameters of individual

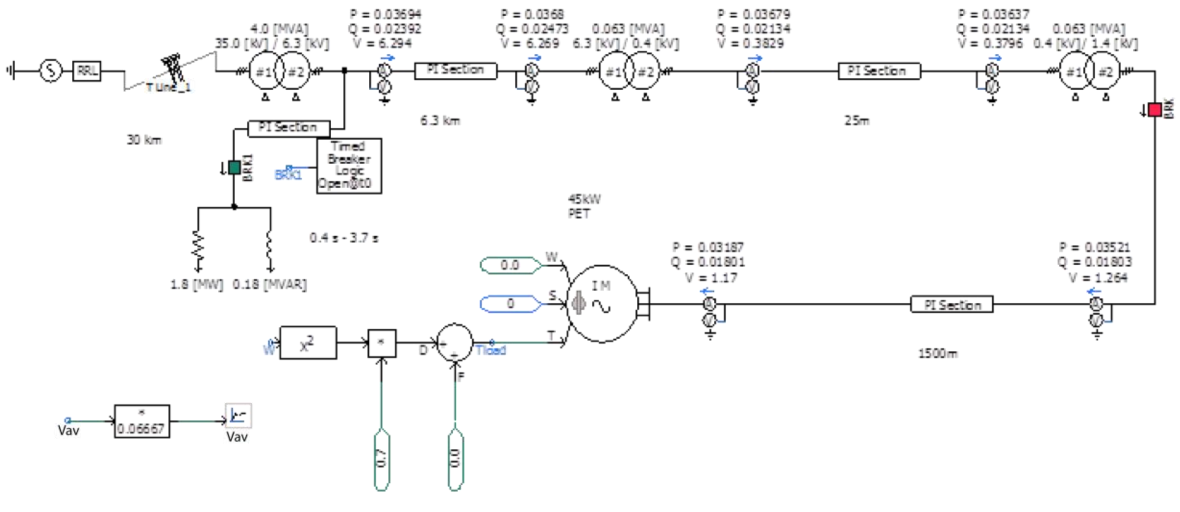

Fig. 2. Simulation model of ECofPW without compensating installation.

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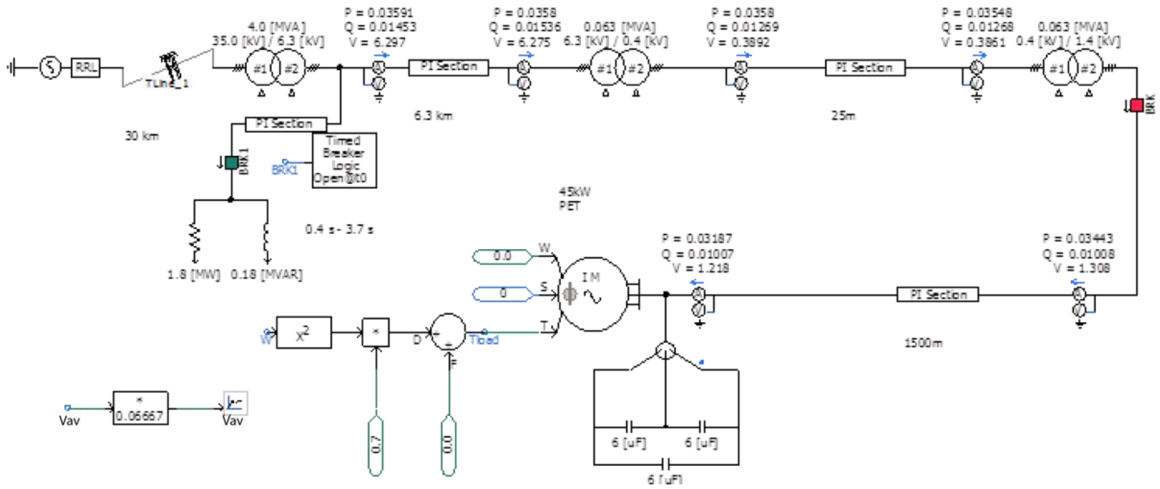


Fig. 3. Simulation model of ECofPW with submersible compensating installation.

compensating installation and adjoining parameters of guaranteed start and self-start of electric drive of the considered complex were obtained from mathematical modeling.

The PSCAD program was used to develop the simulation model of power supply system of electrotechnical complex of producing well, which takes into account all elements of its schematic diagram. This model is supplemented by parameters of outgoing line, equivalent load, centralized compensating installation and power transformer of field substation. The simulation model of ESPI electric drive with electrical submersible motor included a submersible individual compensating installation, which is not available in standard library of PSCAD/EMTDC software package.

Simulation model allows one to simulate operation mode of electric drive in steady-state and transient modes, as well as group start of electric drives of electrotechnical complex of producing well.

Figures 2 and 3 show the developed simulation model for starting sequence modeling of ECofPW electric drives without compensating installations and by means of submersible individual compensating installation. Energy parameters of stationary operating condition of the ECofPW are given in table 1. Practical implementation of submersible electrical motor with increased power factor [5], i.e. with a submersible individual compensating installation attached to it, is shown in Fig. 4.

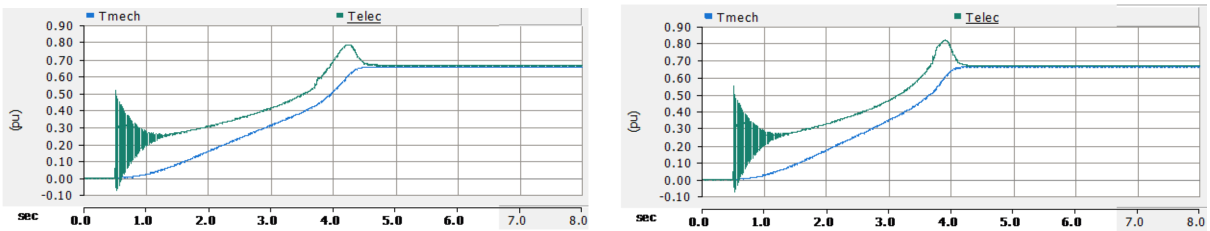
Fig. 4. External view of submersible individual compensating installation and its attachment to submersible electrical motor.

3 Results and Discussion

Analysis of energy parameters obtained from simulation models of ECofPW showed that usage of submersible individual compensating installation (table 1) allows one to reduce the loss of active power by 1.38 kW (3.1%), to increase efficiency by 3.6%, and power factor by 0.067 r.u. in SEM supply cable of 1.5 km length, and to reduce

Table 1. Comparison of energy parameters.

Energy parameters of ECofPW operation mode	Mode SEM-45 without compensating installations	Mode SEM-45 by means of compensating installations	Difference between energy parameters
P_{SEM}, kW	31.87	31.87	0
Q_{SEM}, kvar	18.01	10.07	-7.94
$P_{nom.CL}$, kW	35.81	34.43	-1.38
$Q_{nom.CL}$, kvar	11.55	3.43	-8.120
tgφ	0.503	0.293	-0.211
cosφ	0.893	0.960	0.067
η	0.890	0.926	0.036



a) b)

Fig. 5. Relationships between electromagnetic moment and moment of resistance: a) without compensating installation, and b) with individual submersible compensating installation.

reactive power factor by 0.211 r.u.

Electromagnetic torque and resistance torque correspond to actual parameters and are 6.8 OE (Fig. 5). The start-up time of the electric drive without compensating installation is 4.7-0.5=4.2 seconds (Fig. 5). With submersible compensating installation the start-up time is reduced by 12% and is 4.2-0.5=3.7 seconds.

4 Conclusion

The developed mathematical and simulation models allow us to determine the optimal voltage levels at specified points of the distribution grid, the optimal parameters of compensating installations and energy parameters of the ECofPW operating mode in steady-state and transient modes.

The simulation model is ready for further studies of ECofPW operation mode, taking into account centralized and submersible individual compensating installations for various disturbances in the supply and distribution electrical networks.

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