Development of the Oil Well Electrotechnical Complex Model in LabVIEW: Application Work Package

Anton Petrochenkov, Alexander Romodin, Sergey Mishurinskikh and Pavel Speshilov
Perm National Research Polytechnic University, Komsomolsky avenue 29, Perm, Russia
{pab, romodin, msv, spm}@ msa.pstu.ru

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Abstract: When planning the technological modes of an oil and gas producing enterprises, an important task is the energy consumption assessment of the electrical complex equipment. Most of the electrical and mechanical equipment operates in non-nominal modes, respectively, this equipment has non-nominal operating parameters. In this paper, it is proposed a method for building the electrotechnical complex models of an oil well in LabVIEW environment using the principles of object-oriented programming. The methodology is tested on the example of two wells. The results evaluation shows that the proposed approach gives results which is permitted for rapid assessment.

1 INTRODUCTION

Considering application work package is aimed to development of the scientific-methodical complex for modeling systems and power system optimization, support of power complex operational reliability; development of off-optimum situation training systems for personnel training and staff certification.

It is an universal software, allowing to check in complex the possibility of application of technical decisions connected with the circuit formation at the stages of variants' comparison during the process of design and within the changing conditions of exploitation of industrial enterprises' electric supply systems by means of calculation methods. The program is intended for investigation of the enterprise's electric supply system and as a result, for increase of its operating reliability and also for running on a schedule of the electrical equipment's scheduled-preventive works.

The program-technical complex is based on the unified analytical environments and is a component of the technological process automatic control system and communicates with the higher hierarchy levels of the automated control and electric power calculation system and anti-damage automatics.

Deliverables of this package are:

- Training and Simulation Software.
- User's Manual.
- HelpDesk.

2 STRUCTURE OF ELECTROTECHNICAL COMPLEX

Let's consider the structure of electrotechnical complex regarding to oil prodicing enterprises. The oil production process is a complex technological process, which interact various technological subsystems. In a mechanized method of oil production using electric drive centrifugal pumps, an electromechanical energy converter is a submersible induction motor (SIM). In addition, the oil well electrotechnical complex (ETC) includes: cable line (CL), transformer (T) and control station (CS) [1].

Modeling of power consumption in branched power supply systems (PSS) is performed, as a rule, by matrix calculation methods. Usually L- and T-shaped equivalent circuits are used. But sometimes more complex multi-circuit equivalent circuits of PSS elements can be used [2-4]. With large dimensions of the object, this may require large computing power. Another problem in modeling the electrical modes of an oil producing enterprises (OPE) is that the technological process parameters are not fully taken into account [5, 6]. In turn, taking into account the equipment features and the technological process may require significant complication of computational algorithms.

Thus, the development elements models of the ETC of an oil producing enterprise and models of their interaction taking into account technological parameters is an urgent task.

According to well-known approaches, the structure of OPE ETC can be represented as a three-level system [6, 7]:

- Level of transformer substation (TS). The power source is an external power grid (PG). Usually, the power supply voltage at this level is 35-110 kV.
- Level of complete transformer substation (CTS). The power source is the TS, and the distribution of electricity through the CTS occurs. Usually, the power supply voltage is 6-20 kV.
- Electric centrifugal pumps (ESP). The power source is the CTS, and the ETC of ESP installation is directly supplied. Usually, the power supply voltage at this level is 0.4-1 kV.

In the process of oil production, subsystems of various physical nature interact with each other. In our case, these are electrical, mechanical and hydraulic subsystems. The oil reservoir and the ESP interact as the hydraulic and mechanical subsystems. ESP and SIM interact as the mechanical and electrical subsystems. The scheme of the ESP elements interaction is shown in Figure 1.

The algorithm for the ETC elements parameters calculation taking into account the oil reservoir parameters and technological parameters, as well as an algorithm for calculation of the electric mode parameters is shown below.

2.1 ETC Elements Parameters Calculation

2.1.1 Electric Centrifugal Pump

The power required to drive the pump is calculated by the formula:

$$P_{\text{ESP}} = \frac{\rho_l g \left(H_{\text{dyn}} + \dfrac{P_{\text{wh}}}{\rho_l g} \right) \cdot Q_{\text{ESP}}}{\eta_{\text{ESP}}} \cdot 10^{-3}, \quad (1)$$

where ρ_{fl} – liquid density, kg/m^3; H_{dyn} – dynamic liquid level, m; P_{wh} – wellhead pressure, Pa; Q_{ESP} – ESP pumping rate, m^3/day; η_{ESP} – ESP efficiency.

It should be noted that the ESP efficiency is determined by its nameplate characteristic, taking into account the operating point and frequency regulation.

2.1.2 Submersible Induction Motor

Based on the power needed to drive the pump and the nameplate motor power, the motor load factor is determined by the formula:

$$k_{\text{LOAD}} = \frac{P_{\text{ESP}}}{P_{\text{SIM.NP}}} \cdot 100\%, \quad (2)$$

where P_{SIMNP} – nameplate motor power, kW.

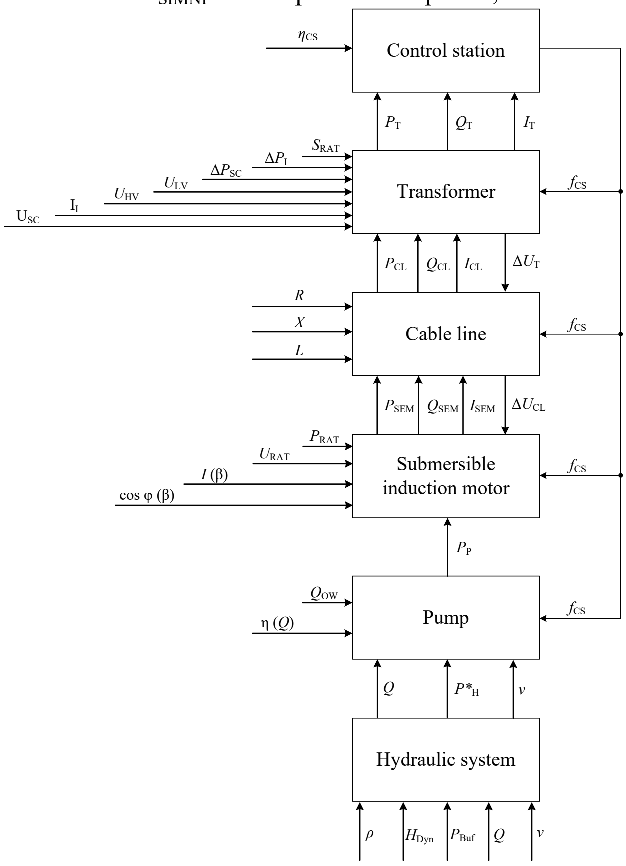

Figure 1: Scheme of the ESP elements interaction.

Then, based on the motor load characteristics, which are presented in the equipment catalog, the motor power factor and efficiency at the current load are determined. After that, the active and reactive power consumed by the motor are determined according to the formulas:

$$P_{\text{SIM}} = P_{\text{ESP}} + P_{\text{ESP}} \cdot (1 - \eta_{\text{SIM}}) \quad (3)$$

$$Q_{\text{SIM}} = P_{\text{SIM}} \cdot tg(\arccos \varphi) \quad (4)$$

2.1.3 Cable Line

$$r_{\text{CL}} = r_0 \cdot l_{\text{CL}}, \quad (5)$$

$$x_{CL} = x_0 \cdot l_{CL} \cdot \frac{f}{50}, \quad (6)$$

where r_0, x_0 – specific CL active and reactive resistances, Ohm; f – voltage frequency, Hz.

CL power losses are calculated by the formula:

$$\Delta\dot{S}_{CL} = \left|\dot{I}_{CL}\right|^2 \cdot \left(R_{CL} + iX_{CL}\right), \quad (7)$$

where $\left|\dot{I}_{CL}\right|$ – CL current modulus.

2.1.4 Double-Wound Transformer

The equivalent circuit parameters of a double-wound transformer are calculated by the formulas:

$$r_T = \frac{\Delta P_{SC} \cdot U_{HV}^2}{S_{T,NP}^2}, \quad (8)$$

$$x_T = \sqrt{\left(\frac{U_{SC} U_{HV}^2}{100 S_{T,NP}}\right)^2 - r_T^2}, \quad (9)$$

where U_{HV} – transformer high voltage wound voltage, kV; $S_{T,NP}$ – transformer nameplate power, kVA; ΔP_{SC} – transformer short circuit losses, W; U_{SC} – transformer short circuit voltage, %.

Transformer active and reactive power losses are calculated by the formulas:

$$\Delta P_T = \Delta P_I \cdot \left(\frac{f}{50}\right)^{1,3} + \Delta P_{SC} \cdot \beta^2, \quad (10)$$

$$\Delta Q_T = \left(\frac{I_I}{100} + \beta^2 \cdot \frac{U_{SC}}{100}\right) \cdot S_{T,NP}, \quad (11)$$

where ΔP_I – transformer idle losses, W; I_I – transformer idle current, %; β – transformer loading, p.u.

2.1.5 Control Station

Control station power losses are calculated by the formula:

$$\Delta P_{CS} = P_{CS} \cdot \left(1 - \eta_{CS}\right), \quad (12)$$

where P_{CS} – control station output power, kW; η_{CS} – control station efficiency, p.u [1, 8].

2.2 Algorithm of the Electric Mode Parameters Calculation

The calculation of the PSS steady mode parameters is performed by the iteration method. The method algorithm implements the following basic relations for determining the mode parameters [9]:

- currents in branches of load:

$$\dot{I}_{ij}^{(p)} = \frac{\left|\dot{S}_i\right|}{\sqrt{3} \cdot U_i^{(p-1)}}, \quad (13)$$

where p – iteration number; $\dot{S}$ – total power, kVA; U – voltage, kV.

- branches power:

$$\dot{S}_{ij}^{(p)} = \sum_{j \in n^*} \dot{S}_j^{(p)} + \Delta\dot{S}_{ij}^{(p)}, \quad (14)$$

where $\Delta\dot{S}_{ij}$ – branch power losses, kVA; $i = \overline{1,n}$; n^* – the s[illegible]f nodes incident to node j, except node i.

- branches currents:

$$\dot{I}_{ij}^{(p)} = \frac{1}{N_{ij}} \cdot \sum_{k \in m^*} \dot{I}_{jk}^{(p)}, \quad (15)$$

where $i = \overline{1,n}$; N_{ij} – ij branch transformation ratio; m^* – the set of nodes incident to node j, except node i, however, this set must include at least 2 nodes, excluding node i.

- branches voltage losses:

$$\Delta U_{ij}^{(p)} = \frac{P_{ij}^{(p)} \cdot R_{ij} + Q_{ij}^{(p)} \cdot X_{ij}}{U_i}, \quad (16)$$

where P_{ij} – active power in branch; Q_{ij} – reactive power in branch.

- node voltage:

$$U_j^{(p)} = \frac{1}{N_{ij}} \cdot \left(U_i^{(p)} - \Delta U_{ij}^{(p)}\right), \quad (17)$$

- condition for convergence of the iterative process:

$$\left|U_j^{(p)} - U_j^{(p-1)}\right| \le \varepsilon. \quad (18)$$

The algorithm works as follows: it is assumed that initial voltage are equal supply source voltages and equipment nameplate voltages in load nodes; the reverse direction (the first stage) is the load currents are calculated from the end of the network (load) to the beginning of the network (supply source); the forward direction (second stage) consists in determination of branches voltage losses nodes voltages from the beginning of the network to end of the network, as well as in controlling convergence and iterative process.

3 MODELLING

The proposed algorithm is implemented in the LabVIEW development environment. Figure 2 shows fragment of the virtual instrument with implementation of the proposed approach.

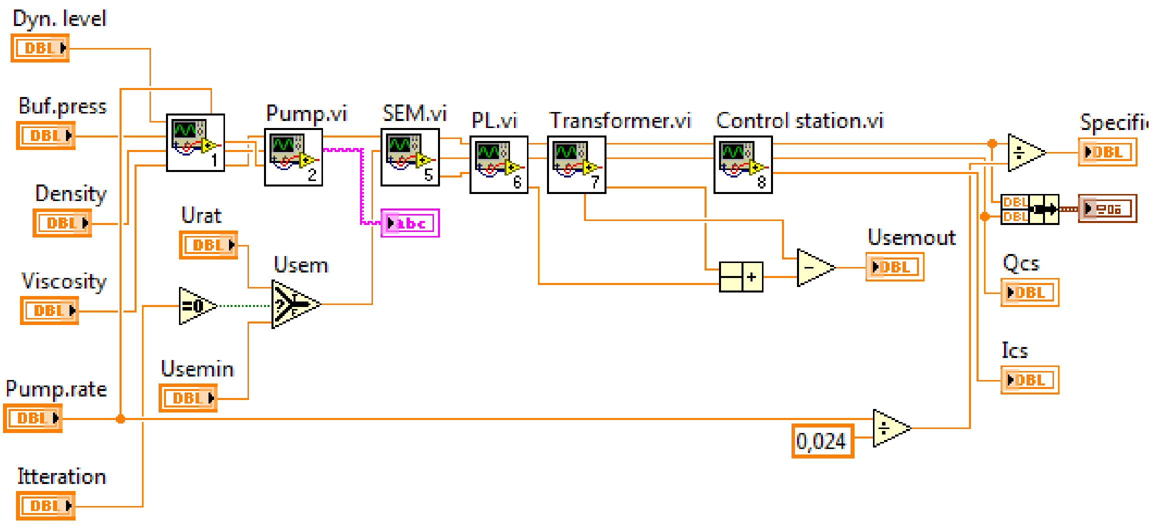

Figure 2: ESP Virtual Instrument.

4 RESULTS

For the test example calculation, the CTS-2310 of the Sukharev's field of the "LUKOIL-PERM" Ltd. is chosen. It feeds 2 wells.

The used initial data for the calculation corresponds to the technological mode on June 18, 2019 and are presented in Table 1. The parameters of the electrical equipment are presented in Table 2.

Table 1: Technological process parameters.

Well position	Pumping rate, m^3/day	Liquid density, kg/m^3	Dynamic level, m	Wellhead pressure, MPa
115	60,9	891	626	2,9
318	72,3	846	908	1,78

Table 2: Electrical equipment parameters.

Well posi-tion	Frequ-ency, Hz	SIM nameplate power, kW	Cable line	Pump nameplate flow, m^3/day
115	43	40	KPBP 3x16 L=1941 m	50
318	48	45	KPBP 3x16 L=2028 m	60

The absolute relative calculation error was calculated as the ratio modulus of the difference between the calculated and measurement values to the measurement value [10]:

$$\delta = 100 \cdot \left| \frac{x - X}{X} \right|, \tag{19}$$

where x – calculated value, X – measurement value.

Table 3 presents a comparison of the modelling results with the data from the SIM control station.

Table 3: SIM modelling results.

Well posi-tion	Parameter	Measur-ment value	Calcu-lated value	Error δ, %
115	Current, A	19,2	19,5	1,56
	Power factor, p.u.	0,65	0,69	6,15
	Loading, %	56,1	58,6	4,46
318	Current, A	18,9	17,7	6,35
	Power factor, p.u.	0,64	0,69	7,81
	Loading, %	54,0	51,3	5,00

Table 4 presents a comparison of the modelling results with the results of instrumental measurements on CTP low voltage buses.

Table 4: ESP modelling results.

Well position	Parameter	Measurment value	Calculated value	Error δ, %
115	Active power, kW	28,6	27,5	3,85
	Reactive power, kvar	-	34,2	-
318	Active power, kW	36,3	34,0	6,34
	Reactive power, kvar	-	38,9	-

5 CONCLUSION

Based on the simulation results, it was revealed that the proposed models allow us to accurately determine the current parameters of the SIM. The error in determining the SIM current is not more than 6.35%, when determining the power factor is not more than 7.81%, and when determining the loading is not more than 5.00%.

The results of modeling the electricity consumption of an ESP (on low voltage buses of a complete transformer substation) show that the maximum error in active power is 6.34%. For reactive power, error estimation was not carried out due to the fact that during measurements these values were not measured.

These errors can be caused by the fact that the used technological parameters are averaged values over several days. This is due to the collecting and accounting features for these parameters in the enterprise under study.

The proposed approach allows a comprehensive assessment of electricity consumption by installing an electric centrifugal pump, taking into account the influence of technological factors, parameters of the electrical network, as well as electrical and mechanical equipment. A feature of the model is that it can take into account the mutual influence of wells through the parameters of the electric mode. Evaluation of the results shows that the proposed approach gives results that are acceptable for rapid assessment.

In the future, it is planned to accurate the models of electrical equipment and take into account its features, as well as the features of its functioning in non-nominal operating modes.

The methods and engineering strategies described above were tried on the set of mineral resource enterprises (LUKOIL, GAZPROM etc). The project is also aimed at supporting of a new Master's program "Conceptual design and engineering to improve energy efficiency" for preparing of engineers, scientists and administrative specialists in power industry, network companies, and related industries [1].

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