Development of methods for modeling of oil and gas producing enterprises electrotechnical complexes

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Abstract. The article presents the mathematical description of minerals industry enterprises electrotechnical complexes. The presented development and modification of algorithms and methods for calculating the parameters of electrical complexes structural elements are taking into account the specifics of the technological process. The developed methods of studying the operating modes of electrical complexes of oil and gas production enterprises are planned to be used to identify various promising dynamic modes, which, in turn, will allow determining the optimal operating conditions of electrical complexes regardless of their structure, including in conditions of uncertainty and incomplete information.

1. Introduction

Currently, the issues of evaluating the functioning efficiency of electrotechnical complexes (ETC) of oil and gas producing enterprises (OGPE) are characterized as weakly structured problems with the presence of quantitatively immeasurable components, which are characterized by the lack of methods for solving on the basis of direct data transformation.

For modeling and calculation of the steady state modes of electrotechnical complexes use multiple programs that don’t allow to estimate electrical systems including system adjustments of settings of the controls take into account the expert rules for coordination the actions of ETC elements.

At the same time increasing the requirements for the intellectualization degree of OGPE electric power systems’ equipment, flexibility structure and topology is impossible without development of scientific methods of research, assessment, prediction and calculation of ETC operation modes.

All of the above, as well as state policy in the energy sector makes the actual task of improving the development of the concept of "Intelligent oilfield " allows to estimate the parameters of OGPE ETC taking into account characteristics of equipment and technological process.
2. Development of a mathematical description of minerals industry enterprises’ electrotechnical complexes

The typical ETC structure of an oil field is backbone power supply structure with concentrated loads [1, 2]. It can be structurally divided into 3 levels:

- Load level;
- Complete transformer substation (CTS) level;
- Transformer substation (TS) level.

![Figure 1. Structural scheme of the OGPE ETC.](image)

where PSS is power supply system, T is transformer, OPL is overhead power line, CL is cable line, SM is submersible motor, ESP is electric submersible pump, CS is control station, ESPI is electric submersible pump installation, IM is induction motor, RM is rocking machine, TS is transformer substation and CTS is complete transformer substation and R is reservoir)

The load level is considered as a set of different physical nature interacting subsystems: hydromechanical and electromechanical. This determines the features of modeling the elements interaction, namely, the set of initial and observed parameters.

To build models of OGPE ETC elements, taking into account the specificity of their interaction, 3 areas of ETC structure are considered:

- **Area A**: oilfield power supply system (PSS), there is no frequency control (electrical subsystem). Controlled parameter is voltage (U). Observed parameters are active power (P), reactive power (Q) and current (I).

- **Area B**: electromechanical load subsystem, frequency and voltage control is performed. Controlled parameters are voltage (U) and frequency (f). Observed parameters are active power (P), reactive power (Q) and current (I).

- **Area C**: hydromechanical load subsystem, control is carried out by changing the electromechanical subsystem parameters. Observed parameters are dynamic level ($H_{\text{dyn}}$), wellhead pressure ($P_{\text{WH}}$), fluid density ($\rho$), fluid flow rate (Q) and fluid viscosity ($\nu$).

The most convenient, but often economically unprofitable, and sometimes technically impossible method for power consumption assessing, due to the specifics and operating conditions of the equipment, is the installation of monitoring systems. In such cases, the monitoring energy consumption problem can be solved using mathematical modeling [3]. To create ETC elements models, an analysis of the oil field equipment composition was performed, the depth of the elements decomposition was determined, where the model element corresponds to an ETC equipment unit.
The models of an L-shaped equivalent circuit of elements were selected during the analysis of the ETC elements representation forms. When developing models of elements, it was taken into account that the functional model of any element of the ETC should be correlated to the technological modes of operation of oil production facilities. This fact determines the requirement for the feedback loop, including monitoring system and consumer. The method of calculating the distribution (consumption) of electric energy is based on the matrix-topological method using the topological list [4].

The nodal voltages calculation is performed using expressions made up of equations in a single generalized form of mathematical description (1). After that the differential equations are solved and the currents are found. The procedure is repeated at each step of numerical integration of differential equations.

\[ pI = -A_U - B_I - H_I, \]  

where \( I \) is a currents vector of element \( i \), \( pI \) is a currents derivative vector of element \( i \), \( U \) is vector of voltages applied at the terminals of the element \( i \). \( A \) and \( B \) are matrices whose dimension depends on the coordinate system in which the structural element is modeled, as well as on whether these equations are complete or simplified and \( H \) is vector of impact on the element \( i \) [5].

The main models of elements in the transformed coordinates \( d, q \) of the OGPE ETC are shown in table 1 (the generally accepted notations are used when writing systems of mathematical description).

Table 1. Mathematical description of the main models of element of the OGPE ETC

| A | B | H |
|---|---|---|
| Power supply system | Power line | Static load |
| Transformer | Induction motor |

Incomplete information from the accounting node of technological parameters is leveled out by detailed calculation of independent power consumers’ electrical parameters and registration of the technical condition parameters of the electrical equipment [6, 7]. When comparing the parameters of the technological mode and the power consumption, the dependence of these parameters is estimated with subsequent correction of the mathematical description of the OGPE ETC.

3. Modification and development of algorithms and methods for calculating the parameters of structural elements of electrotechnical complexes, taking into account the specifics of the technological process.

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The transition to HIL-models provides the development and testing of complex embedded real-time systems: the mathematical model of the control object works in real time, and the tested control unit is connected to the hardware module and controls the object model [8]. The use of these models has a number of advantages over natural experiments:
- the ability to detect errors in laboratory conditions, i.e. there is no necessity for lengthy field experiments to identify errors in the system;
- the ability to assess the impact of various influences on the control object without damage to the object itself;
- flexible configuration of the stand, which makes it possible to change the stand for use according to the needs of various projects.

Elements for modeling within the framework of an information digital model, in addition to power equipment, are also equipment for various functional purposes:
- sensors of parameters and states of network elements;
- information processing and transmission systems (with real-time status assessment);
- systems for making decisions and issuing control actions at different control levels (programmable devices, algorithmic and software);
- executive bodies and mechanisms (both low-current and power installation).

**Figure 2.** Equivalent circuit of ETC with division into sections controlled by various agents

Figure 2 shows the electrical equivalent circuit of the electrotechnical complexes’ part at the oil and gas field of LLC LUKOIL-PERM with division into areas controlled by various agents. An agent is understood as an autonomous computer program or system capable of acting in a dynamic, continuously and unpredictably changing external environment in a purposeful manner [9] (at figure 2 AL is load agent (CS of a well, etc.), AT is agent transformer (power transformer of CTS, for example), APL is power line agent, AG is agent generation (conditional source, power supply system)). When developing the ETC multi-agent system (MAS), losses in each element were taken into account. In the electrical equivalent circuit, active and reactive resistances are indicated by $R$ and $X$, respectively ($R_{sh}$ and $X_{sh}$ are the resistances of the shunt, respectively).

The LabVIEW software package also allows you to simulate the operation of data transfer protocols. When simulating conditional mode, requests are transmitted and processed with the same delay of 2000ms.
With an increase in the accuracy of the model, it is planned to add a module for calculating the reliability of channels, transmitting emergency and system automation commands, calculating the throughput of these communication channels, which is not unimportant in view of the streaming data transmission in real time.

Figure 3 shows an algorithm for the agents’ interaction. It consists in the application of two systematic organization methods of the regulation process. The first one carries out parallel work of all MAS agents. Its use in cases requiring the agents’ coordination will not be correct, since it is impossible to assess their individual consequences and apply the rules of actions coordination. The second method consists in the implementation of MAS agents sequential work, it is correct in all cases, but has a lower speed [10].

![Agent interaction algorithm in the LabVIEW software package](image)

When modeling, you need to talk about the simultaneous use of the first and second methods. The first is used for agents that do not require coordination of their actions with the actions of adjacent agents, and the second is used for the rest.

A feature of MAS modeling is the agent’s adaptability to the conditional power mode and the regulation area, and this adaptability is expressed not by a functional connection, but by a complex logical one, represented by the rules of the expert and coordinating blocks [11]. Let's represent this connection as an expression:

$$\Delta S_i = k \times (R(M(S^i)) + G(M(S^i))) \times B(M(S^i)),$$

(2)

where $\Delta S_i$ is adjusting the conditional power mode of the agent $i$, $k$ is the gain in the adjustment loop, $M(S^i)$ is full set of nodes of the targeted area of the agent $i$, $R$ is a logical operator (system of rules) which forms an independent pointer adjustment (such as “1” is increasing, “0” is unchanged and “-1” is decrease), $M(S^i)$ is the full set of nodes of the controlled area within controlled areas related agents.
of the agent $i$, $G$ is logical operator (system of rules), forming a request for assistance in regulation from adjacent agents (such as “1” is increasing, “0” is unchanged and “-1” is decrease), $B$ is logical operator (system of rules), forming prohibitions on the claimed actions of the agent $i$ from adjacent agents (such as “1” is permission and “0” is prohibition).

It should be noted, what, firstly, in the steady-state mode $\Delta S_i$ of all agents for which the operating range of regulation has not been exhausted have a value of 0 either by meeting all the rules for adjusting the setpoint, or by blocking actions by adjacent agents and, secondly, it is impossible to replace logical operators with functional dependencies, which does not allow reducing the steady-state model to a system of equations and applying well-known solution methods to it.

The assessment of the adequacy of the proposed methods was carried out for a sample of wells based on the instrumental measurements results and the parameters of the ETC technological regime, observed during the measurements of the electrotechnical complexes’ part at the oil and gas field of LLC LUKOIL-Perm. The maximum deviation of the simulation results from the instrumental measurements results is no more than 6.35% for loads current, no more than 7.81% for power factor, and no more than 5.59% for load factor.

4. Conclusion

1. An algorithm has been developed for the formation of accumulated data sets on power consumption in the OGPE ETC, depending on the current parameters of the equipment.
2. A mathematical description of electrotechnical complexes of minerals industry enterprises has been developed.
3. Algorithms and methods for calculating the parameters of the structural elements of electrical complexes of oil and gas production plants, taking into account the specifics of the technological process, have been developed.
4. A method has been developed for calculating the power consumption parameters of the ETC of an oil field, which explicitly allows taking into account the parameters of equipment, control and disturbing influences, as well as assessing the distribution of power flows in the field as a whole based on the data of the technological process.
5. For a section of the power supply system of one of the fields of LLC LUKOIL-Perm, the principles of generating data sets on power consumption in accordance with the technological modes of operation of equipment for lifting oily liquid were considered. The mathematical model of the installation with an electric driven centrifugal pump was checked for the adequacy of its power consumption, under various operating modes. The error of the mathematical model from the real values was less than 10%, which allows us to assert its adequacy.

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