Digitalization of the electric consumption system of oil and gas production enterprises

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Abstract. The provisions of the digital transformation of power consumption management systems for oil and gas companies are considered. The characteristics of the random process are obtained by the type of the probabilistic distribution of the electrical loads graphs coordinates. New analytic dependencies allow to determine the updated probabilistic characteristics and build a digital model of the random process for changing the enterprise power consumption.

1. Introduction
Digitization is an important current trend to improve the efficiency of industries, including energy sector. Digitalization may be called the base part of the architecture of the fourth industrial revolution, the so-called 'Industry 4.0'. This global trend implies the development of Russian high-tech companies. In 2017, the digitalization of the economy was included in the priority list of the country strategic development lines until 2025.

At oil-and-gas production enterprises (OGPE) digital transformation of the entire structure is also underway, optimization and changing the logic of technological processes due to the introduction of digital technologies based on the analysis of large databases is carried out. The digitalization of the power generation sector of all branches of mineral raw material complex related to the exploration, production, transportation and processing of liquid, gaseous and solid raw materials becomes the part of the digital economy.

So in Rosneft PJSC the general outlines of 'Rosneft-2022' strategy have been defined. Digitalization of all areas of activity, implementation of advanced digital technologies and new standards of the industrial Internet [1] has been called its most important element. The same trends are kept with by one of the largest Russian oil production companies Tatneft, where the instruments to implement strategic projects will be innovative technologies, digitization and automation of production processes, improvement of organizational structure and reduction of operating costs and growth of investment efficiency [2].

Currently, Tatneft is actively developing and introducing into production the basic elements of such structures as the Digital Enterprise and Digital Field [3].

The use of digital technologies allows to implement operational interaction between the centralized power system and OGPE consumers by introducing optimization algorithms for controlling the operation of electrical and technological equipment. A new possibility emerges to adjust consumption modes and generation of active and reactive power, regulate the voltage level in the load nodes, integrate...
and combine various IT control technologies while applying local and remote control and the use of digital forecast models and power consumption planning.

2. Probabilistic characteristics of an oil and gas production enterprise power consumption

According to the results of certification of the gas-and-oil producing enterprises electrical loads, the results of statistical processing of experimental studies of oil-and-gas producing companies [4] electric loads curves (ELG). The algorithm for intelligent control of power consumption has been proposed based on the profiles and loads nature analysis, with loads built on results of big data processing, instrumental measurements of the loads curves profiles of supply centers and field substations. It allowed us to obtain profiles of the averaged load curves in general.

Most of the plants related to technology operates on OGPE with steady or predetermined periodically varying load. It is established that averaged curve of OGPE substation satisfies the condition of the generalized periodicity. The relationship between the curve coordinates is random and probabilistic in nature. This is due to the absence of deterministic relations between technological independence of individual centers of power supply and of electrical loads curves. As a consequence, to study and forecast ELG characteristics of power substations and centers of electrical load, a mathematical apparatus of the theory of random processes is used which reflects the probabilistic nature of the loads [5] to the highest extent. Classification of random process by a probabilistic distribution of ELG y-axes allows us to determine the average probabilistic characteristics and to construct a mathematical model of the load change random process. The probabilistic characteristics of the random process are: the average value of the active power ($P_{av}$), variance ($D$), root-mean-square deviation ($\delta$) and coefficient of power variation ($K_{av}$) for each time interval considered $t_j$, which are determined by the known formulas:

$$P_{av}(t_j) = \frac{1}{n} \sum_{i=1}^{n} P_i(t_j); \quad D(t_j) = \frac{1}{n} \sum_{i=1}^{n} [P_i(t_j) - P_{av}(t_j)]^2; \quad \delta(t_j) = \sqrt{D(t_j)}; \quad K_{av} = \frac{\delta(t_j)}{P_{av}(t_j)}.$$

The range of these values variation for the oil-and-gas industry enterprises is: $P_{av}(t_j) = 0.05\ldots2.0$ MW, $K_{av} = 0.05\ldots0.20$, and in the hours of maximum loads $P_{av}(t_j) = 1.0\ldots3.0$ MW, $K_{av} = 0.35$.

The probabilistic relationship between the values of the y-axes in the ELG cross-sections is determined by the correlation function linking the values of the curves y-axes $P_i(t)$ at time moments $t_j$ and $t_2 = t_1 + \tau$: $K(t_1, t_2) = \frac{1}{N} \sum_{i=1}^{N} [P_i(t_1) - P_{av}(t_1)] \cdot [P_i(t_2) - P_{av}(t_2)]$.

To evaluate the correlation between the ELG y-axes, separated by interval $\tau$, the correlation coefficients of the load curve were determined $P_i(t)$:

$$r(t_1, t_2) = \frac{K(t_1, t_2)}{(n-1) \cdot \delta^2(t_1) \cdot \delta^2(t_2)}.$$

A feature of the correlation function is that it makes it possible to determine the probabilistic characteristics of load graph’s emissions and dips.

The probability of exceeding the level of maximum active powers: $E_i = 1 - \phi(\Pi_i)$, where $\phi(\Pi_i)$ is the tabulated integral function of the normal distribution; $\Pi_i$ – the relative value of the stated level of the maximum active power ($P_{max}$): $\Pi_i = \frac{P_{max} - P_{av}}{\delta}$.

The average frequency of emissions ($\bar{\nu}$): $\bar{\nu} = \frac{\delta}{\sqrt{2\pi} \cdot \delta} \cdot \phi(\Pi_i)$, where $\delta_i$ – the standard for the rate of the process change deviation, $\phi(\Pi_i)$ – tabular density function of the normal distribution. The amount
of emissions per time of observation $T : N_l = \bar{\nu}_l \cdot T$, average duration of one release: $\bar{t}_l = T_l / E_l$ and the total duration of all exceedances over time $T : T_\ell = E_l \cdot T$.

For the curves of field substations at different levels of the stated maximum, calculations for values of $P_{av} = 1$ and $\delta = 0.05$ have been performed. The results are summarized in table 1.

### Table 1. Indices of load releases for different values of the stated maximum $P_{s_{\text{max}}}$

| $P_{s_{\text{max}}}$ | $P_{s_{\text{max}}} - P_{av}$ | $\Pi_l$ | $\phi(\Pi_l)$ | $\bar{\nu}_l$ 1/hour | $N_l$   | $\Phi(\Pi_l)$ | $E_l$     | $\bar{t}_l$ hour |
|---------------------|-------------------------------|--------|----------------|-------------------------|--------|---------------|----------|-----------------|
| 0.9                 | -0.1                          | -2     | 0.054          | 0.0220                  | 0.081  | 0.0231        | 0.9771   | 4.78            |
| 0.95                | -0.05                         | -1     | 0.24           | 0.0853                  | 0.382  | 0.1580        | 0.8221   | 3.77            |
| 1.0                 | 0                             | 0      | 0.5            | 0.1620                  | 0.561  | 0.5213        | 0.5212   | 3.57            |
| 1.05                | 0.05                          | 1      | 0.24           | 0.0853                  | 0.382  | 0.8412        | 0.1612   | 1.68            |
| 1.1                 | 0.1                           | 2      | 0.054          | 0.0230                  | 0.081  | 0.977         | 0.0230   | 1.25            |
| 1.15                | 0.15                          | 3      | 0.0045         | 0.0016                  | 0.006  | 0.498         | 0.0021   | 1.15            |

### 3. Management of an oil and gas production enterprise power consumption values

To implement the reducing the stated maximum $P_{s_{\text{max}}}$ for the oil-and-gas industry enterprises, the task of its more precise definition is important, as well as development of methods and algorithms of load control with allocation of users-controllers, while ensuring conflict-free process.

The obtained values are the basis for coordination of electric loads of the enterprise, which means matching the electric enterprise workloads to their optimal values, which provide minimization of the energy component in the production costs, considering the differentiated electricity payment rates. Capacities profiles curves on field substation buses with compensating plants (CP) connected to them and synchronous motors (SM) were considered. When carrying out adjustment it was noted that increase in reactive power consumption occurs in specific inputs and the value of $\phi_{tg}$ increased as well. It follows that carrying out regulation of active power requires synchronization with the actions aimed at reactive power compensation.

Given the continuity of the technological process of oil production, minimizing energy component in the production cost can be obtained by control of voltage and reactive power modes, as well as by transforming the shape of the curve of power consumption to reduce the power purchased by the consumer.

The obtained characteristics of a random process by a probability distribution of ELG coordinates allow us to determine the refined probabilistic characteristics and to build a digital model of the random process for changing the power consumption.

To implement energy monitoring, the OGPE distribution network control system was developed providing solutions for calculating the steady-state mode at the buses of substations, as well as analysis and calculation of losses in the elements of power supply systems.

According to the OGPE electrical loads certification results a generalized scheme of the field power substation supply was compiled, taking into account the features of these enterprises. For the generalized scheme of the field substation power supply (figure 1) based on an analytical representation of the power supply configuration diagram using graph theory and matrix algebra, a digital model of this substation is developed based on the state equations for the steady-state mode.
Based on these new analytical dependencies of transcendental equations systems for capacities, currents and voltages, taking into account the particular configuration of the external and internal OGPE power supply systems, a mathematical model has been developed and existing method of calculation has been improved in the steady state for the definition of capacities and currents in the elements of power supply systems (PSS), stress values in its nodes.

The digital model equations type is determined by the forms of the state equations describing the steady-state operation mode of the substation. Given the topological structure of the network, the first and second matrix incidence, generalized equations of state have been obtained to calculate the PSS steady-state operating mode of the field of the substation in the form:

\[ A \dot{I} = \hat{F} \]

where the matrix \( A = \begin{bmatrix} M \\ N \cdot Z_B \end{bmatrix} \) consists of two units of matrices: \( M \) – matrix of connections of branches at the nodes without balancing node and unit, \( N \cdot Z_B \), where \( Z_B \) the diagonal matrix of resistances of branches \( Z_B = \text{diag}(Z_i) \), \( i = 1, \ldots, m \), \( m \) – number of the circuit branches.

The matrix \( \dot{F} = \begin{bmatrix} \dot{j} \\ \dot{E}_i \end{bmatrix} \) also consists of two matrix units: \( \dot{j} \) – matrix-column of reference currents at the nodes, \( \dot{E}_i = \begin{bmatrix} N \cdot \hat{E} \end{bmatrix} \) – the matrix-column of loop electromotive forces (EMF), \( \hat{E} = (\hat{E}_i) \) – matrix-column of EMF in the branches \( i = 1, \ldots, m \), \( \dot{I} = (\dot{I}_i) \) – matrix-column of currents in the branches.

Generalized state equations allow us to describe the PSS steady state using the equations that are linking power, setting currents and voltages at the nodes.

For a substation with a generalized scheme of figure 1, studies have been conducted to determine the...
most economical operating mode from the point of view of power losses minimization in the power supply system elements.

Values, which are determined in the course of calculation are: voltage at specified points of the circuit, the voltage dips in the circuit branches, the currents in the branches, the losses of active and reactive power in the branches of the circuit and total power losses. The developed mathematical model is a digital twin of electrical engineering complex which includes the field substation, supply and distribution power lines, centralized compensating plants on bus sections and a large capacity SM at the end of the outgoing lines.

As a known calculation method the Newton iteration method WAS adopted which uses analytical dependences, taking into account the PSS features of OGPE field substations. An algorithm was introduced for this calculation method that allows to calculate, for each $k$-th network node, the imbalances of active and reactive power, own and mutual conductance of the nodes given the topology of the equivalent circuit and characteristics of OGPE power supply system parameters. The calculated values of active and reactive powers in the circuit branches allow us to determine the loss of power in these branches.

In the steady state, when the voltage values at the circuit nodes correspond to GOST 32144-2013, while ensuring the set technological process, the studies of the influence of the flows of active and reactive power on the loss of active and reactive power in circuit elements have been performed, both for the individual circuit elements and for total losses, the cost of which is included in the energy component of the cost of the final product. The study on the mathematical model helped to solve the problem of the mode choice for compensation of reactive power in the lines by using synchronous motors that are in the process to reduce losses of active, and reactive power and voltage losses with a further correction of a parameter of centralized compensation plant of the field substation.

The analysis of the results obtained shows that given the parameters of the field substation PSS external circuit, at a consistent operating mode of the individual nodes of the centralized compensating plants and the SM in the mode of reactive power generation a considerable economic effect can be achieved. For an average scheme of a field substation, the reduction in the active power consumption by reducing active power losses in the network elements, is on average, 135 million kWh per year.

4. Conclusion
The considered provisions of power consumption management systems for oil-and-gas production companies aim to create digital twins of electrical engineering complexes, which are the basic elements of the overall structure of the digital enterprise. Due to the probabilistic nature of power consumption, the mathematical apparatus of the theory of random numbers is used. The obtained refined characteristics by the type of the probabilistic distribution of coordinates of the electric loads allow us to build a digital model of power consumption change random process. The application of the obtained model allows us to determine the most economical mode of the power supply system with minimization of power losses while getting a significant economic effect.

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