Practical Aspects of Software Developing for the System of Structural and Functional Analysis of Power Supply Systems in Oil Companies

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Abstract: The article presents practical questions of software developing for system of structural and functional analysis of electric power supply systems (ESS) in oil companies. Software structure is described and internal structure and functions of each software element are considered. Software package includes four modules. Energy object data storage includes all data connected with ESS. Energy efficiency estimation module calculates current electric grid parameters an estimates energy efficiency of existing ESS structure. Energy efficiency control module is used for making recommendations on improving structure and functionality of existing ESS to achieve high energy efficiency under given constraints. User interface provides interaction between all modules of software package and end user. The approaches for energy efficiency analysis and control are discussed. The approach for planning arrangements on energy efficiency increasing is suggested.

1 INTRODUCTION

Under present-day conditions, oil companies face complicated task. Annual growth of oil output is needed for providing steady income. At the same time companies must fulfil government requirements on decrease of power consumption in oil fields. One way of achieving high energy efficiency is implementing intelligent control systems such as SMART GRID or Intelligent Well (Cochrane, 2013). Implementing these technologies requires upgrading of existing equipment and control technologies. The concepts also require logistical and structural changes in power supply system of a company as a whole.

Today automation level of different oil fields is not the same. System reengineering and applying new technologies are performing non-systematically. Reengineering often means installation of additional control system without replacing existing ones. It causes increase of amount of hardware and software systems. Each of them is used for solving a single task. Software and hardware systems often have proprietary interfaces that not allow interconnection between them. In addition, data stored in different systems are duplicated due to problems with data interchange.

Despite large variety of methods for ESS design and analysis (Brand, 1989, Chunmin, 2012), the method for structural and functional analysis of system as a whole and making concrete decisions on structural and functional optimization is not exists. One way of solving this task is developing of software and hardware package for modelling structural and functional schemes of PSS and testing them in a various operational modes (Kavalerov, 2013).

2 OIL FIELD AS AN ENERGY OBJECT

Structural scheme of oil field is presented on figure 1.

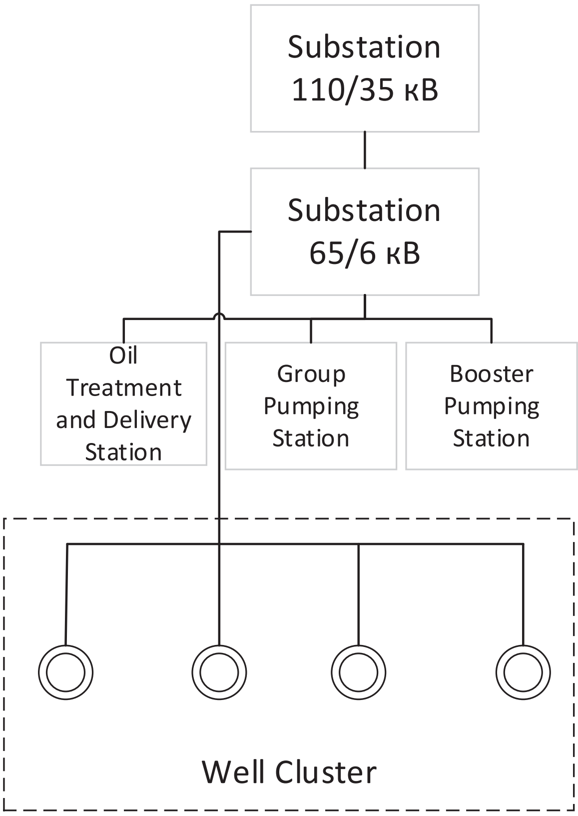

Figure 1: Structural scheme of oil field.

Oil fields ESS has large amount of consumers and complex topology. The main consumers are electric motors, heater cables and electric furnaces.

Because of connecting different types of load in different parts of grid, the unbalanced conditions appear. Long power lines cause additional power loses and make necessary to consider reactive components of their loads (Petrochenkov, 2012). Load changes depend on operational conditions of oil field and a season.

ESS is functioning in stationary and transient regimes. Transient regimes correspond to dynamic changes in electric grid (e.g. load connection and disconnection). They can be represented as a sequence of stationary regimes with a small time lapse. Therefore, modelling of stationary (quasi stationary) regimes is very important task of the study.

The aim of structural and functional analysis is finding problems in functioning of the ESS to make decisions on structure and functions changes and finally improve energy efficiency. To do this, existed system must be studied in different regimes. This task requires using of large variety of data describing ESS.

Besides the data, mathematical models and elements connection scheme need to be used in analysis procedure. Collection and storage of this information is a complicated task.

3 CONCEPTUAL MODEL OF SOFTWARE PACKAGE

Existing software systems for structural and functional analysis of ESS are usually developed for concrete system. They solve only single tasks and are not able to provide user with a complex tool of analysis the system as a whole. Software package (SP), proposed in the article, provides universality, portability and scalability within certain limits. General scheme of SP is presented on figure 2.

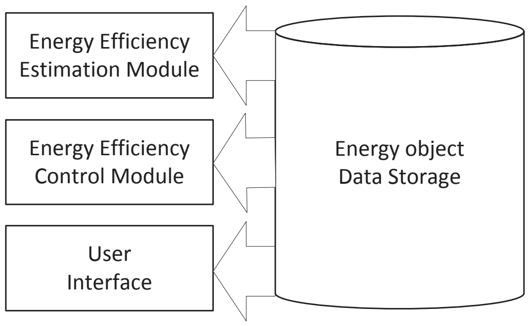

Figure 2: Structural and functional scheme of software package.

Energy object data storage (ODS) includes all data connected with ESS. Energy efficiency estimation module (EEM) allows calculating current electric grid parameters and estimating energy efficiency of existing ESS structure. It has two subsystems: calculation subsystem and estimation one. Energy efficiency control module (ECM) is a decision support system (DSS). It is used for making advices on improving structure and functionality of existing ESS to achieve high energy efficiency under given constraints. User interface (UI) includes graphical elements library and user interconnection system.

Next sections describe structure and functions of each SP module in detail.

4 ENERGY OBJECT DATA STORAGE

Data required for EES structural and functional analysis is presented on figure 3.

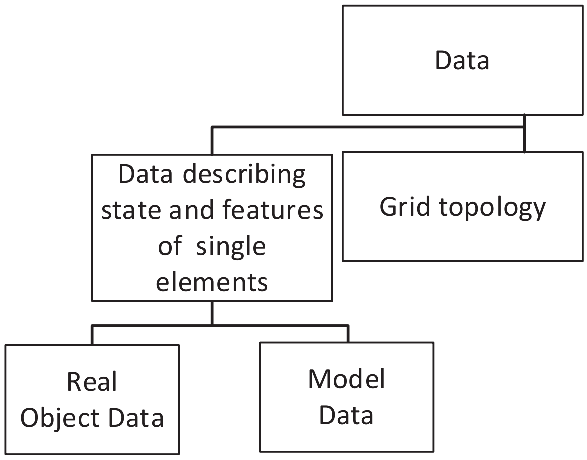

Figure 3. Data required for ESS structural and functional analysis.

These data can be divided into two groups: data describing state and features of single elements of the grid and data representing grid topology and interconnection between elements.

The first group is also divided into real objects data and model data. Real object data is presented in the form of single values and numerical series. Elements Models is describing by their equations (1-5)

Synchronous motor model

$$\begin{pmatrix} U_d \\ U_q \end{pmatrix} = \begin{pmatrix} r & X_d \\ -X_q & r \end{pmatrix} \begin{pmatrix} i_d \\ i_q \end{pmatrix} + \begin{pmatrix} 0 \\ E_q \end{pmatrix}. \quad (1)$$

Power line model

$$\begin{pmatrix} r_L & x_L \\ -x_L & r_L \end{pmatrix} \begin{pmatrix} I_d \\ I_q \end{pmatrix} = \begin{pmatrix} U_{d1} \\ U_{q1} \end{pmatrix} - \begin{pmatrix} U_{d2} \\ U_{q2} \end{pmatrix}. \quad (2)$$

Double-wound transformer model

$$\begin{pmatrix} r_\text{T} & x_\text{T} \\ -x_\text{T} & r_\text{T} \end{pmatrix} \begin{pmatrix} I_d \\ I_q \end{pmatrix} = \begin{pmatrix} U_{d1} \\ U_{q1} \end{pmatrix} - \begin{pmatrix} U_{d2} \\ U_{q2} \end{pmatrix} \quad (3)$$

Reactor model

$$\begin{pmatrix} 0 & x_\text{r} \\ -x_\text{r} & 0 \end{pmatrix} \begin{pmatrix} I_d \\ I_q \end{pmatrix} = \begin{pmatrix} U_{d1} \\ U_{q1} \end{pmatrix} - \begin{pmatrix} U_{d2} \\ U_{q2} \end{pmatrix}. \quad (4)$$

Complex static load model

$$\begin{pmatrix} r_{RLC} & x_{RLC} \\ -x_{RLC} & r_{RLC} \end{pmatrix} \cdot \begin{pmatrix} I_d \\ I_q \end{pmatrix} = \begin{pmatrix} U_d \\ U_q \end{pmatrix}. \quad (5)$$

Models are considered as branches of the equivalent circuit of electric grid i.e. they have two external terminals. Models equations determine currents and voltages of these terminals based on internal parameters of elements (complex resistances). Therefore, current values of voltages and currents as well as internal parameters of elements need to be stored in the ODS for describing the models. Since measuring of real changes of internal parameters in elements is difficult, reference parameters of elements are used in the models. These data can vary during the analysis. Data described above can also be presented as numerical series. Interaction between elements is carried out using currents and voltages in boundaries of the elements.

Second group of data includes information about grid topology. It is determined with the help of incidence matrix (nodes and branches matrix). The matrix defines the order of elements connections. For building it, electrical grid is represented as a graph. Each branch of the graph has its beginning and ending at the certain node and each element is placed in the branch. In this way, information about relative positions of nodes and branches can be stored in a table containing branch numbers with their beginning and ending nodes. Connection between branches and elements is also organized by the branch number.

In the SP a single relational database is used for data storing.

5 ENERGY EFFICIENCY ESTIMATION MODULE

Structurally EEM can be divided into calculation and estimation subsystems. The task of calculation subsystem is calculation parameters of electrical grid in the given regime.

The matrix topology approach is used for calculation. This method is very simple and provides highest calculation performance in comparison with other ones. As an input data an incidence matrix and conductivity matrix is used. Formula (6) is used for calculation of voltages and currents (Petrochenkov, 2014).

$$\mathbf{\Pi A \Pi}^{\mathrm{T}}\mathbf{U} = \mathbf{\Pi W} - \mathbf{\Pi' I}\,, \qquad (6)$$

where **I** is the extended current vector,

U is the extended vector of the voltages applied between the element's external terminals,

$\mathbf{W} = -\mathbf{BI} - \mathbf{H}$, **B** is a matrix, which dimensions depend on the coordinate system in which the structural component is simulated; **H** is a vector that determines the effect on the element of the means of controlling the electric parameters,

Π is a cellular incidence matrix. The cells of this matrix are zero matrices or transform matrices,

$\mathbf{\Pi'}$ is a cellular matrix whose elements are zero cells or cells derived elements of the transform matrices,

A is a block quasi-diagonal conductance matrix of the branches (elements) that form the ESS.

Active and reactive power in nodes of electric grid is used as input data. Necessary parameters of elements are given by their models and equivalent scheme of their interconnection. As a result of calculation, nodal currents and voltages are obtained.

Estimation subsystem is used for analyzing current energy efficiency of ESS in the given regime. The main factor of energy efficiency is energy loses in electric grid and their distribution between elements. Loses are caused in two cases: distribution along power lines and consumers operation. Estimation subsystem must calculate the amount of loses. Subsystem calculates nodal loses in electric grid. Elements parameters allow estimating the distribution of loses between elements and causes of loses in each element. By this way one can estimate the energy efficiency of single elements. Overall efficiency is calculated as a sum of elements efficiencies.

6 ENERGY EFFICIENCY CONTROL MODULE

ECM must provide energy efficiency increasing arrangements of existing energy objects in oil fields. Input data for the module are electric grid calculation results and energy efficiency estimation. There are two approaches of energy efficiency improving: equipment upgrading and changing the ESS control methods. This requires significant financial and technological costs. Moreover, when doing these arrangements a number of constraints appear. They need to be taken into account both when planning and implementing arrangements.

One of the ECM functions is finding an optimal structural and functional scheme of ESS that provides given energy efficiency level based on optimization methods. Energy consumption parameters are used as optimization criteria. Gradient methods are used for optimization. Predominantly it seems to use designed classification models to estimate specific energy parameters (Ahmed, 1995, Utkin, 2014).

Optimization methods allow finding an optimal structural and functional scheme of ESS. However, in several cases costs of implementing this model are higher than achieved power saving. For solving this problem, the use of constraint satisfaction method is suggested (Lasota, 2017). The method allows finding a certain set of parameters that satisfies all given constraints at the same time. All constraints can be divided into initial (existing at the beginning of planning) and current (appearing when implementing the plan) ones. Initial constraints can be budget size, technological requirements, time limitations and so on. Current constraints are structural changes in the company budget reduction, increasing requirements on oil producing and so on.

When using the method, an optimal plan of achieving an optimal structural and functional scheme is producing. To allow for current constraints, the method is to be used iteratively when implementing the plan to change it with respect on new constraints. This approach allows fully implementing the plan with high probability.

Planning task is implemented in decision support system based on expert estimation methods. The structure of it is presented on figure 4.

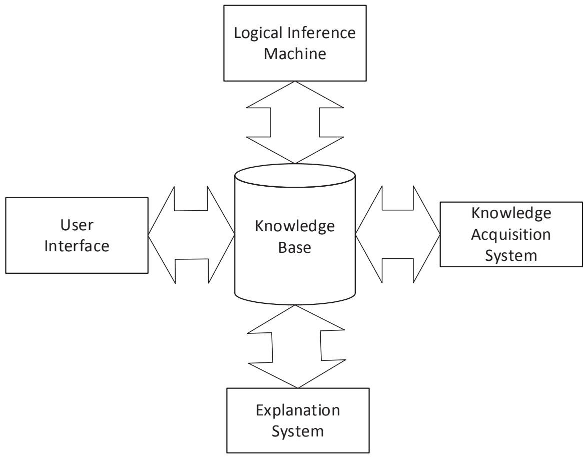

Figure 4. Decision support system structure of ECM.

This system has explanation module that allows expert to understand the way of decision making.

7 USER INTERFACE

UI provides user access for all SP functions. Data visualization is implemented using graphical objects library. User interaction system provides two operational modes of SP: observing and changing one.

In the observing mode user can see all changes in ESS parameters in current regime and get reports about current energy efficiency and ways of its increasing. Developing of energy efficiency increase plan is also allowed in this mode.

In the changing mode user can make changes in grid topology, replace elements of the grid, choose current regime and define its parameters.

8 CONCLUSION

The key aspects of software developing for the system of structural and functional analysis of PSS in oil companies are considered in the article. Requirements to the software functioning described here are the most common. Structural schemes of a whole software package and its parts are only conceptual models now. Despite that, the basic principles of software design that allow decrease programming complicity and increase flexibility of software components are presented. In the following, different tests and experiments will be carried out to find optimal mathematical methods of analysis and optimal data processing scheme. Software package prototype needs to be created. Testing of this prototype is a priority work at the next step of the research.

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