

Development of an Algorithm for Transition from an Electric-power System Visual Representation to a Parametric Representation

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Abstract: Precise estimation of the oil field electric-power system (EPS) parameters is an important task when estimating energy efficiency of oil well equipment. One possible solution for this task is development a software module that is capable both to graphically represent grid topology and to calculate the parameters of EPS on the basis of electrical parameters of equipment. The currently used methods for EPS modeling are based on theoretical approaches that do not completely meet modern requirements on precision and convergence. In addition, the interaction of EPS elements is considered insufficiently in the existing models. Implementing Smart Grid systems require development of new modeling tools. To create them, it is necessary to describe two models and develop transition algorithm between the visual representation of the electric grid and the parametric model of the EPS which determines the main parameters of the system. The paper considers the object model that allows to construct virtual electric scheme using objects (elements) and the calculation model that provide electric-power system parameters on the basis of calculation Kirchhoff's circuit laws. The development of a transition algorithm between the object model of the EPS into a calculation model. To implement this algorithm the LabVIEW is used. Both models are included in a software package which are designed to simulate stationary and quasi-stationary operating regimes and calculate the EPS parameters for further operation analysis. Since the existing solutions do not provide an optimal models' transition technique, the authors propose the based on T-list algorithm. The research results will be useful for developing efficient EPS control techniques in various regimes and improve energy efficiency both on existing oil fields' EPS and new ones.

1 INTRODUCTION

Oil field electric-power system (EPS) is a distributed object with a complex structure. It is an emergent system that has a multilevel structure of rather large dimension with complex energy, technological, information interconnections [1].

In EPS there is actually no time period when the system works in stationary conditions [2][3].

The set of processes that occur in the EPS and determine its state at a specific point of time or within a certain time interval is called the EPS regime.

There are the following EPS regime types:

- Stationary regime when the EPS was designed and its main indicators were defined;
- Quasi-stationary regime when the system moves from one operating state to another;

- Emergency regime when the relay protection devices operation settings are determined, and the parameters change over allowable values;

- Post-emergency regimes when the possibility of further EPS operation with degraded performance indicators is revealed.

In this paper stationary regimes are considered.

The EPS regime has the following parameters: currents flowing through EPS elements and voltages at the clamps of the elements. The EPS regime parameters are interdependent to one another, they include the parameters of the grid elements with connection schemes being taken, power supply parameters and load characteristics. The EPS regime parameters can be determined by computing or experimental methods.

In case of EPS, the full-scale experiment is difficult to conduct due to safety requirements and technological process restrictions, therefore a

mathematical model development is considered [4] [5].

Any EPS include 2 models: visual and calculated. The visual model is the EPS scheme, the calculated one is the system of equations that most fully describing the EPS structure and processes taking place in it. Often these 2 models are in no way connected with each other and fulfil different tasks. Once creating the relationship between them, a software package is created. It allows to practice methods of effective EPS management in various regimes, and to develop measures to increase the electrical equipment (EE) energy efficiency in operating existing oil fields and designing new ones.

The aim of the paper is to develop an algorithm for the transition from the visual EPS representation to the parametric one.

To achieve the goal, many tasks must be performed which related to:

- EPS representation in the form of an object model;

- EPS representation in the form of a calculation model which allows to calculate the main EPS regime parameters. The calculation is realized on the matrix-topological method basis [6];

- The development of an interface that provide a one data transition from the object model to the calculation model, and back another one.

2 SOFTWARE PACKAGE DESCRIPTION

The software package is designed to simulate stationary and quasi-stationary EPS operation regimes and calculate currents in branches and voltages in the nodes of the electric grid in all regimes.

The package under development consists of three interconnected elements (Fig. 1).

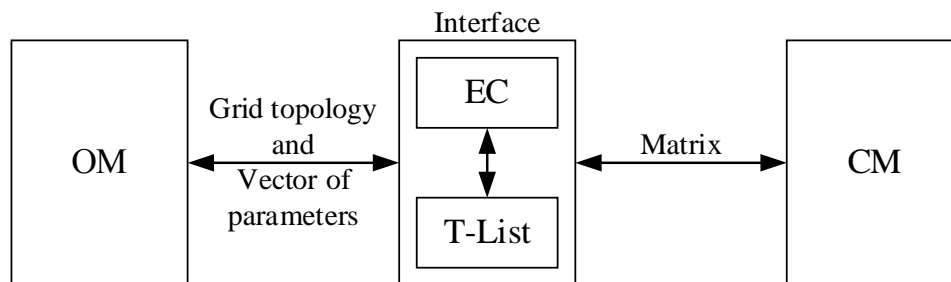


Figure 1: System elements interaction scheme. OM - Object Model; EC - Equivalent Circuit; CM - Calculation Model.

2.1 EPS Object Model Implementation in LabVIEW

Object Model (OM) is a virtual system similar to a real system and capable of reproducing properties and processes occurring in a real system with a certain accuracy. The OM should reflect those concepts and objects of the real world that are important for the developing system.

The structural unit of the OM is an object. A one model objects group is united by a hierarchy (typology). Each object includes a set of parameters that uniquely define this object and become sufficient for the calculations, a set of operations involving the object, as well as interactions with other objects.

The task of OM development is to provide a virtual representation of the real EPS in computer.

The created OM represents an objects tree in LabVIEW [7]. A small fragment is shown in Fig. 2.

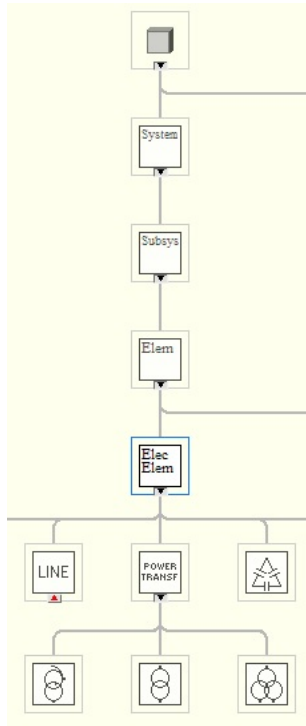


Figure 2: OM fragment in LabVIEW.

The figure shows the inheritance concept, according to which the descendant can inherit the ancestor parameters (properties) and the ancestor functions (methods) [8].

2.2 EPS Calculation Model

Calculation model (CM) is a matrix equations system [9] for nodes and branches; the model's input data are the objects parameters. This system is used to calculate the currents in the branches and voltages at the EPS nodes. The power consumed by the electric receivers is calculated and the losses in the system's elements are estimated in response to these parameters.

The process of creating a mathematical model is considered as a sequence of two stages: creating models of individual elements and creating a model for their interaction.

Approaches to the study of this type systems are subdivided into methods aimed at simplifying or reducing the dimensionality of the model in question and decomposition methods that enable one to solve a large high-order problem in which individual small problems are considered and the solutions obtained are combined [10].

The interaction of electrically connected elements is most naturally organized by means of electrical parameters such as currents and voltages. The calculations of the electric regimes are based on the solution of equations formulated on the basis of one of the two methods derived from Kirchoff's circuit law: the method of the node voltage equations or the method of loop currents equations.

The nodal voltage matrix (NVM) is used to calculate the EPS regime parameters, the calculation is based on the formula:

$$\mathbf{Y}^{-1} \times \mathbf{J} = \mathbf{U} \quad (1)$$

where \mathbf{Y} is the matrix of known nodal conductivities (\mathbf{Y} -matrix); \mathbf{U} is matrix-column of node voltages (\mathbf{U} -matrix); \mathbf{J} is matrix-column of the driving currents (\mathbf{J} -matrix).

For the EC's i -th node, there is a U_{sti} value (the reduced basic voltage of the transformation stage, kV) according to the formula:

$$U_{sti} = U_b \cdot \prod_{a=1}^z K_{Tza} \mathbf{Z} a \quad (2)$$

Where U_b is the basis voltage, kV; K_{Tza} is a transformation coefficient of the a -th branch transformer (if there is no transformer in the branch, $K_{Tza} = 1$); z is the number of branches from the basic to the i -th node, equal to the number of \mathbf{Z} -vector elements; \mathbf{Z} is a vector column containing the ordinal branches numbers of the smallest path from the basic node to the node i .

The reduced base branch voltage is equal to the value of its starting node:

$$U_{sti}^{SN} = U_{stj} \quad (3)$$

where U_{sti}^{SN} is the reduced basis voltage of the branch j starting node, kV; U_{stj} is the reduced base voltage of the branch j , kV.

Active and reactive conductivities are calculated and brought to the basis voltage through the known equivalent resistances and reactances of the composed circuit elements, then it forms the conductivity matrices (\mathbf{G} - and \mathbf{B} -matrices). After that, the conductivity matrices form an \mathbf{Y} -matrix.

$$\left(\begin{array}{c} \left[\begin{array}{ccc} G_{11} & \dots & G_{1k} \\ \dots & \dots & \dots \\ G_{k1} & \dots & G_{kk} \end{array} \right] \\ \left[\begin{array}{ccc} B_{11} & \dots & B_{1k} \\ \dots & \dots & \dots \\ B_{k1} & \dots & B_{kk} \end{array} \right] \end{array} \right) \rightarrow \left(\begin{array}{ccc} Y_{11} & Y_{12} & \dots & Y_{1m} \\ Y_{21} & Y_{22} & \dots & Y_{2m} \\ \dots & \dots & \dots & \dots \\ Y_{m1} & Y_{m2} & \dots & Y_{mm} \end{array} \right) \quad (4)$$

where k is the number of the EPS EC nodes, $m = 2 \cdot k$.

The p -th element of the \mathbf{J} column-vector is determined by the formula:

$$J_p = \begin{cases} \sum_{j=1}^n \left(\frac{E_{gj} \cdot R_j}{R_j^2 + X_j^2} \cdot \frac{U_{stj}}{U_b} \right), & \text{while } p = 1..k \\ \sum_{j=1}^n \left(\left[\begin{array}{c} E_{gj} \cdot X_j \\ - \frac{E_{gj} \cdot X_j}{R_j^2 + X_j^2} \end{array} \right] \cdot \frac{U_{stj}}{U_b} \right), & \text{while } p = k + 1..m \end{cases} \quad (5)$$

Where E_{gj} is the value of Electromotive Force (EMF) of the branch i EC equivalent voltage source (VS), kV; R_j - equivalent resistance of the j -th branch EC, Ω ; X_j - equivalent reactance of the j -th branch EC, Ω ; TN_j is the j -th branch's daughter node which is determined from the T-list.

The \mathbf{U} column-vector is calculated by the formula:

$$\begin{pmatrix} U_1 \\ U_2 \\ \dots \\ U_m \end{pmatrix} = \begin{pmatrix} Y_{11} & Y_{12} & \dots & Y_{1m} \\ Y_{21} & Y_{22} & \dots & Y_{2m} \\ \dots & \dots & \dots & \dots \\ Y_{m1} & Y_{m2} & \dots & Y_{mm} \end{pmatrix}^{-1} \times \begin{pmatrix} J_1 \\ J_2 \\ \dots \\ J_m \end{pmatrix} \quad (6)$$

The voltage drops of the $\Delta \mathbf{U}$ column-vector are calculated from the formula, based on the known nodal voltages:

$$\Delta U_q = \begin{cases} U_{SNja} - U_{TNja} + E_{gja}, & \text{while } q = 1..v \\ U_{SNjr} - U_{TNjr} + E_{gjr}, & \text{while } q = v + 1..w \end{cases} \quad (7)$$

where ΔU_q is the q -th element voltage drop (branch j) of the $\Delta \mathbf{U}$ column-vector, kV; U_{SNja} - the active component of the j -branch starting node voltage, kV (U_{SNjr} - reactive); U_{TNja} - the active component of the j -branch daughter node voltage, kV (U_{TNjr} - reactive); E_{gja} - the active component of the j -

branch's EMF (E_{gjr} - reactive); v is the number of the EPS EC branches, $w = 2 \cdot v$.

According to the received voltage drops, the \mathbf{I} column-vector currents are calculated from the formula:

$$I_q = \begin{cases} \frac{\Delta U_q \cdot R_j}{R_j^2 + X_j^2}, & \text{while } q = 1..v \\ - \frac{\Delta U_q \cdot X_j}{R_j^2 + X_j^2}, & \text{while } q = v + 1..w \end{cases} \quad (8)$$

where I_q is the q -th element of the \mathbf{I} column-vector (branch j), A.

The branches' currents and the nodes' voltages were calculated as reduced to the base voltage, so it is necessary to inverse transformation according to the formulas:

$$I_{aj} = \begin{cases} I_q \cdot \frac{U_b}{U_{stj}}, & \text{while } q = 1..v \\ I_q \cdot \frac{U_b}{U_{stj}}, & \text{while } q = v + 1..w \end{cases} ; \quad (9)$$

$$U_{ai} = \begin{cases} U_p \cdot \frac{U_{stj}}{U_b}, & \text{while } q = 1..v \\ U_p \cdot \frac{U_{stj}}{U_b}, & \text{while } q = v + 1..w \end{cases}$$

where I_{aj} is the value of the j -th branch's current, A; U_{ai} is the voltage value which belongs to the i -th node, kV.

2.3 OM-CM Transition Algorithm

The interface is used for the interaction of OM and CM. It performs the function of organization the T-list based on the EC and technical data of scheme elements. The T-list provides the initial data for the EPS regime parameters calculation.

The T-list formation algorithm can be presented in the form of a block diagram (Fig.3).

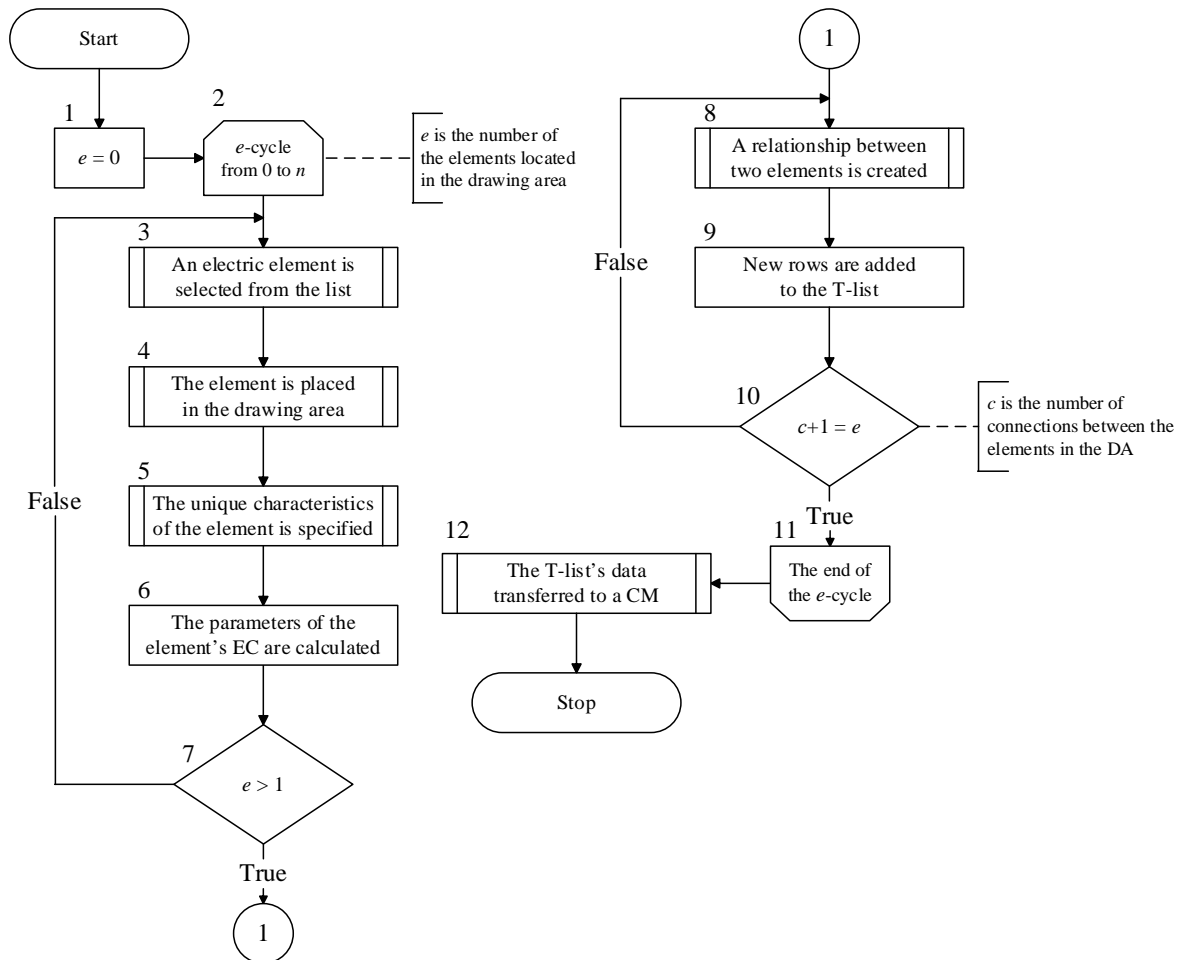


Figure 3: The interface algorithm in the form of a block diagram.

Block 1. At the first stage the number of elements (e) in the drawing area (DA) is zero. The drawing area is a field intended for a visualization of an electrical circuit and its modification by interaction with graphic primitives. An element is an object stored in the OM.

Block 2. A cycle adds new elements and a scheme formation is initiated (begin).

Block 3. The electric element is selected from the list. This list includes transformers, lines, generators, motors, switching devices and compensating devices [11].

Block 4. The selected element is placed in the DA.

Block 5. At this stage, the element parameters are entered and recorded into a cluster of private data. The EE parameters and the input power (IP) voltage are defined. Then the transformation coefficients of all the system transformers are

determined, and the IP voltage is automatically taken as the basis voltage.

Block 6. Equivalent resistances and reactances, the EMF of the equivalent source and the current of each EC branch element are calculated according to the given technical data. The EC is a model of the real circuit, which has at least two nodes and one branch. Each branch connects two nodes, each node is able to contain two or more branches. Each branch is characterized by an equivalent impedance, an equivalent voltage source and an equivalent current source. The impedance is calculated by formulas with the equipment's technical data. The EC is stored in the cluster of element's private data in the form of an array and its filled when specifying the element technical data. The EC of each element has input and output nodes. The exception is IP (it has only an output node) and electric consumer (it has only an input node). The number of element EC branches depends on the type of this element:

1) If the IP's EC is considered (Fig.4), then the number of branches is 1;

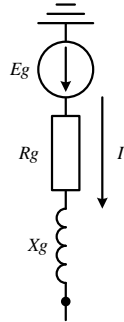


Figure 4: Input power equivalent circuit.

2) For the EC of all other elements, the number of branches is 2, for example, overhead transmission line (OL) EC (Fig.5);

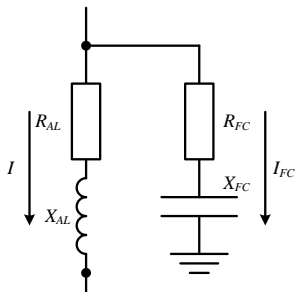


Figure 5: OL equivalent circuit.

Block 7. The condition of existence in the DA at least two elements are checked.

Block 8. A link between two electrical elements is created in the DA. To create a link, the output node of one element (the parent element) is connected to the input node of the second element (the child element).

Block 9. The elements EC arrays and the string, corresponding to the connection between them, are entered in the topological list (T-list). The T-list is a table with a fixed number of columns and a variable number of rows (Table 1). T-list is used for recording, storing and transferring the system EC characteristics to the CM. An alternative to the T-list is the incidence matrix, however, in the framework of this study it is not used because it has a weak fullness. This leads to an excessive expenditure of computing time and the computer's storage space.

The main advantage of the T-list is the free order of the lines numbering, i.e. entering the information in any order into the T-list is possible.

Interaction with the T-list is realized as follows:

1. Once a new element or/and a new link between elements (branch) is added to the DA, new rows with information about the element are added to the T-list. To write a new electrical element, one or two rows are allocated to the T-list, depending on the element's EC (Fig. 4, 5).

2. Each branch and each node of the EC acquires a unique identifier (ID) in the T-list.

There are three types of nodes are distinguished:

1) Generator node - no superior node is defined for it;

2) Load node - it is not superior to any other node;

3) Intermediate node - it has superior nodes and is a superior node to other nodes;

3. The rows are removed from the T-list when corresponding branch or element is excluded;

4. The element parameters are recalculated when the technical data of electrical elements is changed, or/and the branches higher and lower nodes are overridden when system is reconfigured.

Table 1: T-list example.

Branch ID	Starting Node ID	Daughter Node ID	R, Ω	X, Ω	E, kV	Transformation coefficient	J, A
1	1	2	5	3	0	1	0
...
n	b	c	d	e	f	g	h

The T-list includes the following positions:

1) The first column contains the unique identifier of the graph's branch (*Branch ID*);

2) The second column contains the unique identifier of the graph's branch starting node (*Starting Node ID*);

3) The third column contains the unique identifier of the graph's branch daughter node (*Daughter Node ID*);

4) The fourth column contains the value of the branch's equivalent resistance (*R*);

5) The fifth column contains the value of the branch's equivalent reactance (*X*);

6) The sixth column contains the branch's equivalent IP EMF value (E);

7) The seventh column contains the magnitude of the branch equivalent driving current (J).

Block 10. The condition of all elements connection that placed in the DA is checked.

Block 11. A cycle adds new elements and a scheme formation is initiated (end).

Block 12. The matrix of nodal conductivities (4) is organized, the base voltage and transformation coefficients of the transformers (2) are formed, as well as the equivalent IP EMF values of each EC branch for the driving currents calculation (5) are formed based on the information contained in the T-list.

3 CONCLUSIONS

The paper discusses the question of the relationship between the EPS graphical model and the EPS parametric model. The existing methods of transition from one model to another are not optimal. An algorithm for the OM-to-CM transition through the T-list was developed in order to decrease the computation time and reduce the computer's storage space. It was necessary to create an EPS object model in LabVIEW, create a calculation model in LabVIEW, and create an interface that allows for transferring one data from the object model to the calculation model, and the other data back, to implement the algorithm. The key element of the interface is the T-list, which is convenient for storing and transmitting the grid topology, and it also has a number of advantages over other frequently used structures, for example, the incidence matrix. This approach is consistent with the work of other authors who use the matrix-topological approach and graph theory in the EPS calculation [10]. Unlike known methods, the method of reduction to a single baseline level is used [2]. Based on the calculation of stationary and quasi-stationary EPS regimes, it will be possible to proceed to the calculation of the dynamic EPS regimes.

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