V. Z. Zelinskyy, Cand. Sc. (Eng.), Assist. Prof.; V. V. Zelinskyy

SIMULATION OF GRAPHS IN THE TASKS OF ELECTRIC POWER SYSTEM MANAGEMENT

On the basis of methods of theory of graphs there had been suggested methodics for simulation and optimization of design model of electric power system which allows to form adaptive models for systems of operative-dispatch management of normal modes of EPS.

Key words: *design model, adaptive model, graph tree, independent circuit, chord, heterogeneity.*

Development of automated system of dispatch management (ASDM)of electric power system requires improvement of methods for simulation and optimization of calculation circuit of electric net, algorithmic and software provision for tasks of control over modes and automation of process of realization of controlling actions in the controlling systems of normal modes of EPS. Traditional mathematical models and methods do not completely meet new requirements to realization of principles of automated control over EPS modes. It is expedient to form mathematical model for controlling over normal modes on the basis of contemporary methods and means for simulation, using theory of optimal control over complex technological system and methods of graph theory [1, 4].

The main objective of the conducted researches is to determine conditions for formation and optimization of graph tree of design model of EPS, ensuring definite conditions of synthesis and realization of optimum control actions in ASDM as well as adequacy of the model to real conditions of technological modes in EPS.

Formation of target function of tasks of optimal control over normal modes of EPS requires task-oriented formation of design model aimed at synthesis on their basis optimal control actions for regulating devices which are engaged into the process of controlling over technological modes in EPS. The task of synthesis of optimal control actions in general kind is formulated as task of theory of optimal control over complex technological processes [1], the solution to which is law of control over regulation devices in the kind, convenient for its further practical realization in the automated or automatized systems for mode control. Generally, the law of control may be presented by an equation:

$$u(t) = -W\,y(t), \qquad (1)$$

where $\mathrm{u}(t), y(t)$ – vectors of control and observation, W – matrix of feedbacks, reflecting connection of topology of net with its constant parameters.

The determination of control laws (1) requires to build design model following the definite algorithm. First of all it means to form the model of graph tree in a way to single out transformer branch as an independent circuit chord.

It will enable to realize in the circuit of equivalent circuit the compensating electromotive force in linear dependence upon the parameters of regulating devices. On the stage of pre-design it is necessary to make ranking and regulating transformers as for priority of control over mode.

Simulation of graph tree stars from analysis of the results of dependences of losses in active capacity on factors of transformation of regulating devices $\Delta P = f(K_T)$ for all types of transformers with on-load operation in electric net and their ranking as for priority of control in ASDM [1, 2]. For example, for electric net (fig. 1) these dependences may look as is shown in fig. 2.

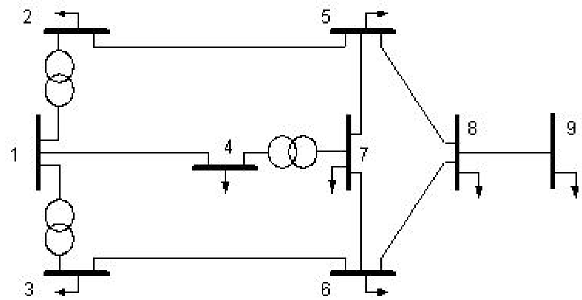

Fig. 1. Scheme of connections of modeled electric network

During the simulation of independent circuits, the branch 4-7 shall be selected as the first one as chord of the first independent circuit, since the sensitivity to decrease in power loss in this branch is the highest. For the second circuit we choose the branch 1-2, for the third – 1-3. Model of graph tree of electric net shall be formed as root tree, where the balancing unit is the root of the tree. All the allowed variants of development of graph tree of the model form the initial set of trees optimization of which under formulated for ASDM tasks, allows to synthesize the optimal design model.

Initial conditions for simulation process is selection of balancing node, chords (result of ranging) and system of independent circuits heterogeneity of branches is equivalent circuit of electric net is chosen as a criteria of formation of optimal path tracing [1, 4]. Branch of graph $N_{i,j}, i = 1,\dots n; j = 1,\dots n$ are provided specific weight which is determined as a value of heterogeneity of each branch. Chords for circuits are chosen upon the results of previous analysis following methodic, suggested in [2]. The corresponding matrix of chords L_j is formed, where $j = 1,\dots k$ – number of regulating devices. Building model graph tree starts with choosing balancing net and finding minimum distance between the two fixed tops of chords of graph from array L_j, that is, the first branch, which, following the results of ranking of transformers is selected by chord in the first circuit.

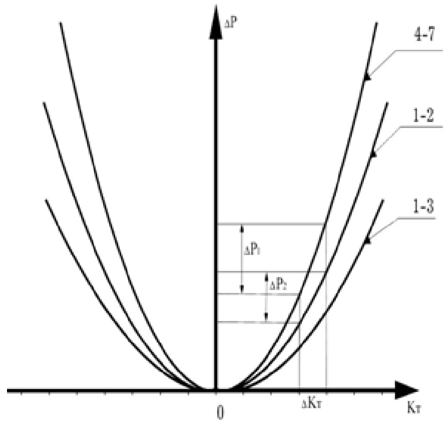

Fig. 2. Determination of regulating effect of transformers with RUL

Let us consider random graph tree G of equivalent circuit of electric net with tops $\overline{1,m}$ and set length (weight) w_{ij} of edges $\overline{1,n}$. Let us form the matrix of weight coefficients of branches with dimensions $n \times n$, in which the value of heterogeneity of equivalent circuit branches is chosen as non-diagonal element.

$$W = (w_{ij}), \tag{2}$$

where w_{ij} – length (weight)of edge.

During formation of diagonal elements , when $i = j$, value $w_{ij} = 0$. If the branch, which is directly connects the nodes i and j is absent, the value $\mathrm{w}_{ij} = \infty$. Starting with matrix $W^{(0)} = W,$ there forms the sequences $W^{(0)}, W^{(1)},\dots, W^{(n)}$ of such $n \times n$ matrices, where element $w_{ij}^{(n)}$ of the matrix $W^{(n)}$ – is measure of distance between i and j nodes in graph G. Matrix of scales $W^{(m)} = \left(W_{ij}^{(n)}\right)$, for the whole set of top m_{ij} shall be determined as

$$W_{ij}^{(m)} = min\{W_{ij}^{(m-1)}, W_{im}^{(m-1)} + W_{mj}^{(m-1)}\} \quad (3)$$

Path of minimal length of the circuit among all oriented $i-j$ paths, which use the top m_{ij} of the set, is determined as $P_{(ij)}^{(m)}$. For all tops $0 \le m \le n$ the set $W_{ij}^{(m)}$ determines the length of path tracing $P_{(ij)}^{(m)}$.

Apart from minimal length of graph branches, are determined during choosing of path tracing it is necessary to receive circuits of minimal length. It is achieved as follows: building sequences $w^{(0)}, w^{(1)}, ..., w^{(n)}$ simultaneously sequences of matrix $P^{(0)}, P^{(1)}, ..., P^{(n)}$ is built in a way that the element $p_{ij}^{(m)}$ of matrix $P^{(m)}$ points to the top which follows the top i in $p_{ij}^{(m)}$, then

$$p_{ij}^{(0)} = \begin{cases} 1, if \ w_{ij} \ne \infty \\ 0, if \ w_{ij} = \infty \end{cases}. \quad (4)$$

Elements of matrix $P^{(m-1)} = (p_{ij}^{(m-1)})$ we receive from condition in accordance with,

if $M = min\{w_{ij}^{(m-1)}, w_{im}^{(m-1)} + w_{mj}^{(m-1)}\}$, then

$$p_{ij}^{(m)} = \begin{cases} p_{ij}^{(m-1)}, if \ M = w_{mj}^{(m-1)} \\ p_{im}^{(m-1)}, if \ M < w_{ij}^{(m-1)} \end{cases}. \quad (5)$$

If $M = w_{mj}^{(m-1)}$, the length $p_{ij}^{(m)}$ equals the length $p_{ij}^{(m-1)}$, therefore $p_{ij}^{(m)}$ coincides with $p_{ij}^{(m-1)}$.

On the other hand, it $M < w_{ij}^{(m-1)}$, then $p_{ij}^{(m)}$ – concatenation of path $p_{ij}^{(m-1)}$ and $p_{mj}^{(m-1)}$, and therefore $s_{ij}^{(m)} = s_{im}^{(m-1)}$. The shortest way is determined by sequences of tops $i, i_1, i_2, ...,$ where

$$i_1 = s_{ij}^{(n)}; i_2 = s_{ij}^{(m)}; i_3 = s_{ij}^{(n)}; ... i_j = s_{ki}^{(n)}. \quad (6)$$

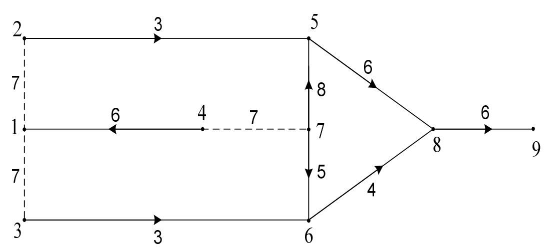

Fig. 3. Graph of electric net with chosen chord and weight coefficients

If $w_{ij}^{(m)}$ or $w_{ij}^{(m-1)}$ equal ∞, then $w_{ij}^{(m)} = w_{ij}^{(m-1)}$. The algorithm also stipulates for procedures of checking the graph connectivity in design model of net.

The developed algorithm and its program realization allow to find the minimal path of both, the first independent circuit by gradual search of all matrix of weight coefficients of branches, and ways for formation of other independent circuits, which should include subsequent chords from array L_j.

If it appears impossible to realize in the model the whole list of planned array of chord , formatted upon the results of analysis of ranging of regulating devices there had been stipulated for building graph by excluding from this list the transformer branches, sensitivity to decrease in losses in which is small, and controlling which does not give us the substantial effect from modes optimization. The suggested algorithm for searching mini mal length (weight) of circuit as for heterogeneity criteria of its branches is used fir writing matrixes of connections and formation of nodes and circuit equations of the state of electric net.

Process of simulation and optimization of design model was considered on the of electric net work (fig. 1), the graph of which with weight coefficient for each of the branches is presented on fig. 3. For the circuit under consideration there had been determined the matrix chords L_j, which combines by priority transformers branches 4 – 7, 1 – 3, 1 – 2. These branches during the simulation process will be included as chords of independent circuits with simultaneous search for minimum length (weight) of each of circuits around this branch (chord).

Simulation resulted in design model of graph tree (fig. 4) with three independent circuits of minimum length and selected on the stage of preliminary calculations chords.

Length of each independent graph circuit is:

1 circuit, chord 4 – 7 (w_{47} =7), path tracing (number of branch and weight) – 7 – 6 (5), 6 – 3 (3), 4 – 1 (6), 3 – 1 (7), total length of circuit – $P_{1к.}$ = 28.

2 circuit, chord 1 – 3(w_{13} =7), path tracing (number of branch and weight) – 3 – 6 (3), 6 – 7 (5), 7 – 5 (8), 5 – 2 (3), 2 – 1 (7), total length of circuit – $P_{2к.}$ = 33.

3 circuit, chord 1-2(w_{12} =7), path tracing (number of branch and weight) – 2-5 (3), 5-8 (6), 8-6 (4), 6-3 (3), 3-1 (7), total length of circuit – $P_{3к.}$ = 30.

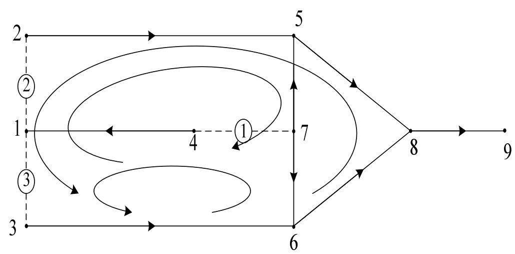

Fig. 4 Independent graph circuits of design model

Circuits of minimum length of graph tree in electric network formation by the criteria of heterogeneity is used for formation of equations of state of EPS and determining parameters of both, steady state and optimum modes. During the simulation of graph tree for real EPS of large dimension, realization of formed full chord list array during the preliminary analysis may appear difficult and in some cases in expedient, from technical and economic point of view. This is because sensitivity to the decrease in losses of active capacity of transformers with inclined characteristics (fig. 1) is small and their control does not have sufficient influence on parameters of optimum mode of EPS.

Thus, simulation of graph tree following the preliminary algorithm in the tasks of formation of adaptive pattern mode of EPS and realization of the controlling actions in ASDM by normal modes allows to improve the efficiency in operative and dispatch control of modes and use the resource of OLTC transformers more efficient. Purposeful formation and optimization of design model ensures its flexibility, high level of adaptivity and controllability, which is one of the determining factors during the development and modernization of the existing ASDM by normal modes in EPS.

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Zelinskky Victor – Cand. Sc. (Eng), Associate Professor with the Department of Electric Power Stations and Systems.

Zelinskyy Vadym– Master student.
Vinnytsia National Technical University.