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Stability Analysis Methods of Discrete Power Supply Systems in Industry

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Abstract. The paper offers the research techniques for stable operation of discrete power supply systems in industrial enterprises. The methods for developing predictive models in control systems and decision-making support for nonlinear non-stationary objects are proposed. The methods are based on the application of associative search procedure to virtual model identification as well as Gramian techniques. The methods use intelligent process knowledge analysis. The knowledgebase is created and extended in real-time process operation. Intelligent algorithms are offered for predicting power plant dynamics in optimization tasks. The operator's decision-making process is modeled using associative search algorithms. Gramian technique of stability analysis of discrete system is used for investigating linear virtual model stability.

Keywords: process identification, knowledgebase, associative search models, wavelet analysis, Gramian technique.

1. INTRODUCTION

Under conditions of enterprise technical modernization and implementation of new equipment, which allows to improve the performance, special importance obtains improving the reliability of power supply of industrial enterprises, where the main energy consumers are electric alternating current (AC) motors. Modern technological facilities require a reliable electricity supply, providing the required quality indicators of electric energy. In particular, the task of forecasting the state of the energy system approach to the boundaries of sustainability is important.

In order to predict the process approach to dangerous limits the following scheme is used. We construct a predictive model using associative search technique. For essentially nonlinear objects, a virtual model is built at each time point by selecting analogues from the process history database fitting (with respect to selected criterion) the current input data. The prediction is made using least squares techniques.

Stability of linear dynamic objects is studied by the *Gramian technique* (Yadykin and Galyaev, 2013). It implies the unbounded growth of the Frobenius norm of controllability's Gramian when a dangerous limit is approached. The associative search allows to apply this technique to nonlinear object investigation.

The authors propose a new method for the discrete power system stability analysis based on a consideration of the contribution to the total energy of the part, which is accumulated in the dominant weak-stable modes. The energy of weak-stable modes is calculated by means of the Gramian spectral decomposition or spectral decomposition of squared Frobenius norm of the system transfer function. One need to know a power system linearized model matrices and weak stable eigenvalues of the dynamics matrix. Correlating this energy to the total energy of the system motion one can evaluate the degree of system proximity to the border of stability and stability loss risk. This allows to identify early enough the thread of the system approaching to cascading failure (blackout) and identify potential center of ill-stable swings for power system.

It was proved (Sukhanov et al., 2012) that the investigation of the Frobenius norm of the dynamic object's transfer function would be sufficient.

In recent years, significant advances were recorded in the fields of intelligent systems of various types, decision-making and decision support, information processing and pattern recognition, diagnosis, and automatic control.

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Automatic control systems based on knowledge processing have been evolving rapidly (Kasabov, 2015). Application of such systems in control tasks is reasonable under insufficient a priori information about the control object as well as in cases of poorly formalized input signals, weakly structured systems, and nonlinear models. The paper discusses the identification techniques and algorithms based on knowledge processing technology.

2. MATHEMATICAL MODELS AND ALGORITHMS FOR AUTOMATIC ON-LINE ESTIMATION OF THE ACTUAL STATE OF SYSTEM

In (Bakhtadze et al., 2011) the intellectualization of identification methods, in particular, the employment of additional a priori information about the object for system teaching, is outlined as a key trend.

Associative search algorithms based on the design of *virtual* predictive models, which use intelligent analysis of historical process data for dynamic tuning of identification models, can be attributed to this type of methods.

The procedure of input vectors selection from process history imitating the associative search of optimal decision by process operator in a specific situation can be applied for virtual models design. The linear dynamic model looks as follows:

$$y_t = a_0 + \sum_{i=1}^{r} a_i y_{t-l_i} + \sum_{j=1}^{s}\sum_{i=1}^{r} b_{t-l_i,j} x_{t-l_i,j}, l_i \le t \quad (1)$$

where y_t is the object's output forecast at the *t*-th step, x_t is the input vector of the dimension *s*, *r* is the output memory depth, *s* is the input memory depth.

The equation (1) differs from the ordinary regression because $t-l_i$ are being selected not in chronological sequence but rather according to a certain criterion, which describes the proximity of input vectors with the index $t-l_i$ to the current input vector x_t. Such criteria are named *associative impulses*.

The original dynamic algorithm consists in the design of an approximating hyper surface in the input vector space and the related one-dimensional outputs at every time step. To build a virtual model for a specific time step, the vectors close in a manner to the current input vector are selected. (Bakhtadze et al., 2013). This selection procedure is called *associative searching.* The output value at the next step is further calculated using least-squares method (LSM).

For the algorithm (1), this predicate can be selected as a sentential function predicating the verity or the falsity of the current input vector's membership of a specific domain in the input space. The distance between the points of *n*-dimensional input space in $\Re^s$ will be defined as follows:

$$d_{t,t-l_i} = \sum_{j=1}^{s} \left| x_{tj} - x_{t-l_i,j} \right|, \; l_j \le t$$

were introduced as distances (metric in $\Re^s$) between points of s-dimensional input space, where, generally, $l_j \le t$, and x_{tj} are the components of the input vector at the current time step t. Assume that for the current input vector x_t:

$$\sum_{j=1}^{s} \left| x_{tj} \right| = d_t .$$

To build an approximating hyper surface for x_t we select such vectors $x_{t-l_i}, i = 1,...,r$ from the input data archive that for a given D_t the following condition will hold:

$$d_{t,t-l_i} \le d_t + \sum_{j=1}^{s} \left| x_{t-l_i,j} \right| \le d_t + D_t, \; i = 1,...,r .$$

The preliminary value of D_t is determined on the basis of process knowledge. If the selected domain does not contain enough inputs for applying LSM, i.e., the corresponding SLAE has no solution, then the chosen points selection criterion can be slackened by increasing the threshold D_t. Of course, the solution may be not unique. If so, any one may be selected (the optimization task is not yet considered).

3. APPLICATION: AUTOMATIC REMOTE DIAGNOSIS OF READINESS FOR GENERAL PRIMARY FREQUENCY CONTROL IN THE POWER SYSTEM

The use of transient mode monitoring technique to analyze dynamic property of energy system allows to solve many problems by multi agent systems in real time. This technique is realized by special hardware for information registration and transmission. The energy system dynamics determines the transient modes dynamics for specified perturbation. Modern primary frequency control systems contain digital models of generator excitation, turbine rotation speed controllers, dynamic load models, models of safeguard and automation devices. Let consider multi agent approach for general primary frequency control in power system.

In case of dangerous situation resulting in voltage drop, primary frequency control is to be carried out by all power stations by means of power changing through automatic controllers of turbo aggregates rotation frequency, productivity of boilers, nuclear reactors, etc.

Normalized primary frequency control is to be carried out by fixed power stations (power units), which possess prescribed characteristics of primary control. In these plants, the necessary primary reserve is created and constantly supported. It is important to estimate the generating equipment state with respect to its accordance to conventional standards. The par-