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Monitoring the State of Power Systems

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Abstract: - The paper presents improved models, which are used for monitoring operation modes, and identification and analysis of emergency situations in power systems. The presented models serve as a part of theoretical foundation for a geoinformation system of decision making support during emergency situations in power systems. Integration of the proposed models into the system of decision making support will effectively improve the control of emergency situations in power systems.

Key Words: - Power Network, Balance Model, Identification of Unbalance, Decision Making Support

1 Introduction

The intensive proliferation of information technology in area of engineering communications, in particular power systems, has caused intensive development of geoinformation systems (GIS) devoted to control of power systems. The primary task of GIS is to manipulate geographically distributed information, which reflects natural and artificial objects located on the controlled territory, their characteristics and relationships between them. Therefore, one of the most important economical demands now is the development of effective approaches of reactive control of power systems through effective and efficient processing of geo information. Geo information is the set of information about physical (natural and artificial) objects and human resources, which reflects a degree of the system's organization. On the other hand, geo information is the set of control objects acting in a stochastic environment. Therefore, the primary tasks of geoinformation control can be formulated as follows:

1. Building the model of functional environment for geo information.
2. Building models of the processes of elicitation of geo information.
3. Identification of parameters of the models, and the model's adequateness checking.
4. Development of models and methods of prediction of geo information.

This paper presents improvements of methods and models of geoinformation control and use of these methods and models in the improved Geoinformation System of Decision Making Support at emergency situations in power systems.

2 The object model of power systems

The *intended product* of power systems is electric current (in terms of nature), and electric energy (in terms of common sense). It is reasonable to consider a power system as a distributed network with the complex aggregation and non-uniform structure. A fragment of the object model of a power system is presented in figure1. The network consists of unequal nodes:

- power generation nodes;
- power distribution nodes;
- power consumption nodes.

The system consists of the super-system S_0 and subsystems S_1, S_2, ... S_n supervised by the super-system. The super-system can be the united power system of a state, a province, or a region as well as a set of states/provinces/regions. The super-system can supervise subsystems of lower levels in order to achieve goals assigned for the whole systems. These goals are:

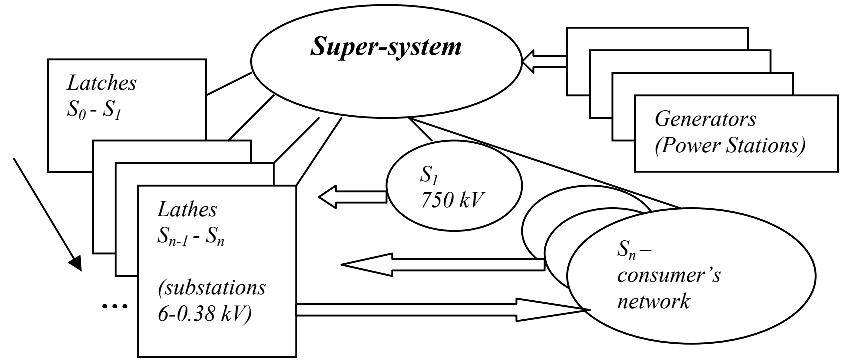

Figure 1 – The object model of power systems

- faultless power supply to power consumer nodes;
- efficient and effective control of re-distribution of the intended product.

Let us consider the context of classification of the subsystems $S_1, S_2, \ldots S_n$, where each subsystem has its own properties. There is a classification of power networks by voltage (Ukraine): 750, 500, 330, 220, 110, 35,10, 6, 0.38 (power consumer's network, three phases), 0.22 (power consumer's network, one phase) kV. 750 and 330 kV stations are the most structured because of their large scale. Each class of power subsystems contains node-generators (generating plants, or power stations), node-distributors (transforming the intended product), and node-consumers (consuming the intended product). The goal of control of power systems is to achieve high level of quality of the intended product to provide effective interaction between subsystems of the power system. The present work extends the papers [1, 2] and provides some improvements in the adjusted balance model of power systems and identification of emergency events [2]. These improved methods and models have been embedded in the System of Decision Making Support at emergency situations in power systems [1, 3].

3 The improved balance model for monitoring the state of power systems and identification of emergency events

Let us present a model of parameter space of the power system. In this model information parameters are represented by the space of signals measured in power system by the special devices - event recorders. The given set of signals is considered to be an adequate representation of the power system's parameter space. The full (and even abundant) set of signals from the power system is represented as the following vector:

$$S = \{I, U, \varphi, P_i\} \qquad (1)$$

where, $I = \{I_0, I_1, I_2, I_3\}$ – current vector representing currents in the power system phases;

$U = \{U_0, U_1, U_2, U_3\}$ – voltage vector representing voltages in phases;

$\varphi = \{\varphi_0, \varphi_1, \varphi_2, \varphi_3\}$ – phase vector representing phase shifts.

P_i – characteristics of consumed or injected power;

The models of flow-distribution in power systems based on consumed and injected power balance as well as on Jacobi matrix of active and reactive load vectors are proposed to be applied for determination and identification of emergency mode [4]. Both models are accurate enough for regular or close to regular consumption modes in power systems.

At the emergency mode the balance equation can be represented as follows:

$$\sum \Omega_S - \sum W_i = 0, \qquad (2)$$

where Ω_S - set of injected power from power sources;

W_i - set of consumed power by consumers in the power system;

i - consumer number, which is a source for parameter signals;

s – source number.

In an emergency situation or irregular operation mode of the power system, the equation (2) leads to a poorly convergent result due to the desired "null" on the right side of the equation.

Let us denote the set of input parameter signals in (1) as a subset (a_{ij}) [5]. For the identification of an emergency mode and the corresponding control action, the input subset (a_{ij}) must be transformed to the subset (b_{ij}) of output (determining) parameters of the power system's mode. Both of the subsets are discrete. The described transformations of the input subset to the output subset, as well as transmission of the output subset (b_{ij}), are performed on the subset of data transmission channels $\{v_i\}$, which constitute the information channel $\{V\}$. The information channel $\{V\}$ is hereafter denoted as the system channel.

In the topological space of parameters of the power system's mode, a norm predicate variable is introduced as follows:

$$P(b_{ij})=a_{ij}^{\ bij} \qquad (3)$$

This variable logically connects input elements (a_{ij}) with corresponding output elements (b_{ij}).

Let us consider that $P(b_{ij})=1$ if power balance takes place in the power system. The balance is determined as the sum of all injected and consumed power, which is limited by the value called the Fluctuation Corridor (FC). If the sum is not in the FC, the system is unbalanced. The FC is determined by the given set points of the relay protection. Let us distinguish the local and global norm predicates. The local norm predicate is determined as $P_i(b_{ij})$ in each input point (in the power system node). Then:

$$\vee_i P_i(b_{ij}) = 1, \qquad (4)$$

if all subsystems of the power system work in the regular mode. There is a countable set of local non-balances in power system caused by stochastic nature of electric energy consumption.

The power system, as well as any complex-organized system, tends to converge to the balance state appropriate to the set mode. Thus, disturbances appeared in power system can be divided into the following three classes:

1) disturbances caused by planned switching (power flow);
2) unplanned disturbances, which do not lead to norm predicate change;
3) unplanned disturbances, which lead to norm predicate change.

It is obvious that the computer-aided system for identification and control of irregular and emergency situations must manage the third class of disturbances.

The analysis of power supply-consumption shows that unbalance is cyclic, static and predictable. Let us distinguish a range of periodic components.

The first component $\pm\delta_d$ is a predicate fluctuating component related to daily rhythm (day and night power consumption).

The second component $\pm\delta_w$ is a predicate fluctuating component related to weekly period (working days and days off).

Then, let us denote the third and fourth components as components related to monthly and annual circadian changes in consumption, respectively.

Processing statistical data of given components, the intervals of their acceptable changes can be figured out. Thus, the global predicate fluctuating component is

$$\Delta = \sum \pm\delta_i , \qquad (5)$$

where $\pm\delta_i$ – local periodic component.

Processing of these series of components requires analysis and prediction of loading and frequency during daily, weekly, monthly, and annual periodic intervals. Let us propose to use neural networks to predict these series of time intervals, using the ability of neural networks to approximate non-linear function. The input information (received from detectors – measuring transformers) at the time moment t is represented in the file of event [3] as a vector $y[t]$. So, the functioning of the neural network can be described as follows:

$$y[t+1]=NN(y[t]),$$
$$y[t+1]=NN(y[t],y[t-1],..,y[t-k]), \qquad (6)$$

where NN – a function, which characterizes the structure of the neural predictor;
k – the size of prediction history.

This approach allows using regression models to predict non-liner time series.

The identification of unbalance in the system can be controlled by the current-power measurement devices. The distinction of the periodic components and their analysis will allow controlling the power system settings for faultless operation. The unbalance in acceptable limits does not break down the power system's integrity. The system identifies any fluctuation with the level higher than the fluctuating corridor as an irregular situation and starts an immediate classification and recognition of the event which caused the fluctuation.

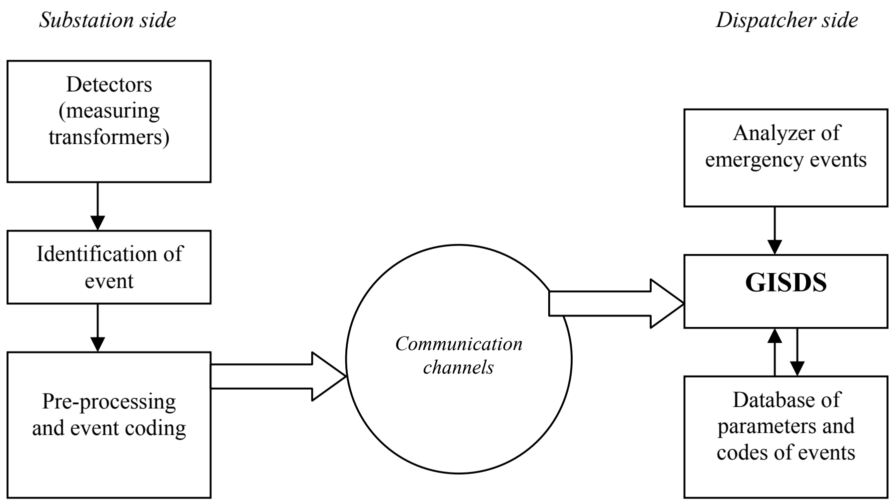

Figure 2 – The structure of the System for control of emergency events

The structure of the system built on the base of the development methods and models is represented in figure 2. The analyzer of emergency events is based on the conception of the file of events [3]. This file stores the measured and statistical (historical) parameters of a power system. The subsystem of decisions generation (in figure 2 – the Geoinfirmation System of Decision Making Support, or GISDS) is an intelligent system, which is based on knowledge about parameters of operation modes of the power system.

4 The improved System of Decision Making Support at emergency situations in power systems

There are two approaches to realization of the Geoinformation System of Decision Making Support:

1. Decisions are generated by several expert systems, which are located at the same node; but these expert systems use different methods for evaluation of the situation and generation of decisions. This approach requires interactive augmentation of the decision to eliminate the raised decision conflicts.
2. Decisions are generated by different expert systems, located at different nodes of the power network, but the expert systems use the same (or similar) methods for evaluation of the situation and generation of decisions. In this case the probability of a conflict is very low; and ideally it is even possible to avoid the manual augmentation.

The present system adopts the second approach. The proposed structure of the Geoinformation System of Decision Making Support is presented in figure 3. The System embeds knowledge based software, which proposes various pre-defined decisions (depending on the event) to the dispatcher. This approach allows decreasing response time during identification of operation modes and emergency events. According to the scheme in figure 3 decision making support is performed in the following sequence:

1. The pre-processing module registers parameters of operation modes of the power system.
2. Dispatcher's node receives the information about the framework of the power network and its components (power lines, transformers, switches, compensators, reactors, loads, etc.). This information is received via the query processing module.
3. This information and information about operation modes is stored in the event record.
4. The system searches similar events in the knowledge base (KB) of emergency events. The search is based on values of the parameters of operation modes in the event record. The knowledge base classifies types of emergency events and hierarchy of the power network components. The knowledge base can be accessed via the intelligent mediator.

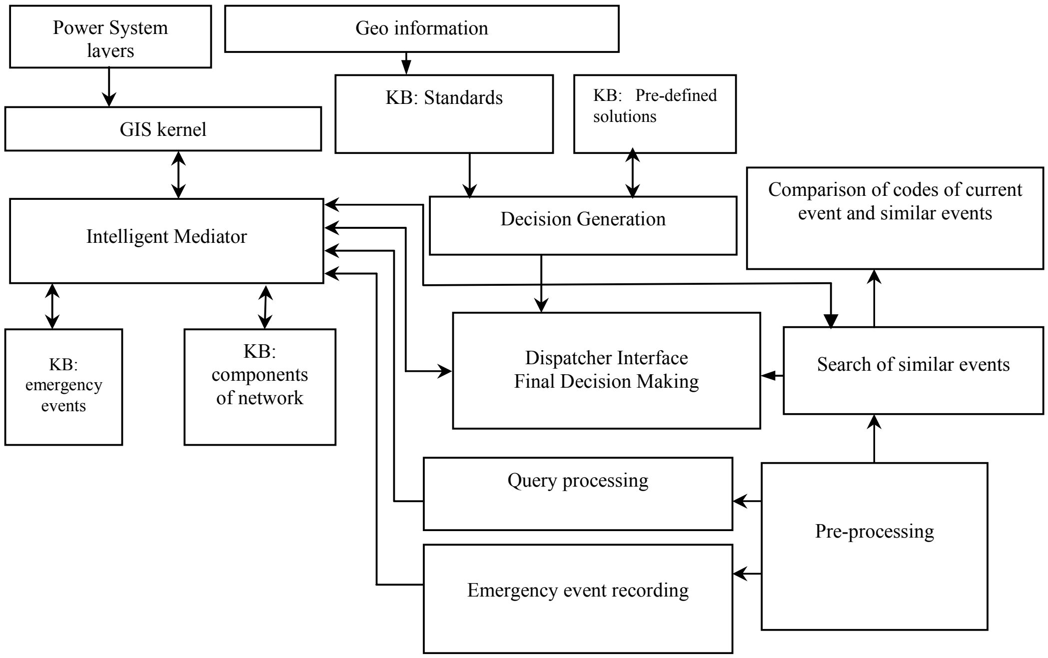

Figure 3 – The structure of the Geoinformation System of Decision Making Support

5. The module of decision generation selects optimal decisions based on the information about the current event and pre-defined decisions and standards.
6. The optimal decision is proposed to the Dispatcher, who is responsible for the final decision. This decision is also recorded in the KB of emergency events for further reuse.

5 Conclusion

The proposed improved methods and models for monitoring operation modes and emergency events provide an effective approach for improving the decision-making process during regular and emergency situations in power systems. The presented models can be used for control of pre- and post- emergency modes in complex-organized systems, such as power systems, as well as for control of various networks with different intentions.

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