Proceedings of the 5th WSEAS Int. Conf. on Power Systems and Electromagnetic Compatibility, Corfu, Greece, August 23-25, 2005 (pp329-333)

Identification of Operation Modes and Emergency Events in Power Systems

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Abstract: - The paper presents two models, which are used for identification and analysis of operation modes and emergency situations in power systems. The presented adjusted balance model of power systems and the model of power system topology serve as the theoretical foundation of the proposed Analyzer of operation modes and emergency events in power systems. Integration of the proposed analyzer into the system of decision-making support at emergency situations in power systems will effectively improve the control of emergency situations, fault allocation and fault fix.

Key Words: - Balance Model, Power System Topology, Fault Allocation

1 Introduction

One of the most important tasks of Electrical Engineering is to provide a faultless power supply to consumers. One of the approaches to solve this task is having the ability to control power systems either in regular, irregular or emergency situations. Power systems belong to the class of complex-organized systems, where a state of the system is identified by the state of its characterizing information parameters. The functioning of any complex-organized control system or real-time decision-making system is determined by the optimal modes of its subsystems. Damages to electric transmission lines usually cause faults in providing electrical power to consumers, a decrease of quality and an increase of power losses. To quickly restore a damaged electric line, it is necessary to immediately identify the exact place of the damage and generate the dispatcher's solution for fixing the causes and consequences of the damage. An important task for dispatching control of power systems is the development of underlying models and methods for the systems of decision-making support in emergency situations. This work is devoted to development of such models and methods, based on processing parameters of operation modes of power systems, with the goal to identify whether it is a regular, irregular or emergency situation. The results of this identification are to be further used in geoinformation control of the power system's operating modes.

Emergency situations can be divided into two classes: acceptable emergency situations and unacceptable ones. On a chronological (time) basis, emergency modes are classified as follows:

1) pre-emergency;

2) emergency (acceptable and unacceptable);
3) post-emergency.

Let us formulate basic requirements to the system of decision-making support by the dispatcher at an emergency situation. Firstly, the system has to perform functions such as: receiving, support and use of the power system operation mode parameter database; information about graphic, non-graphic, space; and attributive electric system components. Secondly, the system has to contain:

1) input devices for power system's operation mode parameter control;
2) software for primary collection, archiving and storing of an emergency event record in a database;
3) communication channels for communication between analyzers of power systems and the dispatcher;
4) fault allocation tools;
5) tools for the generation of decisions, as well as visualization of graphic, space and attributive information for the power system dispatcher.

For successful development of the systems of decision-making support in emergency situations which must effectively assist identification, classification and control of emergency situations, as well as fault allocation, the following models must be developed [1,2,3,4]:

1) the balance model of power systems;
2) the model of power system topology;
3) the model of signal distortion in the emergency mode;
4) the model of fault allocation.

This paper presents the adjusted balance model of power systems and the model of the power system topology as well as their use for identification of operation modes in the power systems.

2 Mathematical models to be used in identification of emergency situation in power systems

2.1 The adjusted balance model in power systems

The first proposed model in this work is the adjusted balance model, which is based on the application of heterostasis principle [5] for modeling of the power system's behavior in pre-emergency mode. The advantage of this principle consists of the capability to control a very wide band of parameters for power systems. In terms of this principle the homeostasis is represented by a set of attractors, which define stable conditions of the functioning power system.

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:

$$S = \{I, U, \varphi, P_i\} \tag{1}$$

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;

φ = $\{\varphi_0, \varphi_1, \varphi_2, \varphi_3\}$ – 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 [2]. 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:

$$\sum \Omega_S - \sum W_i = 0, \tag{2}$$

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}) [1]. 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

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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.

The next subsection presents another important model to be used in identification and control of irregular operation mode of powers systems.

2.2 The model of power system topology

Let us consider topological models of complex-organized power systems. The topology given on a two-dimensional metric space can be considered as the simplest model of power systems. For such topology, all subsystems and their interconnections can be denoted as data matrices of vector sets. Metric topology can provide a visual presentation of the structure in a form of geographic map. So, it can be implemented as the geoinformation system (GIS) of the power system control. However, such topology does not lend itself to machine processing in an emergency situation.

The more complex and informative model for analysis of stationary and non-stationary power flows in the power system is the topology of subsets of the system's parameters (at emergency situation – parameters of the emergency mode). Such a topology defines the structure of "input-output" relationships between subsystems of complexly-organized systems. The described model of topological parameter space of the power system's mode can be represented in a form of sets of connected consumers W_{Si} and suppliers Ω_S. Any level of hierarchy s presents the sets $\{\Omega_S, W_{Si}\}$. The elements of each set $\{\Omega_S, W_{Si}\}$ can belong to different classes of equivalence R_i according to values of parameters in (1). The level of voltage U can serve as the determinate parameter for such classification in power systems. Then, the local consumers of power energy (380 V) can be included in a class of equivalence. Regarding this, the structure of supplier's "connection-output" sets belong to the class of equivalence R_1, but the structure of "connection-input" sets belong to the class of equivalence R_2. The latter class unites a set of suppliers and consumers of a higher voltage level (6-10 kV).

On each level s of the power system's hierarchy, the set of "connection-output" from suppliers Ω_S to the consumer's set of inputs related to the equivalence class R_i is the following:

$$\Omega_S \leftrightarrow \bigcup_{i \in M^2} W_{si} , \qquad (3)$$

where si – number of consumers on the s level of hierarchy in a class R_i;
M^2 – metric space with the given systems of "input-output connections".

The use of these models for identification and control of irregular and emergency modes is described in the section 3.

3 Identification and control of irregular modes and emergency situations

In the topological space of parameters of the power system's mode [1], a norm predicate variable is introduced as follows:

$$P(b_{ij})=a_{ij}^{\ bij} \qquad (4)$$

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:

$$\vee_i P_i(b_{ij}) = 1 , \qquad (5)$$

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

$$\Delta = \sum \pm\delta_i , \qquad (6)$$

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

The acceptability 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.

Let us adjust the equation (2) for emergency operation mode according to the expression (6). Then, a model of the "real" (imperfect) balance can be figured out as follows:

$$\sum \Omega_S \; - \; \sum W_{Si} = \Delta. \qquad (7)$$

The recognition of an emergency mode is performed through description of classes of R_i objects by definite values of their significant properties. The properties can be defined as matrices of parameters, which are stored in the computer-aided system as the output subset *(b_{ij})*. The matrices of predicates of the fluctuation corridors for balances of power are stored in the system's knowledge base.

The described models, together with the model of signal distortion [5] and the model of fault allocation [6,7,8,9], serve as a theoretical foundation for development of the system of decision-making support during emergency situations in power systems. This system is implemented and briefly described in the section 4.

4 Description of the system of decision-making support at emergency situations in power systems

The present system was developed partially based on the models and methods described in the sections 2 and 3 of this paper. These methods are intended to identify an operation mode of the powers system and recognize an emergency event. The control of emergency events and fault allocation are not covered in this paper. These models and methods are described in [3 ,10].

The Analyzer of operation modes (fig.1) is based on the adjusted balance model in power systems. It receives parameter signals (1) from the power system as a set of input signals (a_{ij}) and transforms it to the set of determining parameters of the power system's mode *(b_{ij}),* which are transmitted via the system channel to the dispatcher's workstation. The Analyzer is to analyze the power system's parameters and then identify whether it is in the regular, irregular, or emergency mode. The Analyzer's software is also responsible to file emergency events.

The file of an emergency event contains digitized data received from the analog-digital converter of the Analyzer (fig.1). The file is processed by the Analyzer's software and recorded, and then the file containing the emergency event record is transmitted to the dispatcher. The emergency event record contains the results of measurements from the transformers of electrical current and voltage. The software builds the graphic of the received real instant values of electrical current and voltage. The system maintains a configuration file that contains information about channels, transformation coefficients and colors of the scheme.

Thus, the operation mode of the power system is identified. If an emergency event occurs, its records are transferred to the dispatcher workstation (which is a part of the geoinformation system (GIS) of the power system control) for the further processing which primarily consists of classification of the emergency event and association of the event with geographic coordinates for further fault allocation.

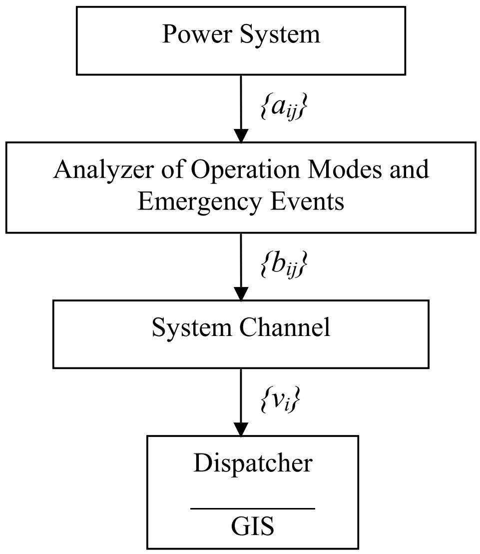

Figure 1 – The scheme of decision-making support at emergency situations in power systems

4 Conclusion

The integration of the proposed Analyzer of the operating modes and emergency events, based on the presented models, provides an effective method for improving the decision-making process during regular and emergency situations in power systems, namely for fault allocation and fault fix. The represented 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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