Modeling multidimensional information flow to control reactive power in free market environment

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***Abstract* – a method of modeling different information flows has been developed. The method allows confirming information flow reliability and restoring information to control power supply system state when power engineering systems are liberalized.**

***Key words* – multidimensional information flow, energy market, reactive power compensation, wavelet-analysis.**

1. INTRODUCTION

Uncertainty is one of the fundamental characteristics of power systems. Energy market liberalization leads to increase in the number of uncertain factors which underlie power system functioning. A typical example of such factors is information deficit. Another factor – stochastic nature of electric energy load of network nodes, which does not allow optimizing power supply system state using traditional methods. This can be attributed to the egoistical interests of companies operating on the energy market: generating companies try to increase «cheap» energy production, network companies tend to increase energy supply and reduce excessive losses, and consumers expect tariffs to decrease. System operator controls power supply state. His main responsibility is providing energy supply to consumers rather than optimizing costs of some power supply companies.

That is why power state parameters are neglected or each energy market player deals with this problem separately which increases uncertainty.

Network companies have high information deficit, resulting from insufficient network accounting as well as intolerable error.

With wholesale and retail energy markets there will be uncertainty of information flow even if electrical supply networks are equipped with sophisticated measuring transmitters. Therefore power supply state parameters should be examined under uncertainty conditions.

Reactive power compensation (RPC) is the most effective method of improving engineering-and-economical performance of power supply network companies. This method allows network companies to reduce all kinds of technological losses of electrical energy and capital investments into network services. World experience shows that RPC allows companies to effectively pursue energy saving objectives, provide standardized power quality, and increase reliability. The need for optimizing operation costs of network companies as a means of increasing their competitiveness suggests that at present RPC is a method of choice when traditional approaches do not bring the desired result.

Uncertainty of information is characterized by insufficiency, unreliability, ambiguity, and is caused not only by physical but also economic factors.

To effectively operate power networks it is necessary to assess uncertainty level to control reactive power under conditions of liberalization of power engineering systems, because traditional methods of RPC effectiveness assessment can lead to intolerable methodical error of optimization results. This can be due to insufficient RPC in some network nodes. Also this can lead to unreasonable money expenditure. Therefore it is necessary to use mathematical model which gives an adequate complete and reliable description of information flow. The aim of the study is mathematical representation of multidimensional information flow to control reactive power. The following objectives have been set to achieve this goal:

- To justify multidimensional information flow use to control reactive power;

- To develop mathematical information flow model;
- To create modeling algorithm for different types of information flow.

2. INFORMATION FLOW MODELING

2.1 Justification of multidimensional information flow application

Traditionally one-dimensional information flow was used for RPC, which was effective only if complete information was available, with the whole process from energy production to energy supply being considered. Liberalization of power engineering systems caused technological processes to split into production, supply, distribution and consumption of power in organizational and financial terms. That is why reactive power flow optimization should be considered for each network company separately, which adds to uncertainty of initial information. That is why one-dimensional information flow cannot be effectively used because this approach does not take into account correlation between power state parameters and different control effect resulting from various companies.

To control reactive power flow and energy in power network it is reasonable to use multidimensional information flow, which has different types {P, Q, I, U}, where P, Q, I, U – aggregation values of active and reactive powers, current and voltage of load nodes with nominal voltage of different classes during different time intervals, respectively. Each array describing concrete power state parameter can have different level of information. This is due to different measuring system errors and different availability of equipment to measure power parameters. The method of multidimensional information flow comprising different types of information makes it possible to determine missing values of reactive power at a given time point using known values of its other components. Therefore multidimensional information flow is a vague set of arrays of the above parameters with different initial information.

Analysis of power networks in the Far East in terms of information quality suggested high level of uncertainty. Figure 1 shows percentage relationship between the rate and reliability of the two components of multidimensional information flow at substations in the north of Khabarovsk Region: active and reactive power. As figure 1 shows, they are different, which justifies the use of multidimensional information flow, represented by a vague set.

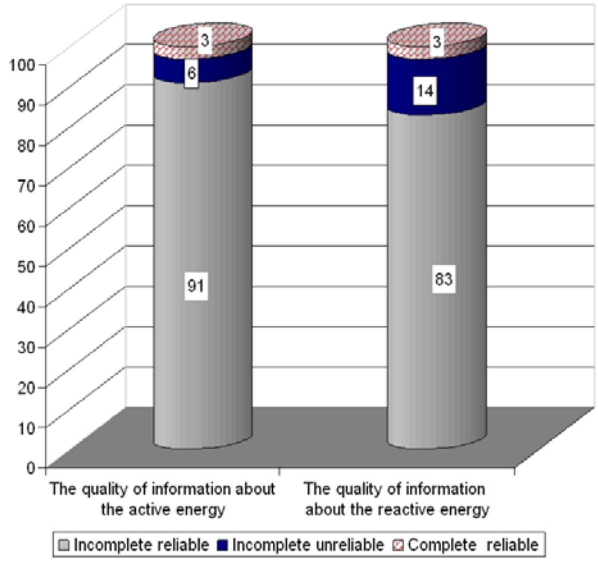

Fig. 1 Percentage relationship between the completeness rate and reliability of the two components of multidimensional information flow at substations in the north of Khabarovsk Region

2.2 Development of mathematical model to describe multidimensional data flow.

In current economic situation traditional approaches to optimizing reactive power flows and voltage levels at the network nodes are unlikely to bring a desired result due to uncertainty of the initial information. Before starting optimal RPC it is necessary to do a quantitative analysis of the information flow quality [1]. The analysis allowed determining threshold level of information availability in the load nodes of the power network, providing the required accuracy of the optimization problem. It has an interval from 0,92 to 0,97. The most complete component of the multidimensional information flow is voltage, and then comes current and active energy, while the least observed array of the examined information flow is reactive energy. Reliability of power flows included into multidimensional information flow can be assessed by checking balances at power network. Voltage array quality can be assessed only by checking measuring systems regularly. The control of active and reactive energy, current and voltage in the network nodes is performed simultaneously at substations with the voltage 35 kV and more at the time of check measurement. For TSS 6-10/0,4 kV control of information flow is not performed, which suggests that the model for optimizing RPC cannot be used for networks with the voltage less than 6 kV.

On the whole, different effects of power state parameters in the load nodes on power state situation in the network are due to discontinuity of the power network. This allows us to use sensor analysis [2]. In market economy there is an increase in power state parameter stochastization, which results from not only technical factors but also power sale transactions, which results in non stationary nature of stochastic processes describing power state parameters. Hence components of vague sets must be represented by the stochastic processes. Thus, mathematical model, describing multidimensional information flow for controlling reactive power must include three components: mean value($X_{cp}(t)$), stationary ergodic process with a zero expectation value ($X_S(t)$) and noise, describing stochastic non stationary component of the process ($\xi(t)$). Thus the model of multidimensional information flow components is given by:

$$X(t) = X_{cp}(t) + X_S(t) + \xi(t)\,. \qquad (1)$$

where $X(t)$ shows actual status of the examined power state parameter with values ***t*** from the prehistory interval (retrospection or present time) and load prognosis with values ***t,*** relating to the future. All model components have dual nature. Therefore the model is used in two modes: parameter assessment and prognosis. Model components are not correlated, since they have different physical nature. $X_S(t)$ is characterized by relatively slow daily change in expectation value in terms of time, due to both energy consumption structure in the load node and seasonal load nature. During the period of twenty-four hours it is constantly changing. The component $X_S(t)$ is given by periodic function and is a basic constituent of the time graph. $X_S(t)$ describes random change in flow constituent during a day and allows us to use the correlative function determined during prehistory interval for prognosis. $\xi(t)$ is a fast changing component resulting from non stationary and non ergodic process. It includes random fluctuation loads which are formed due to a variety of factors including external ones during a day as well as a year. The factors include white noise whose intensity does not depend on frequency with auto-correlative function being δ- Dirac function, or Gauss noise. The benefit of Gauss noise lies in that such process is completely determined by its statistic characteristics of the first and second order. Furthermore, the sum of arbitrary random processes tends to Gauss process with an increase in the number of components. And at the same time convergence is so fast that with the number of components 5 or 6 resulting process is similar to Gauss process.

2.2 Algorithm of creating multidimensional information flow model

Different quality of multidimensional information flow components results in the choice of data flow type [1]: complete reliable information flow, complete unreliable flow, incomplete reliable information flow, and incomplete unreliable information flow. Analyzing non stationary random processes it is advisable not only to obtain mathematical formula describing them but also develop technological procedure which allows dealing with generalized mathematical model of the node data flow in each particular case, which is important for model practical application. To do this we created model algorithm, including existing software products, and determined the sequence of their application and chose for each type of random process and uncertainty the

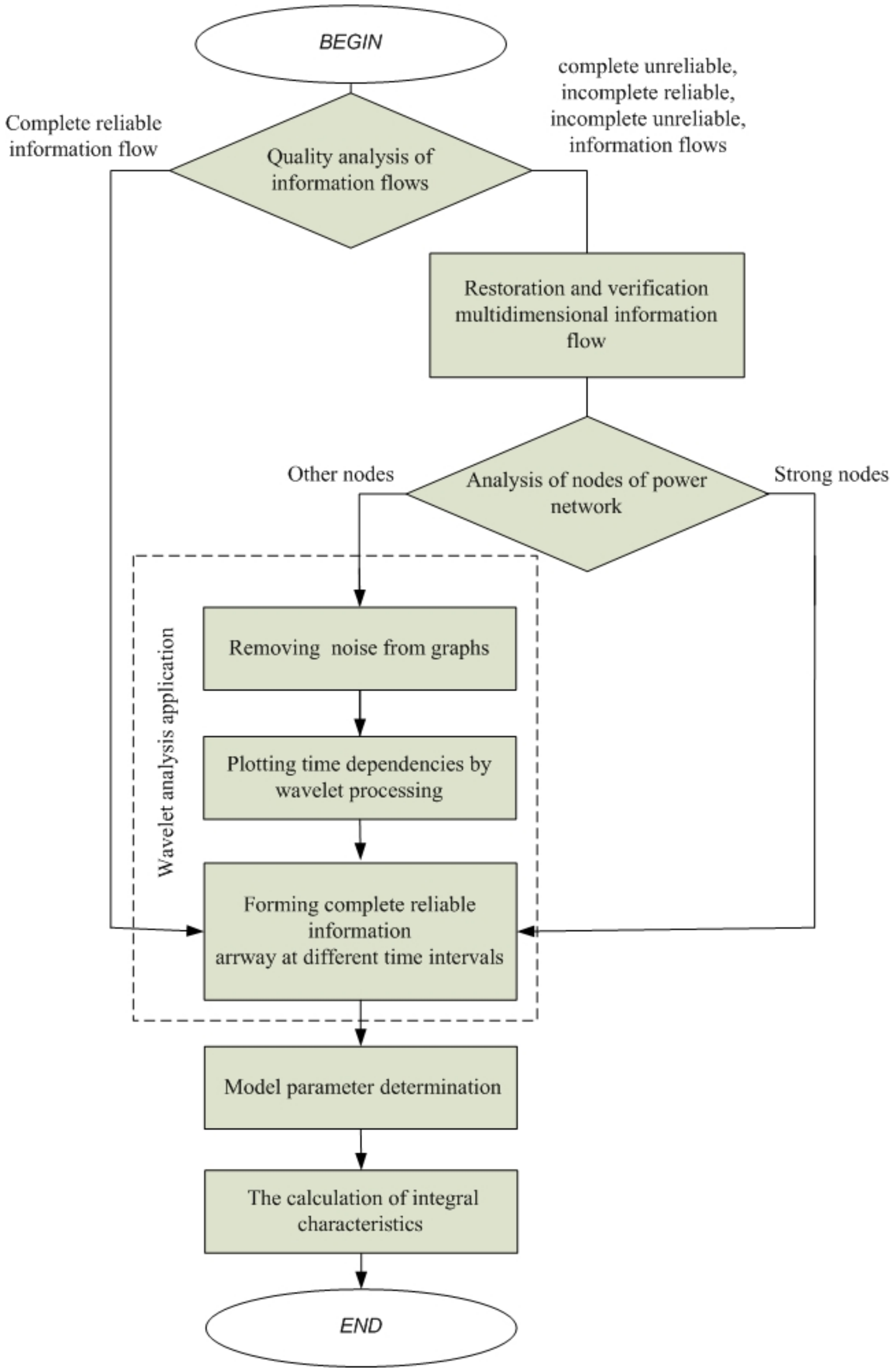

Fig.2. Algorithm of processing initial information used for creating complete reliable multidimensional information flow.

program, which allows performing analysis and synthesis of the model to assess its parameters and make prognosis.

Algorithm of processing initial information used for creating complete reliable multidimensional information flow is shown in Fig.2. Its main stages are as follows: information gathering and analysis in terms of quality, information restoration and verification (when needed), creating complete reliable data flow. Complete reliable flow for controlling reactive power flow can be presented as follows: time dependence graphs and integral characteristics. Time dependences are required for making prognosis and choosing parameters to regulate compensative systems in weak points. Integral characteristics are expedient for choosing capacity and installment place of compensative systems (CS), assessing their effectiveness in terms of maintenance and prognosis. They include mean, maximal and minimal values. Integral characteristics after verification and restoration of information flow are determined by means of traditional methods.

Algorithm presented calls for some clarification. Quality analysis of information flows is an important step of the study at which not only information parameters but also significance of node effect in terms of power state parameters are considered. So in strong nodes information of any quality can be used, whereas in weak points it is advisable to use high quality information for controlling reactive power. In other network nodes required level of the information flow verification is determined by the threshold level of information quality.

Initially basic selection (time dependence) is formed during restoration of time dependences, further noise is removed; resulting reliable (cleared) points are joined to restore required dependence part, followed by an increase in selection dimension during the given time period. After that integral characteristics are estimated over complete information array.

Thus, necessary time dependences and required probabilistic characteristics are determined. Noisy non stationary processes are precisely modeled with wavelet analysis. This analysis is a type of spectral analysis where specific functions called wavelets act as simple fluctuations. Basic function wavelet is not only a kind of a "short" soliton-like fluctuation.

Frequency concept of traditional spectral analysis is replaced here by scale, and, to cover all time axis by "short waves ", function shift in time has been introduced. Hence, basis of wavelets– a function of the type $\psi\left(\frac{t-b}{a}\right)$, where b - shift, a - scale.

Moreover, to be a wavelet the function must have a zero square and the first, second moments, etc., must equal zero [3].

Continuous wavelet transformation is given by the following equation:

$$W_{a,b} = \int_{-\infty}^{\infty} \psi_{a,b}(t) f(t) dt \, , \qquad (2)$$

i.e. it represents signal convolution $f(t)$ with the function $\psi_{a,b}(t)$, transferring the signal from time function to wavelet-area with basic functions:

$$\psi_{a,b}(t) = \frac{1}{\sqrt{|a|}} \psi\left(\frac{t-b}{a}\right), \qquad (3)$$

where a and b represent scale and shifts of one function (parent wavelet).

Inverse transformation is given by the following equation:

$$f(t) = \frac{1}{C} \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} \frac{da\,db}{a^2} W_{a,b} \psi_{a,b} \, , \qquad (4)$$

where $C = \int_{-\infty}^{\infty} \frac{1}{|\omega|} |\hat{\psi}|^2 d\omega$;

a – scale parameter;

b - shift parameter [4].

Wavelet-analysis application and restoration is performed with Matlab package and its application Wavelet Toolbox, because this software product allows us to produce graphical representation of time dependence processing results with additional functions being programmed. To decompose and restore signals it is necessary to use Haar and Db wavelets, and Morle and Gauss wavelet to restore information.

2.5 Algorithm application

To restore data flow more effectively the following sequence of processing and restoring time dependence graphs has been chosen:

1) Array based on the measuring system data is formed;
2) Detailed coefficients are assessed;

3) Noise is removed;
4) Noise-free time dependence based on wavelet-function is restored;
5) Noise is applied;
6) Time graphs and integral characteristics are compared with reference dependence.

Complete reliable flow has been chosen as a reference to confirm effectiveness of the suggested technology for processing information flow of low quality. The reference was formed on the basis of OMC data for introducing active power 10 кV at SS «Centralnaya» in Amur Region. The information is lost from this flow in a random way. The rate of completeness and reliability ranges from 10% to 90 %. At the first stage restoration of initial time dependences (electric load graphs – ELG) is performed with direct and inverse wavelet-transformation. As repeated experiments showed, Wavelet Toolbox of Matlab package allows restoring array of any dimension (from 24 to 240 values) with accuracy to within 10^{-12} - 10^{-14}. As Fig. 3 shows restored and initial arrays are completely congruent. Signal analysis is performed with detailed coefficients, while synthesis is based on inverse wavelet-transformation. Detailed coefficients for restoring the graph are given in Fig.4. Initial array is cleared of noise with De-noise Wavelet Toolbox. In this way it is prepared for modeling different types of information loss- Fig.5.

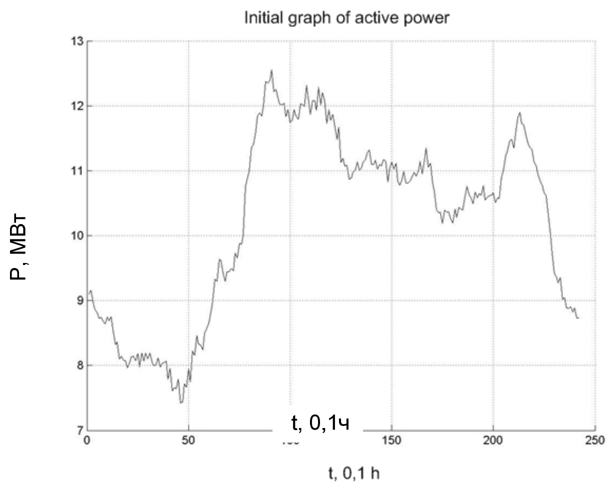

Fig. 3. Initial and reconstructed active power dependence at SS «Centralnaya».

Further, the number of measurements (the number of points) is randomly reduced in the initial array and restored by means of wavelet function. After dependence reconstruction with wavelet function noise is added to restored («noise-free») graph. This is performed with gauss noise, since it is described by standard distribution law and gives an accurate picture of load fluctuation. The difference of instantaneous values from simulated ones is under 2 %, which is shown in Fig. 6. In contrast, the difference between integral characteristics obtained for restored dependence, and reference characteristics makes up less that 1%, which confirms the reliability of the suggested approach to modeling information flows.

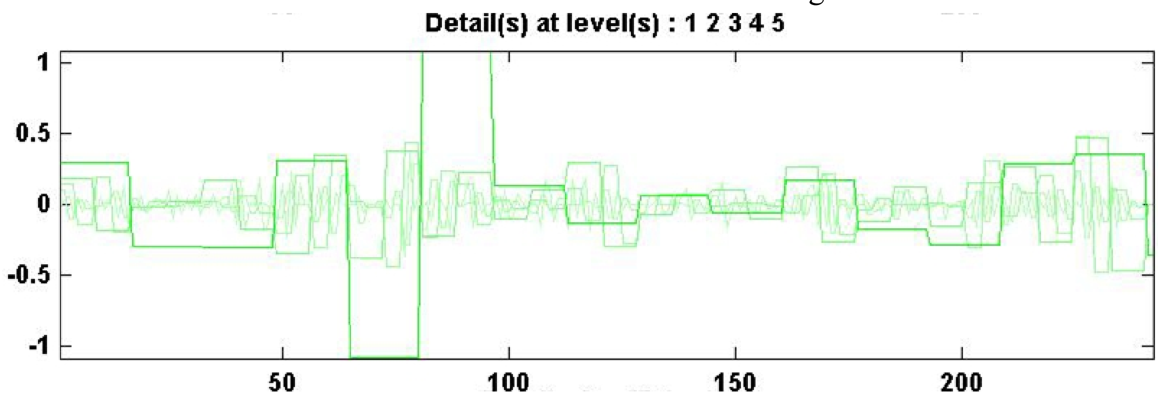

Fig 4. Detailed coefficients for reconstructing ELG

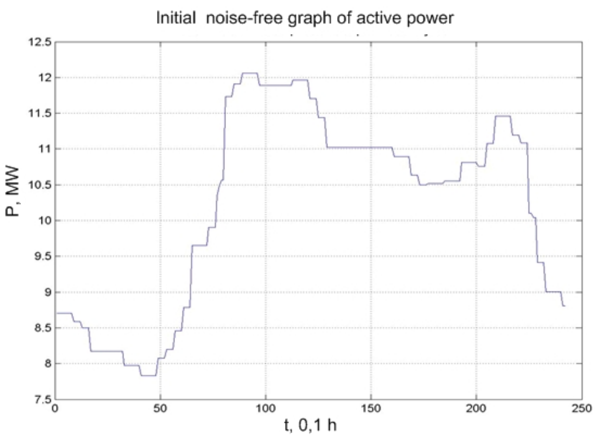

Fig. 5. Noise-free initial dependence of active power at SS «Centralnaya» .

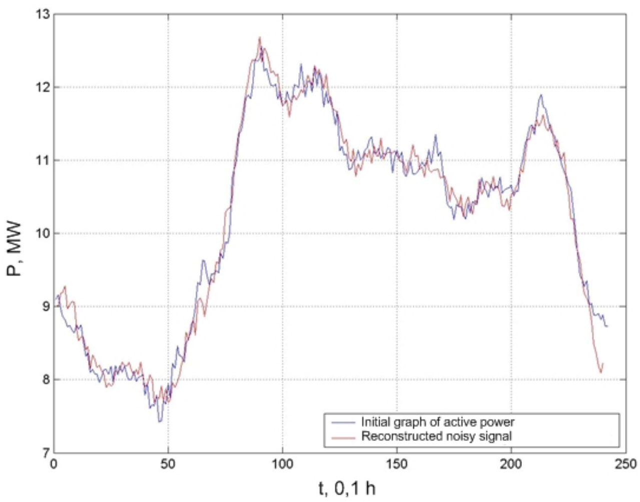

Fig. 6. Reconstruction of ElG active power with wavelet-analysis at «Centralnaya».

3. CONCLUSION

The method of modeling multidimensional information flow using initial information with a different rate of completeness and reliability has been suggested. The modeling process includes the following stages:

- Restoration of initial information flow with fast wavelet-transformation. Moreover, the scheme of optimizing scaling coefficients has been created.

- Verification of the model reliability for low quality information flows with initial information being lost in a random way.

The study carried out with wavelet-analysis allowed us to model multidimensional information flow with complete and incomplete initial data array. Integral characteristics obtained with information of different quality were virtually congruent.

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