



PS2 – S8-05



Estimation of Reliability of Dynamic Models of Complex Power Systems with WAMS Data

Andrei V. ZHUKOV¹, Yury A. KULIKOV¹, Andrei S. GERASIMOV²,
Arkadiy H. ESIPOVICH², Andrei N. SMIRNOV²
SO UPS¹, NIPT²
Russia
smirnov_a@nipt.com

KEYWORDS

Digital dynamic model, transient, verification, adequacy, quality quantity indicators.

1 INTRODUCTION

Increasing of reliability of digital models is reached in the course of their verification.

Verification of digital dynamic model is understood as a procedure of creation, check and necessary adjustment of detailed dynamic model of an electric power system for the achievement of qualitative and, with comprehensible accuracy, quantitative coincidence of the real registered processes arising in an electric power system at various perturbations, to similar modelled processes

The unique tool, allowing to receive the necessary information for verification of dynamic digital model is the system of monitoring of transitive modes (SMTM) which is an analogue of wide area measurement system (WAMS).

From the review of world experience of verification of digital models of electric power systems using WAMS data it is possible to conclude that now there are no any settled criteria on which accuracy of digital model of an electric power system is estimated. Criteria are chosen by experts depending on a specific target for which the verified model is used. It is necessary to underline also, that all applied criteria are used only for qualitative assessment of adequacy of digital dynamic models. There are no references in the foreign literature of any quantity indicators allowing estimating authenticity of developed models.

At the same time in many cases it is useful to have formal acknowledgement of adequacy of the developed model, presented in the form of a quantitative assessment of degree of conformity of model to the real phenomenon or object for which description dynamic model was constructed.

The first domestic experience of verification of digital models using WAMS data has been received within the bounds of the project «Feasibility Study of synchronous interconnection of UCTE and IPS/UPS electric power systems ». As verification parameters the voltage frequency and active power flows were used [1]. Further this experience has been used and considerably expanded during works on creation and verification of base dynamic model (BDM) of IPS/UPS, executed by JSC «NIPT» in 2007 - 2009 [2]. For this time verification of IPS/UPS BDM has been executed on seven emergencies which occurred in a various season, various time of day and in various conditions [3].

The cycle of works on verification of IPS/UPS BDM has allowed to develop the full technology of verification of dynamic models of large and extensive power pools. On the basis of received experience JSC «NIPT» developed the project of «Methodical instructions for principles and criteria of verification of dynamic models». «Methodical instructions ...» include principles and criteria of verification of digital dynamic models of large and extensive electric power systems which can be applied for the researching of dynamic characteristics of real power pools, and also for the analysis of

the reasons of occurrence of large system emergencies. These «Methodical instructions» ... establish the basic requirements produced to such models, and also contain the quantity indicators of the verification, allowing to receive an objective estimation of authenticity of the developed models.

The present is devoted to the description of criteria of verification and quantity indicators of an estimation of authenticity of dynamic models of complex power systems.

2 CRITERIA OF VERIFICATION AND QUANTITY INDICATORS OF AUTHENTICITY OF DYNAMIC MODELS

For the comparison of results of computation of the electromechanical transients executed with the use of digital model of an electric power system, to the data received by means of WAMS during emergency, it is offered to use the following electric parameters:

- meanings of frequency of voltage in nodes of installation of digital registrars;
- meanings of powerflows of active power on lines on which the registration of emergency process is made;
- meanings of relative (mutual) angles of voltage between various points of a power pool.

Frequency and relative angle are the system parameters, a character of their change fully reflects the dynamic characteristics of a power pool as a whole. The character of change of active powers on transmission lines reflects the dynamic properties of separate areas. Experience of use of IPS/UPS base dynamic model has shown, that for the verification of dynamic model of big extensive electric power system it is enough to use three listed parameters.

Quality of digital model of an electric power system is offered to be estimated by the following criteria:

- coincidence of natural frequencies of interzonal fluctuations (in a range of 0.05 Hz - 0.5 Hz);
- reproduction of an antiphase of interzonal fluctuations in various places of a network;
- similarity of damping of fluctuations (reproduction of amplitudes of oscillations of considered parameters and time of their damping);
- time shift of a deviation of the frequency, observed on various sites;
- coincidence of response characteristics, such as speed of change of frequency, the maximum and steady-state deviation of frequency, in nodes of installation of digital registrars.

Visual comparison processes registered with the help of the WAMS and modeled by the offered criteria allows to draw a conclusion on authenticity of the developed digital model. However application for the verification of only qualitative criteria is an insufficient condition for an estimation of degree of adequacy of model. As this estimation is based on subjective opinion of the expert who is carrying out the verification. For objective acknowledgement of degree of authenticity of the developed model it is necessary to execute a quantitative assessment of degree of conformity of a model to the real phenomenon or object for which description the dynamic model was constructed.

As the quantitative characteristics of adequacy of a model it is offered to take a measure of affinity of a model to the original. It can be defined as a distance between model and the original in some metric space. For a quantitative assessment of quality of verification of dynamic model of an electric power system the following indicators are offered:

- 1) the maximum deviations of frequency of voltage in points of installation of WAMS registrars;
- 2) steady-state meaning of frequency of voltage;
- 3) the maximum amplitudes of oscillations of mutual angles of voltage;
- 4) correlation factors between measured and computed changes of considered parameters in the points of installation of WAMS registrars;
- 5) sizes of observable regular oscillation frequencies.

Accuracy of coincidence of the computed and measured **maximum deviations of frequency of voltage** in installation points of digital registrars allows to draw a conclusion on adequacy of modelling of characteristics of primary regulation, and also about load characteristics in various parts of an electric power system. For the obtaining of a quantity indicator of quality of modelling on the constructed graphs of the computed and measured frequency during emergency the meanings of the maximum deviations of frequency from a reference value (fig. 1) are defined. The error of reproduction of the maximum deviations of frequency of voltage ($F_{\max}$) in dynamic model is calculated under the formula:

$$F_{\max} = \left| 1 - \frac{f_{m_dev_e}}{f_{m_dev_c}} \right| \cdot 100\%, \quad (1)$$

where $f_{m_dev_e}$ – the maximum deviation of frequency of the voltage, defined on experimental data; $f_{m_dev_c}$ – the maximum deviation of frequency of the voltage, defined as a result of digital simulation.

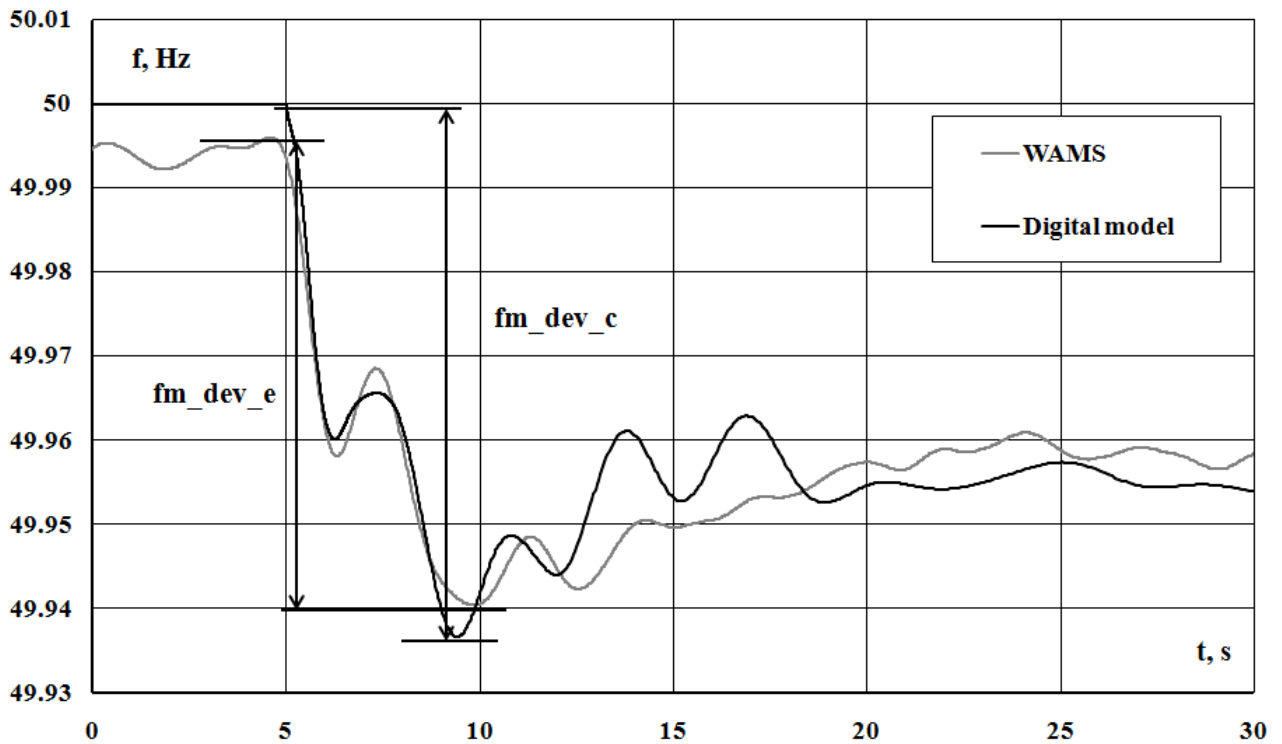


Fig. 1: Definition of values of measured and computed maximum deviations of voltage frequency

Accuracy of coincidence of the computed and measured **steady-state meaning** of a system frequency after occurrence of an imbalance allows to draw a conclusion on adequacy of the rotating power reserves and droops of governors of generating units accounting in digital model of an electric power system. On fig.2 the method of definition of deviations of frequency of voltage from an initial value to the steady-state meaning is shown.

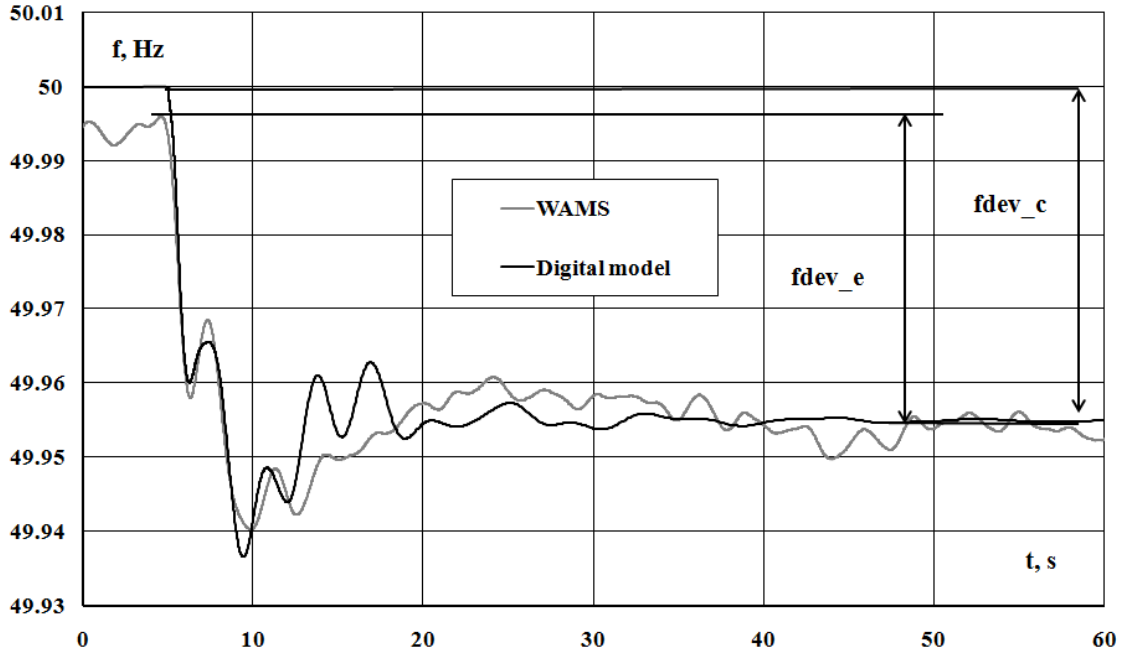


Fig. 2: Definition of sizes of the measured and computed steady-state meanings of voltage frequency

The error of reproduction of steady-state meaning of frequency (F_{sts}) in dynamic model is calculated under the formula:

$$F_{sts} = \left| 1 - \frac{f_{dev_e}}{f_{dev_c}} \right| \cdot 100\%, \quad (2)$$

where f_{dev_e} - a deviation of frequency of voltage from an initial value to steady-state value, defined on experimental data; f_{dev_c} - a deviation of frequency of voltage from an initial value to steady-state value, defined as a result of digital simulation.

Authenticity of the account of the inertial constant generators which are present at model, should be estimated by the accuracy of coincidence of the computed and measured **maximum deviations of mutual angles of voltage** between various points of an electric power system during emergency.

Unlike frequency, preemergency sizes of mutual angles between various points of an electric power system, and also a difference between their initial and maximum meanings, can differ considerably. In this connection use for mutual angles of a merit number of verification on the basis of comparison of absolute values will be inefficient. For reception of a quantitative assessment of adequacy of model it is recommended to compare relative sizes of the maximum deviations of mutual angles.

For this purpose on the constructed graphs of the computed and measured change of a mutual angle during an emergency the initial and maximum meanings of mutual angles (fig. 3) are defined and relative maximum amplitudes of oscillations (for data obtained by registration in real power system (A_E) and by computations (A_C) are computed):

$$A_E = \frac{\delta_{\max_e}}{\delta_{0_e}}, \quad A_C = \frac{\delta_{\max_c}}{\delta_{0_c}} \quad (3)$$

where $\delta_{\max_e}$ – the maximum deviation of a mutual angle defined on experimental data; $\delta_{\max_c}$ – the maximum deviation of a mutual angle received as a result of digital simulation; δ_{0_e} – The initial meaning of a mutual angle defined on experimental data; δ_{0_c} – the initial meaning of a mutual angle received as a result of digital simulation.

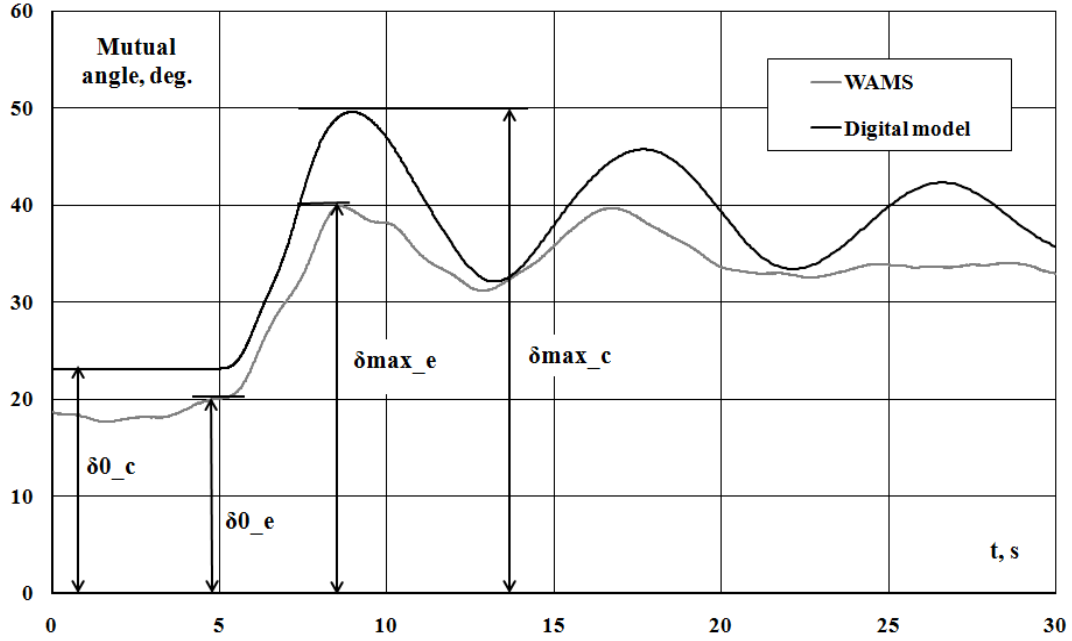


Fig. 3: Definition of sizes of the measured and computed relative maximum deviations of mutual angles.

The error of reproduction of the maximum amplitudes of oscillations of mutual angles of voltage ($A_{\max}$) in dynamic model is calculated under the formula:

$$A_{\max} = \left| 1 - \frac{A_E}{A_C} \right| \cdot 100\% \quad (4)$$

In a case the mutual angle between two points of an electric power system during transient changes its sign, relative maximum amplitudes of oscillations is calculated as follows:

$$A_E = \frac{|\delta_{\max_e}| + |\delta_{0_e}|}{|\delta_{0_e}|}, \quad A_C = \frac{|\delta_{\max_c}| + |\delta_{0_c}|}{|\delta_{0_c}|} \quad (5)$$

For an estimation of accuracy of reproduction on digital model of the character and speed of change of regime parameters of an electric power system it is possible to use the correlation analysis, allowing to define correlation communication between the computed and measured change of parameters of an electric power system. **The Pirson's factor of correlation** for this purpose is calculated:

$$r = \frac{\sum_{i=1}^n (x_i - \bar{x}) \cdot (y_i - \bar{y})}{\sqrt{\sum_{i=1}^n (x_i - \bar{x})^2 \cdot \sum_{i=1}^n (y_i - \bar{y})^2}}, \quad (6)$$

где $x = (x_1, \dots, x_n)$ – sample of the measured meanings of the considered parametre;
 $y = (y_1, \dots, y_n)$ – sample of computed meanings of the considered parametre; $\bar{x}, \bar{y}$ – average meanings of samples x and y .

Calculation of factor of correlation is carried out for two phenomena with equal sampling time step and is carried out for all compared parameters (frequency, capacity and a relative angle) in all points of installation of WAMS registrars. The estimation of adequacy of dynamic model on correlation factors is carried out according to Cheddok's scale.

Adequacy of modelling of frequency characteristics of an electric power system should be estimated on accuracy of reproduction **of observable regular oscillation frequencies**, and in particular natural frequencies of interzonal fluctuations in a range 0,05 - 0,5 Hz.

For definition of factors of reproduction of regular oscillation frequencies in digital dynamic model of an electric power system it is necessary to carry out a spectrum analysis of processes calculated on digital model and obtained in observed data by means of WAMS. Meanings of regular oscillation frequencies received on the basis of measured and calculation data are compared among themselves, and the conclusion about degree of their coincidence is made.

Having compared the measured and computed parametres of an electric power system, and also having calculated the specified indicators, it is possible to receive a quantitative assessment of adequacy of the verified model.

On the basis of experience of verification of IPS/UPS BDM the numerical meanings of each indicator, allowing to define degree of adequacy of developed digital dynamic model have been established. Estimated meanings of indicators are resulted in table 1

Coincidence degree	$F_{\text{макс}}$	$F_{\text{уст}}$	$A_{\text{макс}}$	Correlation factor	Divergence in frequencies
excellent	$\leq 10\%$	$\leq 5\%$	$\leq 5\%$	0,9 – 1,0	$\pm 0,05 \Gamma \Pi$
good	$\leq 15\%$	$\leq 10\%$	$\leq 10\%$	0,7 – 0,9	$\pm 0,1 \Gamma \Pi$
satisfactory	$\leq 20\%$	$\leq 15\%$	$\leq 15\%$	0,5 – 0,7	$\pm 0,2 \Gamma \Pi$

Table 1: Estimated meanings of quality indexes

Each of the considered indicators characterises some dynamic properties of a real power pool. The indicator value helps to understand, how precisely and authentically the developed dynamic model allows to reproduce these properties. Unsatisfactory meanings of any indicators testifies to an incorrectness in dynamic model of corresponding characteristics and parametres of elements of an electric power system. By changing, in the course of adjustment of the dynamic model, necessary characteristics and parametres of elements (load characteristics, inertial constants of equivalent generators, parametres of governors of generating units etc.) it is possible to achieve demanded meaning of a corresponding indicator.

Numerical meanings of quality indicators initially essentially depend on completeness and reliability of initial data about an emergency, necessary for verification of dynamic model of an electric power system. Especially depends on the accuracy of reproduction of a preemergency steady-state conditions, completeness and adequacy of the information on characteristics, parametres, structure and loading of the generating units participating in a covering of a load. Also the accuracy of the account of consumption of a power pool in particular operating conditions has a great value.

Transition from the qualitative criteria accepted now to objective quantity indicators of an estimation of adequacy of dynamic models became possible thanks to the fact that for the verification of IPS/UPS model the IPS/UPS has been used great volume of authentic preemergency information on a condition of electric power systems of East synchronous zone. It became possible because of the System operator of UES of Russia essentially has the exhaustive information on an electric power system conditions, including data on structure and load of the generating equipment in preemergency operation.

3 CONCLUSION

The experience obtained by JSC « NIPT » during verification of IPS/UPS BDM has allowed to develop the «Methodical instructions for principles and criteria of verification of dynamic models» in which for the first time the quantitative criteria of quality of verification of dynamic models were included. The unsatisfactory estimation of quality of verification on any of the offered criteria testifies to the wrong account in digital dynamic model of various characteristics of a real electric power system. «Methodical instructions ...» includes recommendations about the ways of correction of characteristics of dynamic model depending on a criterion on which the unsatisfactory estimation of quality of verification is received.

Practical application of the developed quantitative criteria of verification at several emergencies has confirmed efficiency of the developed technique which allows to receive an objective estimation of quality of dynamic models of complex power systems [4].

REFERENCES

- [1] Ayuev B.I., Gerasimov A.S., Esipovich A.H., Kulikov Y.A.. IPS/UPS dynamic model verification. *Electrichestvo*, №5, 2008.
- [2] IPS/UPS Reference Dynamic Model and its Validation per WAMS Recordings. Ayuev B.I., Dyachkov V.A., Zhukov A.V., Kouzmin S.E., Kulikov Y.A., Levandovsky A.V., Gerasimov A.S., Esipovich A.H., Smirnov A.N. Monitoring of Power System Dynamics Performance, 28-30 April 2008, Saint Petersburg.
- [3] Gerasimov A.S., Esipovich A.H., Kulikov Y.A., Smirnov A.N. Experience of verification of an IPS/UPS dynamic model using WAMS. JSC « NIPT » Proceedings, 2009.
- [4] Smirnov A.N. Application of quantity indicators for an estimation of adequacy of dynamic models of complex power pool systems. The scientific and technical conference «Electric power industry youth eyes», 2010, Ekaterinburg.