Scientific and Technical Center of Unified Power System

Development of the test procedure for phasor measurement units, which are providing measurement of synchronous generator excitation voltage and excitation current

Zelenin Aleksandr,
Eliseev Dmitriy, Kabanov Dmitriy

mailto: zelenin@ntcees.ru
Engineer, Department of Electric Power Systems

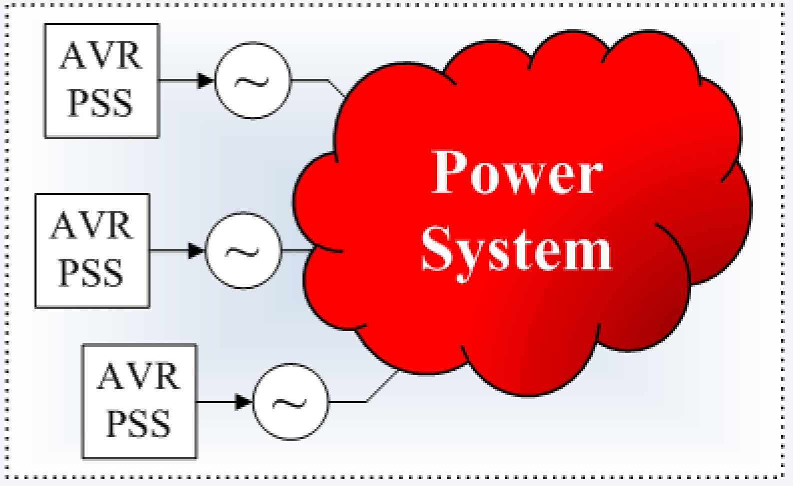
Introduction: Scientific and Technical Center of Unified Power System (JSC «STC UPS») tasks

JSC «STC UPS» solves a wide range of tasks. Tasks can be such as:

- developing models for power system steady-state calculation;
- developing models for power system small and large system stability calculation;
- developing software for power system calculations;
- working with these models (power system mode planning, choosing emergency control device settings and etc.).

Our department is working on power system stability field. A lot of work concentrated around automatic voltage regulators (AVR) and power system stabilizers (PSS) setting, around the analyze correct work of these devices.

Introduction: analyze of work AVRs and PSS



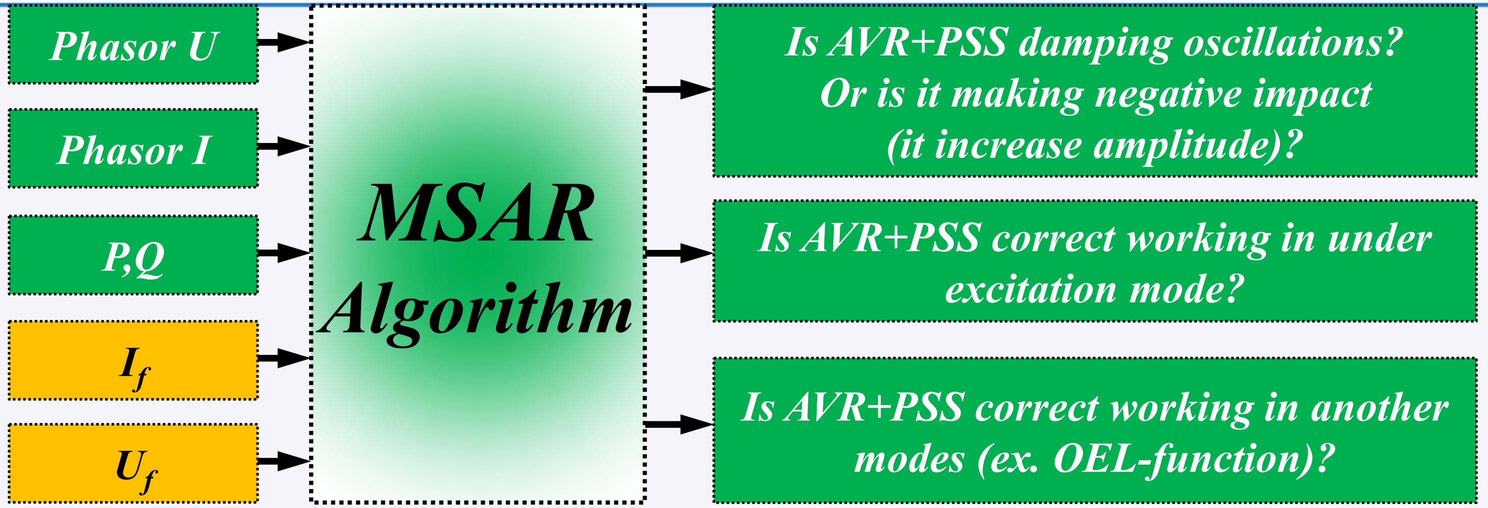
The task of AVR and PSS work analyze contains different steps:

- AVR+PSS test procedure;
- pre-analyze, which give as the result the AVR+PSS setting;
- **online-monitoring AVR+PSS operation with special monitoring system for automatic regulators (MSAR);**
- after emergency analyze.

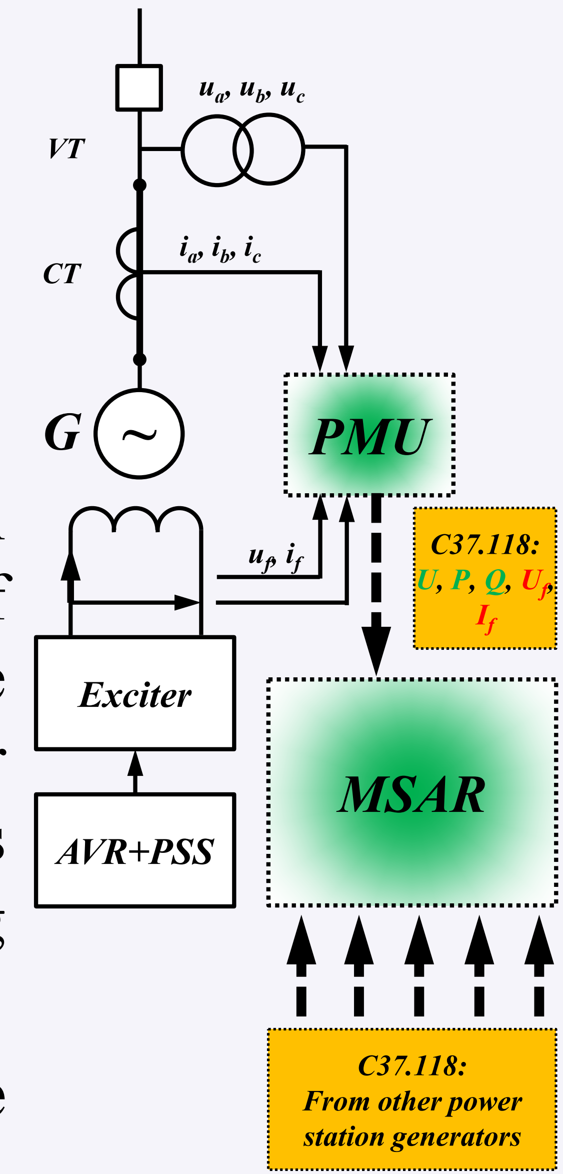
MSAR can give information about incorrect operation AVR function or/and setting by analyze of signals of generator voltages (*U*), currents (*I*), generator active and reactive powers (*P*, *Q*), field current (I_f) and voltage (U_f) in transient modes.

Today these signals ***MSAR*** takes from phasor measurement units (PMUs), which installed on terminals of power station generators.

Introduction:
monitoring system for automatic regulators (MSAR)



PMUs in Russia should be tested with the special procedure, which was developed on the basis of Standard C37.118. So measurements of U, I, P, Q are considered correct. Procedure has not requirements for PMU excitation signals measurement. Without this requirements measured U_f and I_f can cause wrong conclusions of *MSAR* algorithm.

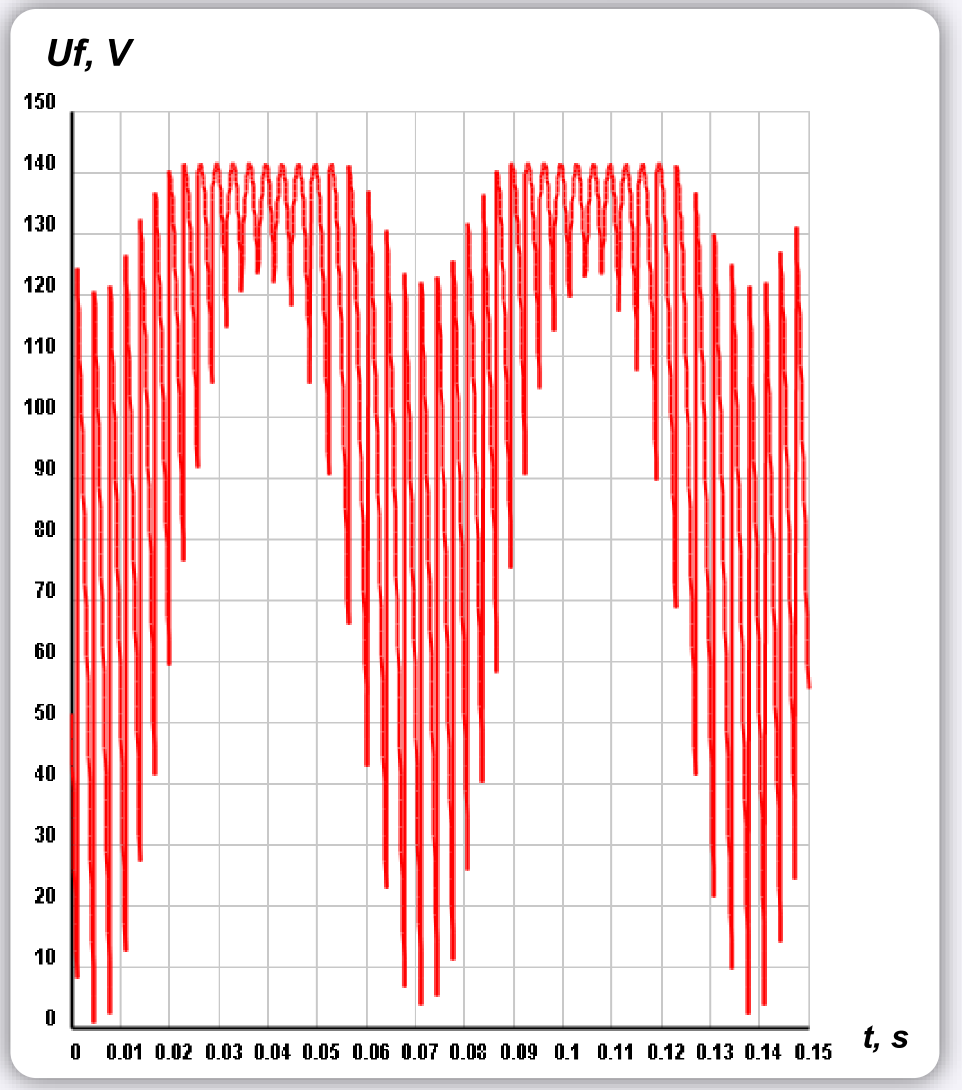


<u>Task of present work</u> was creation of test procedure for excitation signals measurement PMUs.

Chapter I. Develop methodology. Signal types and selected modelling signal type

PMUs can be connected to different types of excitation systems, which can provide different types signals I_f, U_f for measurement. But there are two main classes: signals from DC-exciter based systems and signals from AC-DC converters based systems (as thyristor/diode bridges).

As we assumed, measurement of AC-DC converters signals should be more difficult for PMU:
PMU should have a good «balance setting» between **filter-smoothing** and **quick step-response**.
So AC-DC converter signals type was selected as main signal type for testing.



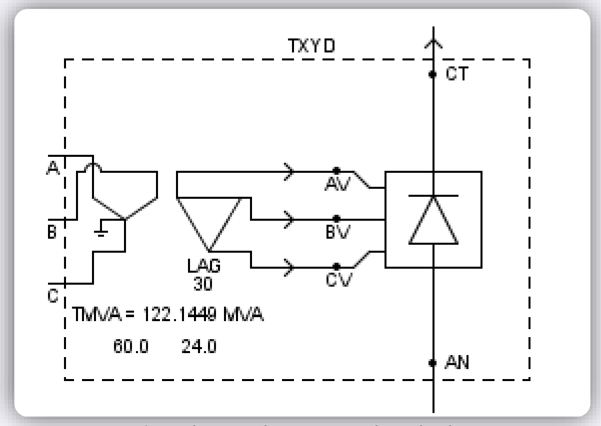
Example of the signal U_f from thyristor-bridge (ideal). Oscillation mode.

Chapter I.
Develop methodology: model of signals (1)

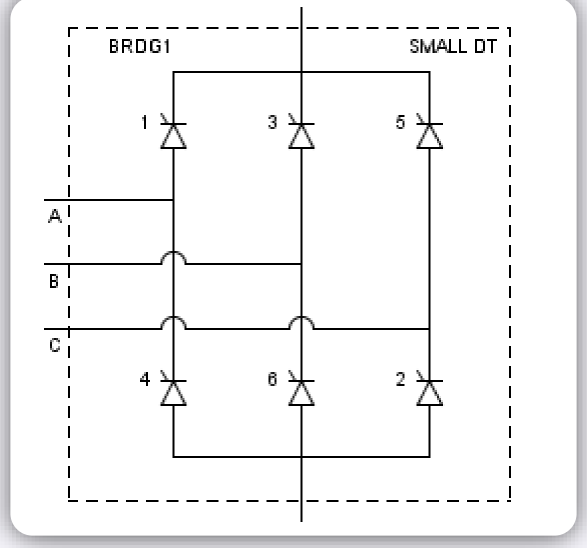
For modelling signals from thyristor-bridge model in RTDS there are next ways:

- get signal from large-dt thyristor-bridge model;
  - **noisy signals;**
  - **is not 100% predicted;**
- get signal from small-dt thyristor-bridge model;
  - **same problems;**
- **create signal mathematical model, which takes into account different input characteristics (*selected way*):**
  - amplitude of power AC voltage $U_{AC}(t)$;
  - frequency of power AC voltage $f_{AC}(t)$*;
  - firing pulse angle α(t);
  - commutation angle value γ / μ.

*In different excitation systems types base f_{AC} value can take values from a wide range (as 50, 150, 300, 400, 500 Hz and etc.). In present work were considered 50, 150, 300 Hz values.

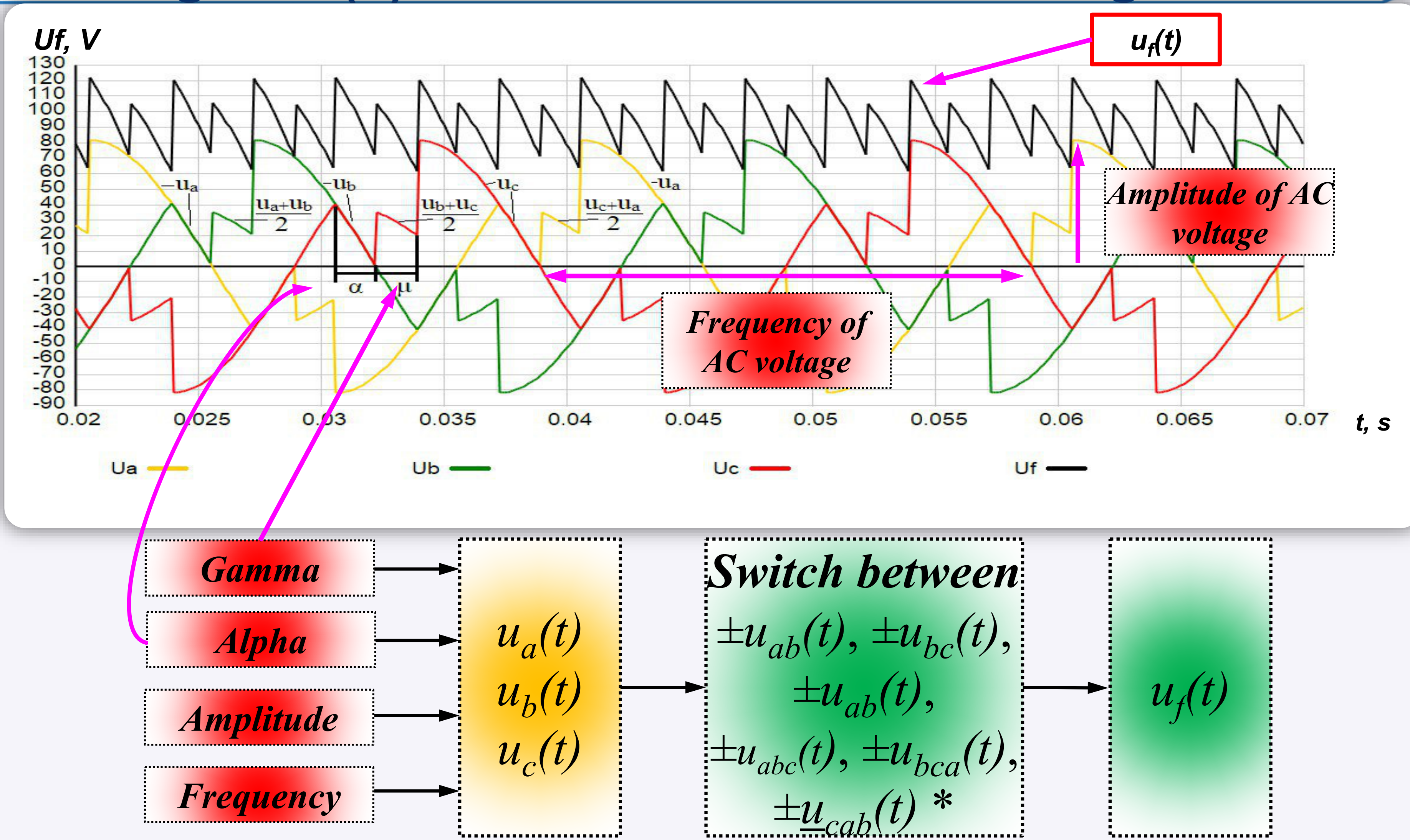


RTDS *Large-dt* thyristor-bridge model with transformer



RTDS *Small-dt* thyristor-bridge model

Chapter I. Develop methodology.
Model of signals (2). MATLAB Simulink testing



For testing was created the signal mathematical model.
Model work was tested in *MATLAB Simulink*.

* $u_{abc}(t)=0.5(u_a(t) + u_b(t)) - u_c(t)$

Chapter I: Develop methodology. Model RTDS Implementation problems

$$u_f(t) = f(U_{AC}(t), f_{AC}(t), \alpha(t), \gamma) \quad (1)$$

$$U_f = mean\left(u_f(t)\right) \quad (2)$$

The main requirement for the PMU test procedure signal: the mean value U_f **should be easily computable** without hard calculations (100% predicted value).

$$U_f(\alpha,\mu) = \frac{3}{\pi}\sqrt{2}\cdot U_{LL}\cdot\frac{(\cos\alpha + \cos(\alpha+\mu))}{2} \quad (3)$$

Example: calculation U_f in steady state mode. As the input we got user given values of AC-DC converter power voltage U_{LL}, firing angle value α, commutation angle value μ.

Implementation problems:

1. Signal (1) and calculation results from (3) are very sensitive to modeling time step value ***dT*** (without details, big *dT* leads to change actual α-value, which will vary to different thyristors);

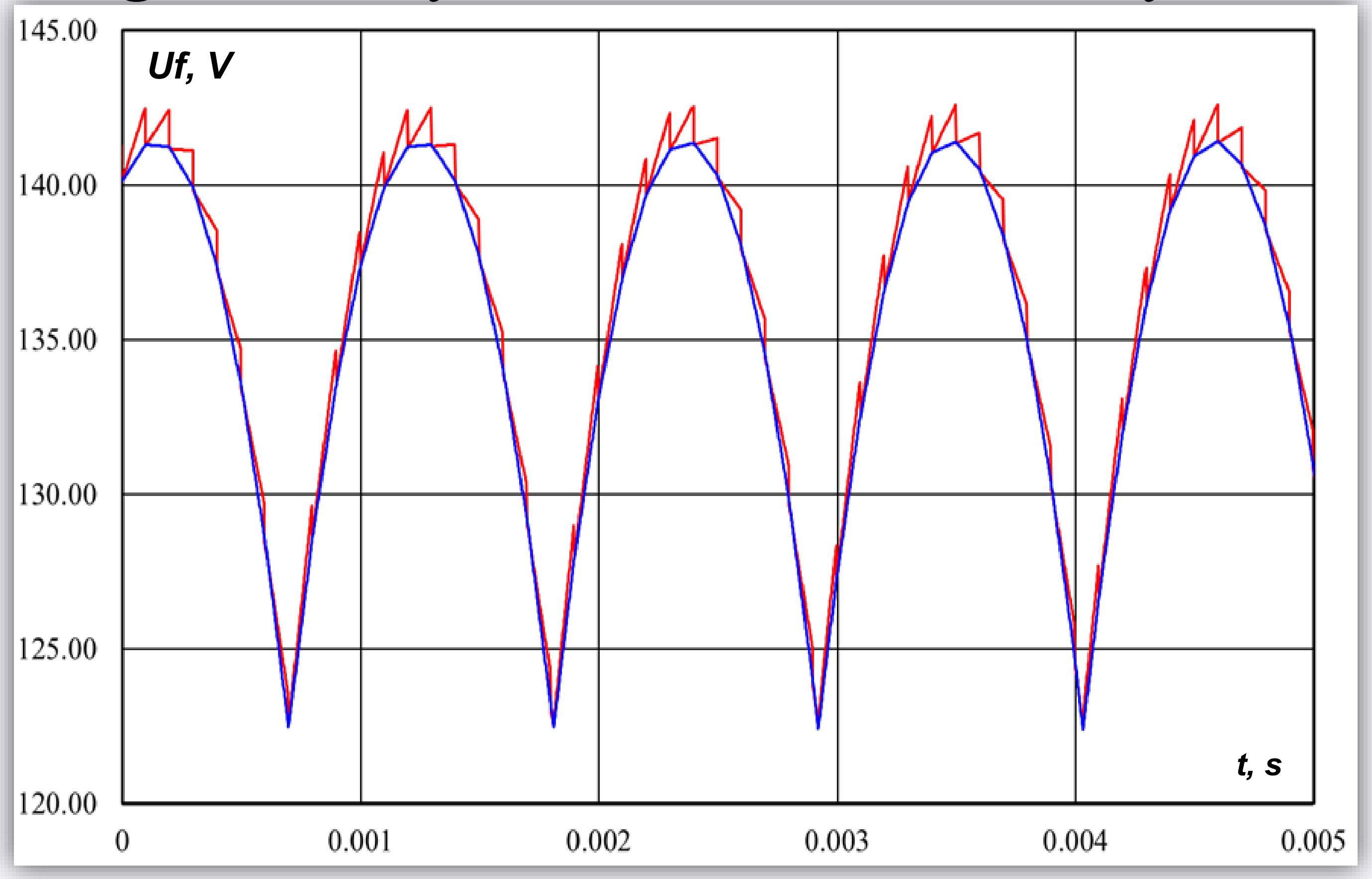
Example: 100 us time step can give maximum Δα = 1.8°.

It make (on α=90° and γ=0°) error of excitation voltage $\Delta U_f \approx 0.03\ U_{f\_max}$.

2. Small ***dT*** subsystem have not big «block-capacity» for large-formula implementation (for implementing the signal mathematical model);
3. Problem for calculated **step filling for analog output (over-sampling)** for step changing signal (U_f signal in commutations).

Chapter I: Develop methodology. solving the implementation problems

The main solution for problems was separation calculation algorithm between the *large-dt* subsystem and *small-dt* subsystem.



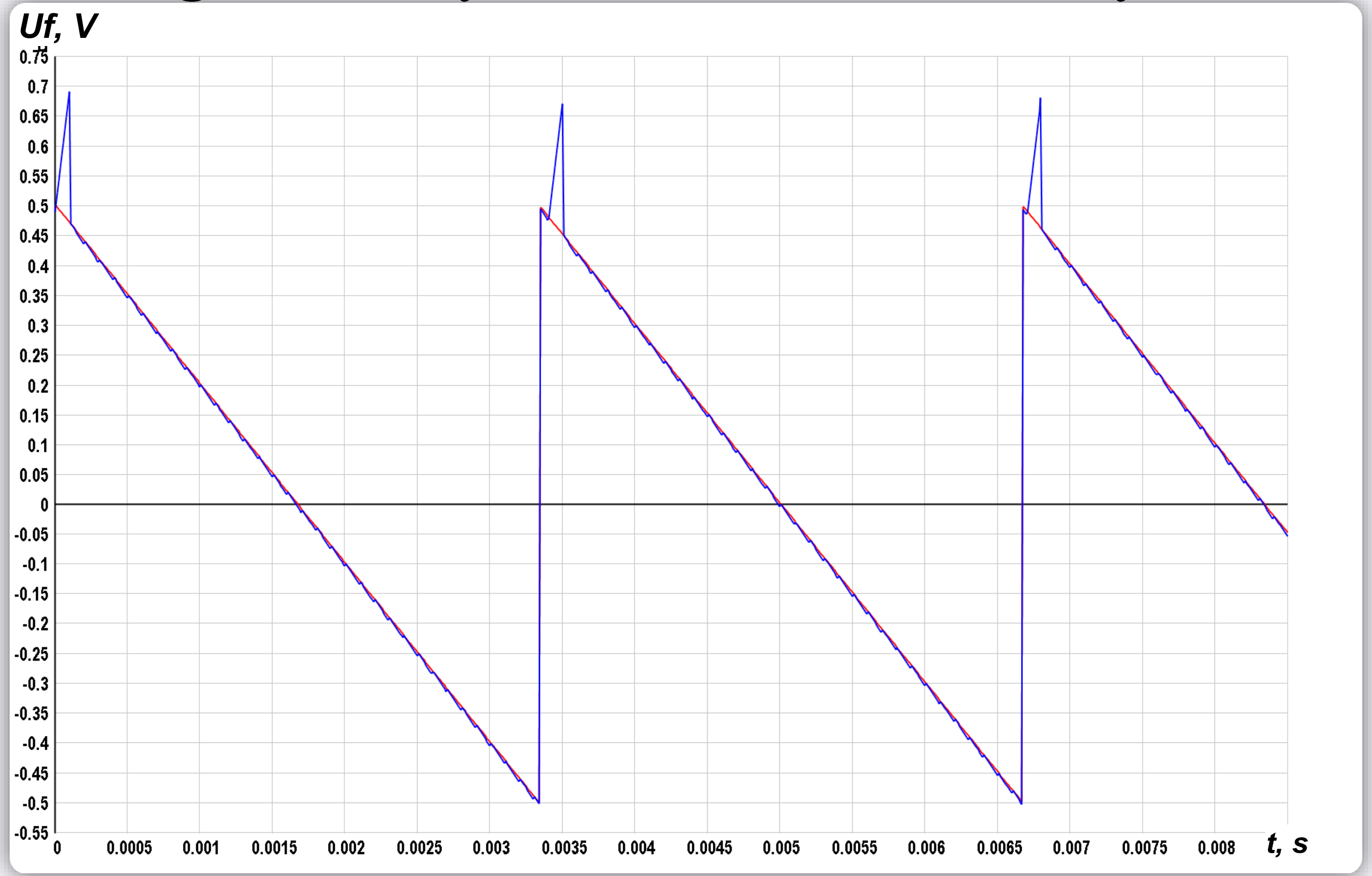
$u_f(t, f_{AC}=150$ Hz) large-dt, $u_f(t, f_{AC}=150$ Hz) large-dt+small-dt

Example of measured voltage amplifier output.

Standard method (large-dt) and **applied** method

Chapter I: Develop methodology. solving the implementation problems

The main solution for problems was separation calculation algorithm between the *large-dt* subsystem and *small-dt* subsystem.



Example of measured voltage GTAO output.
Standard method (large-dt) and **applied** method

Chapter II:
Main test procedure experiments

Test procedure for excitation signal measurement *PMU*

Static conditions

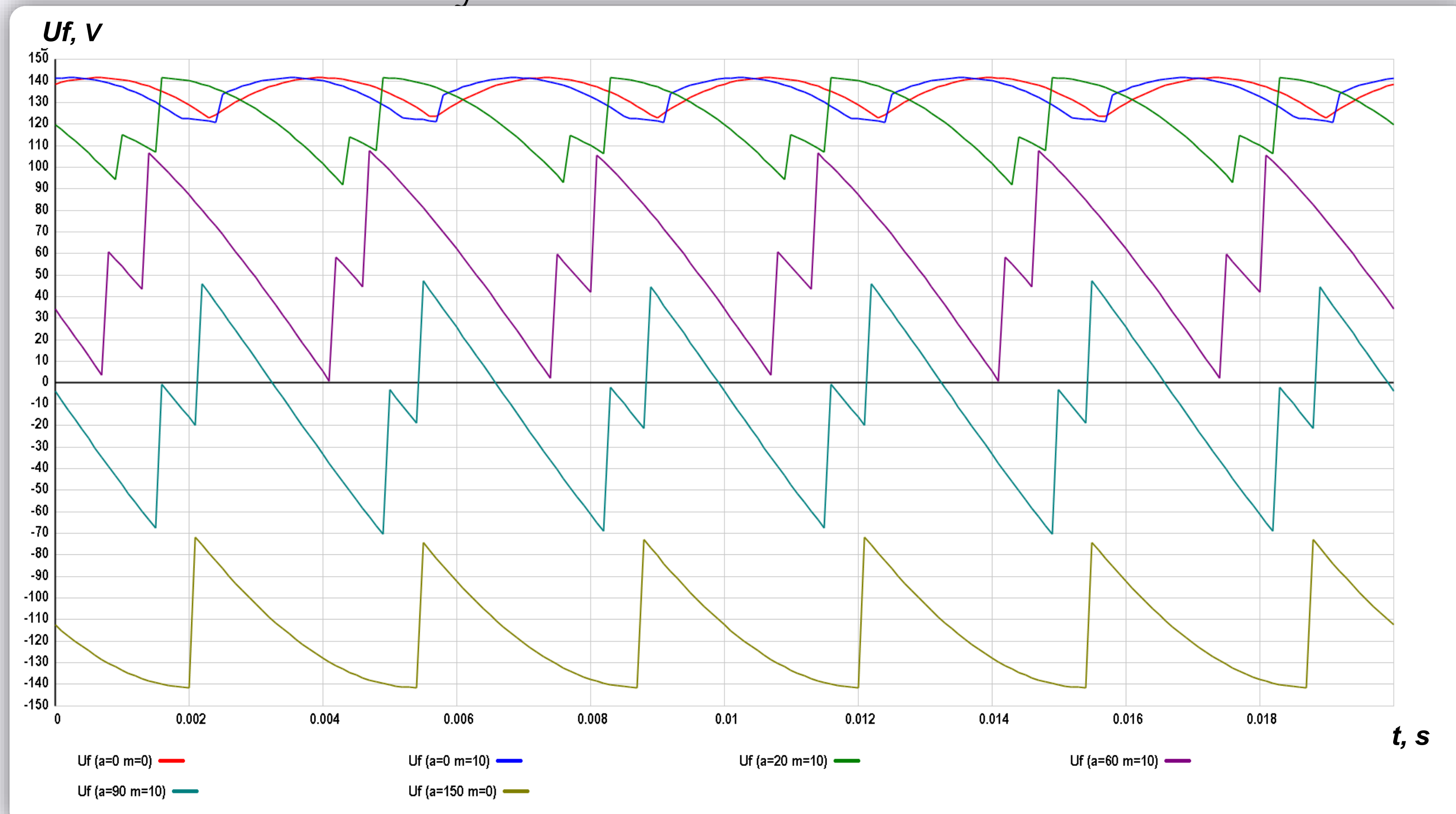
1. Different values of α, μ for U_f
2. Different Values of I_f
3. Different values of f_{AC} for U_f

Dynamic conditions

1. Modelling step change of U_{AC} → step U_f and I_f
2. Modelling pulse change of U_{AC} → step U_f and I_f
3. Modelling step change of α → step U_f
4. Modelling pulse change of α → step U_f
5. Modelling modulation of α → changing U_f
6. Modelling modulation of U_{AC} → changing U_f
7. Modelling stator short circuit → changing I_f
8. Modelling linear change of f_{AC} → changing U_f

Chapter II-1:
1. static conditions testing (test signal)

The main task of static condition testing is preparing for dynamic tests, because the main PMU excitation measurement requirements aimed for dynamic signal measurement analyze for ***MSAR***.



Example picture for test with different values of α, μ for U_f test signals

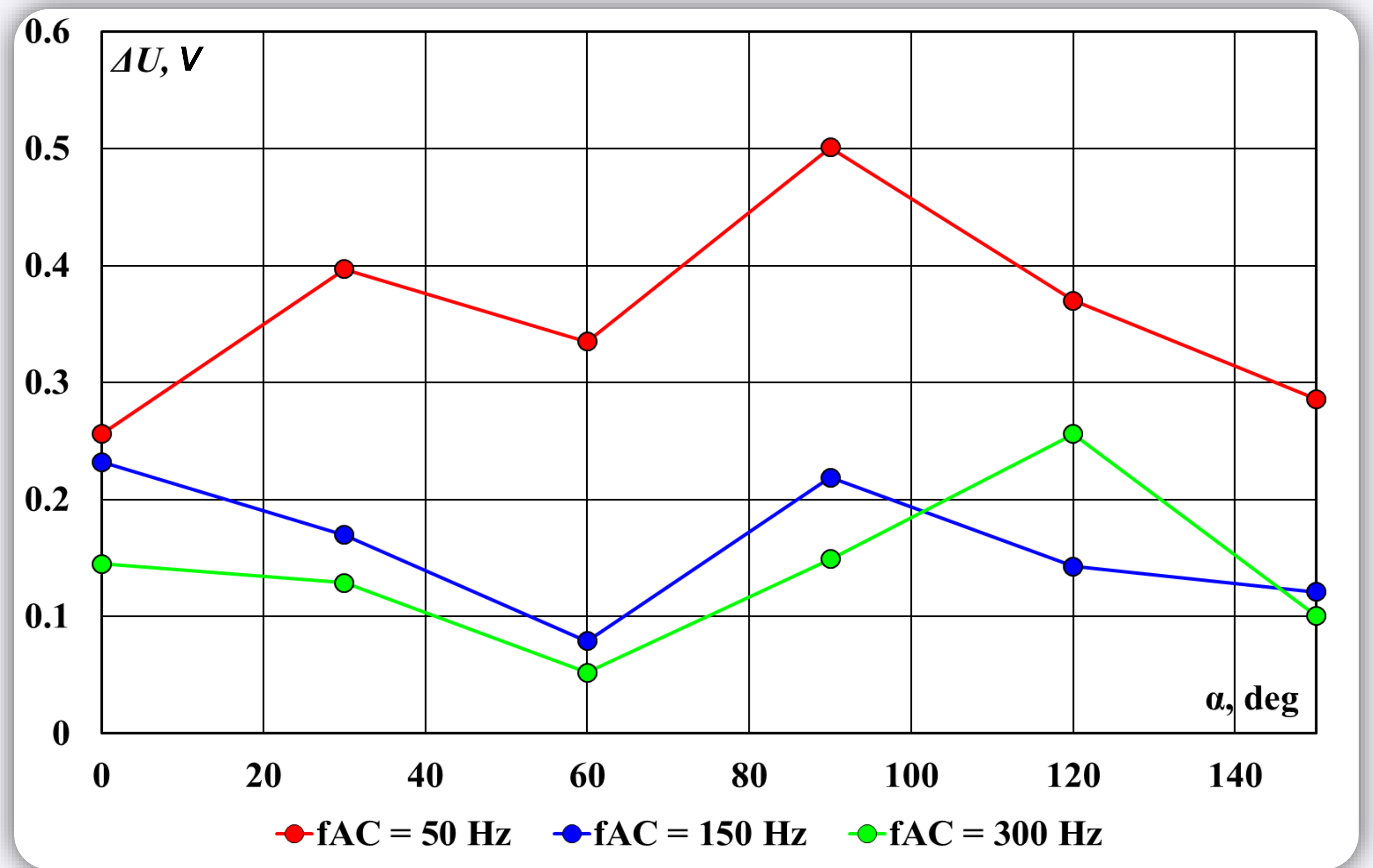
Modeling steady-state work of excitation system with different parameters:

- different generator mode (and values of α, U_f, I_f);
- different type of AC-DC converter excitation systems (frequency of power AC voltage values f_{AC} 50, 150, 300 Hz).

Testing filter-smoothing for different shapes of the curve.

Chapter II-1:
1. static conditions testing (results)

The main task of static condition testing is preparing for dynamic tests, because the main PMU excitation measurement requirements aimed for dynamic signal measurement analyze for ***MSAR***.



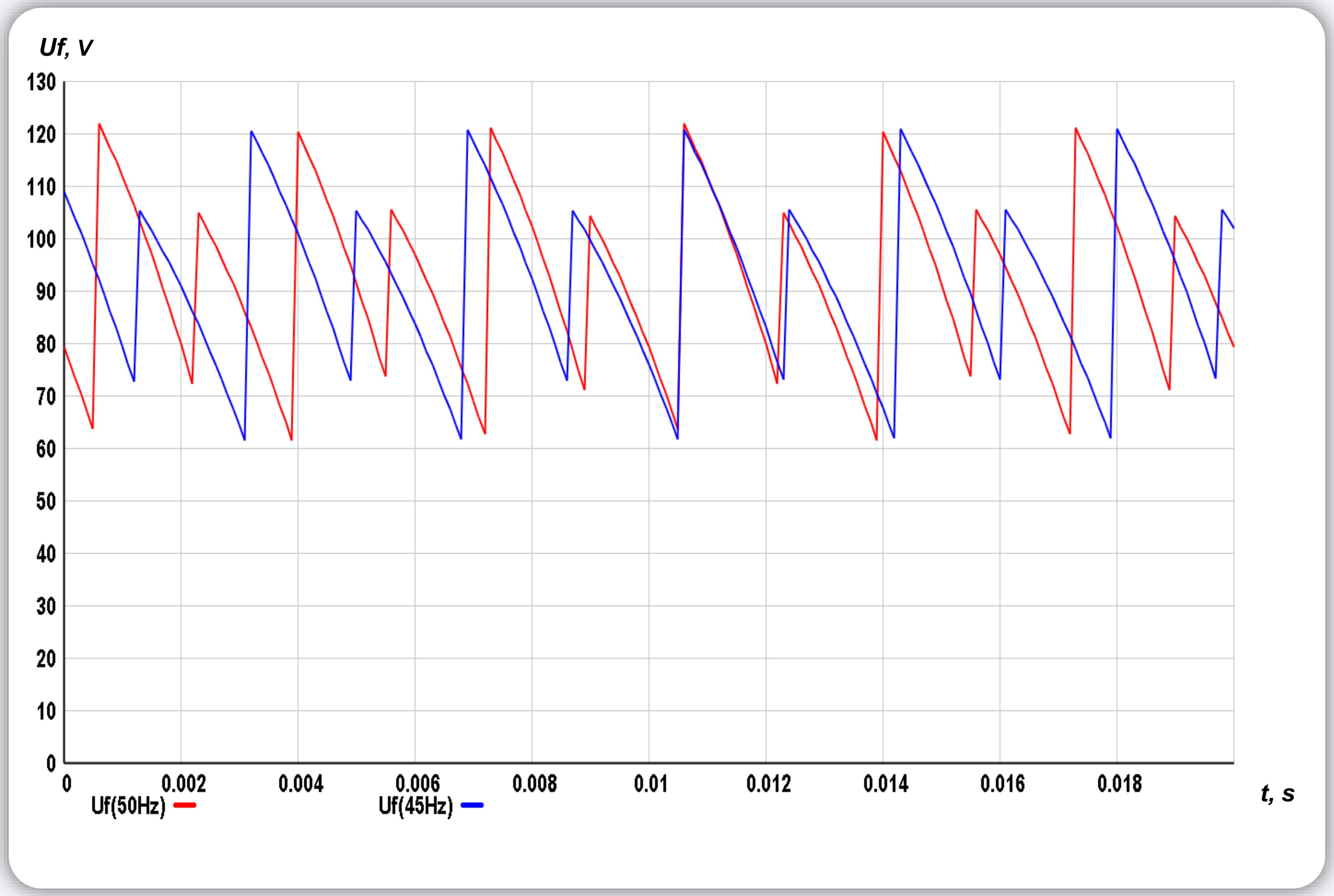
Error measurement results picture for test with different values of α (x-axis) and different frequency of power AC voltage

Modeling steady-state work of excitation system with different parameters:

- different generator mode (and values of α, U_f, I_f);
- different type of AC-DC converter excitation systems (frequency of power AC voltage values f_{AC} 50, 150, 300 Hz).

Testing filter-smoothing for different shapes of the curve.

Chapter II-1:
2. static conditions testing (test signal)



Example picture for test signals with different values of power AC voltage frequency f_{AC} (45, 55 Hz)

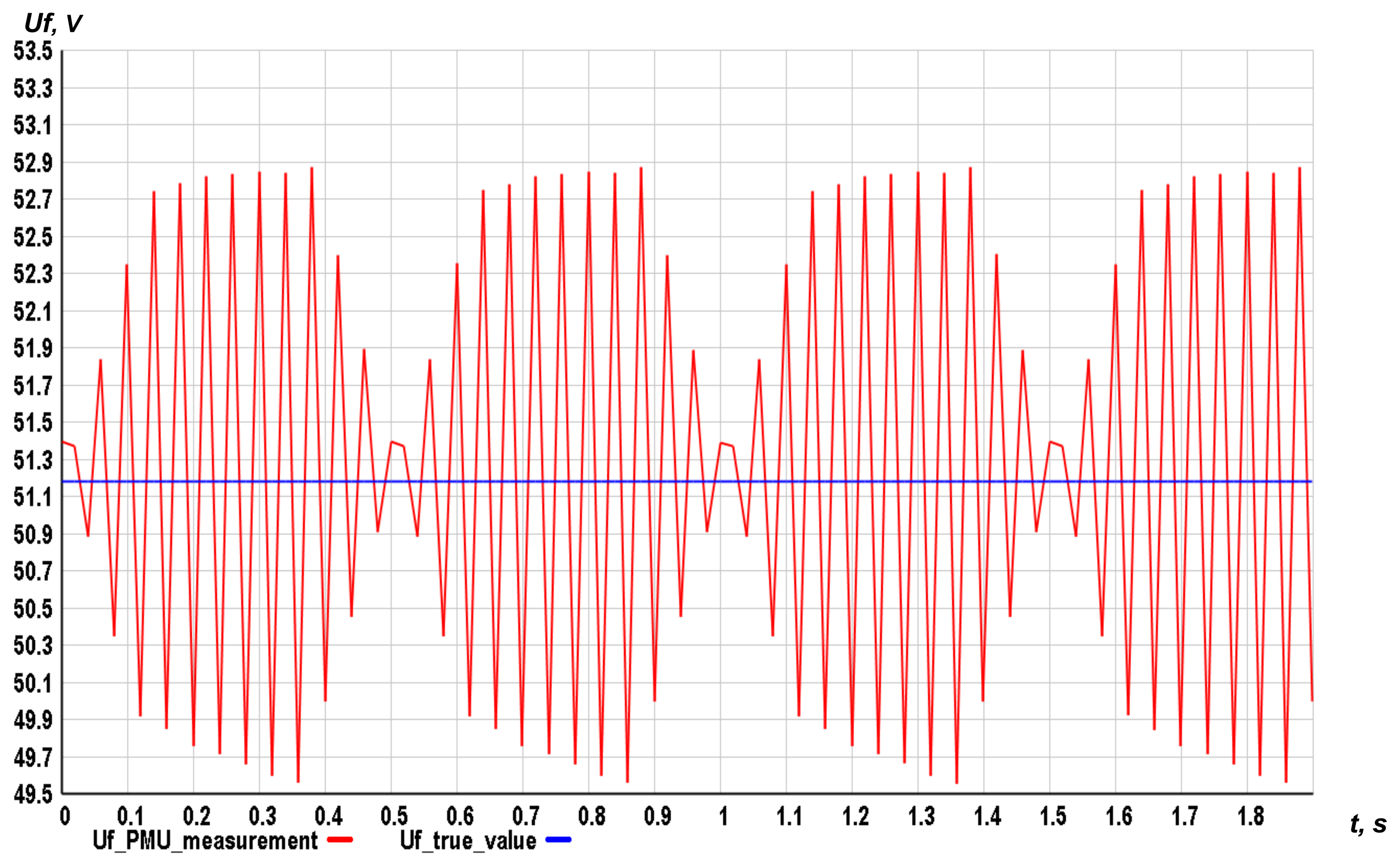
Modeling steady-state work of excitation system after breakdown in the power system.
Different values of frequency's near base values (50, 150, 300 Hz).

Test procedure frequency values:

- 45-55 Hz;
- 135-165 Hz;
- 270-330 Hz.

Testing filter-smoothing for different signal period.

Chapter II-1:
2. static condition testing (measurement result)



Example picture of PMU measurement power AC voltage frequency f_{AC} = 46 Hz.
The calculation window for measurement is not equal the signal period

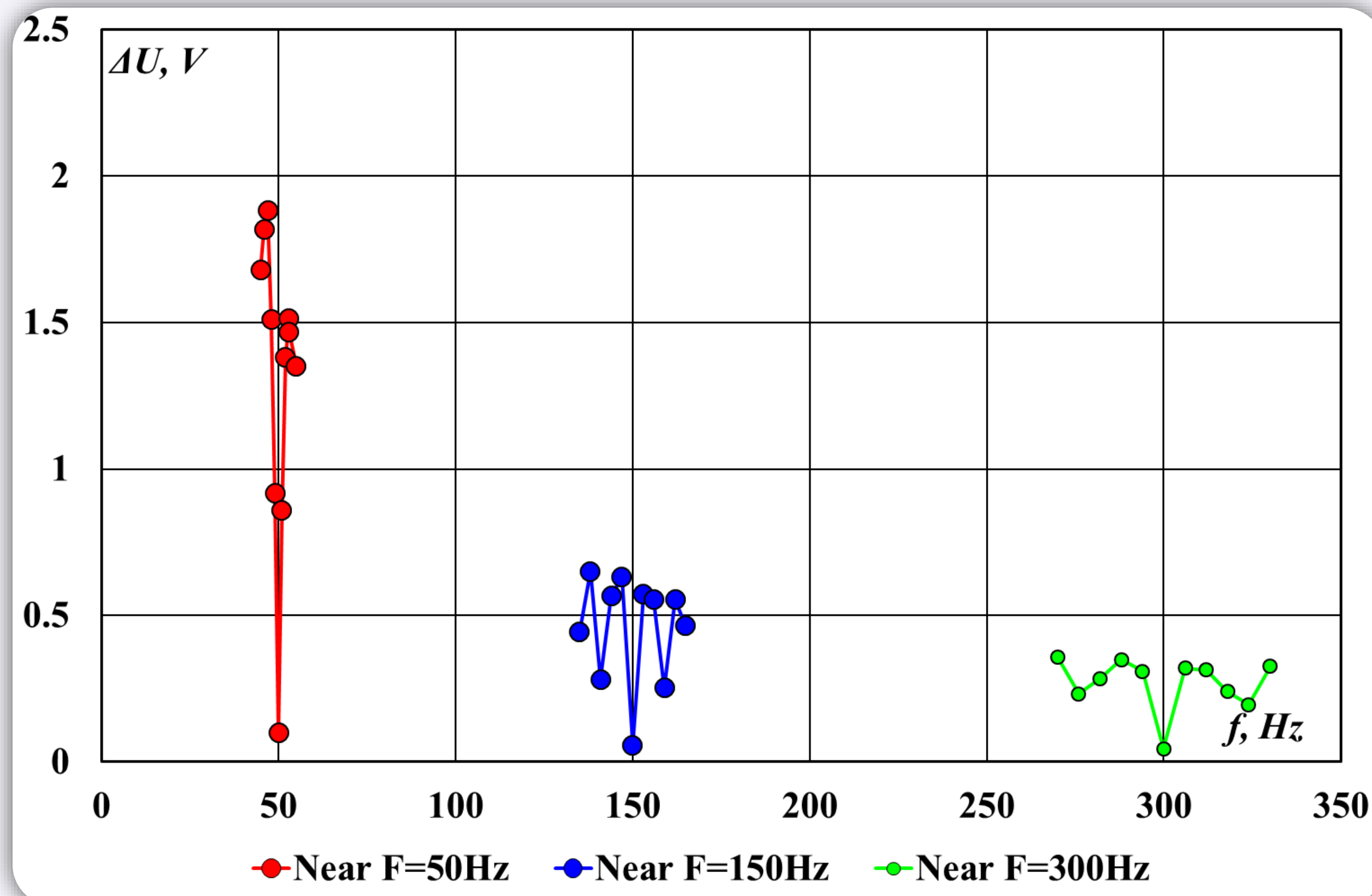
Modelling steady-state work of excitation system after breakdown in the power system.
Different values of frequency near base values (50, 150, 300 Hz).

Test procedure frequency values:

- 45-55 Hz;
- 135-165 Hz;
- 270-330 Hz.

Testing filter-smoothing for different signal period.

Chapter II-1:
2. static conditions testing (results)



Test with different values of power AC voltage frequency f_{AC} results

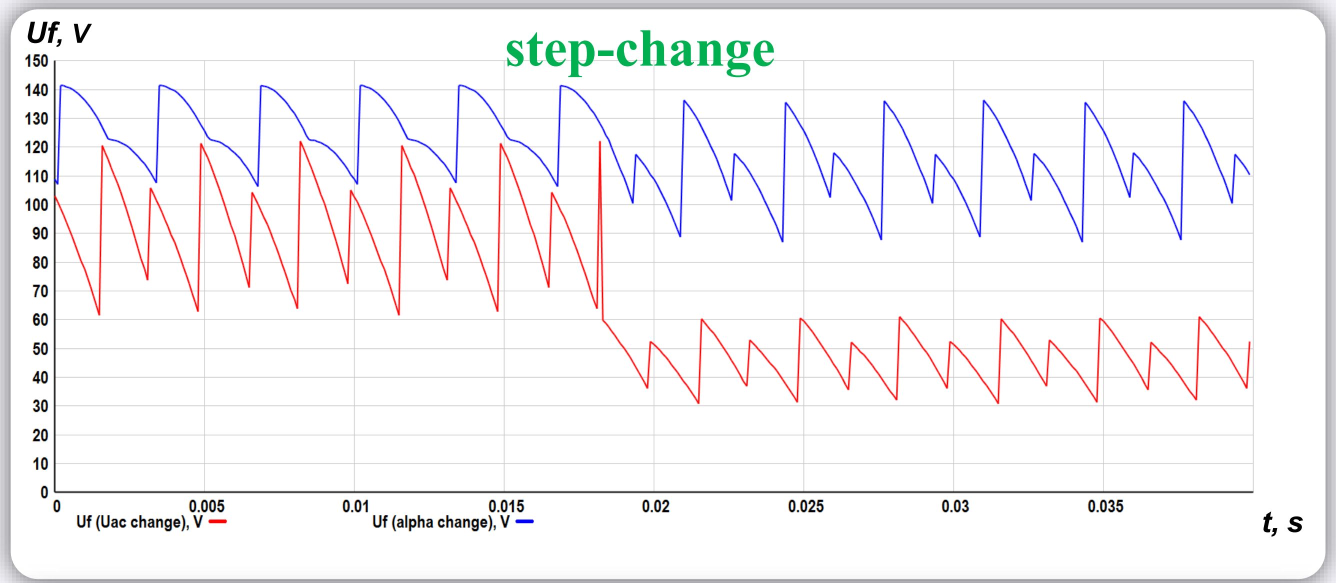
Modeling steady-state work of excitation system after breakdown in the power system.
Different values of frequency's near base values (50, 150, 300 Hz).

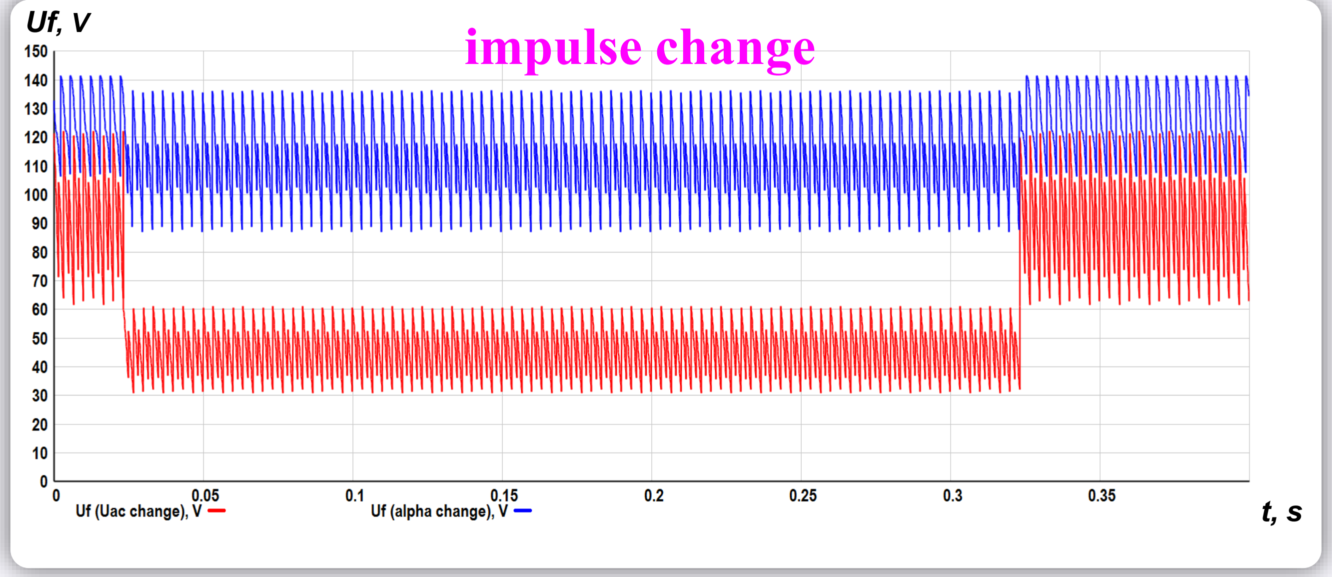
Test procedure frequency values:

- 45-55 Hz;
- 135-165 Hz;
- 270-330 Hz.

Testing filter-smoothing for different signal period.

Chapter II-2: 1-4 dynamic conditions testing





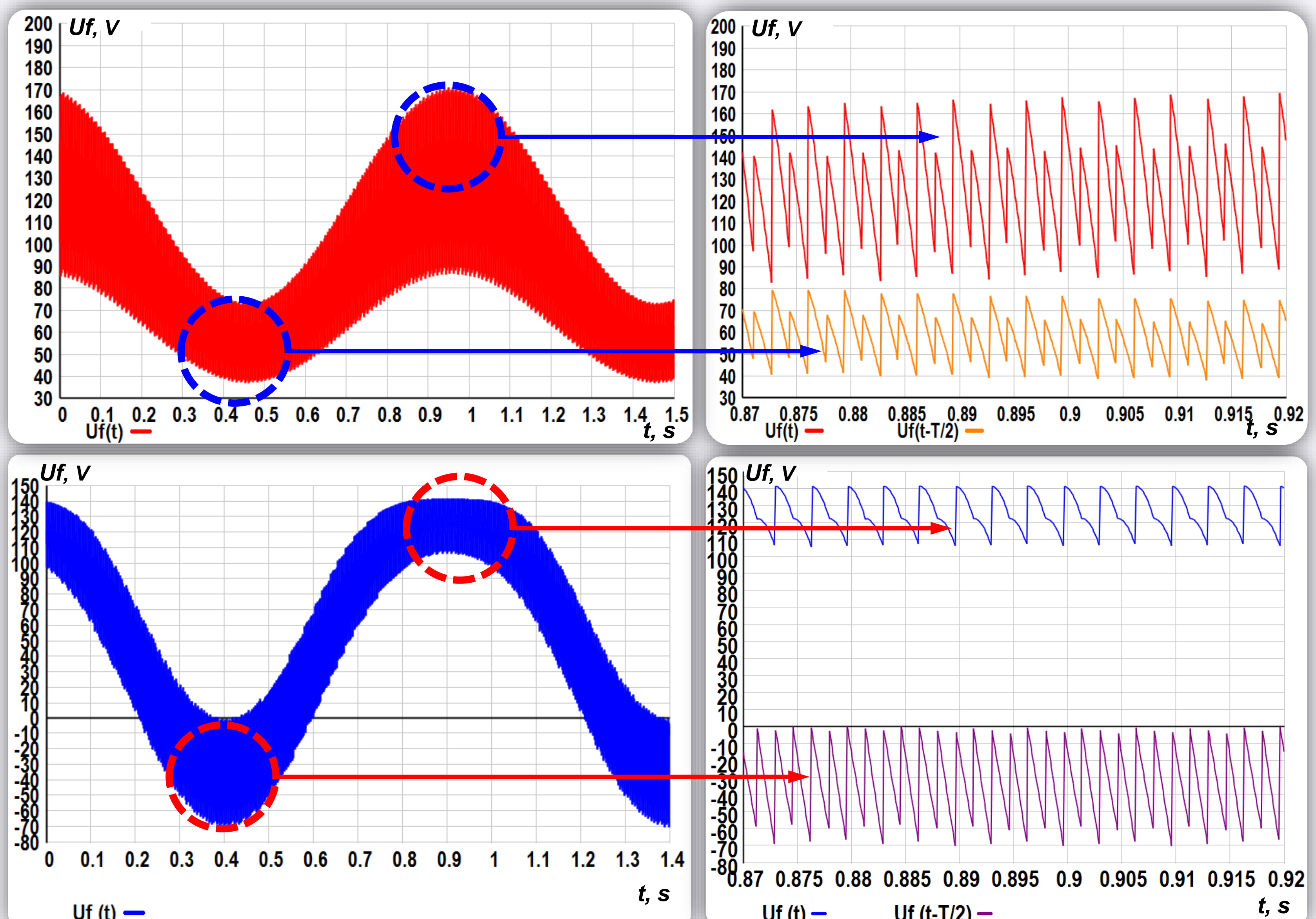
Two types of experiment:

- **step-change**;
- **impulse change** (2 steps with time delay *ΔT*).

Two types of steps/impulses:

- **changing signal amplitude** only (modelling disturbance from converter power AC-voltage; the signal shape is not changing);
- **changing signal shape** (modelling step-change of firing angle value, the RMS value of signal is changing too).

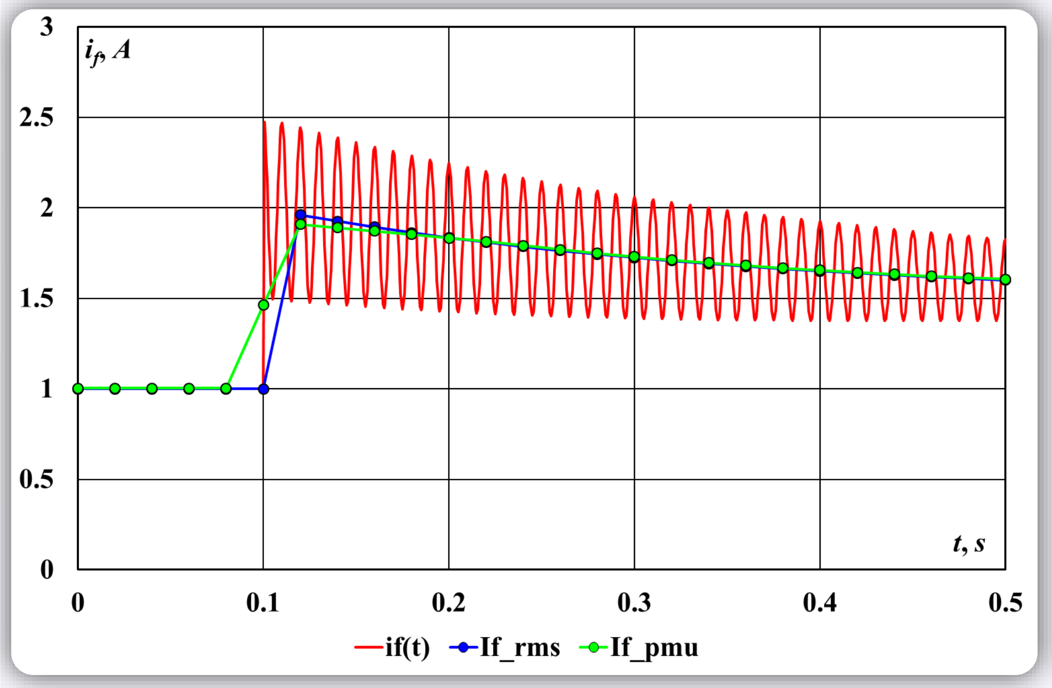
Chapter II-2:
5-6 dynamic conditions testing



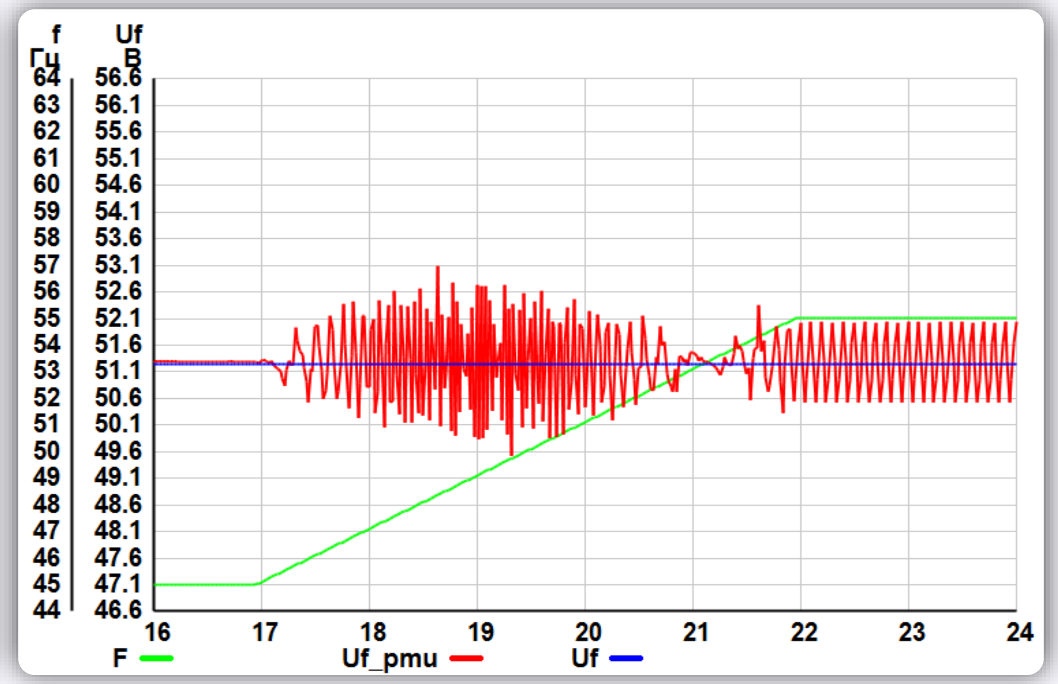
Two types of modulation:

- **modulation of signal amplitude** only (modelling converter amplitude power AC voltage oscillations, the signal shape on base frequency is not changing);
- **modulation signal shape** (modelling AVR+PSS reaction on oscillations on of firing angle value, the RMS value of signal is changing too);

Chapter II-2:
7-8 dynamic conditions testing (results)



Generator stator short current modelling.
Checking filtering $2 \cdot f_{generator\_base}$
The result signal contains aperiodic component, periodic component with $2 \cdot f_{generator\_base}$ frequency, step changing component



Linear changing of power AC voltage
Appearance of pulsating error in measurement result while measurement-window is not equal period of the signal

Chapter III: conclusion and main results

- Actual state of power system stability is the result of a large number of complex measures. A lot of work is aimed to provide good AVR+PSS operation.
- For monitoring AVR+PSS operation in real time the special monitoring system for automatic regulators (**MSAR**) is being implemented in Russian Unified Power System. MSAR is using measure results (P_G, Q_G, U_G, I_G, I_f, U_f) from phasor measurement units (PMU). Phasor measurements from PMUs can be checked with existing test procedure. **For excitation measurements there were no special requirements and test procedure**.
- In present work the main test requirements and test procedure for excitation measurement PMU was created.
  - It was decided to test PMUs with signals from AC-DC-converters in different values of base frequency (50, 150, 300 Hz);
  - The mathematical model of excitation signals was created and implemented in RTDS software;
  - Test procedure includes the static condition experiments (with different firing angles, commutation angle, frequency of excitation power voltage);
  - Test procedure includes the dynamic condition experiments (steps and impulses of excitation power voltage amplitude, firing angle; modulation of excitation power voltage amplitude, firing angle; stator short current imitation; linear changing of power voltage frequency);
- Test procedure was carried out with real PMU-devices. The main measurement problems were in experiments with modelling signals with frequencies, which are not equal base values or it multiple values ($\neq$ 50, 150, 300 Hz).

Contacts

Full name of organization:

Joint Stock Company
«Scientific and Technical Center of Unified Power System»
(JSC «STC UPS»)

Postal address:

194223, Russian Federation, Saint-Petersburg, st. Kurchatov, 1, lit. A

E-mail: ntc@ntcees.ru

Internet: http://www.ntcees.ru

Zelenin Aleksandr
E-mail : zelenin@ntcees.ru

Thank you for your attention :)