**S1-1: Monitoring and system operation control based on synchronized phasor measurements**

# IPS/UPS Reference Dynamic Model and Its Validation per WAMS Recordings

**B.I. AYUEV[1], V.A. DYACHKOV[1], A.V. ZHUKOV[1], S.E. KOUZMIN[1], Y.A. KULIKOV[1], A.V. LEVANDOVSKY[1], A.S. GERASIMOV[2], A.H. ESIPOVICH[2], A.N. SMIRNOV[2]**
**SO for UPS[1], NIIPT[2]**
**Russia**
kulikov.y@so-cdu.ru

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## 1 INTRODUCTION

The first stage of the Wide Area Measurement System (WAMS) has been put into operation in the power systems of the CIS and Baltic countries (UPS/IPS). WAMS is developed on the base of the home-produced Phasor Measurement Units (PMU) and provides the recording of the main operating parameters (frequency, voltage on the bus bars and its absolute angle, active and reactive power of any number of the SS outgoing lines) with sampling period 0,025 – 0,2 s. These parameters are recorded simultaneously by PPS (pulse per second signals), sent by satellites. PMUs are located at the most significant facilities – big power plants and substations, lines of “dangerous” sections of the tie-lines and interstate connections and cover all territory of CIS and Baltic countries [1]. WAMS provides the qualitatively new level of the synchronous interconnection operation and dynamic behavior analysis, since it allows to develop the adequate UPS/IPS dynamic model and to verify it basing on the representative disturbances.

## 2 IPS/UPS REFERENCE DYNAMIC MODEL

The similar reference dynamic model (RDM) has been developed by NIIPT, JSC in the EUROSTAG software format by the order and direct participation of the SO UPS of Russia. RDM comprises models of all operating in parallel power systems: United Power Systems of Russia and Kazakhstan and Interconnected Power Systems of Azerbaijan, Belarus, Georgia, Kyrgyzstan, Latvia, Lithuania, Moldova, Tajikistan, Uzbekistan, Ukraine, Estonia, and Mongolia (UPS/IPS).

The presented in the paper RDM includes 4250 nods, 520 of which – generation nods, 7050 arms, including 5200 lines and 1850 transformers and autotransformers. All significant UPS/IPS power plants which generating units are assigned by their own parameters are presented in the model. All excitation systems of synchronous generators and compensators being on operation at UPS/IPS power plants and HV substations are also considered in RDM. All automatic excitation controllers installed as a part of the fast acting excitation systems and having system stabilizers, are presented in RDM by their detailed models, verified against the experimental frequency characteristics of the Automatic Excitation Controller (AEC). The majority of the controllers have assigned operating setting of the control and stabilization channels according to the station register book data and setting protocols. In general, 192 system stabilizers of real generators or power plants (in case the station is assigned by one generating nod, in which identical generators with identical excitation controllers are connected). Turbines, their control systems and speed controller are considered in all generating units, participating in the frequency primary control (FPC). The speed parameters are set according to the experimental data.

## 3 PROCEDURE OF RDM VALIDATION

System operator to for UPS in cooperation with NIIPT developed the procedure of RDM validation [2]. In accordance with this procedure after disturbance, initiated important imbalance of active power the following steps of validation test are realized:

1) Identification of the disturbance accepted for the validation according to the following criteria:
   - Type of the disturbance – power imbalance, caused by the generating unit outage, separation of the IPS from UPS/IPS, or any other disturbances, initiating significant imbalance;
   - Volume of imbalance – 800MW and above.
2) Creation of the disturbance archives and their transmission to the Control Center of the System Operator.
3) Recording of the pre-fault conditions parameters by means of the IPS Operative-Informational Complex of the UPS/IPS, acquisition of the information on the generation structure and load and available power reserves of the pre-fault conditions. It should be noted that RDM fully coincides in its net structure with the scheme being estimated what provides necessary accuracy of getting the pre-fault conditions in the simulation model.
4) Computation of the pre-fault conditions and its assessment.
5) Computation of the transient parameters caused by the mentioned above disturbance in the points of the PMU allocation by the EUROSTAG software.

RDM validation has been carried out by correlating the results of the electromechanical transient computation by means of RDM with the data registered by PMUs.

By now the full-scale RDM validation has been fulfilled for three disturbances, taken place in UPS of Russia:

- Central Asia systems separation (01.02.2007);
- Balakovskaya TPP units №3 and №4 tripping (04.05.2007);
- Volgodonskaya TPP unit №1 tripping (31.08.2007)

The power imbalance of 1400MW occurred in the UPS/IPS at separation of the part of the Central Asia power system from it. At the same time frequency in the UPS/IPS increases up to 50,043Hz. Tripping of the units №3 and №4 of the Balakovskaya TPP (1000MW each) caused frequency decrease to 49.886HZ. At tripping of the unit №1 of the Volgodonskaya TPP with the load 1010MW, the frequency in UPS/IPS dropped to 49.924HZ. Thus for the RDM validation three disturbances have been chosen at which frequency both increased and decreased. The total load in UPS/IPS was also significantly different and changed within the range from 194 630 MW to 144 530 MW. The RDM integral characteristics for each considered disturbance are presented in the Table and UPS/IPS structure together with the IPS characteristics for the pre-fault conditions for February 01, 2007 is in the figure 1. The Table shows that pre-fault conditions differed significantly in the generation equipment configuration and network structure. If we take into account that disturbance imbalances occurred in different points of the UPS (IPS of Middle Volga, South and Central Asia), then their collection can be considered representative for the RDM tuning and validation.

RDM characteristics

| **Configuration** | **01.02.07 г.** | **04.05.07 г.** | **31.08.07 г.** |
|---|---|---|---|
| Nods | 4161 | 4121 | 4180 |
| arms (total) | 6711 | 6719 | 6700 |
| including: | | | |
| Tie-lines | 4954 | 4886 | 4952 |
| Transformers | 1756 | 1833 | 1728 |
| Circuit Breakers | 1 | 0 | 20 |
| Generator with the individual parameters | 519 | 481 | 510 |

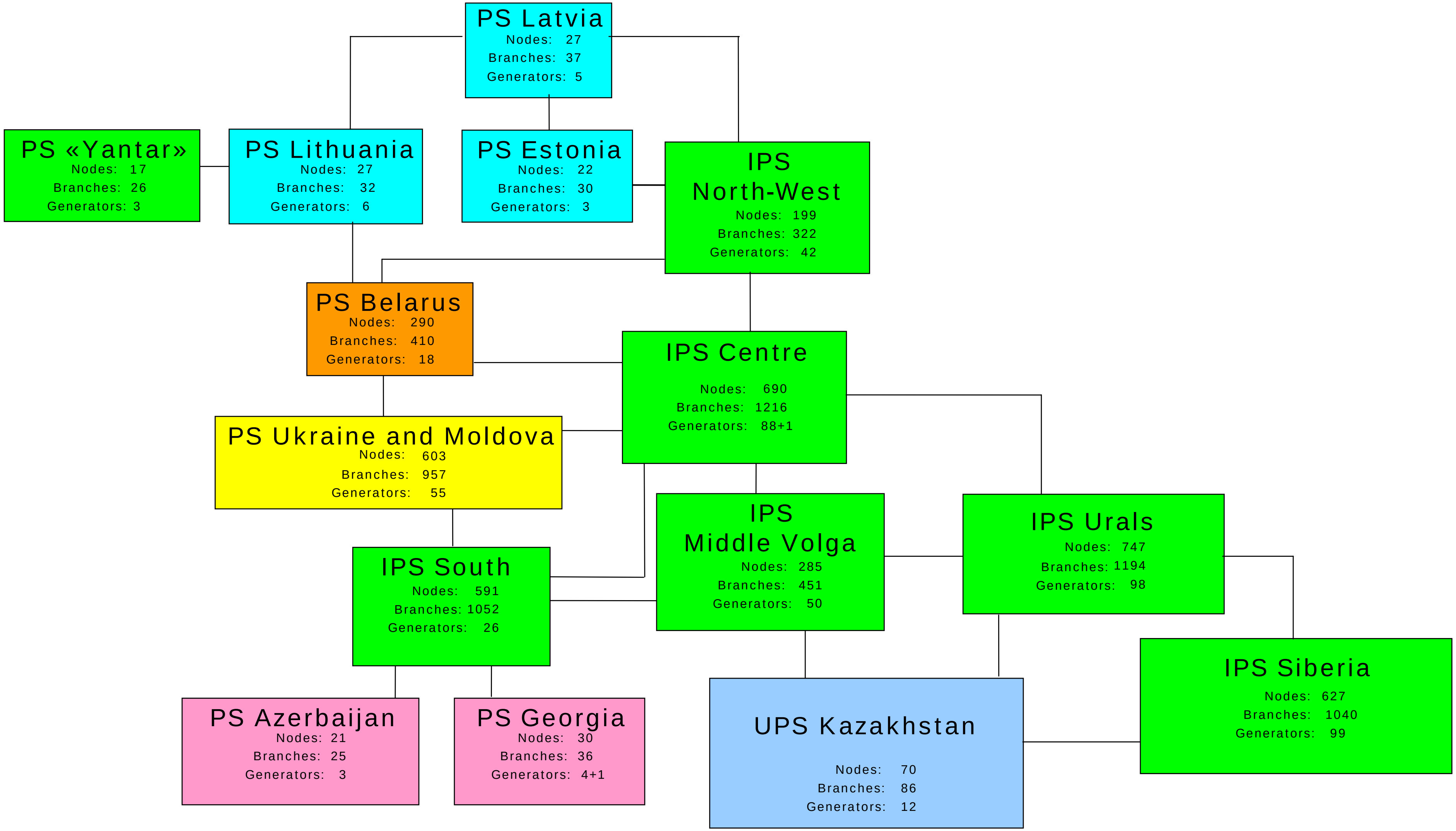


**Figure 1:** UPS/IPS structure for 01/02/2007

RDM validation on each of three disturbances was carried out in the current scheme, in which the pre-fault steady state and also pre-fault load of the UPS/IPS generators were fully represented. Beside, for the first time validation was realized not only basing on the above mentioned parameters, but on the change of the relative angles between electrically and geographically distant UPS/IPS parts.

To adjust RDM while validation there were varied only the turbine speed controllers (the dead band values) parameters and load static characteristics on frequency and voltage, i.e. parameters and characteristics, the real values of which are not known for sure.

The estimation of the RDM was carried out on the compliance of:

- frequency (maximum deviation, the speed of decrease, set value) in separate IPS and UPS/IPS in general;
- frequencies and inter-zonal oscillations phases in the range 0.05Hz – 0.5Hz;
- the oscillations damping;
- frequency deviation time shift;
- the power change character on the separate HVL;
- the change of the relative angles between different UPS/IPS points, located in a significant distant from each other.

## 4 VALIDATION RESULTS

The validation results are shown in fig.2-8. The oscillograms, demonstrating changing of the frequency and voltage in the different points of the UPS/IPS in case of disturbance caused by the South Kazakhstan and Central Asia power systems separation from the UPS of Kazakhstan on 01.02.2007 are in figure 2 (data from the WAMS recorders) and figure 3 (in the RDM). It is clear from the oscillograms comparison, that the divergence in the value of the frequency maximum deviation is about 22mHz, of the quasi state frequency value – 5 mHz, maximum frequency change speed – 10mHz/s, minimal frequency change speed – 5mHz/s.

The change of the active power through the line being a part of the Kazakhstan IPS – Siberia IPS interconnection and HV-500kV of Kostromskaya TPP – SS Luch, is in figure 4 and 5 correspondingly, and basing on the WAMS recorders data and simulated in the digital model at disturbance caused by the tripping of the unit №1 of the Volgodonskaya NPP. The comparison of the active power modification character in the course of the electromechanical transient process in the UPS/IPS and its model indicates the well qualitative coincidence of the results.

The change of the relative angles between Kazakhstan UPS and Ukraine IPS (see fig.6), Siberia IPS and South IPS (see fig.7), Ural IPS and Center IPS (see fig.8) in the power system and its simulation model at the same disturbance is shown in figures 6-8 correspondingly. RDM for sure represents phases of the inter-zonal oscillations between distant parts of the UPS/IPS, what is evident from the figures.

The results obtained allow concluding that the developed model provides good qualitative representation of the UPS/IPS interconnection dynamic performance. Existence of such correct UPS/IPS digital model allows defining the frequencies and range of the inter-zonal oscillations, precising load static characteristics, etc.

The analysis of the international experience of the validation demonstrates that UPS/IPS interconnection digital model is not inferior in its parameters and characteristics to the foreign samples [3]. Cooperation with the UCTE experts within the framework of the project “Feasibility Study: Synchronous interconnection of the UPS/IPS and UCTE power systems” [4] allows concluding that System operator for UPS possesses far more information on pre-fault steady state of the Eastern synchronous zone, then western experts – on the steady state of the UCTE interconnection, especially in the part of the generating equipment configuration and its load. That creates prerequisites for passing from accepted at present qualitative criteria to the quantitative characteristics of the dynamic model adequacy evaluation and allows starting the validation standards development and methodical instructions for the procedure of its realization. The constant actualization of the RDM and its validation basing on the disturbances help to make the model an effective tool for system reliability monitoring.

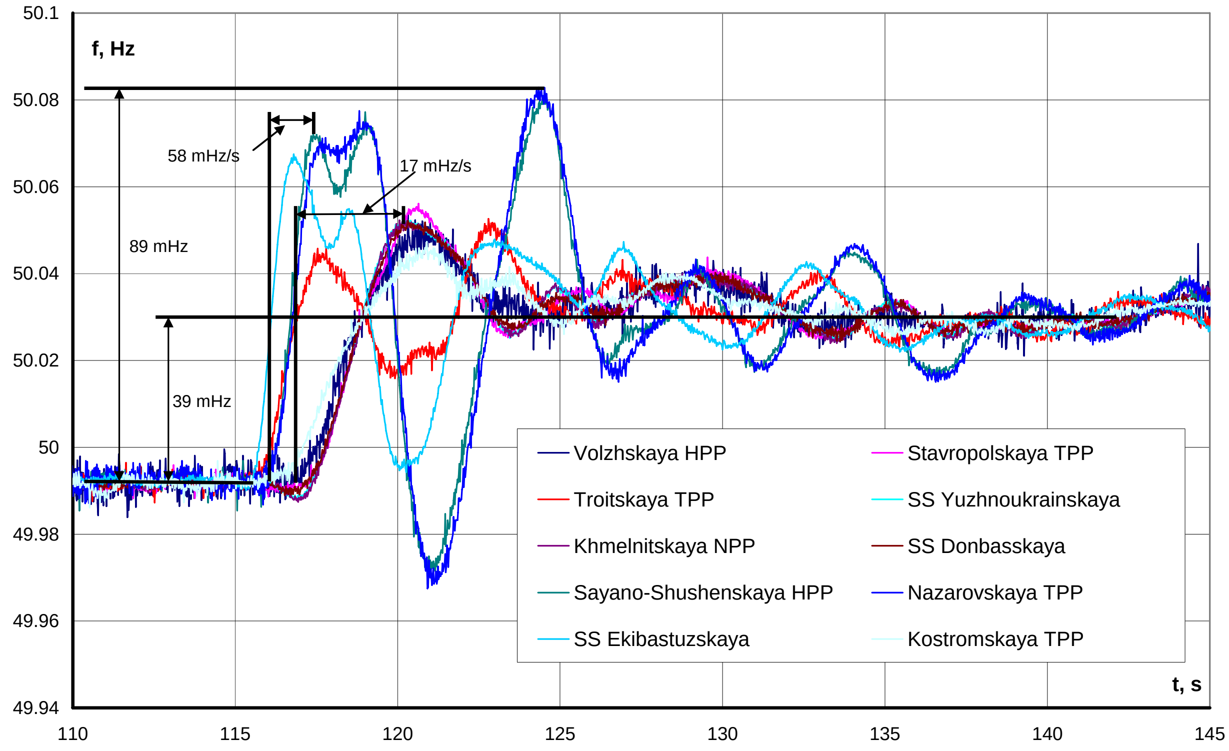


**Figure 2:** WAMS recordings

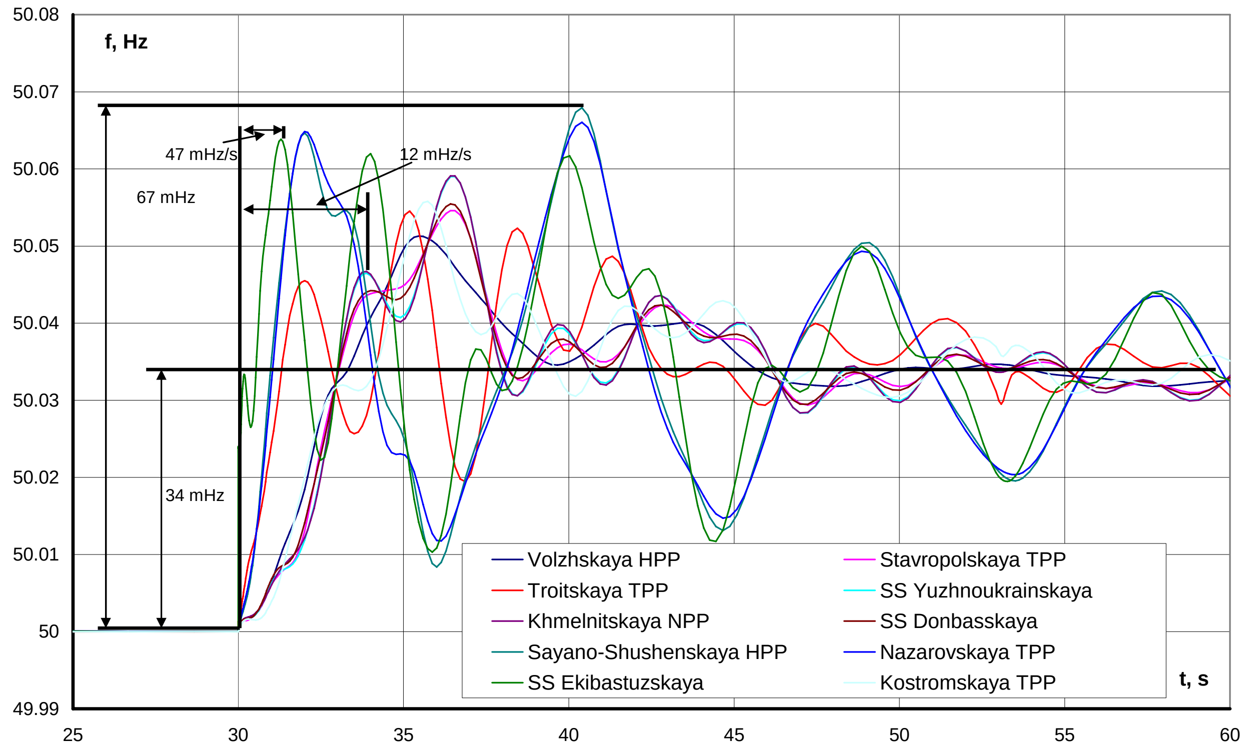


**Figure 3:** Model

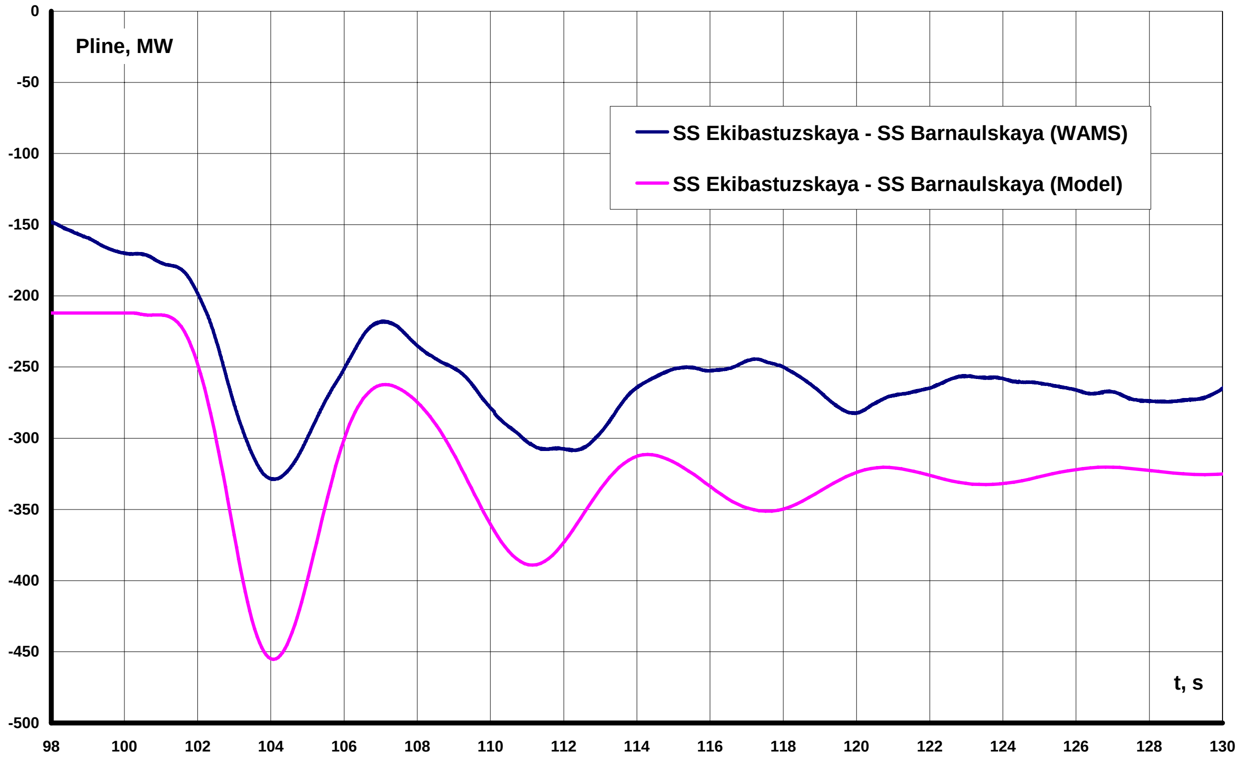


**Figure 4:** Kazakhstan IPS – Siberia IPS interconnection

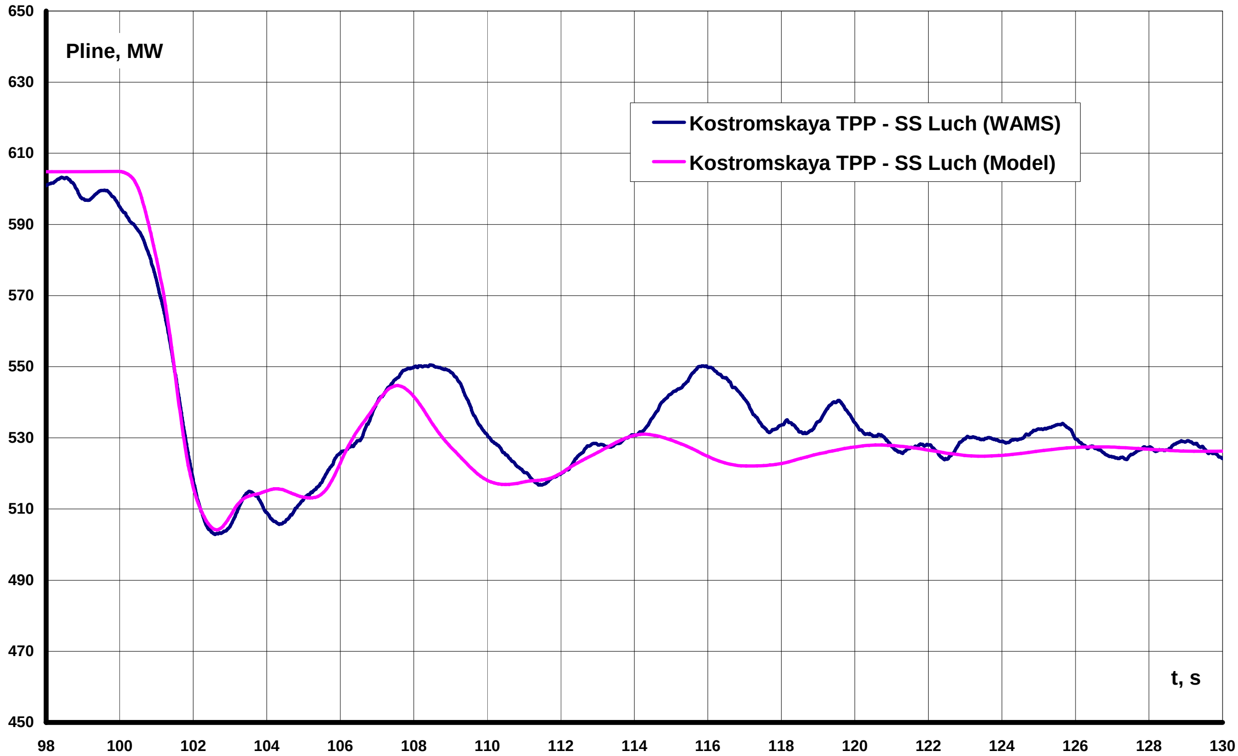


**Figure 5:** IPS of Center

This model takes a special place among others since it is the standard sample. It provides the creation of more similar models of the separate power systems since it also provides their correct “setting”. This quality of the model has already been used while developing the similar digital models of the Ural, Middle Volga, Siberia, North-West, Belarus power systems and now it is also use on developing the digital models of the North-West, Center and South IPS.

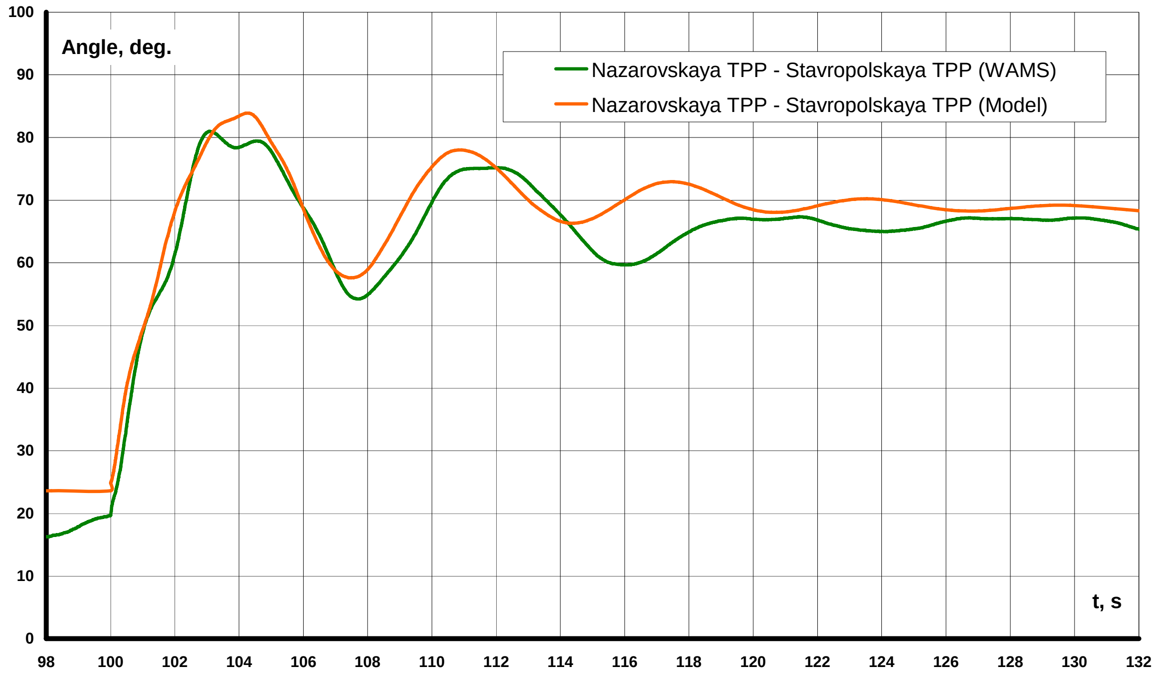


**Figure 6:** IPS of Siberia – IPS of South

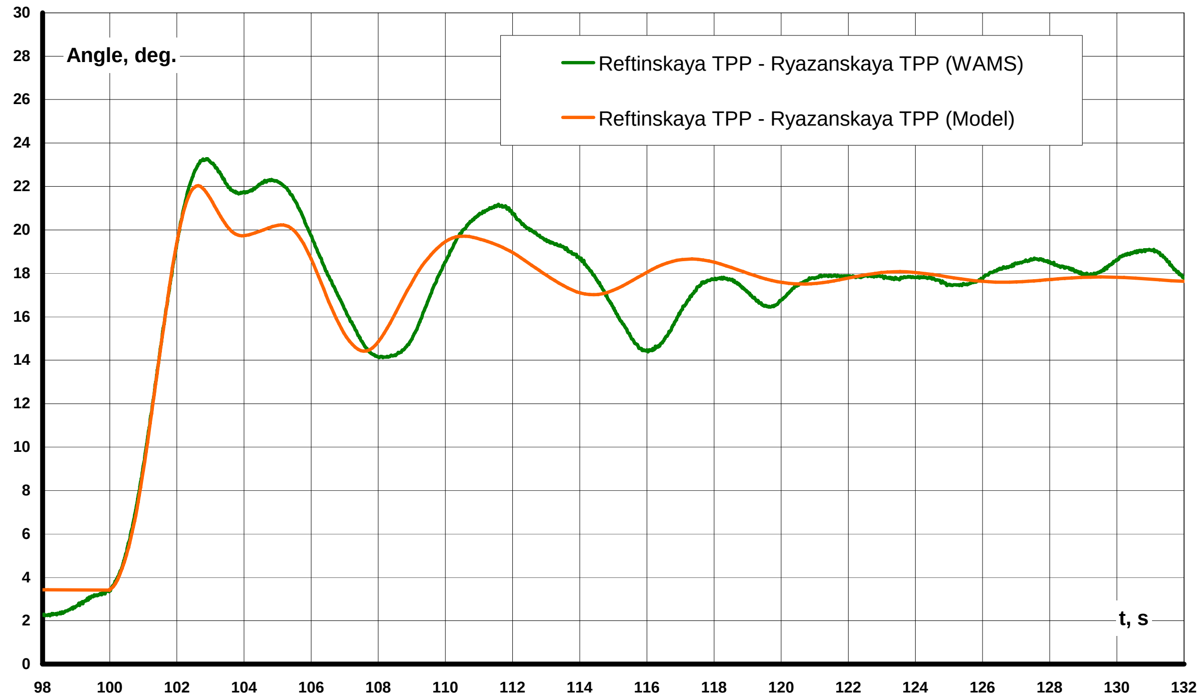


**Figure 7:** IPS of Urals – IPS of Center

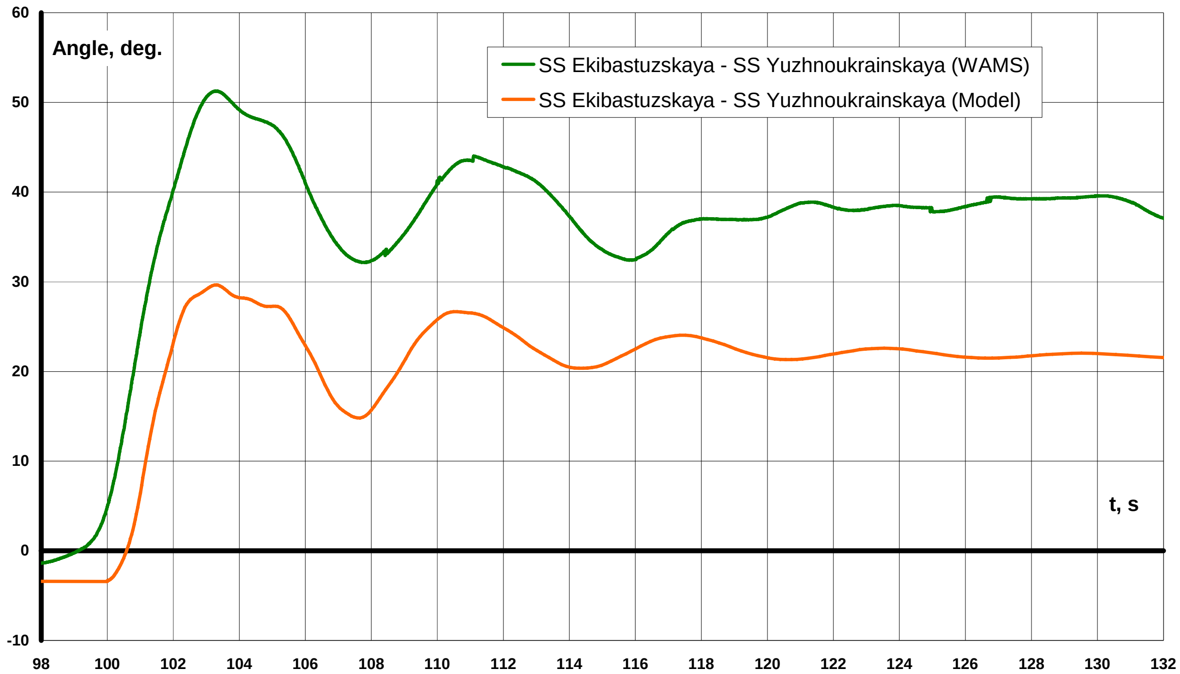


**Figure 8:** IPS of Kazakhstan – IPS of Ukraine

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