Simulation models of the hydro power plants in Macedonia and Yugoslavia

H. Weber and F. Prillwitz

Abstract--**In hydro power plants of Macedonia (FYROM) and Yugoslavia (YU) there is a very high interest in investigations concerning the static and dynamic behaviour of the units for the most frequent events that could occur. This contribution presents the most important steps for the reality oriented creation of mathematical models of hydro power plants which can be used for such investigations. Therefore in the investigated hydro power plants "Vrutok" (FYROM), "Zvornik" (YU), "Tikves" (FYROM) and "Bajina Basta" (YU) measurements were performed to obtain step response time signals of all important functional parts of the plants to be able to identify the most important parameters of the mathematical model. Using the least-square-method with the Matlab-software it was possible to identify all the necessary parameters of the mathematical models. Using the same measured input signals the response from the developed mathematical models show nearly the same behaviour as the real power plants.**

Index Terms—**dynamic behaviour, dynamic modelling, hydro power plant, identification, simulation.**

I. Introduction

In the hydro power plants of Macedonia and Yugoslavia there is a lack of knowledge and information about the static and dynamic behaviour of the units for each contingency that could occur. In that sense the inevitable task was the creation of simulation models of the hydro power plants which can be used on the one hand by experts for analysis of the static and dynamic behaviour and on the other hand by the staff involved with the operation and maintenance of the plant for their training. According to the joint project DYSIMAC (Dynamic Simulation of the macedonian and yugoslavian power plants in a new technological and market environment), the authors investigated dynamic characteristics of units in HPP "Vrutok" and "Tikves" in Macedonia and also HPP "Zvornik" and "Bajina Basta" in Yugoslavia, see Fig. 1. It will be shown, that a model structure developed using the documentations of the power plants together with parameter estimations after suitable experiments will lead to comparatively small simulation models which can guarantee a very good dynamic behaviour compared with the behaviour of real power plants. With this method the modelling was performed for hydro power plants with Pelton turbine, HPP "Vrutok" (FYROM), with Francis turbine, HPP "Tikves" (FYROM), HPP "Bajina Basta" (YU) and with Kaplan turbine, HPP "Zvornik" (YU).

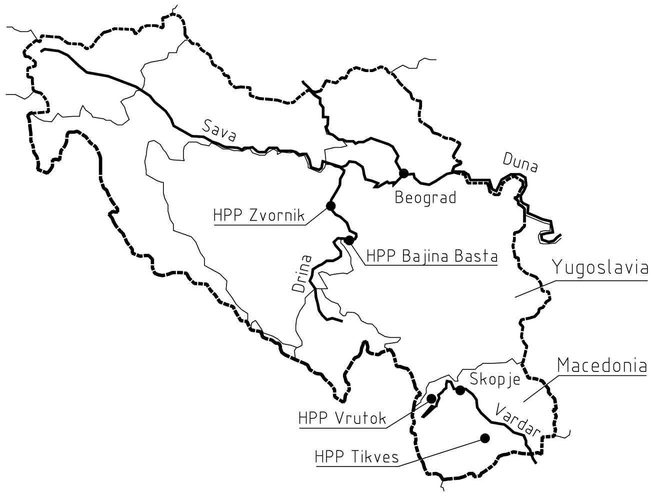

Fig. 1. Map of the investigated hydro power plants in Macedonia and Yugoslavia.

II. Investigated hydro power plants

The HPP "Vrutok" lies in the north-western part of the Republic of Macedonia, 7 km on the west of Gostivar city and 64 km south-west of Skopje. Together with the "Mavrovo Lake" and the HPP "Vrben" and HPP "Raven", it forms a cascade system, see Fig. 2. The HPP "Vrutok" is the largest

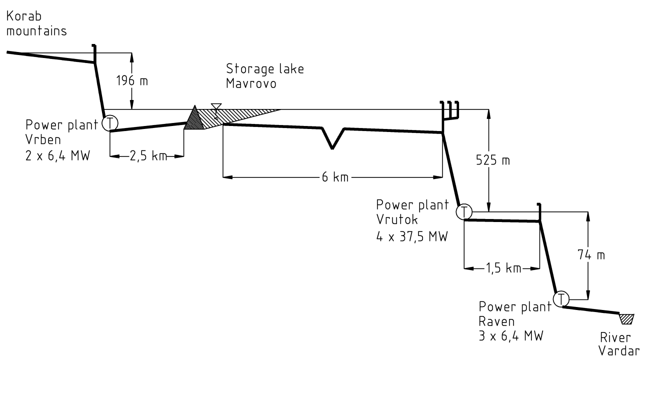

Fig. 2. Profile of the cascade system "Vrben-Vrutok-Raven".

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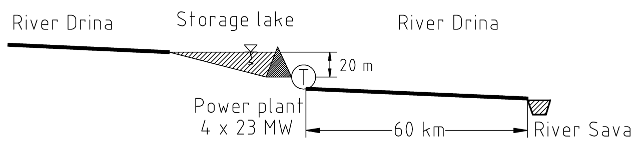

Fig. 3. Profile of the hydro power plant "Zvornik".

hydro power plant in Macedonia and with the Mavrovo accumulation lake has an irreplaceable role in the regulation of the load-frequency control and electricity consumption daily diagram. It's role in restoration studies could be of the highest importance. The HPP "Vrutok" with the entire hydro and electromechanical equipment is arranged in an underground building. It is a derivational, storage type of hydro power plant.

Main data of the HPP "Vrutok" are:

- type of turbines	Pelton
- number of units	4
- rated power (unit)	37,5 MW
- rated voltage	12 kV
- rated speed	500 rpm
- rated flow	4 x 8 m³/s
- net height	525 m
- average yearly production	350 GWh.

In HPP "Vrutok" the following plant equipment is already being rehabilitated:

- turbine regulator for all units,
- voltage regulator for all units,
- control of the turbine inlet valve and brakes,
- synchronization system for each unit.

This new equipment is already built-up and prepared for modern automatic control systems.

The HPP "Tikves" lies in the southern part of Macedonia, 20 km on the south-west of Kavadarci city at the Tikves accumulation lake. The main data of the HPP "Tikves" are:

- type of turbines	Francis
- number of units	4
- rated power (unit)	24 MW
- rated voltage	10,5 kV
- rated speed	300 rpm
- rated flow	4 x 30 m³/s
- net height	91 m.

The HPP "Zvornik" lies in the western part of Serbia, 120 km on the west of Belgrad at the river Drina, see Fig. 3. The main data of the HPP "Zvornik" are:

- type of turbines	Kaplan
- number of units	4
- rated power (unit)	24 MW

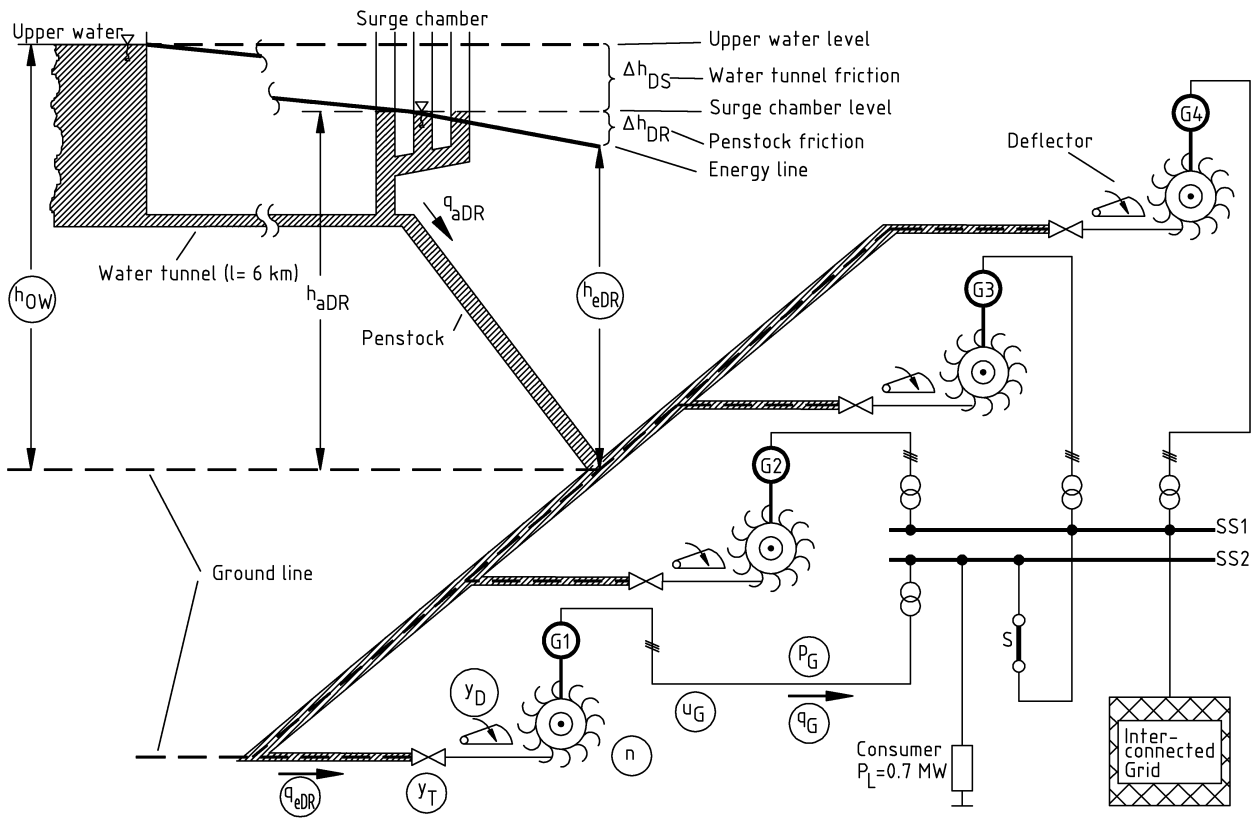

Fig. 4. Scheme of the hydro power plant "Vrutok", Macedonia.

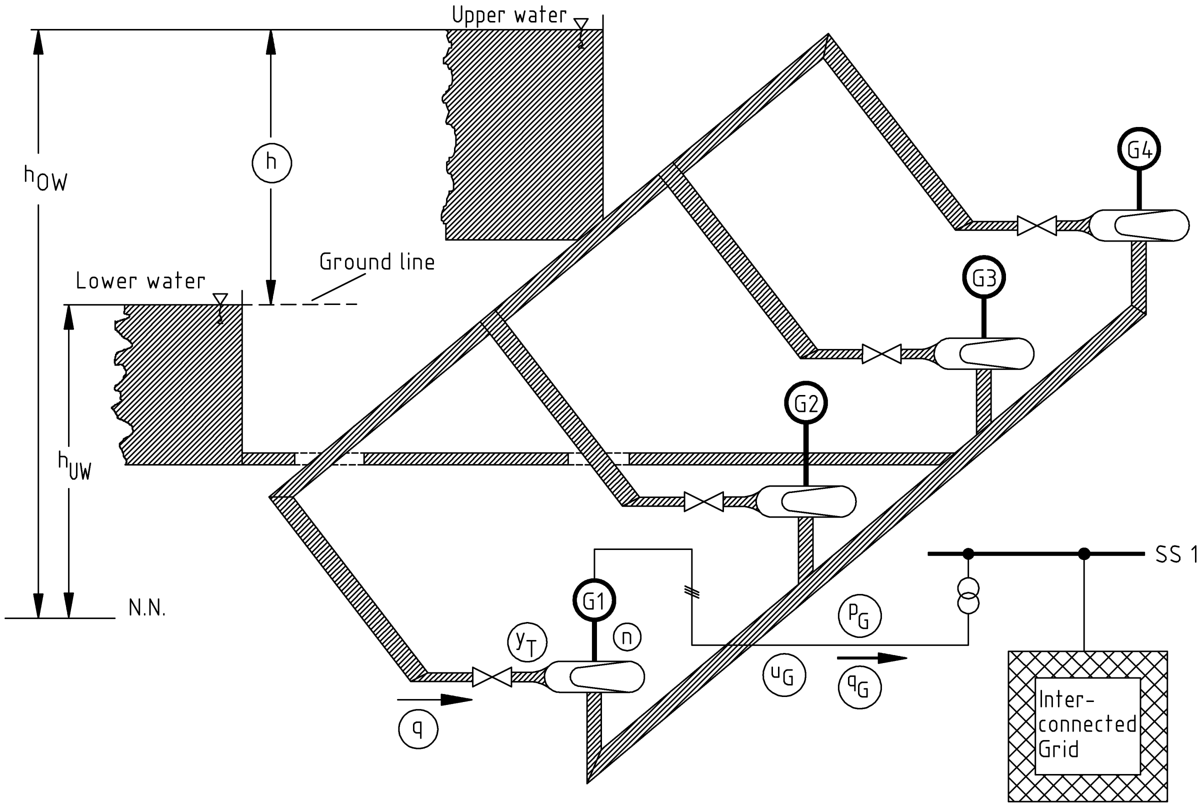

Fig. 5. Scheme of the hydro power plant “Zvornik”, Yugoslavia.

- rated voltage 11 kV
- rated speed 150 rpm
- rated flow 4 x 155 m³/s
- net height 19,3 m.

The fourth investigated hydro power plant, HPP “Bajina Basta”, lies 55 km on the south of HPP “Zvornik” at the same river Drina. The main data of the HPP “Bajina Basta” are:

- type of turbines Francis
- number of units 4
- rated power (unit) 92 MW
- rated voltage 15,65 kV
- rated speed 136,4 rpm
- rated flow 4 x 161 m³/s
- net height 65,1 m
- average yearly production 1500 GWh.

III. MEASUREMENTS

The measurements are conducted on only one generator-turbine system in each of the power plants. The other systems are similar. As step input for the measurements there has been selected an immediate reduction of the active and reactive power, because this guarantees that all the concerned frequencies of the unit’s time response can be identified. As depicted in Fig. 4 the investigated machine delivers energy to the interconnected network via busbar 2 and a bus coupler circuit-breaker. Also connected to busbar 2 is a load of approximately 0.7 MW (some small villages). One test consists of the following steps:

- adjustment of a defined export via the coupler breaker (active and reactive power);

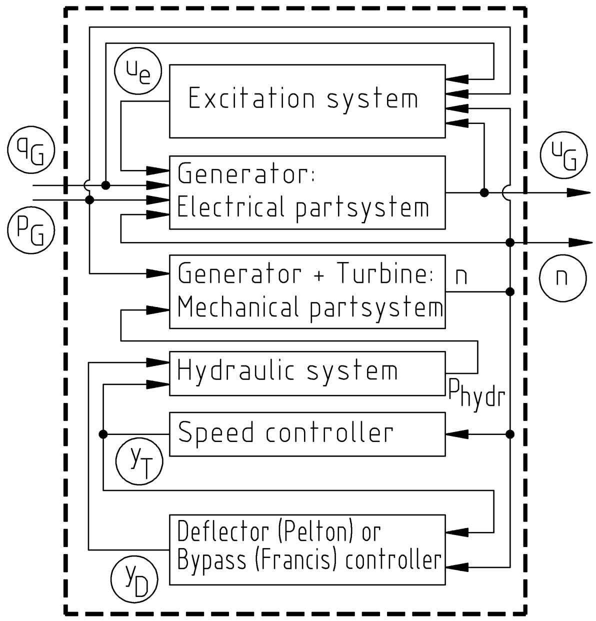

Fig. 6. General block diagram for hydro power plants.

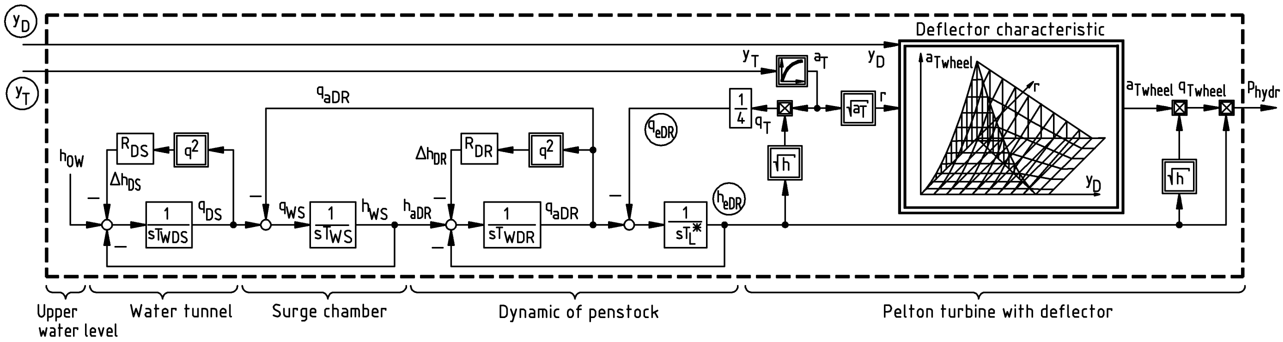

Fig. 7. Hydraulic system of HPP “Vrutok”.

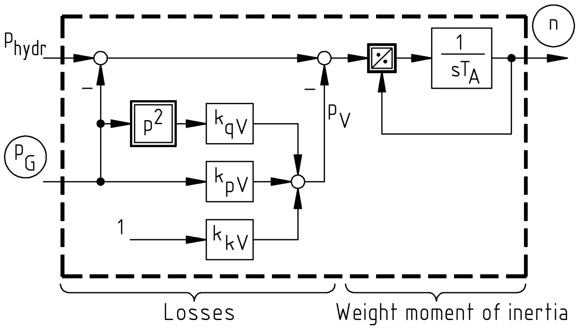

Fig. 8. Mechanical part of hydro power plants (generator, turbine, losses).

- opening of the breaker;
- measurement of the transient behaviour of the system until a new stationary operating point is reached.

After the opening of the breaker the system works in isolated operation and has to supply only the small load of the island. In this way the input signal of the system can be understood as a step input.

For the case, that there is no isolated operation possible, as occurred in HPP “Tikves”, “Zvornik” and “Bajina Basta”, the steps have to be performed by another way. In this case the measurements must take place in normal operation during:

- starting of the unit,
- stopping of the unit,

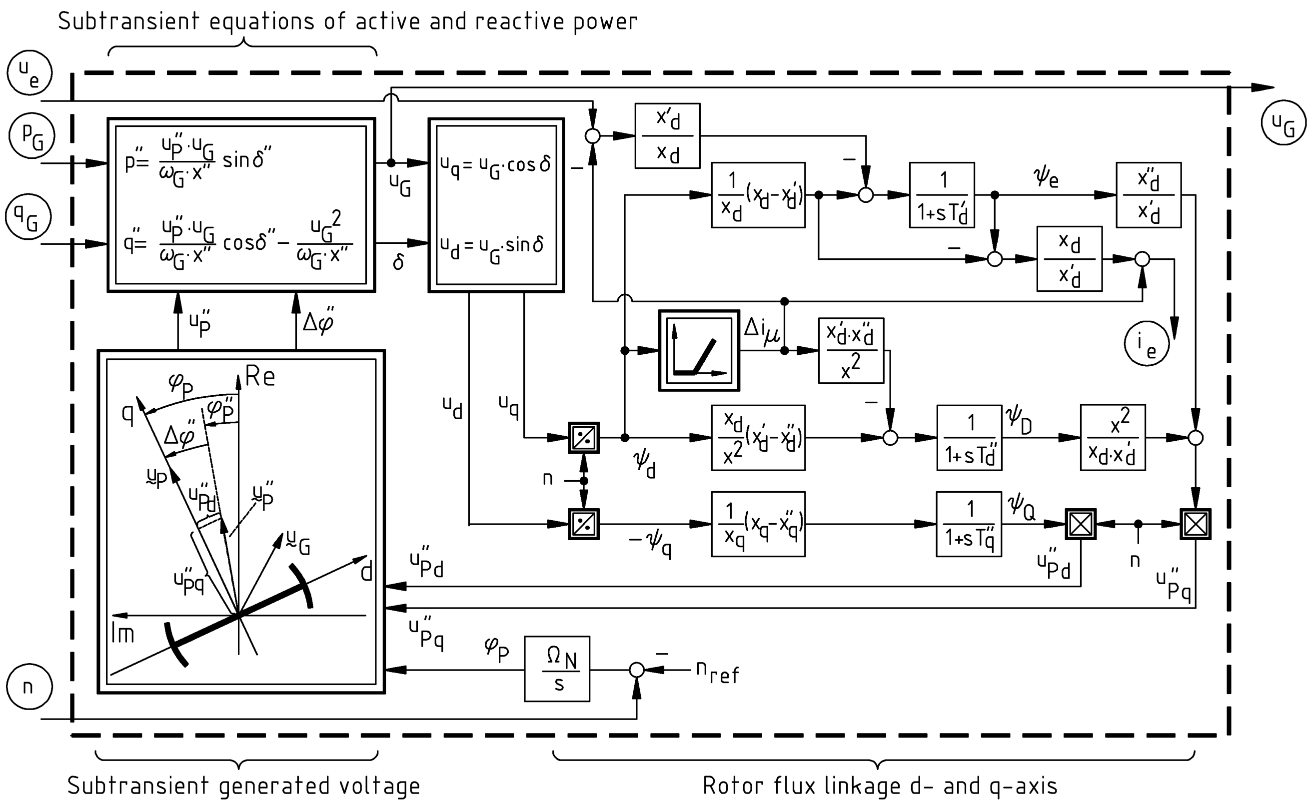

Fig. 9. Electrical part (generator).

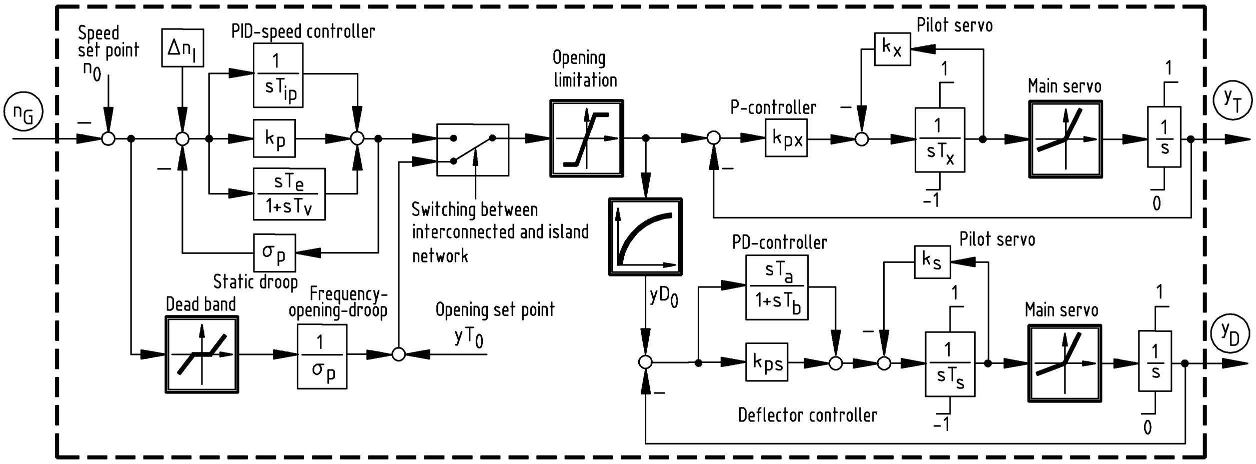

Fig. 10. Speed controller with deflector controller in HPP "Vrutok".

- changing step by step the setpoint for active power or speed,
- changing step by step the setpoint for reactive power or generator voltage.

As depicted in Fig. 4 and Fig. 5 the circled signals are measured ones. All measured signals of the HPP "Vrutok" are:

- active power p_G
- reactive power q_G
- generator voltage u_G
- excitation voltage u_e
- excitation current i_e
- frequency f
- speed n
- turbine gate position y_T
- deflector/bypass position y_D
- water pressure at the storage lake h_{OW}
- water pressure at the turbine input h_{eDr} .
- water flow at the turbine input q_{eDr} .

Additional in HPP "Tikves", "Zvornik" and "Bajina Basta" the following signals were measured and recorded:

- active power setpoint p_0 or speed setpoint n_0
- reactive power setpoint q_0 or voltage setpoint u_0.

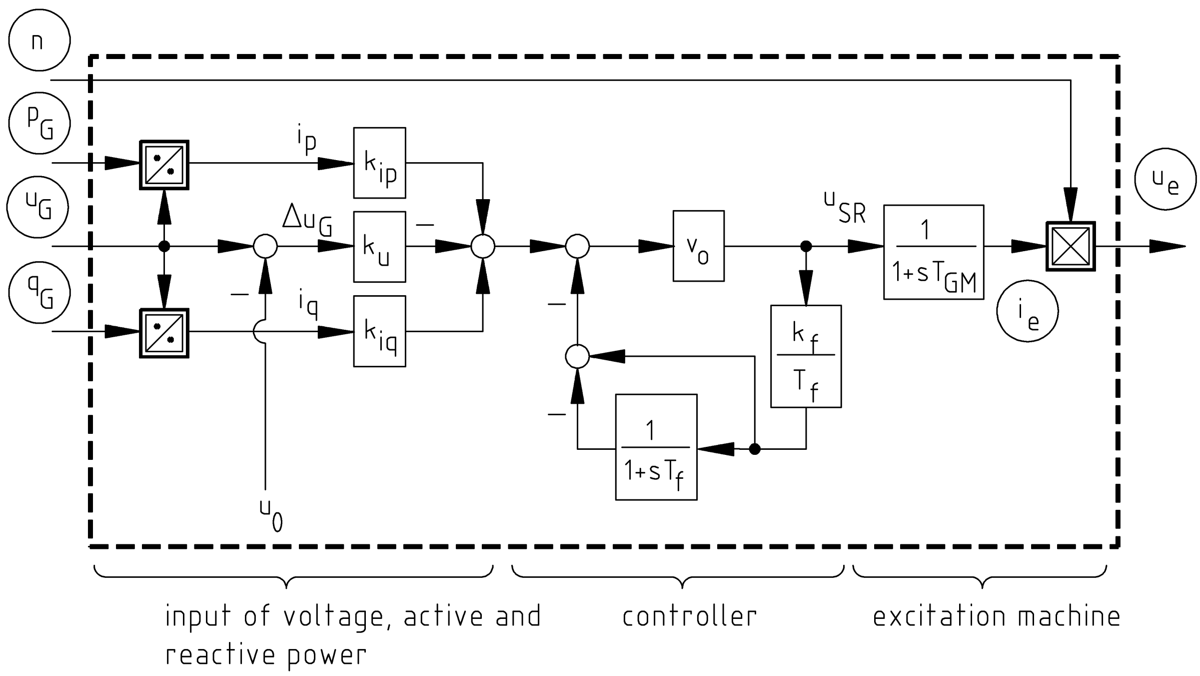

Fig. 11. Excitation system in HPP "Vrutok".

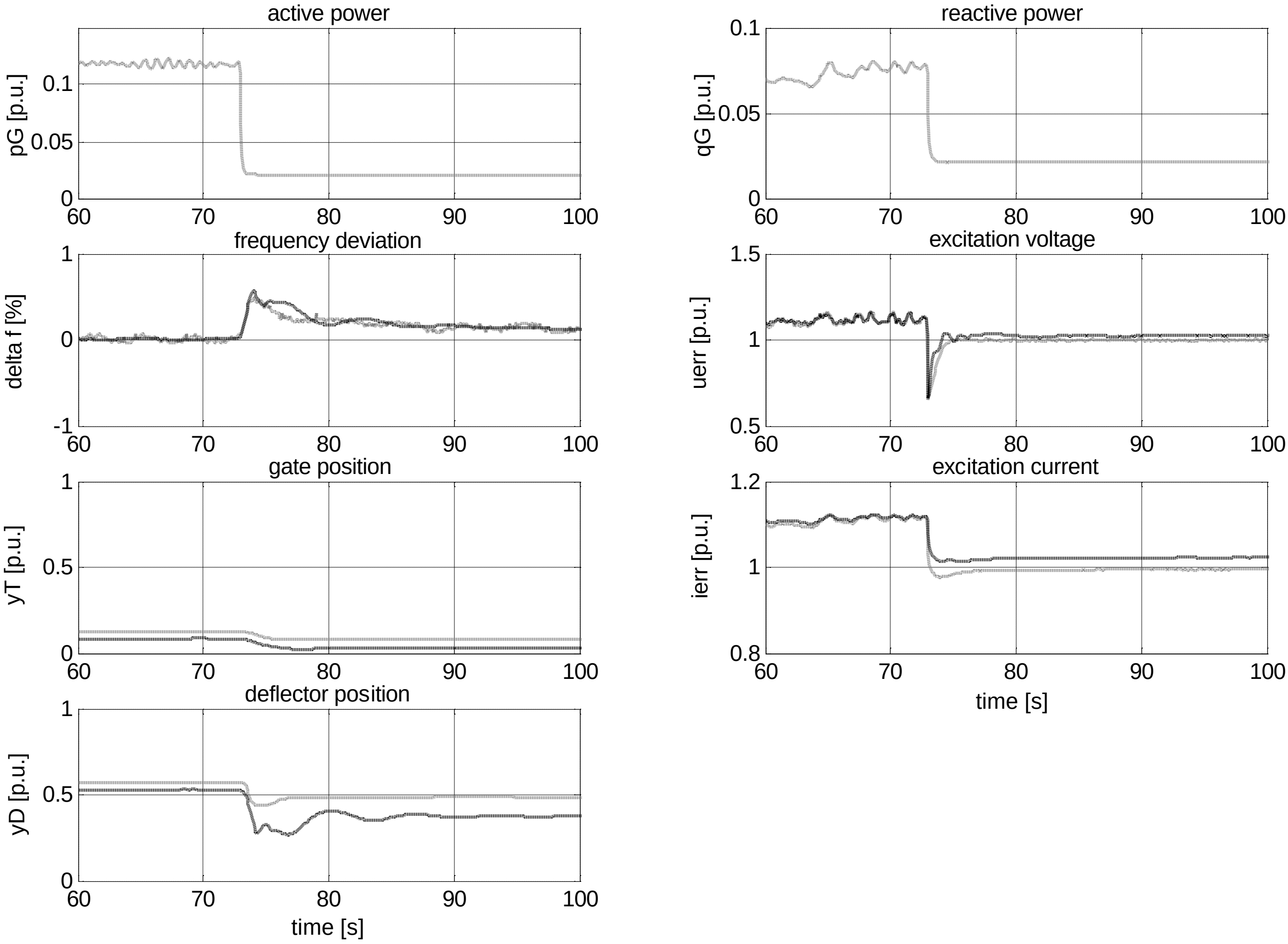

Fig. 12. Comparison of measured (grey) and simulated (black) signals after a +4 MW exchange-power-step in HPP "Vrutok".

Besides in HPP "Zvornik" the blade angle of the Kaplan turbine y_B. was also measured. The measured signals are recorded by a PC-based Labview system with 16 channels. The sampling rate is 100 ms.

IV. Modelling and Identification

Using the schemes of the hydro power plants, as for instance depicted in Fig. 4 and Fig. 5, and all available technical documentations, the models of the different part systems shown in Fig. 6 were developed using the Matlab/Simulink software. The created overall model for each of the plants consists of 14 state variables and 32 unknown parameters which have to be identified. For the HPP "Vrutok" the developed models of the hydraulic part [1], the mechanical part with losses [2], the electrical part and the speed governor are shown in Fig. 7 until Fig. 11. The circled signals are again measured ones.

The identification is conducted in Matlab using the Least-Square-Method [3]. In the first step only the hydraulic part, together with the mechanical part, is identified using the turbine gate position as input and the water pressure and the speed of the turbine as outputs.

In the second step, the parameters of the turbine and deflector/bypass controllers are identified using the hydraulic and mechanical system as identified before. In this case the active power is the input and the positions of turbine gate and the deflector are the outputs.

In a third step, the electrical part of the generator and the excitation system are identified using the active and reactive power as inputs and the generator voltage, the excitation voltage and the excitation current as outputs.

V. Results

The identified parameters of the hydraulic, mechanical, electrical part and some parameters of the speed controller and the excitation system are shown in Table 1 (HPP “Vrutok”) and in Table 2 (HPP “Zvornik”).

TABLE 1
IDENTIFIED PARAMETERS OF HPP “VRUTOK”

R_{DS}	T_{WDS}	T_{WS}	R_{DR}	T_{WDR}	T_L
0,08	6,7s	700s	0,02	1,46s	0,34s
k_{kV}	k_{pV}	k_{qV}	T_A	x_d	x_d'
0,043	0,1	0,054	6,8s	1,5	0,4
x_d''	x_q	x_q''	T_d'	T_d''	T_q''
0,22	1	0,24	1,5s	0,03s	0,03s
σ_p	T_{ip}	k_p	k_u	k_f	T_f
3,8%	1s	9,3	22	1	0,54s

TABLE 2
IDENTIFIED PARAMETERS OF HPP “ZVORNIK”

R_{DR}	T_{WDR}	T_L	k_{kV}	k_{pV}	k_{qV}
0,0001	1,5s	0,1142s	0.022	0.333	0.266
σ_p	σ_t	T_A			
3%	3%	8s			

For HPP “Vrutok” in Fig. 12 the simulation results of the identification after an exchange power step of +4 MW are shown. The input signals are:
- active power p_G
- reactive power q_G

and the fitted output signals are:
- frequency deviation *Df*
- excitatiuon voltage u_e
- excitation current i_e
- turbine gate position y_T
- deflector/bypass position y_D .

For HPP “Zvornik” in Fig. 13 some simulation results are shown. In the active-power-diagram the non-minimal-phase-behaviour is clear to see. During this experiment the generator was all the time interconnected to the serbian grid. The input signal is the speed setpoint n_0. The output signals are:
- active power p_G
- turbine gate position y_T
- blade angle y_B .

As depicted, a good correspondence between measurement and simulation can be achieved. The real power plants and the developed practical simulation models are showing nearly the same dynamic behaviour.

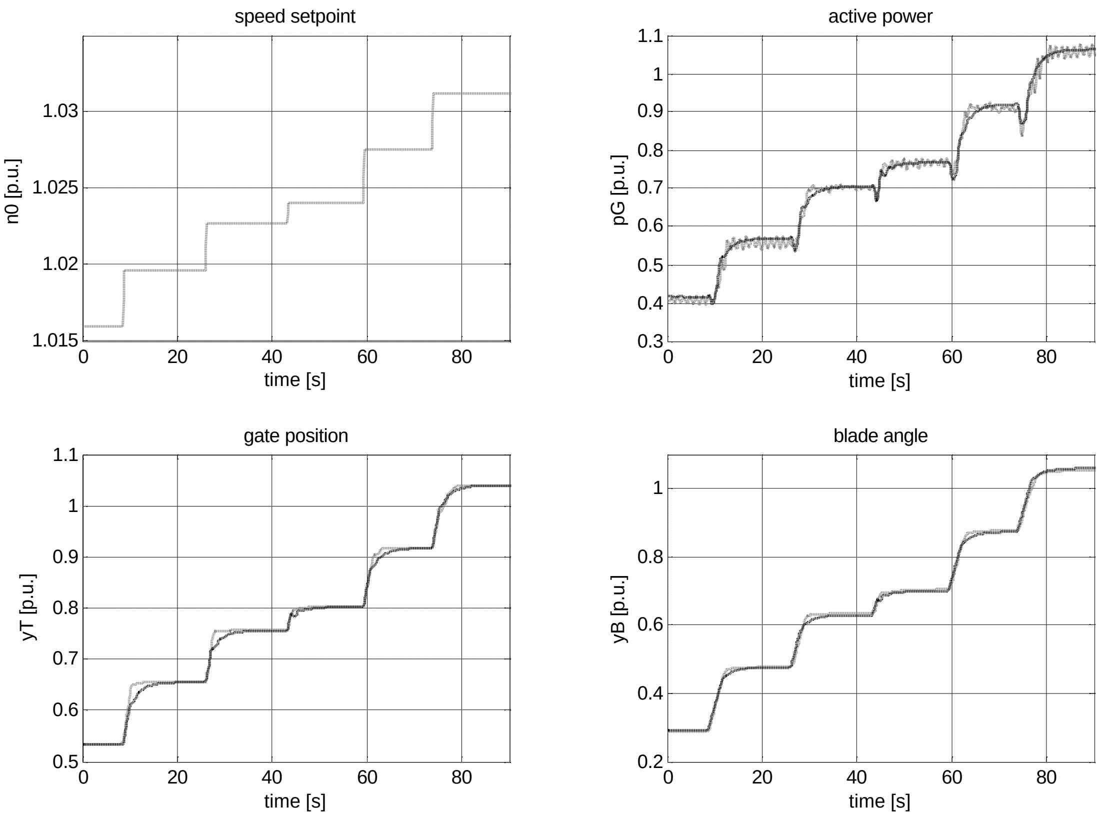

Fig. 13. Comparison of measured (grey) and simulated (black) signals during changing the speed setpoint in HPP “Zvornik”.

VI. Conclusion

In Macedonia and Yugoslavia there is a growing interest in investigations concerning the static and dynamic behaviour of the power plants. For these investigations correctly developed nonlinear dynamic models of the power plants are necessary. These models have to be reliable for all operating working points of the system from zero to full operation. On the other hand, the complexity and order of the models should not be too high because, in some investigations, for example restoration scenarios, a lot of power plants can act together in reality oriented simulations [4], [5].

In this contribution the modelling of hydro power plants is presented. The contribution has proved that the practical and user-friendly mathematical model of the complex system, as it is a hydro power plant, can be created. These models can be practically used for expert's analysis, staff training and can be incorporated in the future in the Energy Management System to be installed in the companies of electrical energy supply in Macedonia (ESM) and Yugoslavia (EPS).

VII. Acknowledgement

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VIII. References

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IX. Biographies

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Fred Prillwitz was born 1960 in Teutschenthal, Germany. He received his Ph.D. degree from University of Rostock in 1992. His area of interests includes modelling and simulation of power systems and High Voltage Techniques.