Practically oriented simulation model for the Hydro Power Plant "Vrutok" in Macedonia

H. Weber, V. Fustik, F. Prillwitz, A. Iliev

***Abstract*--In hydro power plants of Macedonia 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 creation of a mathematical model of the hydro power plant "Vrutok" that can be used for such investigations. Therefore in the hydro power plant "Vrutok" measurements were performed to obtain step response time signals of all important functional parts of the plant to be able to identify the most important parameters of the mathematical model needed for such investigations. Using the least-square-method with the Matlab-software it was possible to identify all the necessary parameters of the mathematical model. Using the same measured input signal the response from developed mathematical model shows nearly the same behaviour as the real system unit in the hydro power plant "Vrutok".**

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

I. Introduction

In the hydro power plants of Macedonia 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 an simulation model of the hydro power plant that 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 included in the operation and maintenance of the plant for their training. The HPP "Vrutok" is considered as a case study, since the plant is the biggest hydro power plant in Macedonia and it's role in restoration studies could be of the highest importance. According to the joint project DYSIMAC (Dynamic Simulation of the Macedonian Power Plants in a new Technological and Market Environment), the authors investigate dynamic characteristics of the unit A in HPP "Vrutok". It will be shown, that a model structure developed by investigating the documentation of the power plant together with a parameter estimation after islanding experiments will lead to comparatively simple simulation models which can guarantee a very good dynamic behaviour compared with the real power plant.

Fig. 1. Hydro power plant "Vrutok" in Macedonia.

The HPP "Vrutok" is located 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, see Fig. 1. Together with the "Mavrovo Lake" and the HPP "Vrben" and HPP "Raven", it forms a cacade system, see Fig. 2.

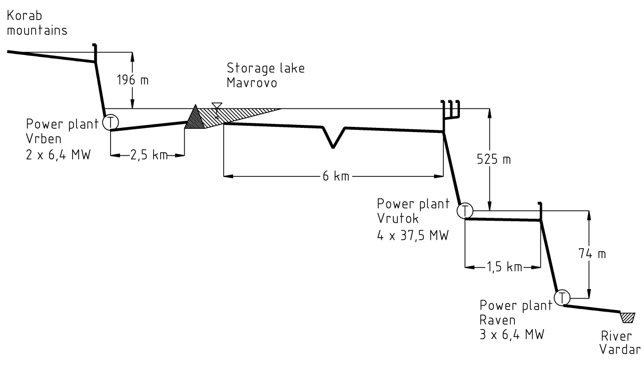

Fig. 2. Profile of the cascade system "Vrben-Vrutok-Raven".

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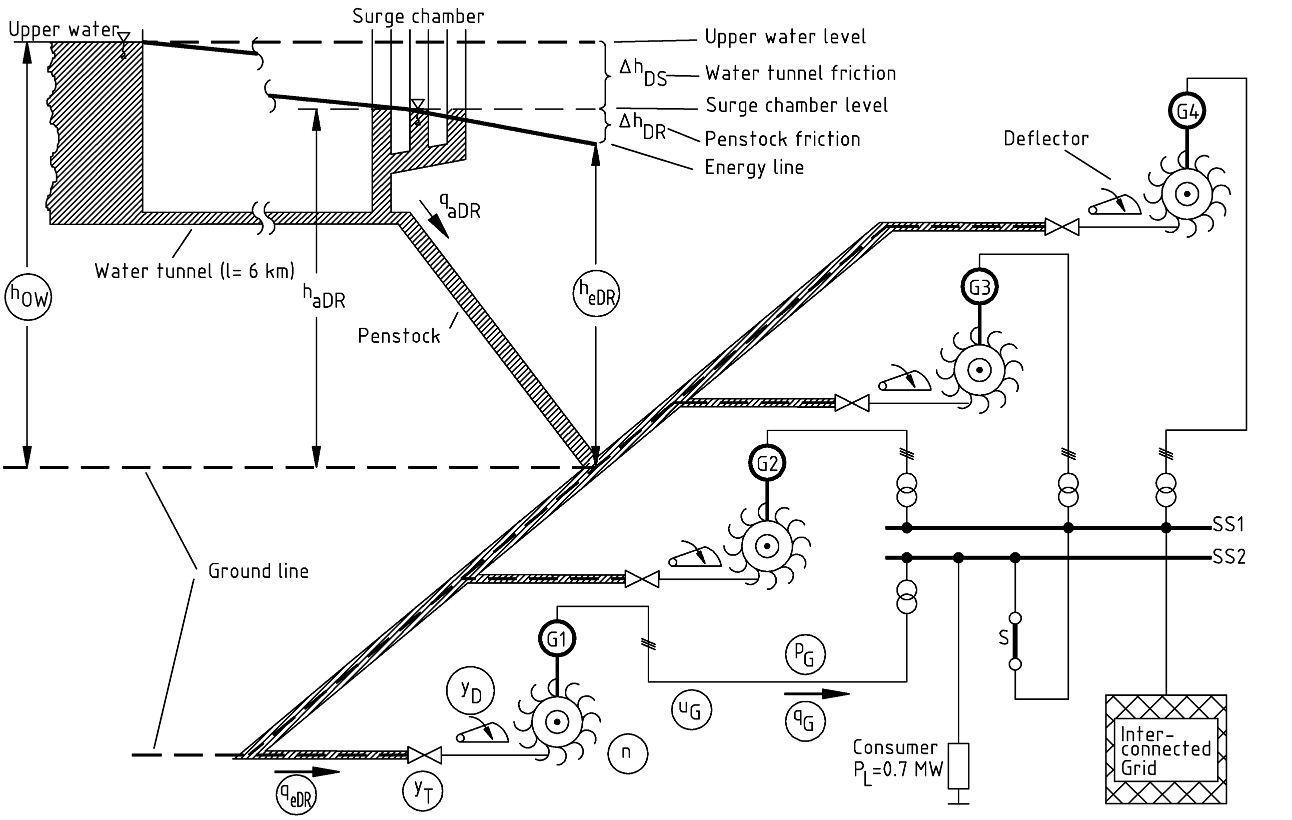

Fig. 3. Scheme of the hydro power plant "Vrutok".

The HPP "Vrutok" is the largest hydo 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. 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:
- number of units 4
- rated power 42 MVA
- rated voltage 12 kV
- rated speed 500 rpm
- rated flow 4 x 8 m³/s
- net height 525 m
- average yearly production 350 GWh.

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.

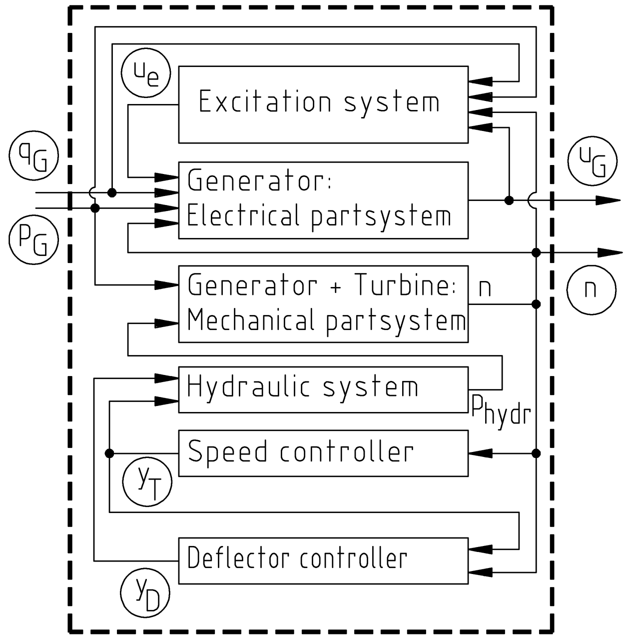

Fig. 4. General block diagram for the hydro power plant.

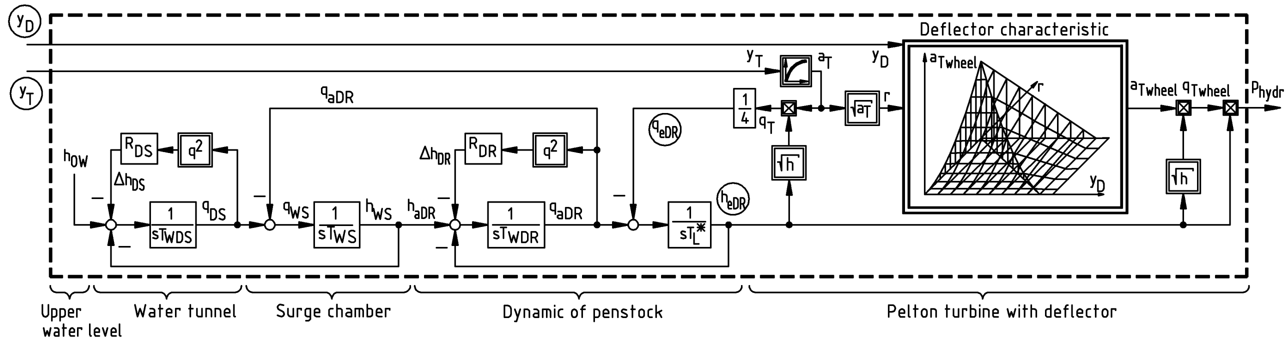

Fig. 5. Hydraulic system.

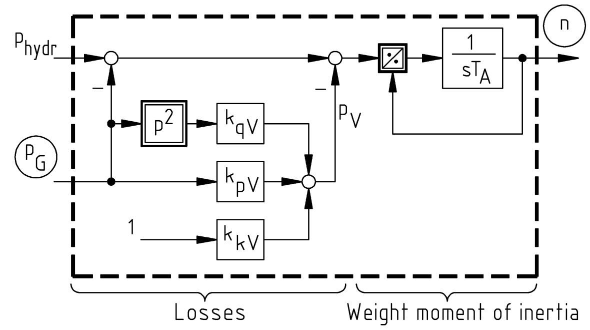

Fig. 6. Mechanical part (generator, turbine, losses).

II. Tests and measurements

The measurements are conducted on only one generator-turbine system, the unit A in the power plant. The other systems are similar. As depicted in Fig. 3 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);
- 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

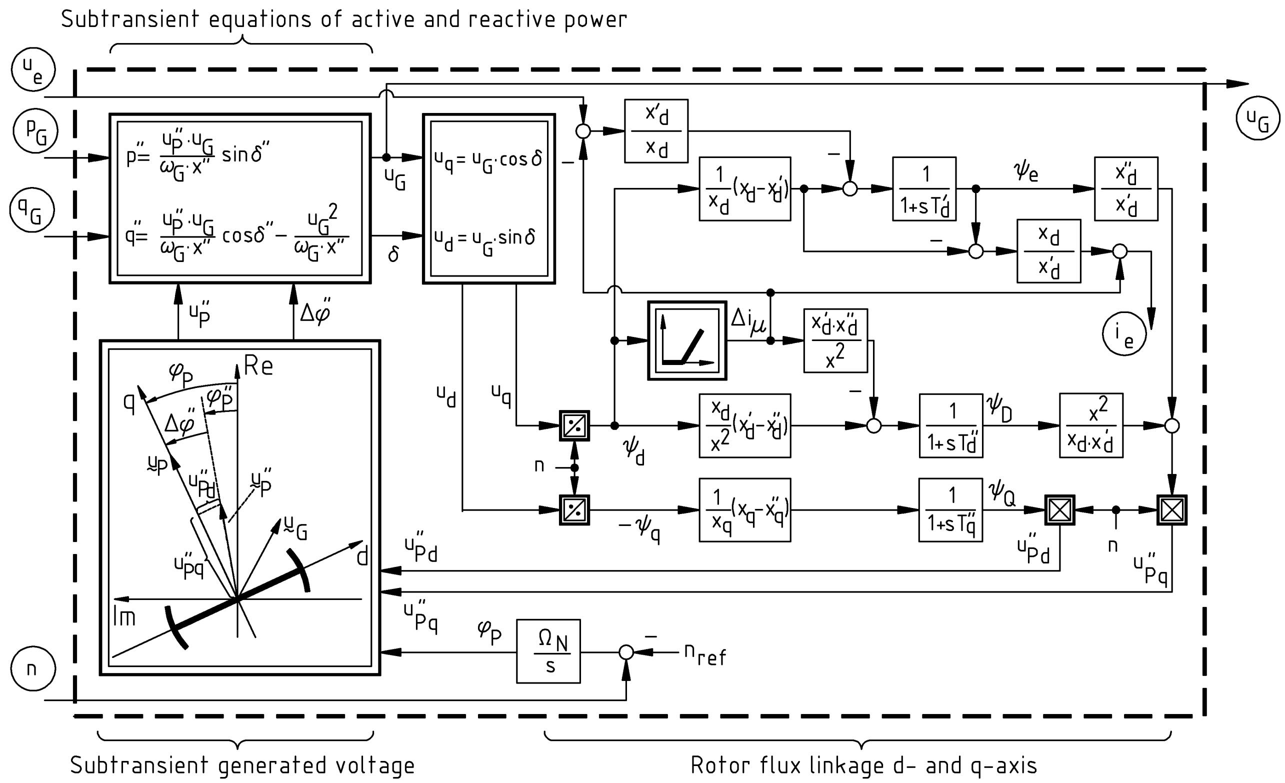

Fig. 7. Electrical part (generator).

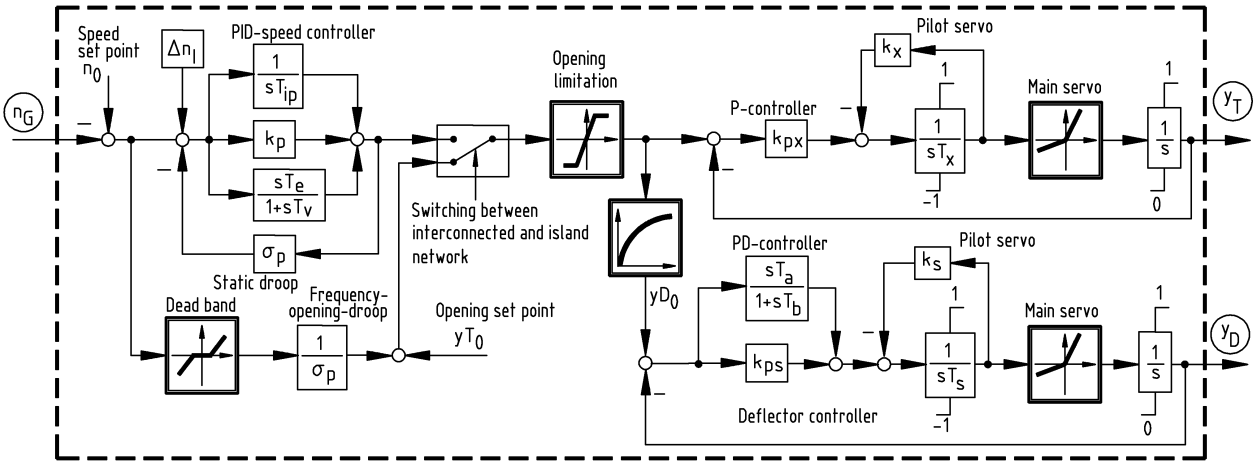

Fig. 8. Speed controller with deflector controller.

island. In this way the input signal of the system can be understood as a step input. The measured signals of the system are:

- active power p_G
- reactive power q_G
- speed n
- generator voltage u_G
- excitatiuon voltage u_e
- excitation current i_e
- turbine gate position y_T
- deflector position y_D
- water pressure at the turbine input h_{eDr} .

The measured signals are recorded by a PC-based Labview system with 16 channels. The sampling rate is 100 ms.

III. Modelling and Identification

Using the scheme of the hydro power plant in Fig. 3 and all available technical documentations, the models of the different part systems depicted in Fig. 4 were developed using the Matlab/Simulink software. The created overall model of the plant consists of 14 state variables and 32 unknown parameters which have to be identified. 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. 5 until Fig. 8. The circled signals are 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 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.

IV. Results

In Fig. 9 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 position y_D .

As depicted, a good correspondence between measurement and simulation can be achieved.

V. Conclusion

In Macedonia 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 simulation [4], [5].

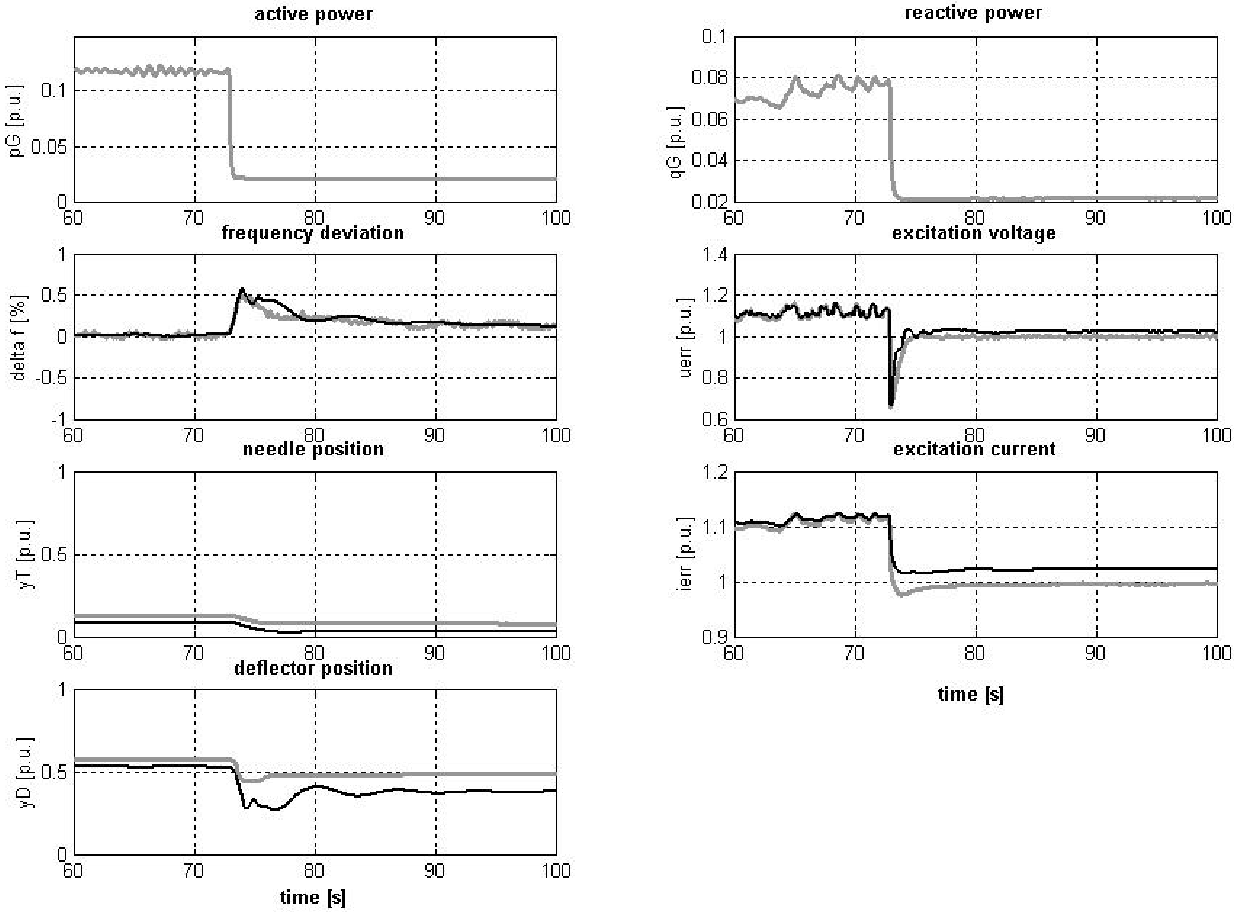

Fig. 9. Comparison of measured (grey) and simulated (black) signals after a +4 MW exchange-power-step.

In this contribution the modelling of a high pressure hydro power plant 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. This model can be practically used for experts analysis, staff training and can be incorporated in the Energy Management System to be installed in Electric Power Company of Macedonia. Furthermore, these investigations have proved that unit A in HPP "Vrutok" has reacted and responded to dynamic disturbances as it has been designed by installation of the new turbine's regulation and generator's excitation system from Swiss grant [6].

VI. Acknowledgement

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VIII. Biographies

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