

SIMULATION MODEL OF THE HYDRO POWER PLANT SHKOPETI

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Abstract

The energy sector is one of the most important sectors of the Albanian economy. Over 90% of the electric power is produced by hydro power plants, mainly by five important power plants in Northern Albania. Some of these power plants already have been rehabilitated with financial support of the World Bank and other donors. The situation in the Albanian transmission grid is characterized till this day by frequent interruptions every day. For planning of a safe and reliable operation in the future it's very important to have current simulation models, which can describe the static and dynamic behavior of the whole network including any elements. This contribution presents the most important steps for creation of a reality oriented model of the hydro power plant Shkopeti. Therefore in the hydro power plant measurements were performed to obtain step response time signals of all important functional parts. The setpoint for active power and the setpoint for generator voltage were changed stepwise during the power plant was working in interconnected mode. The transient behavior of the power plant was measured and recorded by a PC-based LabVIEW system with 16 channels. On the basis of available technical documentations and commissioning reports a general model including different submodels of the power plant was developed. Using the software MATLAB/Simulink it was possible to identify all the needed parameters of the mathematical model. The entire model of the hydro power plant consists of separate models of hydraulic part (water tunnel, surge chamber, penstock), turbine regulator, Kaplan turbine, voltage regulator with power system stabilizer, network model and generator. The simulation results show a good correspondence between measured and simulated values. The created model can be implemented as a part of an Albanian dynamic grid model realized for example with the software DIGSILENT.

Keywords: hydro power plant, modeling, identification, simulation, power system.

Presenting Author's biography

Fred Prillwitz. He was born 1960 in Teutschenthal, Germany. He received his Ph.D. degree from the University of Rostock in 1992. He made his doctoral thesis on the subject "Operating conditions of ship networks with variable frequency". Now he belongs to the scientific staff of the Institute of Electrical Power Engineering at the University of Rostock. His area of interests includes dynamic modeling and simulation of power systems and High Voltage Techniques.



1 Introduction

The further described project is part of the so called Stability Pact for South Eastern Europe and is supported by the German Academic Exchange Service.

The main problem today in the Albanian power sector is the limited generation capacity [1]. Albania must import over 25% of the total electricity. The increase of electricity consumption especially in households (cooking, cooling, space heating) has lead to high levels of technical and non technical losses. At the same time the security and the reliability of supply is decreasing. Daily interruptions of electricity supply are usual. This situation will continue in the future until new power plants and new transmission lines are constructed. Older facilities have to be reconstructed. The state own company KESH is responsible for generation and transmission of electric power. For the technical preparation of all constructions and renewings it's very important, to have actual models of the power system. With these models the static and the dynamic behavior of the system can be simulated in different scenarios. Only on this way it is possible to meet decisions on practical measures to be carried out.

Over 90% of the electric power is produced by hydro power plants. The five main hydro power plants (Table 1) belong to cascades at the river Drin and Mat in the North of Albania.

Tab. 1 Main hydro power plants in Albania

Hydro Plant	Power	River	Capacity [MW]
Komani		Drin	600
Fierze		Drin	500
Vau I Dejes		Drin	250
Ulza		Mat	26
Shkopeti		Mat	24

These hydro power plants play a dominant role in a dynamic model of the Albanian power system. Later these overall simulation models can be used by the staff for their training but also by experts for investigations like [3]:

- Black Start Capabilities after Black Out
- Behavior in isolated operation
- Primary and secondary power reserve capabilities
- Stability analyzes in the whole system.

The authors investigated dynamic characteristics of the hydro power plant Shkopeti. Using the

documentation of the power plant the simulation models were developed. After suitable experiments the model parameters could be estimated. In consequence the developed mathematical model shows nearly the same behavior as the real power plant. Similar modelings and identifications are already realized in Switzerland [4], Serbia [6] and Macedonia [7].



Fig. 1 Albania with the power plant Shkopeti

2 The hydro power plant Shkopeti

The hydro power plant Shkopeti is located in Northern Albania at the river Mat, approximately 25 km upstream from the mouth of the Mat into the Adriatic Sea, see Fig. 1 and Fig. 2. It is a run-of-river type and was put in operation 1963 with help of the former USSR. Together with the hydro power plant Ulza it forms a cascade system.



Fig. 2 Layout of the power plant Shkopeti

During the years of operation the power plant was poorly maintained. In the 90's the rehabilitation of the power plant Shkopeti was started. It was part of the so called "Drin River Cascade Rehabilitation Project" (DRCRP), financed by different international donors and lenders. The subject of the DRCRP was to rehabilitate and modernize the mechanical and electrical equipment of two power plants at the Drin River Cascade and two power plants at the Mat River Cascade [2]. The aim was to increase:

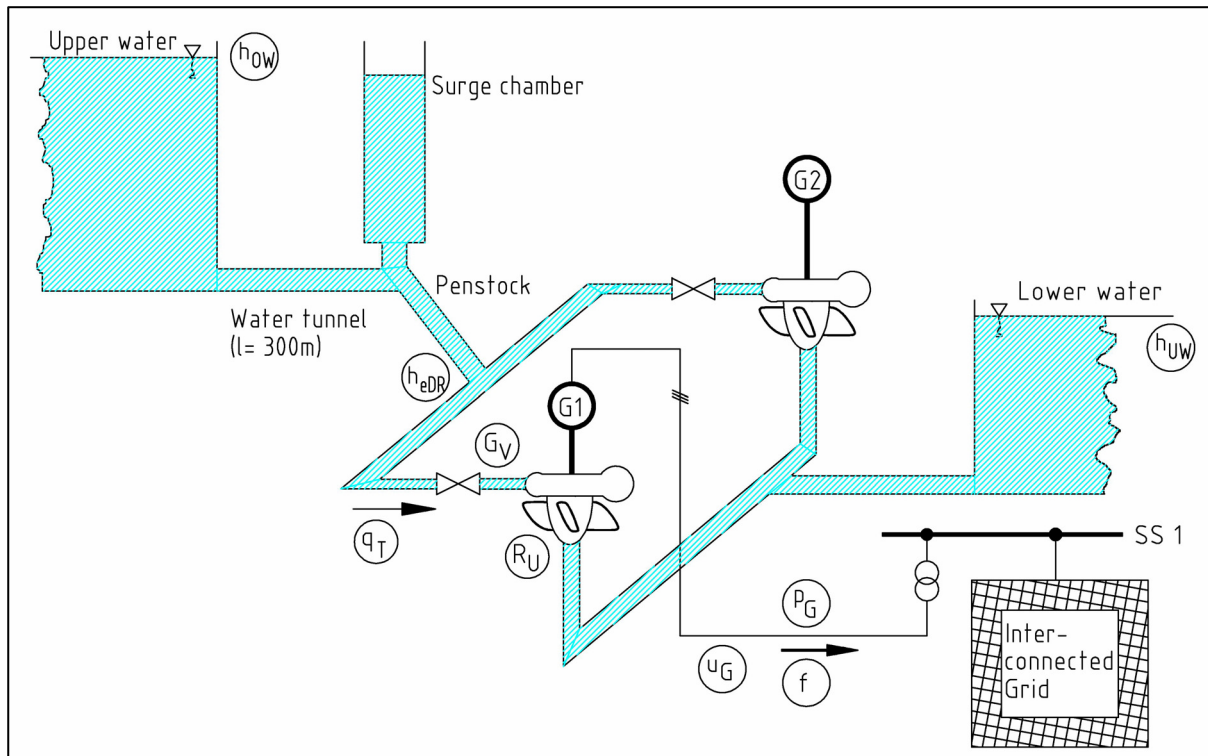


Fig. 3 Scheme of HPP Shkopeti

- the efficiency,
- the production output,
- the lifetime and
- the availability.

As result in the power plant Shkopeti the new hydro mechanical equipment was delivered by the Austrian company Andritz during the electrical equipment was rehabilitated by the Croatian company Koncar.

The main data of the hydro power plant Shkopeti are shown below:

Number of units:	2
Type of turbines:	Kaplan
Power / unit:	12 MW
Rated speed:	300 min ⁻¹
Rated flow / unit:	35 m ³ /s
Net height:	40 m
Gravity dam:	53 m high, 90 m long
Rated voltage:	10 kV

3 Measurements

The scheme of the hydro power plant Shkopeti is shown in Fig. 3. The measurements are conducted at only one generator-turbine system. The other unit is treated as similar. The circled signals are measured ones. But also further signals of the different controllers were measured. The overall signal list is shown in Tab. 2. The signals were measured and recorded by a PC-based LabVIEW system with 16 channels. The sampling rate was 50 ms. The measurements have to be performed during the transition from one stationary working point to another. These changes of the working points can be initiated by a manually changing of the setpoint for active power. All experiments were executed in interconnected operation. The stepwise changing of the setpoint can be understood as a step input for an unknown system which has to be identified. The procedures:

- starting of the unit and synchronizing,
- switch off and stopping of the unit

should also be measured to receive additional informations.

There was no possibility to run the investigated unit in isolated operation. There was also no option to realize a step input to the voltage controller. The signal "reactive power" from generator was not available.

Tab. 2 Measured signals

Channel No.		Signal
1	h_{OW}	Upper water level
2	h_{UW}	Lower water level
3	p_{Gset}	Setpoint active power
4	h_{eDR}	Spirale pressure
5	p_G	Active power
6	y_{GV}	Position control valve guide
7	G_V	Position guide vane
8	q_T	Water flow
9	y_{RU}	Position control valve servo runner
10	R_U	Position runner
11	f	Generator frequency
12	u_G	Generator voltage
13	i_e	Generator excitation current
14	u_e	Generator excitation voltage

4 Model of the power plant

All available technical documentations and commissioning reports of the power plant were studied. After this investigation an overall dynamic model of the power plant could be developed.

The block diagram of the complete model with its submodels is presented in Fig. 4. The model was created by using the software Matlab / Simulink as a "per unit" model. The "per unit" notation enables the interface between the submodels.

The circled signals in the general block diagram and in all submodels are measured ones. The location of the measured signal points plays an important role for dividing of the general model into submodels and the possible separate identification of the submodels.

Wherever its possible, the parameters of the submodels (time constants, gains and characteristics) can be taken from the documentations, if they are certainly known and not modifiable.

5 Identification

The identification is divided in a few steps. The basis for the identification is a table with measured stationary state values in different stationary working points. With this its possible to define time independent characteristics and to detect offsets. The identification has been carried out in the following order:

- Approximation of the function between guide vane position G_V and active power p_G ,
- Approximation of the function between runner position R_U and guide vane position G_V ,
- Identification of the turbine regulator,
- Approximation of the function between turbine cross-section a_T and guide vane position G_V resp. runner position R_U ,
- Identification of the hydraulic part,

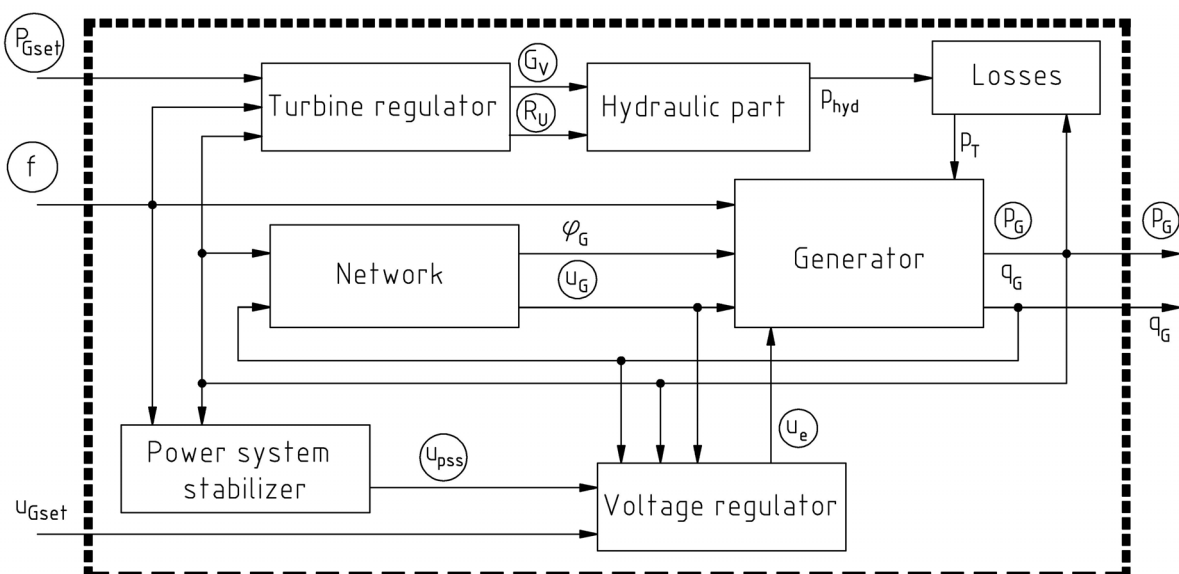


Fig. 4 General block diagram of HPP Shkopeti

- Identification of the losses characteristic together with generator and network,
- Identification of the power system stabilizer,
- Identification of the generator voltage setpoint together with the voltage regulator,
- Test of the complete model with p_{Gset} , f and u_{Gset} as input signals and p_G and q_G as output signals.

For identification the least square error method is used, see Fig. 5.

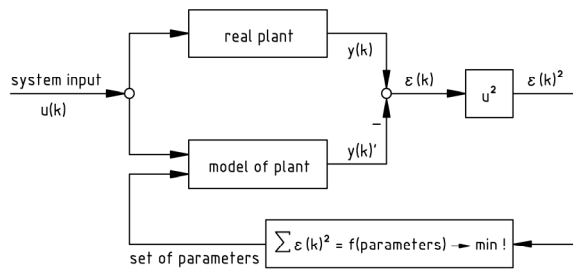


Fig. 5 Least square identification method

The squared difference between measurement and simulation will be minimized by variation of the model parameters. When identifying more than one parameter at a time the weight of the parameters can be changed. Therefore the algorithm was programmed in Matlab. The starting parameters can be taken from documentations, estimations resp. experiences.

6 Submodels

Shkopeti is a low pressure run-of-river type of power plant. Because of the relatively long distance (approximately 300 m) from the dam to the machine house the power plant was constructed with water tunnel, surge chamber and penstock. This fact is not typical for a run-of-river power plant. The model of the hydraulic part is shown in Fig. 6. The inertia of the water was taken into consideration by the time constants T_{WDS} (water tunnel), T_{WS} (surge chamber) and T_{WDR} (penstock).

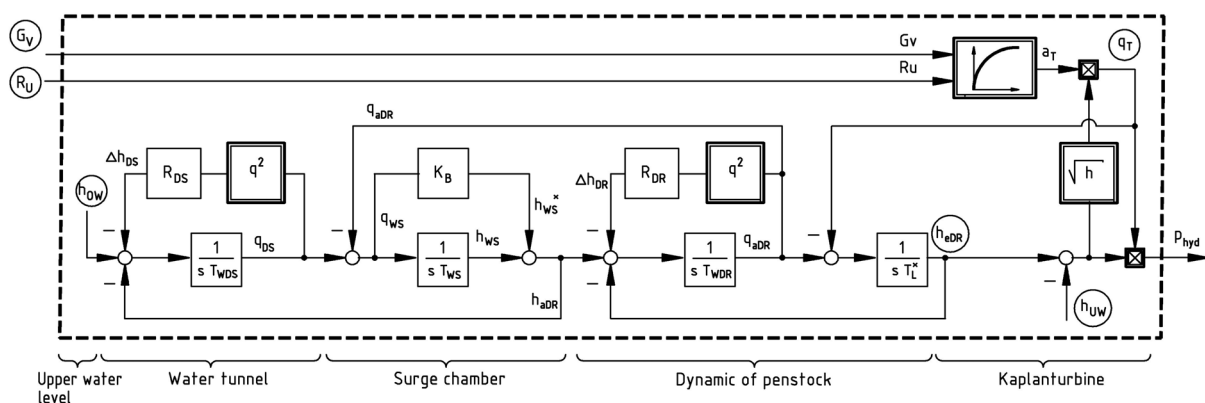


Fig. 6 Model of the hydraulic part

The elasticity of the water and the penstock is simplified modeled by the time constant T_L^* . The friction losses were represented by the factors R_{DS} (water tunnel) and R_{DR} (penstock). The Kaplan turbine is controlled by the position of guide vane G_V (turbine opening) and the position of runner R_U (blade angel). These positions are defined by corresponding servo motors which are provided by the turbine regulator. The turbine cross-section physically represents the equivalent cross-section of the water inflow into the turbine. The function between guide vane G_V , runner R_U and cross-section a_T could be identified from the stationary measurements, see Fig. 7. In doing so the Torricelli equation, Eq. 1

$$q_T = a_T \cdot h^{1/2} \quad (1)$$

is the basis for the identification of this characteristic.

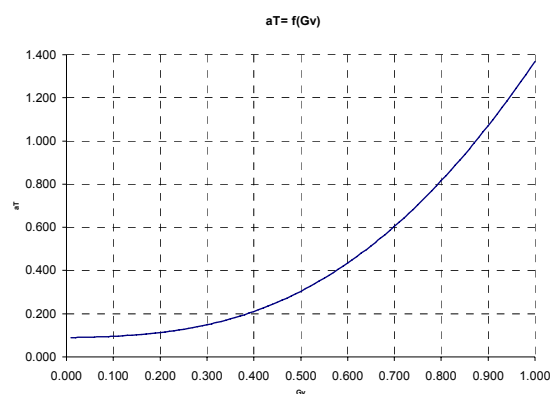


Fig. 7 Characteristic of turbine cross-section

Finally the hydraulic power p_{hyd} is calculated with Eq. 2

$$p_{hyd} = \Delta h \cdot q_T \quad (2)$$

At the same time the hydraulic power p_{hyd} represents the input signal of the losses submodel, see Fig. 8. This model includes all turbine losses, friction losses in the bearings and also the complete electrical losses of the generator. The resulting losses function, Eq. 3, can be identified from the stationary values of hydraulic power p_{hyd} and generator active power p_G .

The output signal of the losses submodel is the turbine power p_T . In stationary working points the turbine power p_T is equal to the generator active power p_G .

$$p_V = k_{kV} + p_G \cdot k_{pV} + p_G^2 \cdot k_{qV} \quad (3)$$

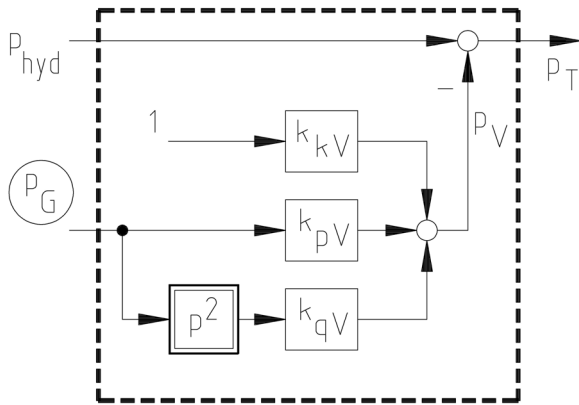


Fig. 8 Submodel losses

The turbine regulator in the power plant is a rather new type. The regulator consists of two parts, the electrical and the electro-hydraulic part, see Fig. 9. The heart of the electrical part is a PID-controller. This controller defines the opening positions of the guide vane and the runner. Via a system of auxiliary and servo motors in the electro-hydraulic part the guide vane and the runner move to the required position. The input signals of the electrical part were completely measured. The frequency of the grid is needed if the power plant will participate at the primary regulation. In the current case the frequency path was not in operation because the droop σ_p was adjusted to zero. The setpoint for active power p_{Gset} is not directly connected to the PID-controller. There is a ramp generator interconnected to avoid abrupt setpoint

steps. The function between the output signal of the PID-controller y_{PID} and the setpoint for the position of guide vane G_{Vset} could be identified from the stationary measurements of p_G and G_V , see Fig. 10.

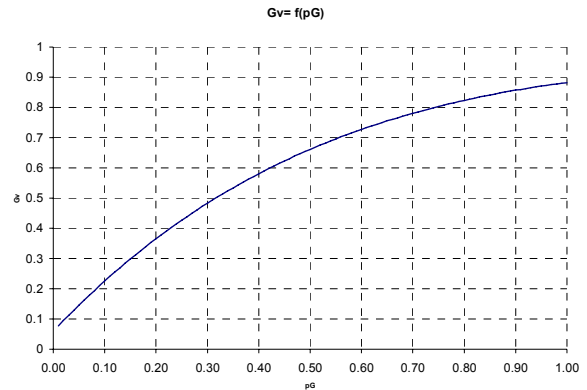


Fig. 10 Characteristic of guide van position

In the same way the function between the setpoints for guide vane G_{Vset} and runner R_{Uset} could also be identified from stationary values, see Fig. 11.

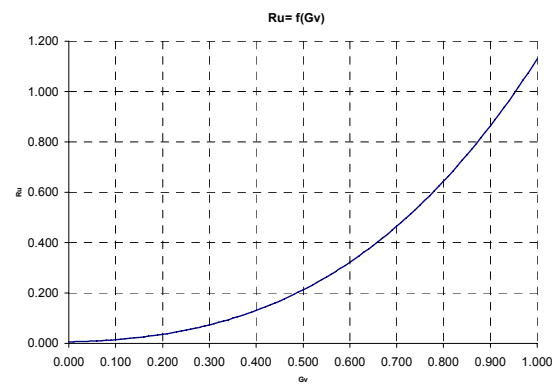


Fig. 11 Characteristic of runner position

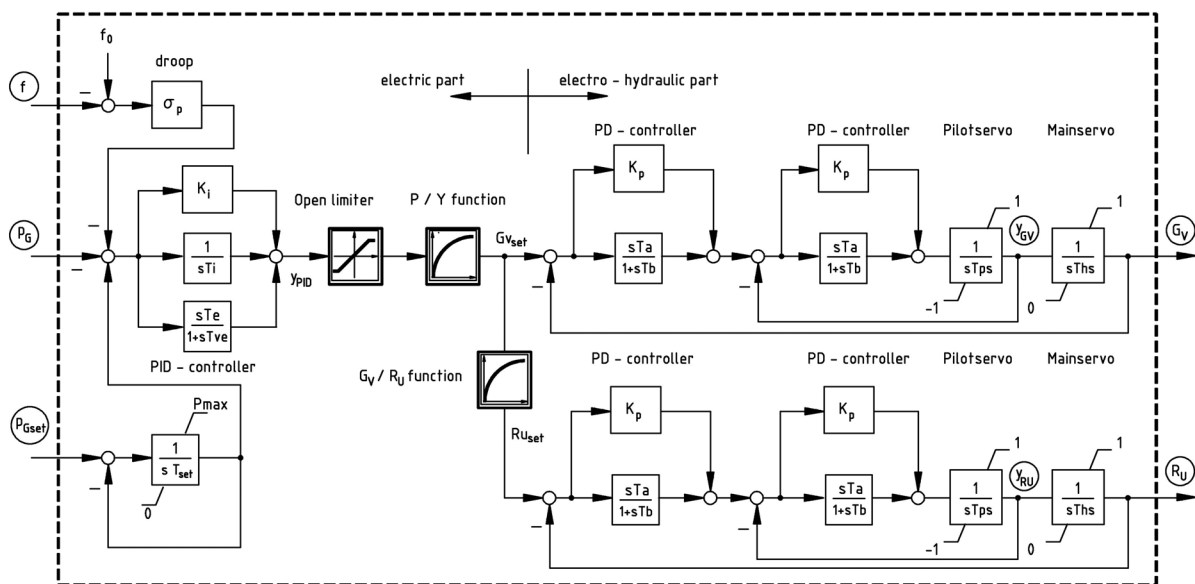


Fig. 9 Model of the turbine regulator

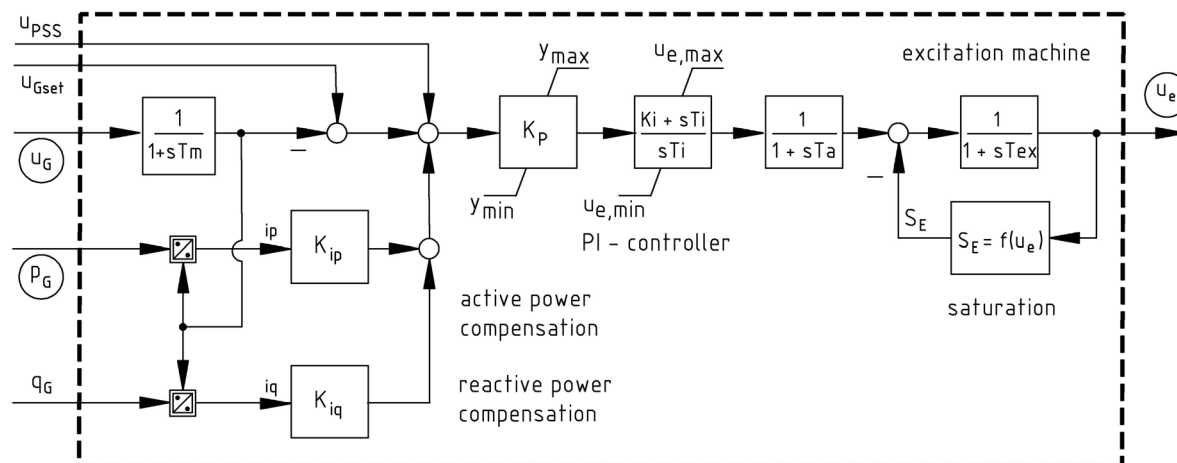


Fig. 12 Model of voltage regulator

The model of the generator is based on the non-linear fifth order model of a synchronous machine [5]. This model has been qualified to simulate the interconnected operation mode of a generator. The input signals are excitation voltage u_e , frequency f , turbine power p_T and the voltage u_G , φ_G at the connected network busbar. Voltage u_G and phase angle φ_G are the results from a load flow calculation in the network submodel. The inertia of the generator turbine set is also included in the generator model. The output signals are active power p_G and reactive power q_G . The parameters of the generator were taken from the power plant documentations.

The voltage regulator is a new type from Koncar. It's constructed as a PI-controller with active and reactive compensation, see Fig. 12. The output of the PI-controller supplies a DC-machine, which works as an amplifier. This DC-machine is modeled as excitation machine with saturation. The active power compensation was not in operation because the gain K_{ip} was adjusted to zero. The setpoint for the generator voltage u_{Gset} is one of the input signals. Unfortunately this signal could not be measured. In those experiments where this setpoint was not changed, the value can be calculated as in Eq. 4.

$$u_{Gset} = u_G - u_{PSS} - i_q \cdot K_{iq} \quad (4)$$

In the other case when the setpoint was changed stepwise, the time behavior of u_{Gset} has to be identified. Generally the setpoint was changed by the commands increase/decrease with a constant control speed. The input signals of the voltage regulator are the generator voltage u_G , the mentioned voltage setpoint u_{Gset} , active and reactive power and the signal from power system stabilizer u_{PSS} . The only output signal is the excitation voltage going to the generator.

The input signals of the power system stabilizer are the frequency f and the active power p_G . The only output signal u_{PSS} depends on the gradient of frequency and active power. The parameters of the model, see Fig. 13, could be taken from the documentations.

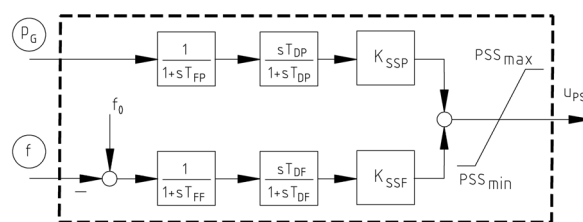


Fig. 13 Model of the power system stabilizer

7 Simulations

All submodels were connected to a complete model of the power plant according to Fig. 4. In the following some comparisons of measured and simulated signals are presented. The measured signals are depicted in blue during the simulated signals are depicted in red.

Fig. 14 shows one experiment in which the setpoint for active power was increased in steps of approximately 10%. The procedure takes over 10 minutes. After each power step there is a waiting time for stabilizing of the working points. Generator voltage and reactive power are nearly constant all the time. As can be seen the correspondence between simulated and measured signals is relatively good.

In Fig. 15 the results are shown after a relatively big step change of the active power setpoint. After reaching the stationary state at $t = 90$ s, the setpoint for the generator voltage was also changed in 3 steps. A good correspondence between measurement and simulation can be achieved.

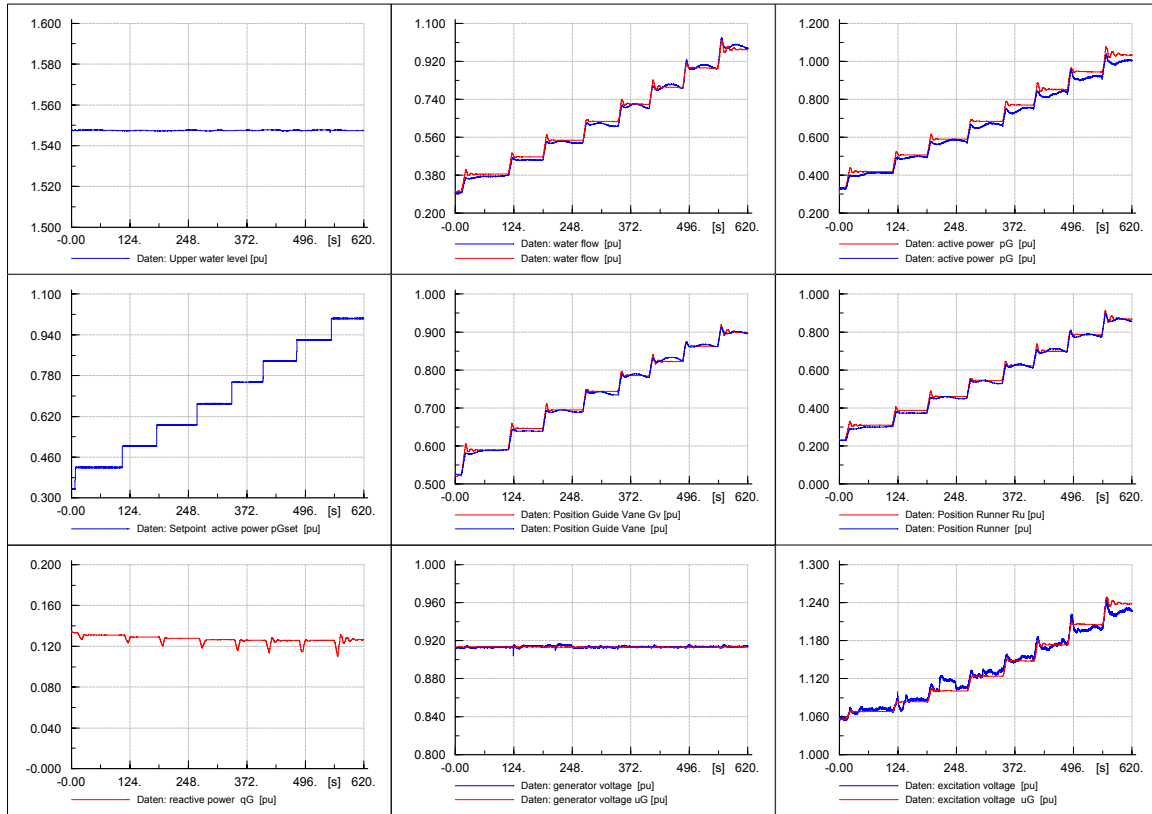


Fig. 14 Measured (blue) and simulated (red) signals during changing the setpoint of active power

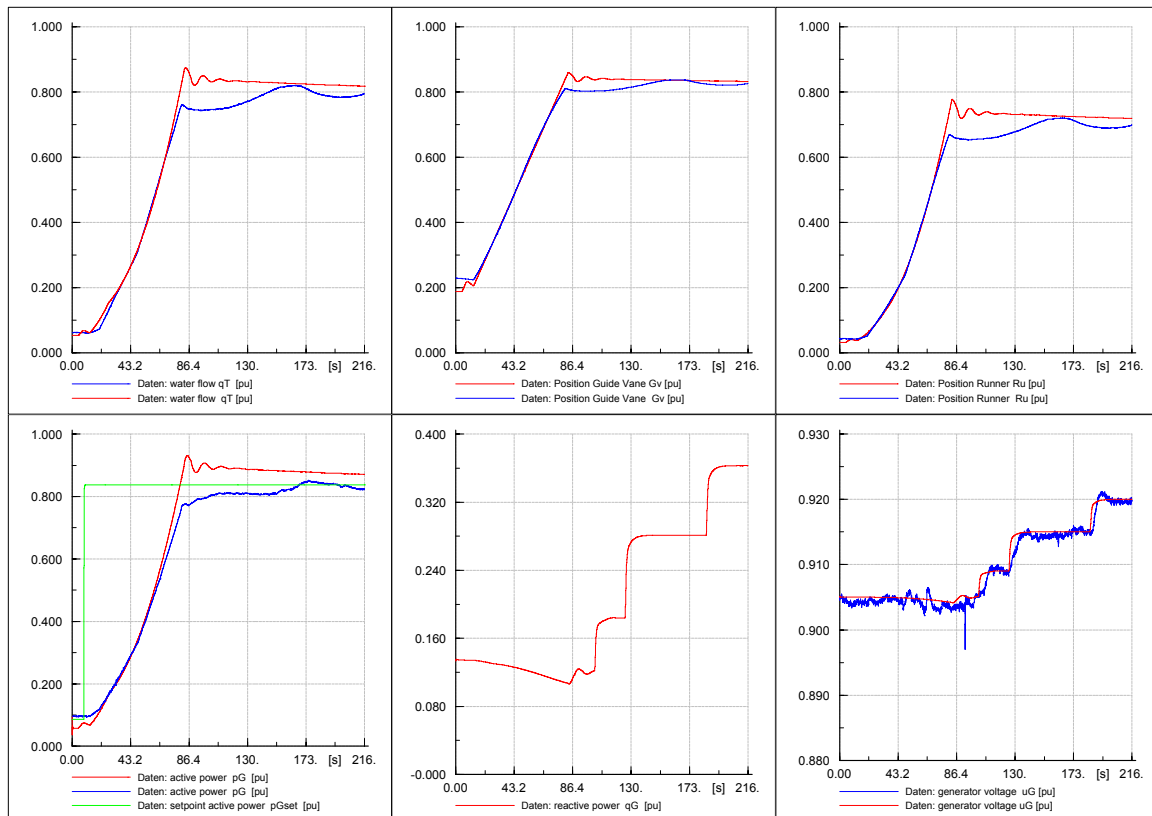


Fig. 15 Signals after a power step of +11 MW

8 Conclusion

Today a very problematical energy situation in Albania can be established. The production of electrical energy is too low, the losses are too high and the facilities are too old. Therefore a lot of renewings, rehabilitations and enlargements in the electric power system are necessary in the next years. On that account it will be very useful to have an overall dynamic network model based on up to date conditions.

Based on the measurements in the hydro power plant Shkopeti and on the provided documentations a dynamic model of the power plant was designed and identified. The model and the real power plant show nearly the same behavior. The model can be implemented as a part of an Albanian dynamic grid model.

Because of technical problems it was not possible to measure all the signals, which were ideal needed for the identification process. Those signals must be identified. The created model is only valid for interconnected operation mode. For further investigations it can be recommended to investigate also the isolated operation. The behavior respectively the model of the power plant is different in both operation modes. Because of the current situation in the Albanian grid the usage of both models seems to be necessary.

9 References

- [1] The European Union's CARDS programme for the Balkan region—Contract No.52276, Volume 5: Generation & Transmission Appendices, Final Report, 31 December 2004.
- [2] KEK-CDC Consultans. Evaluation of Austrian Cooperation with Albania 1991/1992 – 2004. Report, Final Version, Zurich, December 2005.
- [3] H. P. Asal, R. Widmer, H. Weber, E. Welfonder and W. Sattinger. Simulation of the restoration process after black out in the Swiss grid. *Bulletin SEV/VSE*, 83, 22, 1992, pp. 27-34.
- [4] H. Weber, F. Prillwitz, M. Hladky, and H. P. Asal. Reality oriented simulation models of power plants for restoration studies. *Control Engineering practice*, 9, 2001, pp. 805-811.
- [5] H. Weber. Dynamic model reduction for the modal analysis of frequency and power oscillations in large power systems. Dissertation, University of Stuttgart, 1990.
- [6] A. Holst, M. Golubovic, H. Weber. Dynamic model of hydro power plant "Djerdap I" in Serbia. International Youth Conference on Energetics, Budapest, Hungary, 31 May – 02 June 2007.
- [7] H. Weber, F. Prillwitz. Simulation models of the hydro power plants in Macedonia and Yugoslavia. Conference IEEE Bologna Power Tech 2003, Bologna, Italy, 23 - 26 June 2003.