

## HIGH QUALITY MODELLING OF HYDRO POWER PLANTS FOR RESTORATION STUDIES

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**Abstract:** The verification of existing plans for network restoration after blackouts in European electrical energy systems becomes more and more important with the ongoing deregulation process. For this verification high quality computer models of the electrical system are necessary which are able to generate exact results for all possible restoration scenarios. The most important elements of these models are the power plants, which have to be developed with high accuracy. Therefore in this contribution the possible quality of power plant modelling will be shown exemplarily for a francis type and a pelton type hydro power plant, both located in the Swiss Alps. *Copyright © 2002 IFAC*

**Keywords:** power plant modelling, simulation of electrical network restoration

### 1. INTRODUCTION

In stability scenarios of electrical networks today often very simple and restricted models of power plants, loads and equipment for control and security purposes are used. The parameters of these models are often estimated only roughly. Models of this kind are sufficient for investigations concerning the so called global behaviour of interconnected networks (oscillations, primary and secondary control), because the related dynamic transients only influence the normally very well modelled main control loops of these models (Weber and Welfonder, 1988). But when it comes to computer simulations dealing with restoration scenarios for electrical networks much more detailed models of power plants and power systems are needed than e.g. with stability scenarios. Because in this investigations, especially for a particular power plant, all control loops and security equipment have to be modelled exactly. In this case, all possible transients are important for the whole working range of the plant, from zero to full operation. Especially security equipment with different triggering values, non-linearities and characteristics play a very important role in these restoration investigations. As examples for the high quality modelling possibilities of power plants two hydro power plants of the Swiss Alps will be

presented, one a francis type and one a pelton type plant.

### 2. THE MODELLED POWER PLANTS

The francis type power plant "Innertkirchen II" is located near the "Grimsel Pass" in the canton Bern as part of the cascade system "Oberhasli" and the pelton type plant "Airolo" is located near the "Gotthard Pass" in the canton Tessin as part of the cascade system "Lucendro", see map Fig.1 and overall overviews Fig. 2.



Fig. 1: Swiss map, location of plants "Innertkirchen II" and "Airolo"

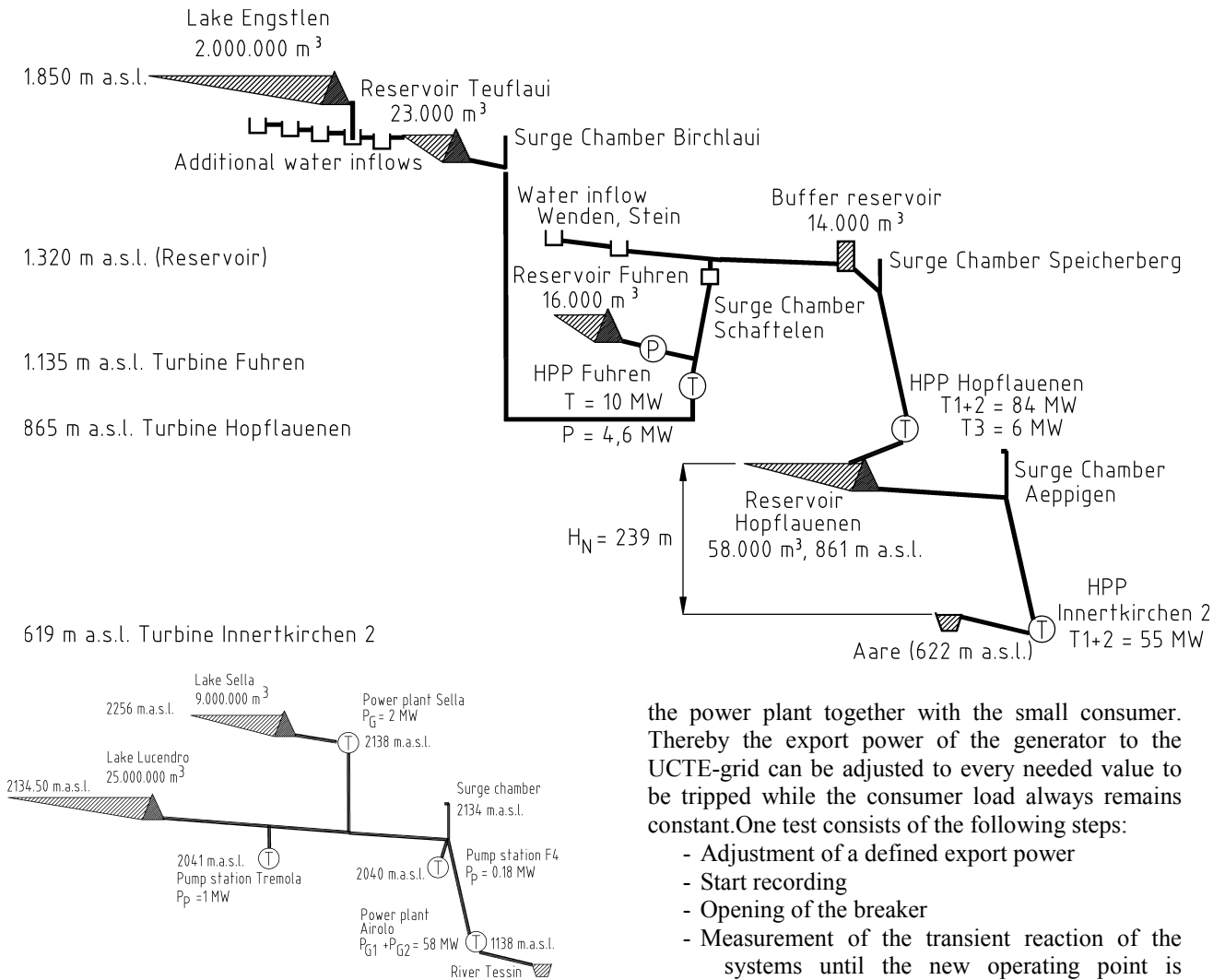


Fig. 2: Overview of 55 MW power plant “Innertkirchen 2” (upper) and 58 MW power plant “Airolo” (lower)

Fig. 3 shows the different schemes of the plants. In Fig. 4 an overview block diagram of the main parts of the developed power plant models is depicted. As shown in this diagram, only the active and reactive power of the plants are the input signals. All output signals and states of the real plants have to be simulated by the developed dynamic model in such a way that the fit between measured and calculated signals is optimised for all operating points of the plants.

### 3. TESTS AND MEASUREMENTS

Even in power plants with more than one generator set, the measurements necessary for the identification of the model parameters are usually conducted only on one set, because the other sets are expected to be identical. As shown in Fig. 3 the investigated generator-turbine-sets always deliver energy in the same time to a smaller consumer and to the European interconnected grid (UCTE-grid). This interconnected grid in both cases can be switched off for islanding

the power plant together with the small consumer. Thereby the export power of the generator to the UCTE-grid can be adjusted to every needed value to be tripped while the consumer load always remains constant. One test consists of the following steps:

- Adjustment of a defined export power
- Start recording
- Opening of the breaker
- Measurement of the transient reaction of the systems until the new operating point is reached.

The measurement equipment consists of a laptop with PCMCIA-DAQ (16 bit, 16 channels), using the Labview measuring software (National Instruments, 1999).

The measured signals of the system are:

- Active power
- Reactive power
- Speed
- Generator voltage
- Excitation voltage and current
- Turbine gate position
- Water flow to the turbine
- Water pressure at the turbine input
- Deflector position etc.

### 4. MODELLING AND IDENTIFICATION

Using the scheme of the plants of Fig. 3 and all available power plant information like commissioning and test data of the non-linear models, the subsystems depicted in Fig. 4 are developed using the Matlab software (The Math Works, 1999).

In Fig. 5a exemplarily the hydraulic part (De Jaeger *et al.*, 1992) of the power plant “Innertkirchen 2” is shown and in Fig. 5b the related turbine controller of “Sulzer-Escher Wyss” type (IEEE Working Group on Prime Mover and Energy Supply 1992). In Fig. 6a

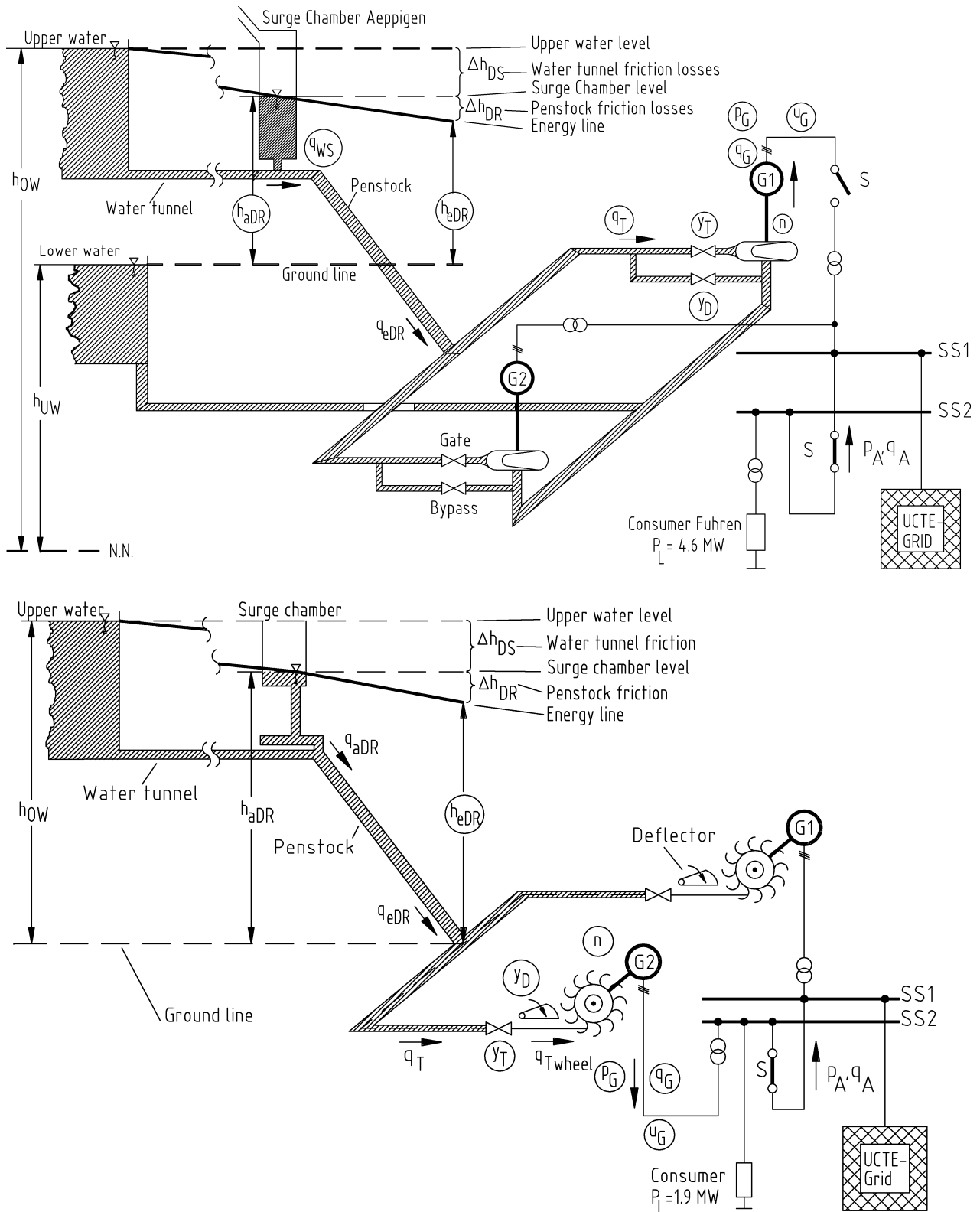


Fig. 3: Schemes of “Innertkirchen 2” (upper) and “Airolo” (lower)

also exemplarily the hydraulic part of the pelton type power plant “Airolo” is shown and in Fig. 6b the related turbine controller also of “Sulzer-Escher Wyss” type. More block diagrams cannot be shown here because of lack of space.

The identification of the power plant models are conducted in Matlab using the Least-Square-Method (Weber and Zimmermann, 1996).

In the first step only the hydraulic parts, together with the mechanical parts, are identified using the gate opening as input and the water pressure and the turbine speed as outputs.

In the second step the parameters of the turbine and bypass/deflector controllers are identified using the hydraulic and the mechanical system identified in step one. In this step the active power is model-input

and model-outputs are gate position and deflector position. The parameters of the hydraulic and the mechanical part remain unchanged in step 2. In the third step the electrical generator part, the voltage controller and the exciter are identified. In

this step the model-inputs are active and reactive power, model-outputs are generator voltage and the excitation current and voltage.

5. RESULTS

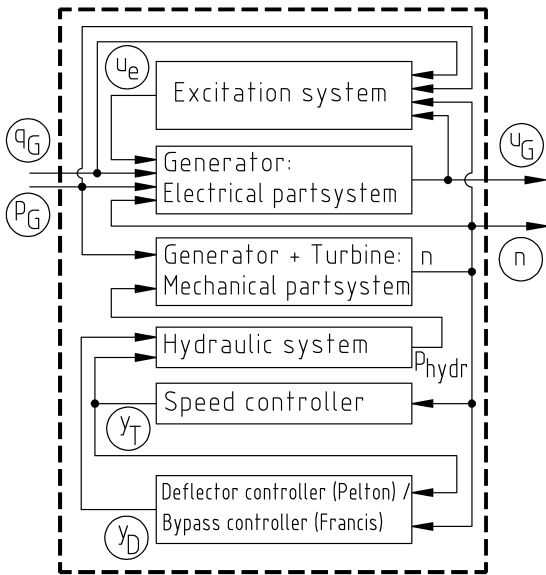


Fig. 4: General block diagram for hydro power plants

In Fig. 7 the measurement and simulation results for the francis type plant and in Fig. 8 for the pelton type plant are shown as a comparison of measured and simulated signals. In both cases an export power surplus was tripped off and therefore the speed of the generator increased. The step size of the switched active power was 30% of the nominal power of the plant in both cases. For the francis type power plant in Fig. 7 the following reaction after islanding can be observed:

- a) Active and reactive power are reduced from the interconnected value to the island value for supplying the small consumer (Fig. 7a,b).
- b) As reaction speed and voltage of the power plant are increasing (Fig. 7c,d).
- c) The turbine controller (Fig. 5) immediately closes the francis turbine gate  $y_T$  (Fig. 7e).
- d) This results in a very fast pressure increase (Fig. 7h).
- e) Therefore the bypass valve  $y_P$  (Fig. 7g) opens also immediately to ensure a slow deceleration of the flowing water column in the penstock.

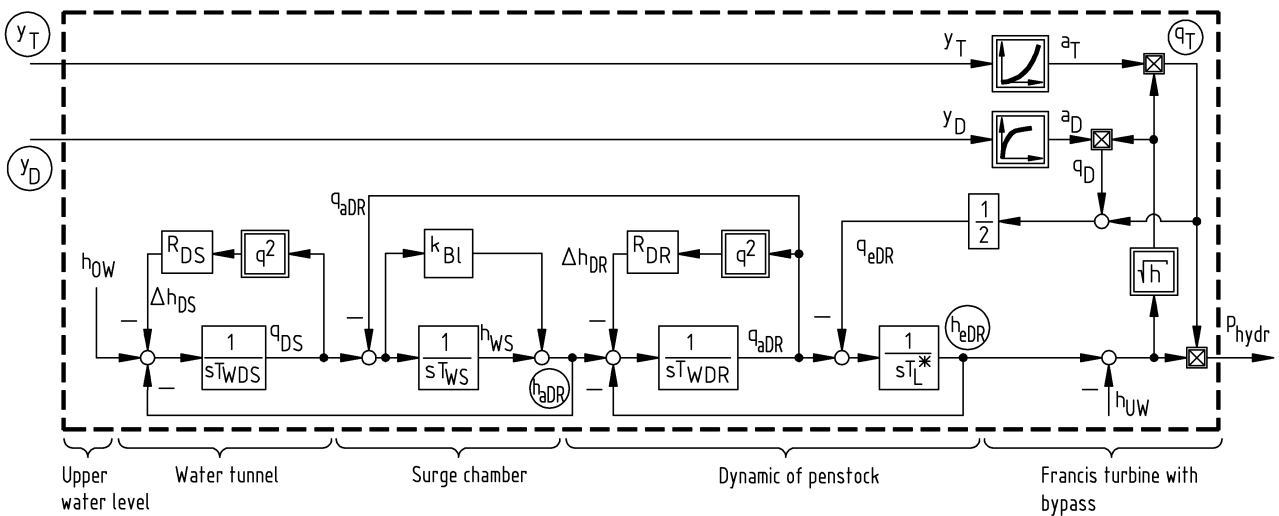


Fig. 5a: Hydraulic part of "Innertkirchen 2"

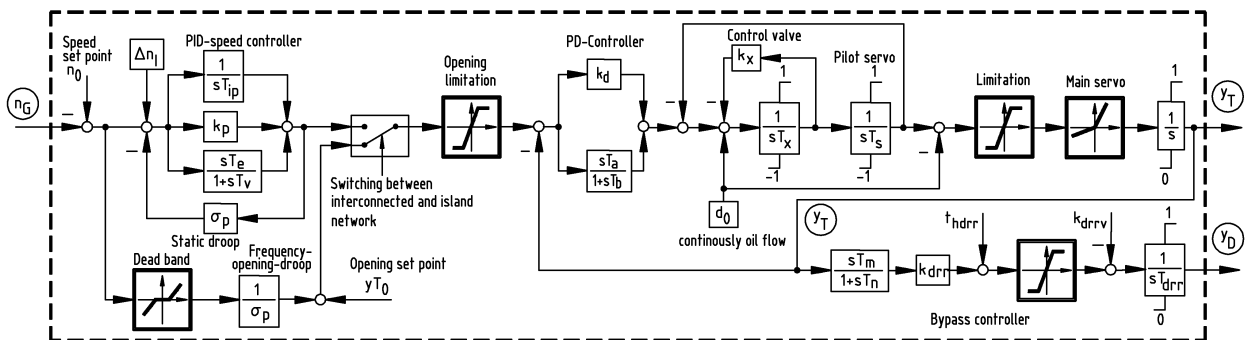


Fig. 5b: Turbine controller "Innertkirchen 2" (Sulzer-Escher Wyss type)

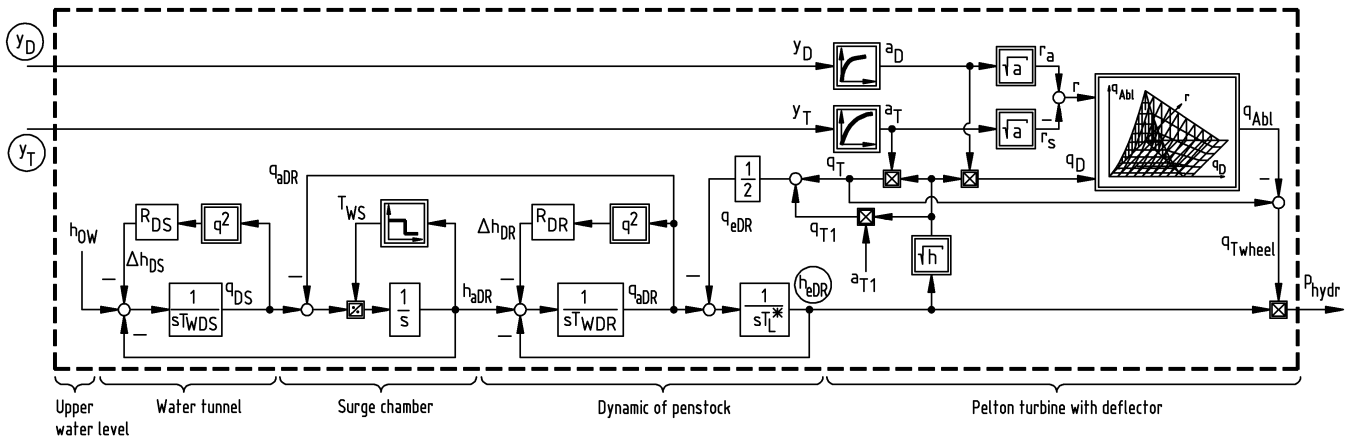


Fig. 6a: Hydraulic part of "Airolo"

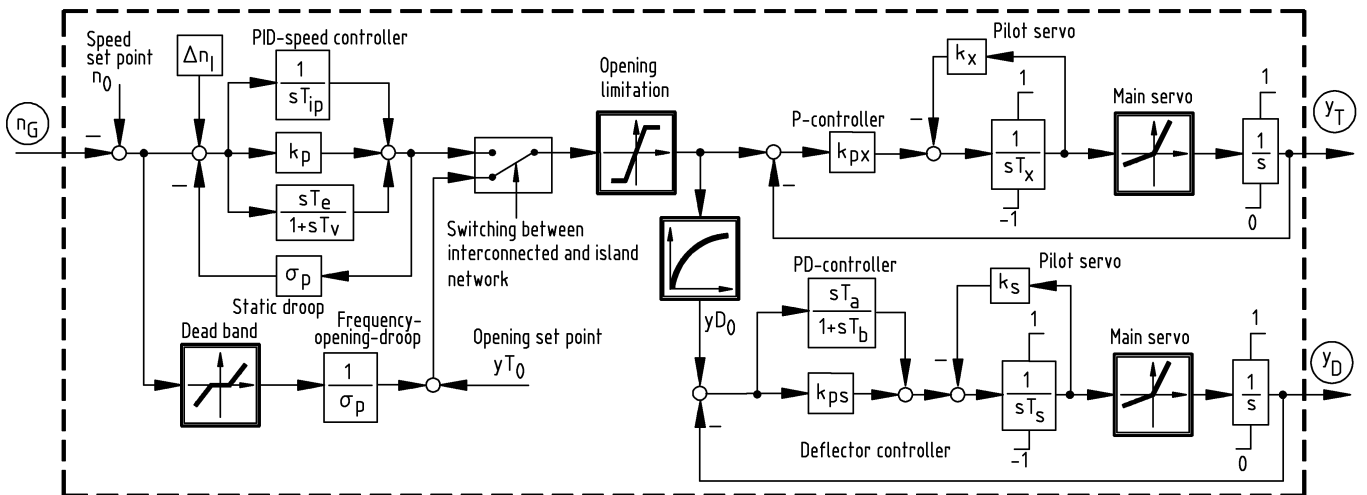


Fig. 6b: Turbine controller „Airolo“ (Sulzer-Escher Wyss type)

- f) This results in a fast reduction of pressure and then in a little overpressure of only 5 % (Fig. 7h).
- g) Also the voltage overshoot is controlled very fast by the voltage controller via the generator excitation voltage. Overvoltage is only 7 % (Fig. 7d).

For the pelton type power plant in Fig. 8 the following reaction after islanding can be observed:

- a) Again active and reactive power changes from interconnected to isolated values (Fig. 8a,b).
- b) Also in this case speed and voltage are increasing (Fig. 8c,d).
- c) But now the turbine controller (Fig. 6b) only slowly closes the needle of the pelton wheel (Fig. 8e).
- d) This causes only a very small pressure increase compared with the francis type power plant (Fig. 8h vs. Fig. 7h).
- e) To avoid overspeed the deflector is reacting very fast to deflect the water jet from the pelton wheel (Fig. 8g).
- f) This results in a small overspeed of only 9 % (Fig. 8c).
- g) Also in this case the voltage is controlled very fast. Maximum overvoltage exceeds only 3 % (Fig. 8d).

In both cases the models of the power plants are producing nearly the same behaviour as the real plants in all relevant signals. This means that this models can be used in all computer studies of power systems where high accuracy results is necessary.

## 6. CONCLUSION

With the ongoing liberalisation of the European Interconnected Network the restoration strategies after severe disturbances of the different national utilities have to be examined in advance (Weber *et al.*, 1996). For this examinations correctly developed dynamic models of the power plants and power systems are necessary. These models have to be generated in such a way that they are reliable for all operating points of the system from zero to full operation. On the other hand, the complexity and order of the models must not be too high because, in restoration scenarios, a lot of power plants can act together in a simulation (Asal *et al.*, 1992).

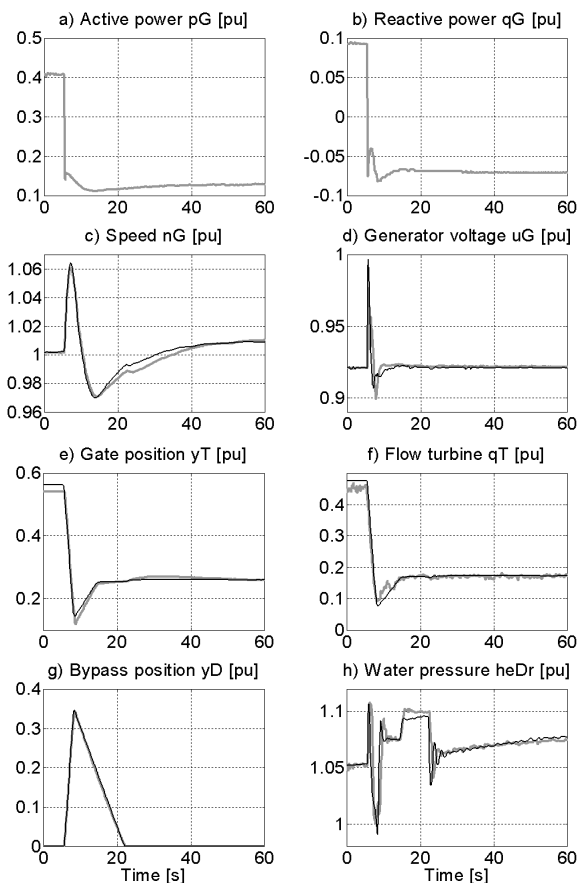


Fig. 7: Francis power plant „Innertkirchen 2“, measurement (grey) and simulation (black)

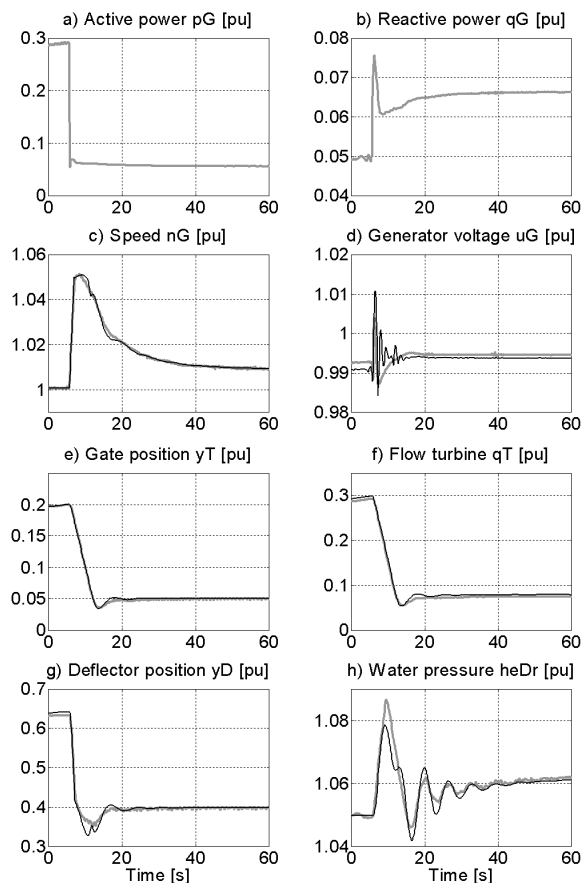


Fig. 8: Pelton power plant “Airolo”, measurement (grey) and simulation (black)

In this contribution the possibilities of high quality modelling are presented for two hydro power plants in the Swiss Alps. Using measurements of the dynamic behaviour of the real plants resulting from islanding a subsystem and using dynamic models based on examinations of existing plant documents, parameter identifications were conducted, which are able to guarantee a very good agreement between measured and simulated dynamic transients.

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#### REFERENCES

Weber, H. and E. Welfonder (1988). *Dynamic Model Reduction for the Modal Analysis of Frequency and Power Oscillations in Larger Power Systems*. In: IFAC Symposium Power Systems, Brussels

National Instruments (1999). *LABVIEW Manual*

The MathWorks, Inc. (1999). *MATLAB Manual*

De Jaeger, E., N. Janssens, B. Malfliet and F. Van De Meulebroeke (1994). *Hydro turbine model for system dynamic studies*. In: IEEE Transactions on Power Systems, **Vol. 9**, No. 4

IEEE Working Group on Prime Mover and Energy Supply (1992). *Hydraulic turbine and turbine control models for system dynamic studies*. In: IEEE Transactions on Power Systems, **Vol. 7**, No. 1

Weber, H. and D. Zimmermann (1996). *Investigation of the dynamic behaviour of a high pressure hydro power plant in the Swiss Alps during the transition from interconnected to isolated operation*. In: 12th Power Systems Computation Conference, Dresden

Asal, H. P., R. Widmer, H. Weber, E. Welfonder and W. Sattinger (1992). *Simulation of the restoration process after black out in the swiss grid*. In: Bulletin SEV/VSE 83(1992)22, 27. November 1992