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# Reality oriented simulation models of power plants for restoration studies

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**Abstract**

With the deregulation of the European Electricity Network a reduction of the stability of the electrical power system has to be expected. In this context the availability of simulation models of power plants becomes more and more important. These models are necessary for pre-fault-scenarios concerning the estimation of stability limits in normal operation and for post-fault-scenarios concerning the restoration process after blackouts. In this paper, the development of a simulation model of a high pressure hydro power plant in the Swiss Alps will be presented. This power plant is a very important one in the restoration plan of the Swiss grid. © *2001 Published by Elsevier Science Ltd.*

*Keywords:* Power plants; Identification; Dynamic modelling; Dynamic behaviour; Simulation; Hydraulic turbines; Hydroelectric systems

## 1. Introduction

Computer simulations dealing with restoration scenarios for electrical networks need much more detailed models of power plants and power systems than those for stability scenarios. In stability scenarios, today, often very simple and restricted models of power plants, loads and equipment for control and security purposes are used. Also 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. But when it comes to investigations concerning the restoration process after blackout, especially for a particular power plant, all control loops and security equipment have to be modelled exactly because, 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 an example for a detailed model of a power plant, the modelling of a high pressure hydro power plant of the Swiss grid, which plays an important role in the Swiss restoration strategy, will be presented in the following chapters. Thereby 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, and this for the whole working range from zero to full power production.

## 2. Investigated power plant

The hydro power plant “Stalden” belongs to the Swiss utility “Electricity of Laufenburg” and is located in the Swiss Alps in the canton of Valais near Brig, see Fig. 1. Together with the “Mattmark Lake” and the plant “Zermeiggern”, it forms a cascade system, see Fig. 2.

Because of the height difference of 1029 m, four Pelton turbines with two nozzles are installed. Fig. 3 shows the scheme of the plant. In Fig. 4 an overview block diagram of the main parts of the plant is depicted. As shown in this

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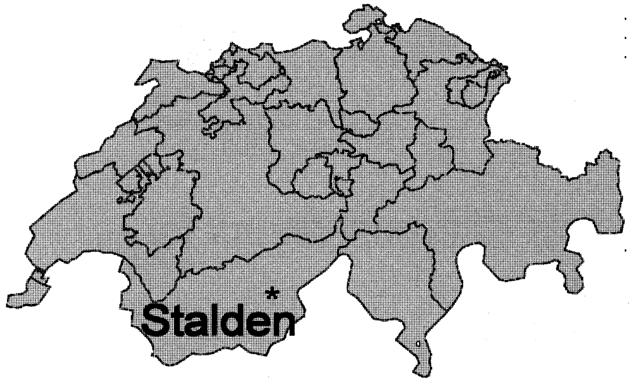

Fig. 1. Hydro power plant Stalden in the canton of Valais, Switzerland.

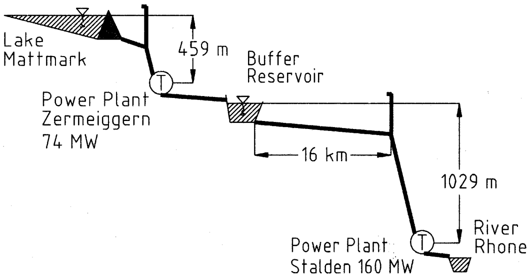

Fig. 2. Investigated cascade system Stalden–Zermeiggern.

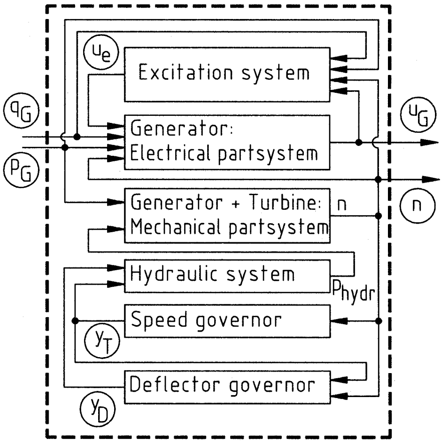

Fig. 4. Block diagram of the hydro power plant Stalden.

diagram, only the active and reactive power of the plant are the input signals. All output signals and states of the real plant 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 plant.

## 3. Tests and measurements

Even in power plants with more than one generator, the measurements are usually conducted on one generator-turbine system. The other systems are expected to be 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 the load of the island which has to be supplied from the investigated generator-turbine-system. For the

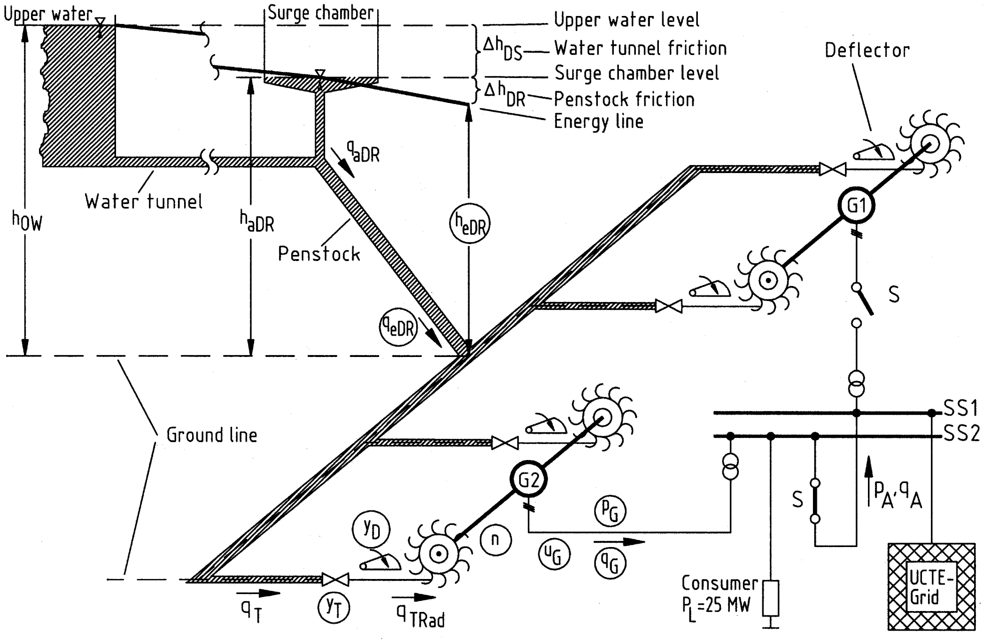

Fig. 3. Scheme of the 160 MW hydro power plant Stalden.

tests this island consists of two pump turbines of each 25 MW in the power plant "Zermeiggern", see Fig. 2. The exchange power of the investigated generator can be adjusted via the coupler breaker to every needed value. The second generator-turbine-system operates uninfluenced during the test via Busbar 1. One test consists of the following steps:

(a) adjustment of a defined export or import power via the coupler breaker;
(b) opening of the breaker;
(c) measurement of the transient reaction of the systems until the new operating point is reached in a stable manner.

After the opening of the breaker, the generator-turbine-system only supplies the load of the island. Therefore the input signal of the system can be understood as a step input. The measured signals of the system are:

(a) Active power $p_G$
(b) Reactive power $q_G$
(c) Speed $n$
(d) Generator voltage $u_G$
(e) Excitation voltage $u_e$ and excitation current $i_e$
(f) Turbine gate position $y_T$
(g) Water flow to the turbine $q_{eDr}$
(h) Water pressure at the turbine input $h_{eDr}$
(i) Deflector position $y_D$ etc.

The measured signals are recorded using a 16 bit PC-based Labview system (National Instruments, 1996) with 16 channels. The sampling rate is 100 ms.

## 4. Modelling and identification

Using the scheme of the plant of Fig. 3 and all available power plant information like documentation and commissioning and test data, models of the part systems depicted in Fig. 4 are developed using the Matlab software (The Math Works Inc., 1999). The created overall model of the plant then consists of 14 state variables and contains 32 unknown parameters which have to be identified. In Fig. 5 the developed model of the hydraulic part (IEEE Committee Report, 1992) and in Fig. 6a the model of the electrical and in Fig. 6b the model of the mechanical part with losses (De Jaeger, Janssens, Malfliet, & Van de Meulebroeke, 1994) of the generator-turbine-system are presented. The developed models of the speed governor, the deflector governor and the excitation system are shown in Figs. 7–9. The circled signals are measured ones.

The identification is conducted in Matlab using the Least-Square-Method (Weber & Zimmermann, 1996). In the first step only the hydraulic part, together with the mechanical part, is identified using the gate opening 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 step, the active power is the input and the positions of the gate and the deflector are the outputs. The hydraulic and mechanical parts remain unchanged.

In the third step, the electrical generator part and the voltage controller together with the exciter are identified. In this step, the active and reactive power are the inputs and the generator voltage and excitation current and voltage are the outputs.

The identified parameters of all part models of the hydro power plant "Stalden" are shown in Table 1.

## 5. Results

In Fig. 10 the simulation results of the identification after an exchange power step of − 20 MW and in Fig. 11 the results after an exchange power step of + 20 MW are shown. The input signals are:

(a) Active power $p_G$
(d) Reactive power $q_G$

and the fitted output signals are:

(b) Speed $n$
(c) Gate position $y_T$
(e) Generator voltage $u_G$

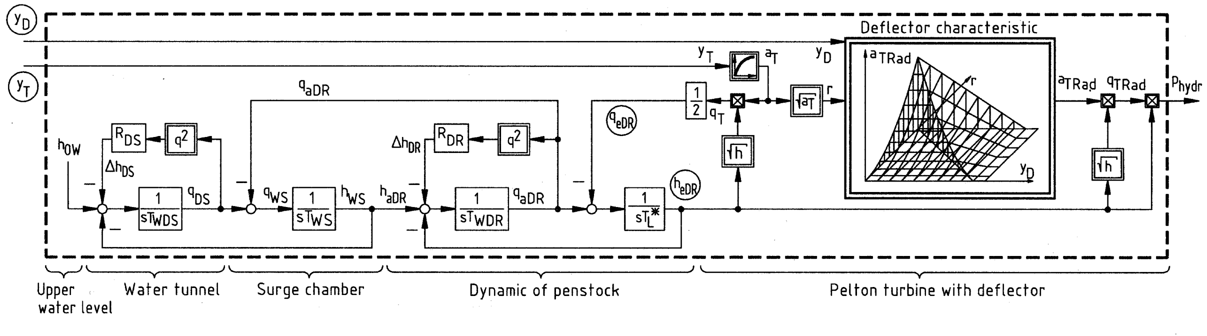

Fig. 5. Hydraulic part of the hydro power plant Stalden.

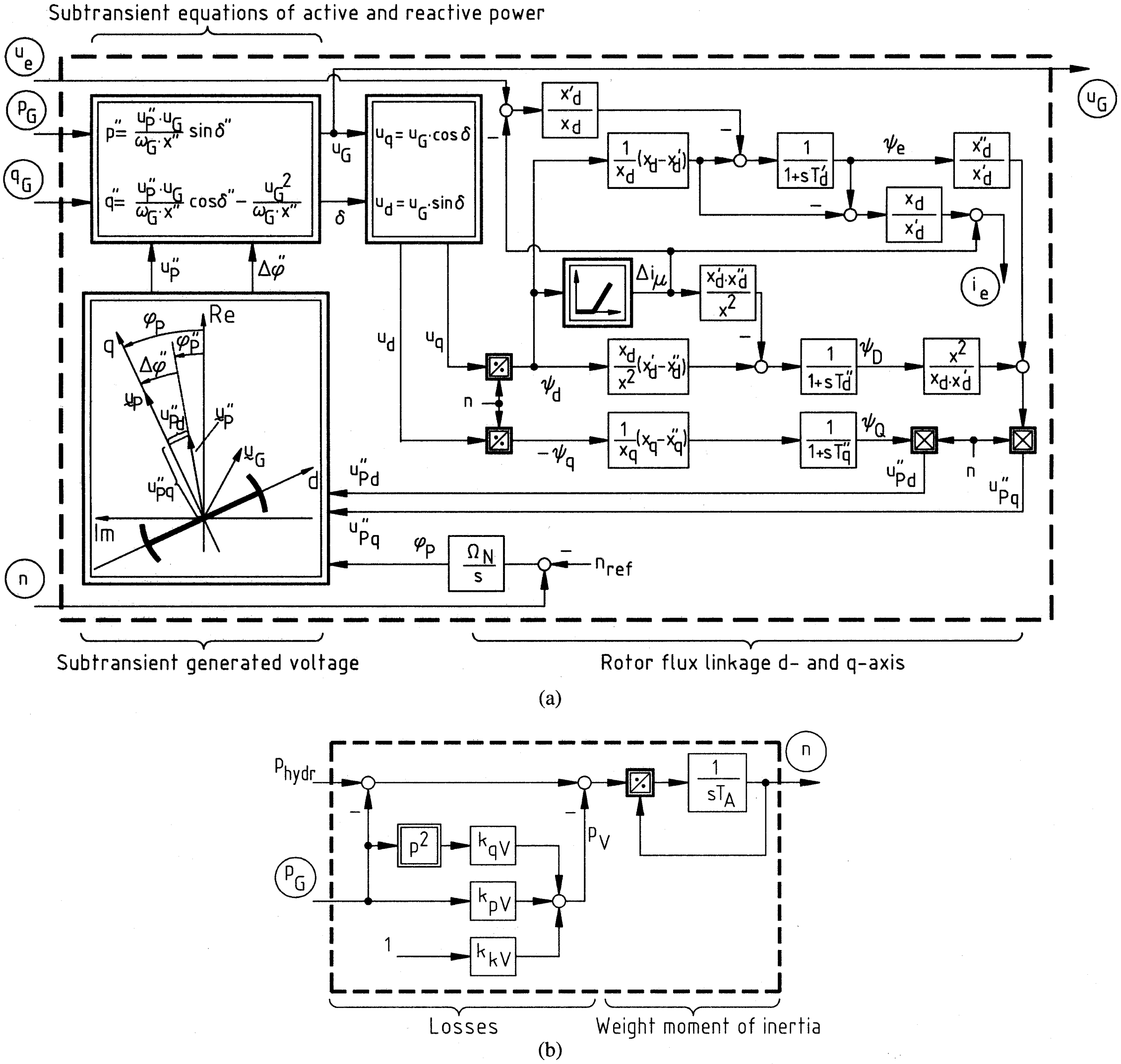

Fig. 6. (a) Electrical part of the hydro power plant (generator). (b) Mechanical part of the hydro power plant (generator + turbine + losses).

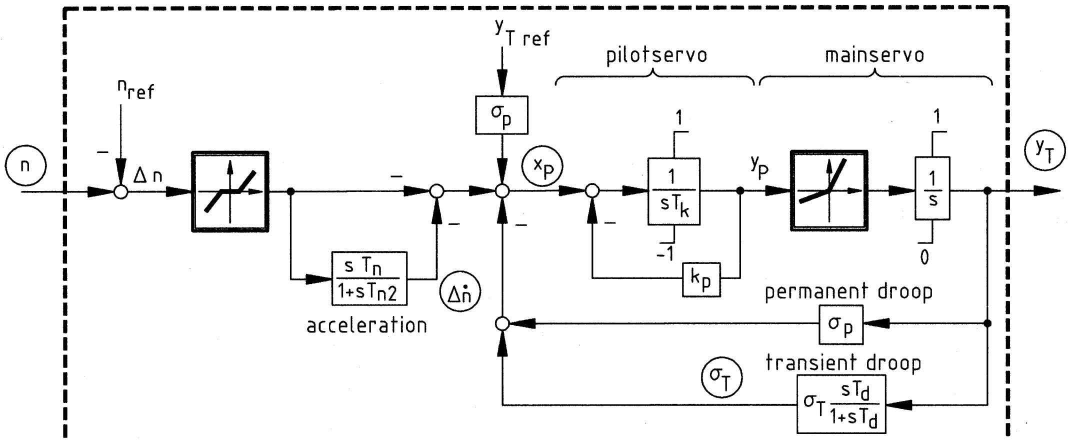

Fig. 7. Speed governor.

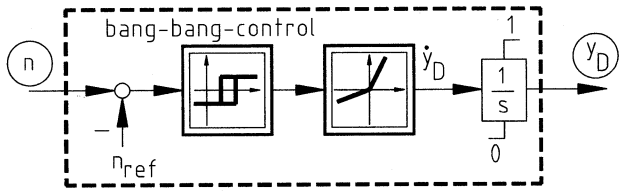

Fig. 8. Deflector governor.

(f) Deflector position $y_D$
(g) Water flow $q_{eDR}$
(h) Water pressure $h_{eDR}$
(i) Generator field current $i_e$.

As depicted, for both power steps, a very good correspondence between measurement and simulation can be achieved. Only the signal "water flow" has a significant deviation. This results from a very high unexpected time delay in the flow measurement equipment in the plant.

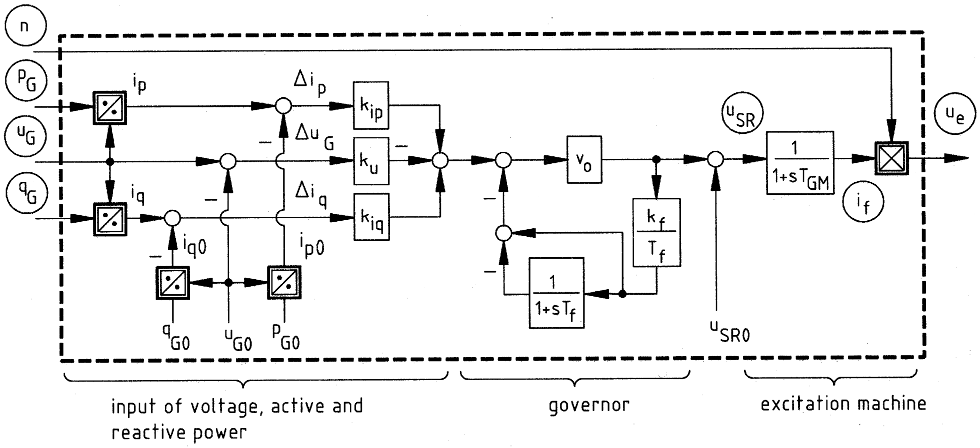

Fig. 9. Excitation system.

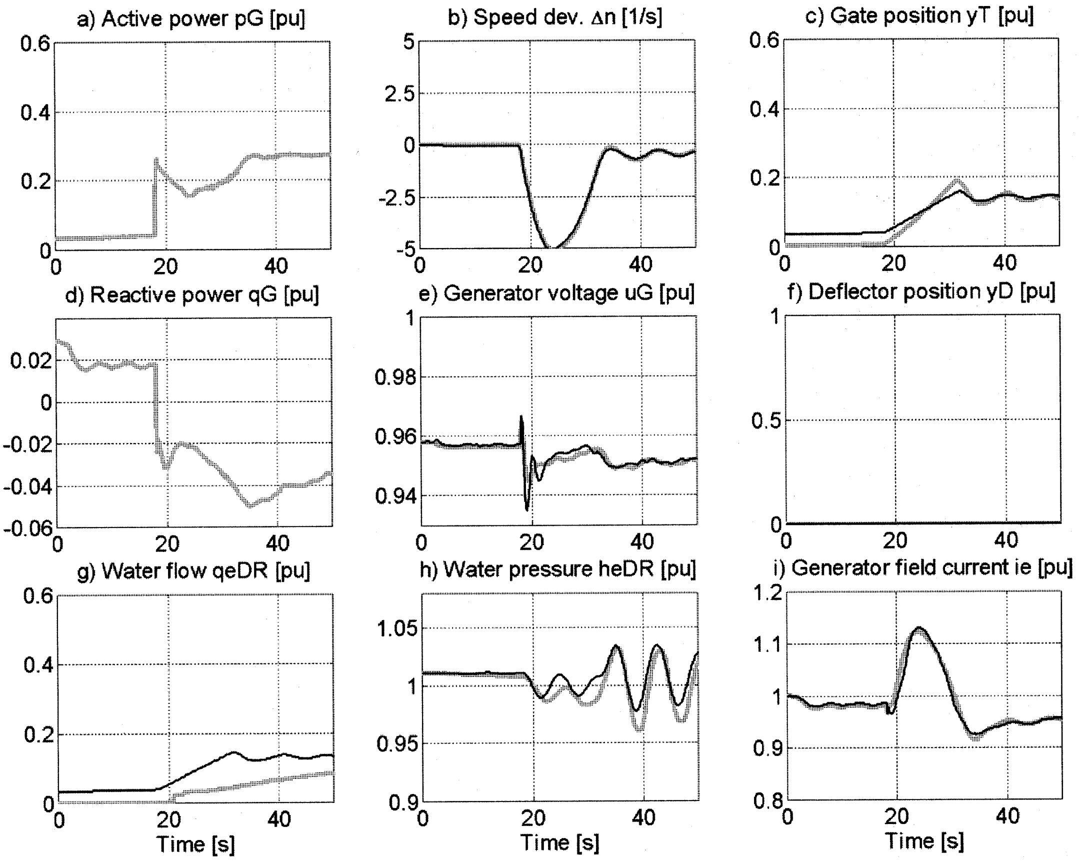

Fig. 10. Comparison of measured (grey) and simulated (black) signals after a −20 MW exchange-power-step.

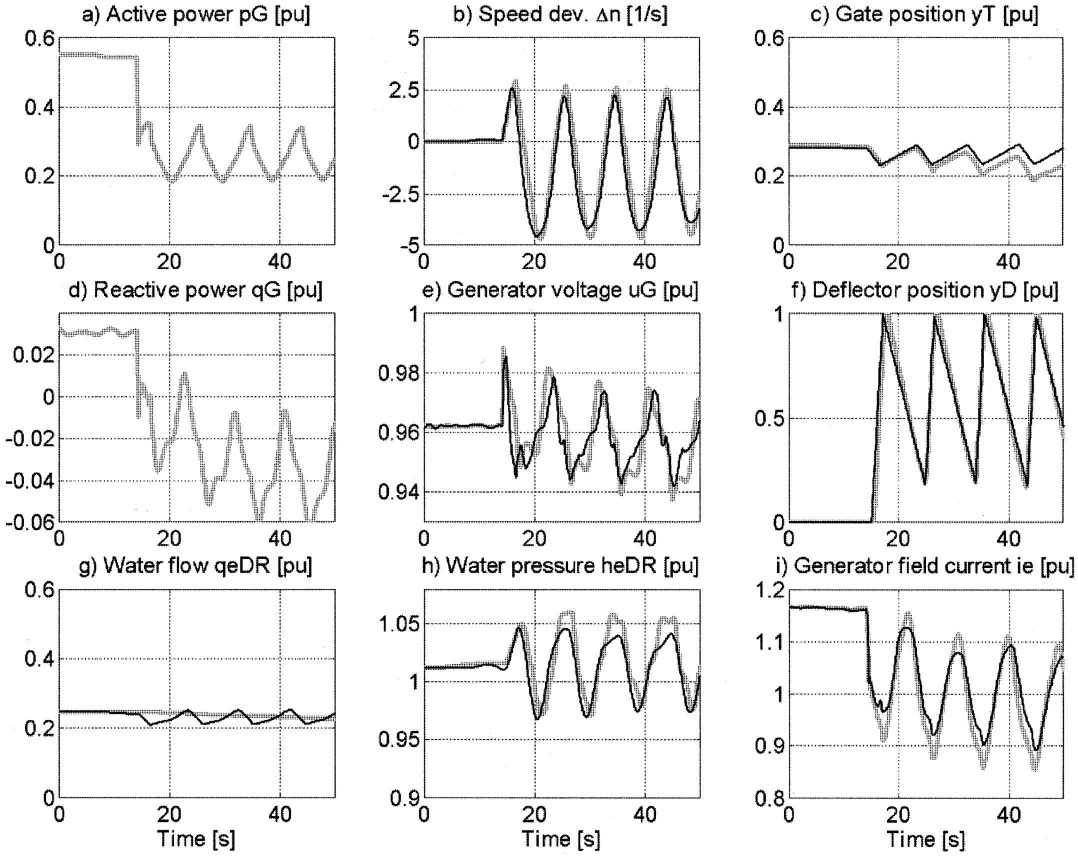

Fig. 11. Comparison of measured (grey) and simulated (black) signals after a + 20 MW exchange-power-step.

Table 1
Identified parameters

| | | | | | |
|---|---|---|---|---|---|
| $R_{DS}$ | $T_{WDS}$ | $T_{WS}$ | $R_{DR}$ | $T_{WDR}$ | $T_L$ |
| 0.0445 | 5.39 s | 523.1 s | 0.00196 | 1.36 s | 0.857 s |
| $k_{kV}$ | $k_{pV}$ | $k_{qV}$ | $T_A$ | $\sigma_p$ | $\sigma_T$ |
| 0.0579 | 0 | 0.0627 | 6.15 s | 0.0746 | 0.12 |
| $k_p$ | $T_d$ | $T_k$ | $T_n$ | $T_{n2}$ | $x_d$ |
| 0.01683 | 4 s | 0.0037 s | 1.07 s | 0.12 s | 1.36 |
| $x'_d$ | $x''_d$ | $x_q$ | $x''_q$ | $T'_d$ | $T''_d$ |
| 0.315 | 0.212 | 0.87 | 0.212 | 0.68 s | 0.034 s |
| $T''_q$ | $k_u$ | $k_{iq}$ | $k_{ip}$ | $v_0$ | $k_f$ |
| 0.034 s | 1.35 | 0.119 | − 0.003 | 200 | 0.095 |
| $T_f$ | $T_{GM}$ | | | | |
| 1 s | 0.5 s | | | | |

In the − 20 MW test the deflector of the plant does not come into operation. The speed control is only realised by the turbine controller.

In the + 20 MW test, on the other hand, the deflector is reacting because of the high speed overshoot. The deflector governor has a simple bang–bang servo control. For this reason the transient behaviour of the plant during this test is an oscillatory one. During the test, these oscillations could only be stopped after tripping the plant from the load. Because of this last result, this power plant can only be used restrictively in a restoration process.

## 6. Conclusion

With the continuation of the deregulation of the European Interconnected Network the restoration strategies after severe disturbances of the different national utilities have do be examined in advance. For these 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 reality oriented simulation (Asal, Widmer, Weber, Welfonder, & Sattinger, 1992).

In this contribution, the reality oriented modelling of a high pressure pelton hydro power plant is presented.

Using measurements of the dynamic behaviour of the real plant 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. In addition, the investigations showed clearly the malfunction of the deflector system in case of islanding, with a power surplus resulting in a high speed overshoot. With this behaviour, the ability of the plant to be part of the Swiss restoration plan is up to now restricted.

This malfunction has to be avoided in the future, either by using better control concepts or by putting the plant in a restoration situation only in such a late stage of operation, when the size of the growing island is appropriate. With this strategy the speed deviations after inadvertent disturbances during the restoration process will be small and, as a result in the case of a power surplus, the deflector will not react. Of course, for this measures the restoration plan of the Swiss grid has to be adjusted accordingly.

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