Investigation of the dynamic Behaviour of a High Pressure Hydro Power Plant in the Swiss Alps during the Transition from interconnected to isolated Operation

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Abstract: In autumn 1994, in the 4x55MW high pressure Bärenburg hydro power plant in the Swiss Alps, tests were carried out to investigate the dynamic behaviour of the plant during the transition from interconnected to isolated operation. During the test, important system variables were recorded. After that an easily comprehensible mathematical model of the power plant was developed and all parameters of the model were identified. The output signals of the whole plant were simulated with the developed model using the same input signals as in the real power plant. The correspondence between measurement and simulation, always tested during the identification process, was very good.

1. Introduction

In Switzerland nearly 35% of the total electrical power production is generated in high pressure hydro power plants in the Alps. The balance is from nuclear and river power plants. For restoration purposes after a severe disturbance or after a black-out only the high pressure hydro power plants are taken into consideration. Of course the developed restoration schedules after black-out cannot be tested in reality but only by appropriate computer simulations. Therefore one needs simple and correct acting dynamical simulation models of the relevant high pressure hydro power plants. These simulation models have to be able to handle the fast as well as the slow phenomena of the restoration process. Therefore the dynamics of the penstock as well as the dynamics of the surge chamber have to be taken into account. In this paper the modelling and identification process of the Bärenburg high pressure hydro power plant is presented. The measured plant dynamics during the transition from interconnected to isolated operation are the input signals of the identification.

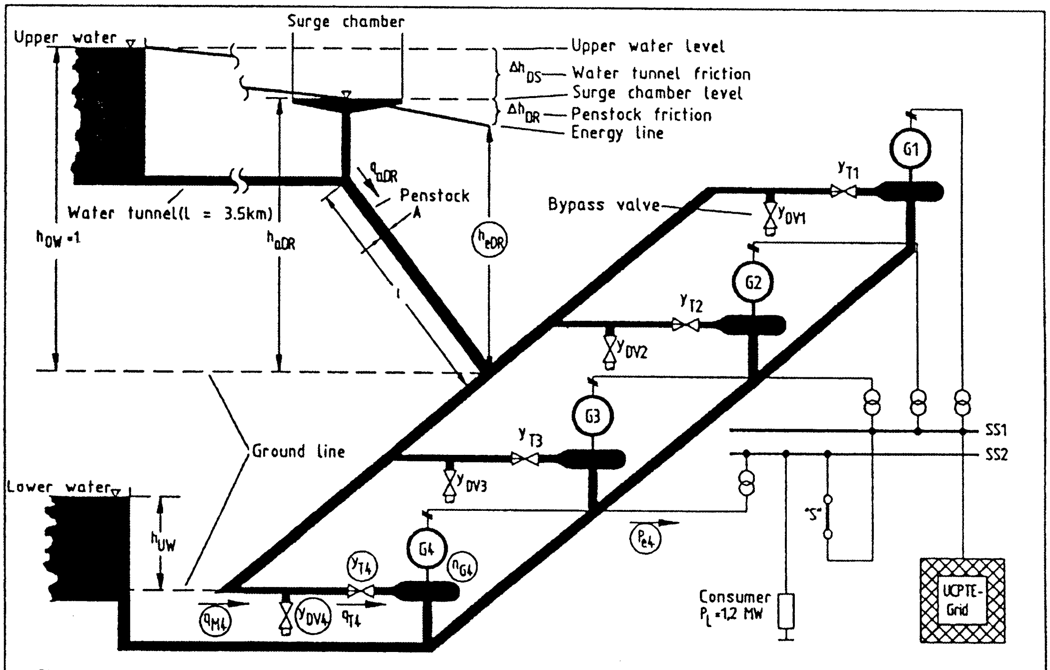

Figure 1: Scheme of the 4x55MW high pressure power plant Bärenburg

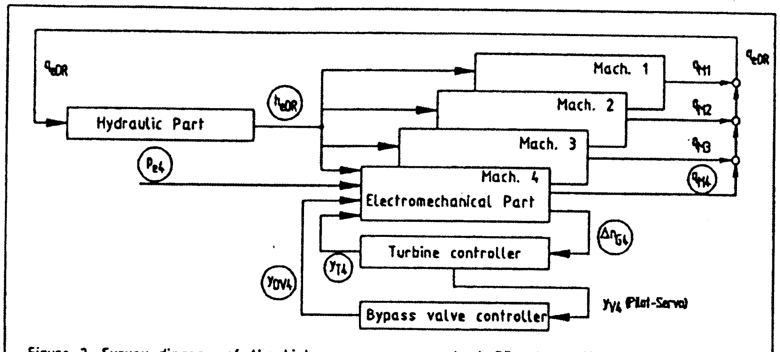

Figure 2: Survey diagram of the high pressure power plant Bärenburg, (4×55MW)

2. The power plant model

Figure 1 shows the scheme of the investigated Bärenburg power plant. The upper water level is H_{OW} = 320m above the ground line, the rated flow of the penstock is Q_{DR} = 80m³/s. The lower water level after the francis turbines is H_{UW} = 20m. Every turbine is equipped with a bypass valve for pressure control. These bypass valves are opened temporarily when the turbines are closed very fast. This is the case during the islanding period. During the tests machines 1-3 of the power plant were working in nominal operation directly via the busbar "SS1" to the UCPTE-Grid. Only machine 4 was switched from interconnected to isolated operation. This was done with the circuit breaker "S". The load of the isolated grid consisted of a 1.2MW load (2% of the nominal power of one machine). The signals marked with circles were recorded during the islanding period.

Figure 2 shows an overview of the interaction between hydraulical and electromechanical parts of the plant and the controllers of turbine and bypass valve. The sum of the flows of every turbine results in the total flow of the penstock. Via the pressure h_{eDR} the individual flows of the machines 1-3 also respond even if only turbine 4 is controlled during the islanding period.

Figure 3 shows the block diagram of the model of the power plant (hydraulic and electromechanical part). The hydraulic part consists of the water tunnel from the reservoir to the surge chamber, the surge chamber itself and the penstock. In the surge chamber only the relation between flow, geometry and head is modelled. The influence of friction and of water column acceleration are neglected. The penstock consists of two parts: the acceleration of the water masses and the dynamics of the compressible water column. The travelling waves of the compressible water column are substituted by a first order integrator block, which represents the fundamental wave of the oscillation of the compressible water column.

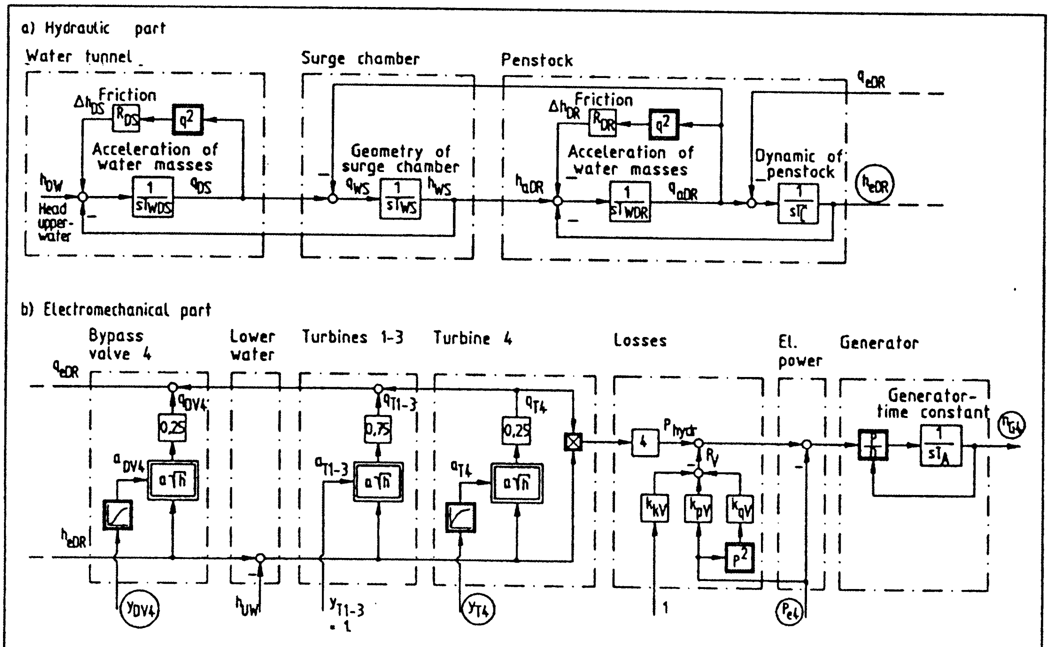

Figure 3: Block diagram of the high pressure power plant Bärenburg

The electromechanical part consists of the controlled bypass and turbine valves of machine 4, the uncontrolled turbine valves of machines 1-3, the influence of the lower reservoir (pressure reduction), the losses (power reduction), the influence of the electrical output power and the acceleration of the masses of machine 4. In the bypass and turbine valves of machine 4 the measured characteristics of the valves are included. In the block "Losses" the factor four is used for the transformation of the penstock pu-system into the generator pu-system.

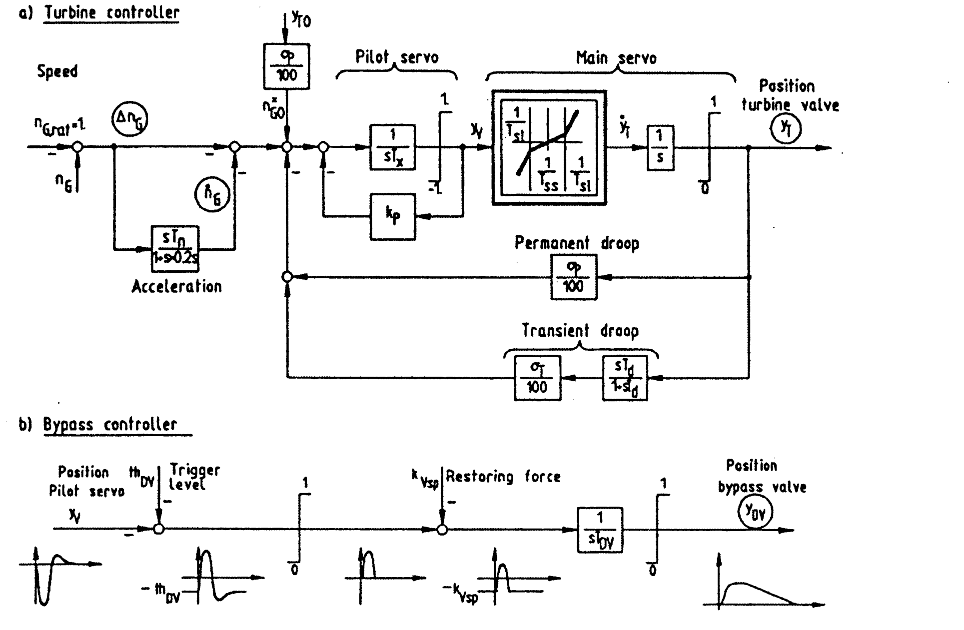

Figure 4: Turbine and bypass controller

Figure 4 shows the block diagrams of turbine and bypass controller. The turbine controller uses the generator speed and acceleration as input. Via the pilotservo the main servo is controlled, which then controls the gate opening of the turbine. The permanent droop and the temporary droop are also included. The main servo has two time constants for operation T_{sl} and T_{ss}, where T_{ss} is much greater than T_{sl}. This enables the main servo to operate very fast during the islanding period reducing the gate opening.

The bypass controller uses the position of the pilot servo of the turbine controller as input. The "Trigger level" ensures, that the bypass valve is only in operation if the pilot valve is in a very high closing rate. The so called "Restoring force" ensures the reclosure of the valve if the input signal is reduced below the trigger level.

3. Parameter identification

The power plant model was generated with the Matlab and Simulink software. The identification routines were developed using the Matlab Optimization Toolbox. The identification steps are shown in table 1.
No total identification of the entire plant was done.

4. Results

With the identification method described above the parameters shown in tables 2-5 were obtained. Three tests with different levels of rated electrical power (50%, 30% and 10% of the nominal power of 55MW) were carried out. During the measurement the recording time was 150 seconds, the sampling time was 100 milliseconds. In the first stage the fast transients of the pen-

Step	Identified part	Used identified parts
a)	Hydraulic part	--
b)	Electromechanical part	Hydraulic part
c)	Turbine controller	Hydraulic and electromechanical part
d)	Bypass controller	Hydraulic and electromechanical part, turbine controller

Table 1: Identification steps

Para-meter	Data sheet value	Identified value
T_{WDS}	3.54s	3.135s
R_{DS}	-	2.133%
T_{WS}	260s	260s
T_{WDR}	1.3s	1.27s
R_{DR}	-	0.9196%
T_L^x	0.45s	0.4921s

Table 2: Parameters of the hydraulic part

Para-meter	Data sheet value	Identified value
k_{kV}	>0	0.09172
k_{pV}	<0	-0.1358
k_{qV}	>0	0.136
T_A	5.95s	6.034s

Table 3: Parameters of the electromechanical part

Para-meter	Data sheet value	Identified value
T_n	1.08s	1.059s
T_x	–	0.06875s
k_p	–	0.1628
T_{el}	–	0.67s
T_{m}	–	3.9s
σ_P	5%	5.81%
σ_T	12%	11.98%
T_d	2.1s	2.026s

Table 4: Parameters of the turbine controller

Para-meter	Data sheet value	Identified value
th_{DV}	–	0.02911
$k_{V_{sp}}$	–	0.03222
T_{DV}	–	0.9528s

Table 5: Parameters of the bypass controller

stock and the turbine and in the second stage also the slow transients of the water tunnel and the surge chamber were identified . Figure 5 shows the hydraulic and electrical power, the losses and the efficiency of the plant for the 50% case. The losses are a quadratic function of the output power p_e. In figure 5d very good correspondence between identified values and data sheet values of efficiency is shown.

Figure 6 shows the comparison between measured and simulated fast transient signals for the 50% case, which served for the identification. Figure 7 shows the same transient signals as figure 6 for the 30% case. This case is simulated with the parameters identified with the 50% case. The results shown in figure 6 and 7 are obtained

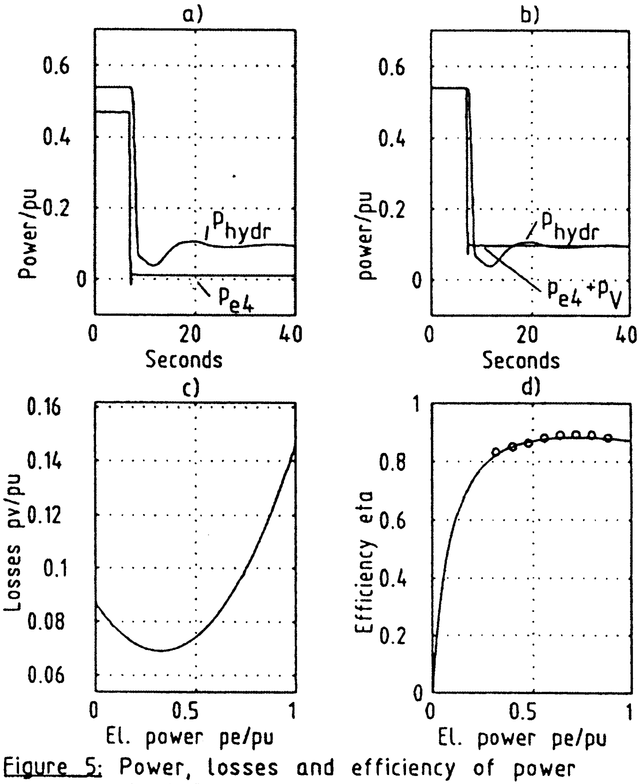

Figure 5: Power, losses and efficiency of power plant Bärenburg

only by using the respective measured electrical power as input to the model. As can be seen, the correspondence is very good in both cases.

The 10% case of the fast transients cannot be shown here because of lack of space. But also in this case the correspondence is very good.

In figure 8 the pressure h_{eDr} and the flow rate q_{M4} for the slow transients of the water tunnel and the surge chamber are shown. As can be seen the correspondence between measurement and simulation of the slow transients is excellent too.

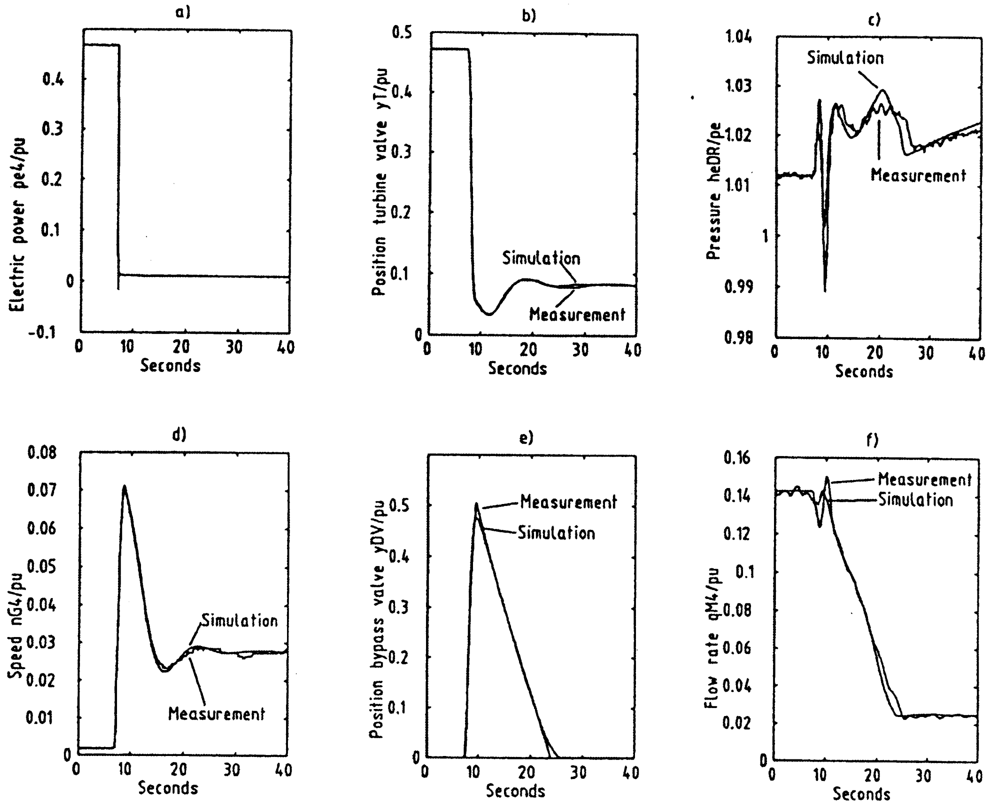

Figure 6: Switching off of 28MW export power; fast penstock, controller and turbine dynamics

5. Investigation of a controller mistuning using the developed power plant model

With the developed power plant model investigations can be carried out concerning the plant behaviour in cases which cannot be tested directly for safety reasons. These are, for example, controller mistunings or equipment misoperations. As an example figure 9 shows the transients for the 50% case if the amplification factor T_n of the acceleration (derivation) path in the turbine controller is reduced to $T_n/2$ (see also figure 4). This mistuning results in a severe reduction of the stability margins of the plant. With this test the high importance of this parameter for plant stability can be seen clearly. Therefore in the commissioning phase of a high

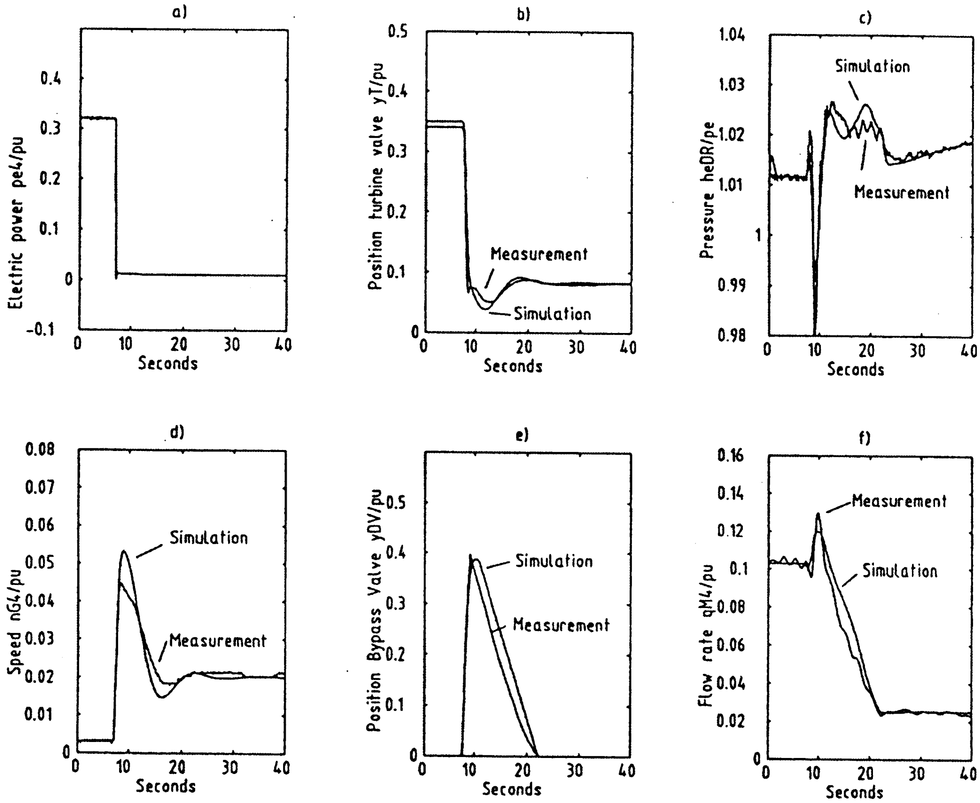

Figure 7: Switching off of 19MW export power; fast penstock, controller and turbine dynamics

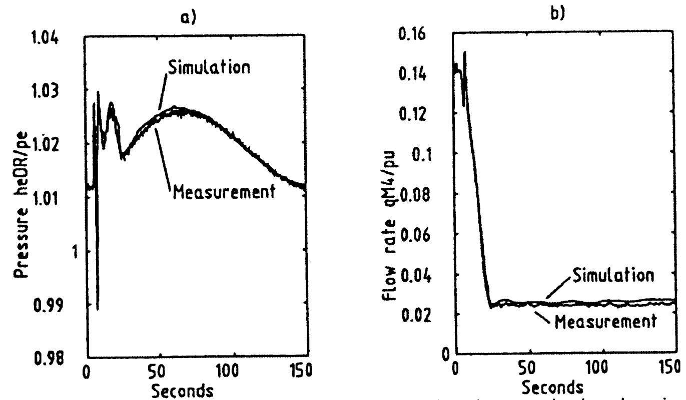

Figure 8: Switching off of 28MW, slow water tunnel and surge chamber dynamics

pressure hydro power plant the correct tuning especially of the acceleration (derivation) path is of critical importance. For the other controller parameters similar investigations can be carried out.

6. Conclusion

In a high pressure power plant in the Swiss Alps islanding tests were carried out to investigate the dynamic behaviour of the plant during the transition from interconnected to isolated operation. During the tests important plant signals were recorded. With these signals the parameters of a plant model were identified. The model is able to simulate the dynamic behaviour of the real plant even at different working points. With the developed plant model the following investigations can be carried out which cannot be tested directly for safety reasons:

- Insulation of the plant from full nominal output power
- Mistuning of controllers
- Misoperation of equipment
- Dynamical behaviour of the isolated network during the period of network restoration after black out
- Test of new developed controller designs.

Development of a dynamic model of the entire Swiss network is planned. With this model additional investigations can be done, such as:

- Interaction of plants during severe disturbances
- Restoration of the entire grid after black out
- Transient and static stability of the network.

7. References

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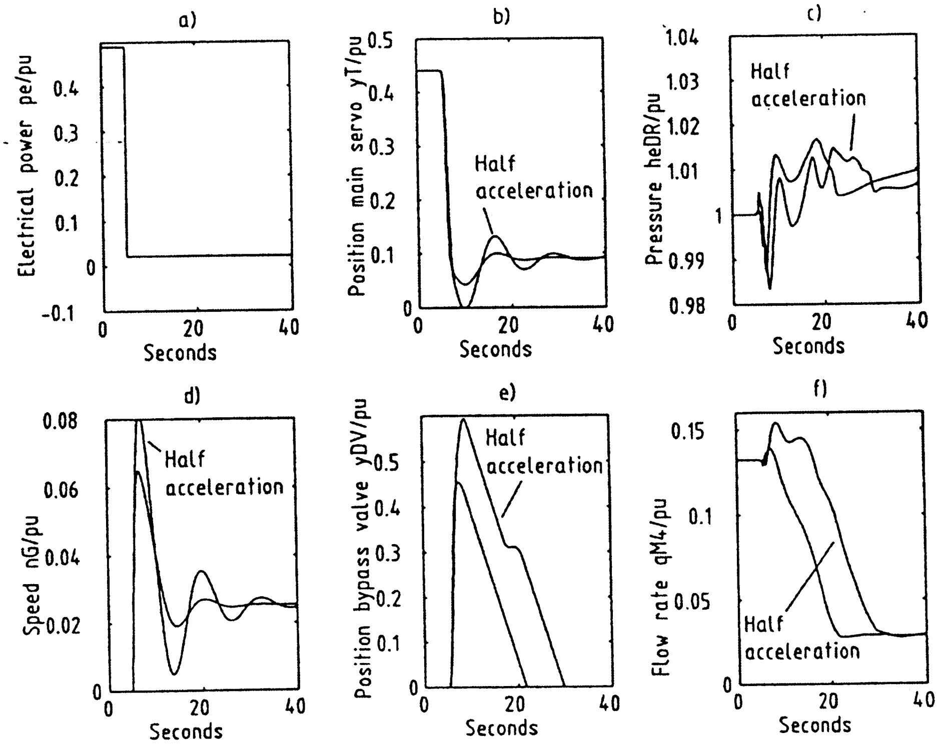

Figure 9: Switching off of 28 MW export power, mistuned turbine controller