Dynamic Model of Unit 1 of Ataturk Hydro Power Plant in Turkey

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Abstract— **This paper presents the modeling, results of island mode, interconnection mode and the step response tests performed at Ataturk power plant, the largest hydro power plant in Turkey with 8*300 MWs total rating. A site visit was realized by Turkey's UCTE interconnection working group members to Ataturk hydro power plant (HPP) between dates 10-12 February 2009. The main purpose of the site visit was to analyze the performance of Ataturk unit 1 governor that was implemented in the new control system. Ataturk power plant units are mainly operating between a minimum continuous operation point of 215 MWs and maximum continuous operation point of 285 MWs, during day hours, connected to Automatic Generation Control (AGC) system for secondary control also with 5% of primary control reserve of 15 MWs each (8% permanent droop). Tests carried out on unit 1 governor were realized, by directly simulating the frequency measurement signal of the governor on the control software. Simulated Island Mode Tests were realized per IEC-60308 which was also programmed in the software prior. 200 mHz steps, 7 second period, 100 mHz peak and 30 second period 100 mHz peak sinusoids were applied with zero mHz dead band on frequency measurement and response of the unit to those inputs were recorded. The model was created using MATLAB / Simulink software.**

Index Term—Hydro power plant, governor, step response, primary control reserve, island mode.

1. INTRODUCTION

The hydroelectric power plant (HEPP) of the Atatürk Dam is the biggest of a series of 19 power plants of the Southeastern Anatolia Project. It is located at 24 kilometers to Bozova town of Sanliurfa, Figure 1. It consists of eight Francis turbine and generator groups of 300 MW each, supplied by Sulzer Escher Wyss and ABB Asea Brown Boveri respectively[1]. The power plant's first two power units came on line in 1992 [2], and it became fully operational in December 1993. The HEPP can generate 8,900 GWh of electricity annually [3] . Its capacity makes up around one third of the total capacity of the Southeastern Anatolia Project [4] .
During the periods of low demand for electricity, only one of the eight units of the hydroelectric power plant is in operation while in times of high demand, all the eight units are in operation. Hence, depending upon the energy demand and the state of the interconnected system, the amount of water to be released from the HEPP might vary between 200 and 2,000 m³/sec in one day.[5]
The main purpose of this test was to analyze the performance of Ataturk Unit 1 governor that was implemented in the new control system, according to the advices of the workshops, during the control system rehabilitation project of Ataturk and HPPs 14 units. The aim was to reach optimum speed and power control parameters and define this unit as a model for the remaining units to be refurbished under this rehabilitation project.
This paper consists of two main parts. In the first part, some information about unit control system at the plant and second part results of the tests.

Figure 1: Location of Atatürk Dam

2. THE UNIT CONTROL SYSTEM OF ATATURK HPP

The unit of Ataturk HPP has two operating modes: Speed Control (SC) and Power Control (PC). SC is used for start-up in island operation. PC mode is used for primary frequency control while the unit is supplying power to 380 kV Turkish networks. Therefore the tests were carried out in this mode. Speed-droop is the change in active power output of the unit proportional to the frequency deviation (open-loop control) as illustrated in the following equation:

$$\text{Speed droop} = \frac{\Delta f / f_n}{\Delta P / P_n} \times 100$$

Where;
Δf = steady-state frequency deviation,
ΔP = change of active power generation caused by turbine governor as a result of the frequency deviation Δf,
f_n = rated frequency,
P_n = unit rated power.

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3. MODEL OF THE POWER PLANT

The model of the power plant was made in Simulink and consists of the following dynamic sub models:

- Controller
- Hydraulic and mechanical system
- Turbine regulator

The block scheme of the complete model with its sub models is presented in Figure 2.

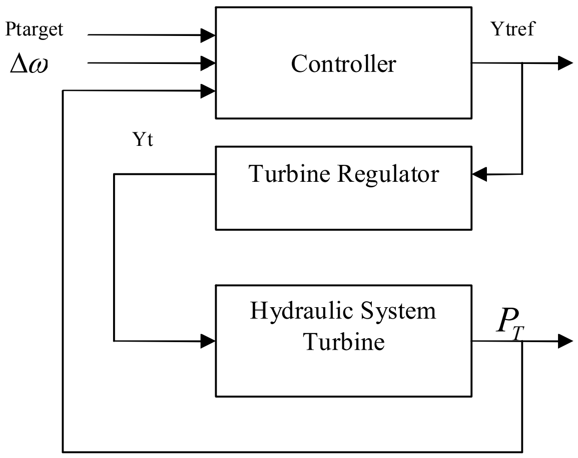

Figure 2: General representation of sub models

Where ;
Ptarget : Power setpoint
$\Delta\omega$: Deviation of frequency
Ytref. : Setpoint position governor guide vane
Yt : Position governor guide vane
P_T : Power of the turbine

This is a per unit, i.e. every signal is given in per units (p.u.).This simplifies the interface between the parts and makes the algorithm for modeling easier.

Main data of the HPP Unit 1 (Ataturk)
-type of turbine : Francis
-rated power : 300 (MW)
-rated flow : 218.5 (m^3/s)
-rated head : 151.2 (m)

4. POWER GENERATION SYSTEM

- **Hydraulic System**

The penstock model is able to simulate the inertia of water (Figure 3). The water starting time Tw (s) represents the time required for water to accelerate from standstill to steady operation. Tw depends on the physical characteristics of the penstocks and on the water flow rate. [6] It is used in the governor model of the hydro turbines (IEEE HYGOV model). Tw of Ataturk HPP is calculated by:

$$Tw = \frac{Q * L}{g * H * A} = 3 \text{ seconds}$$

where ;
Q : water flow rate (m^3/s)
L : length of the penstock (m)
g : acceleration due to gravity (9.81 m/s^2)
H : hydraulic head at gate (m)
A : area of penstock (m^2).

The factor for the friction losses R_{fr} is calculated from stationary values of net (h_N) and gross height (h_B) and water flow (q), in respect to quadratic relation between height losses and water flow:

$$\Delta h = h_B - h_N = R_{fr} * q^2 (p.u.)$$

Average value from all stationary values was used for the model is 0.025.

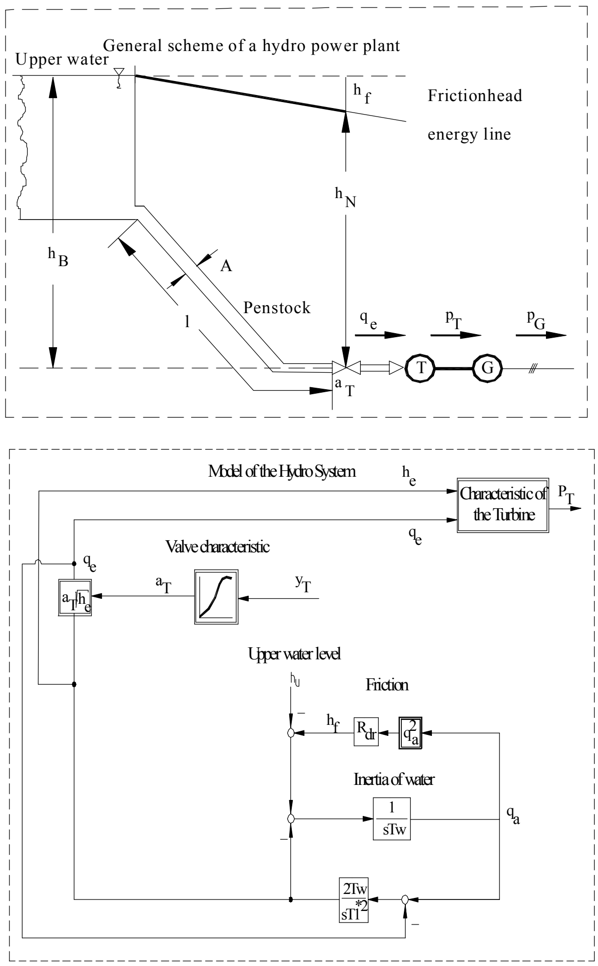

Figure 3: Hydraulic part sub model

Where ;
P_T : Power of the turbine
Tw : Water time constant
T1 : Water wave travel time
R : Friction constant
he : Net head
yT : Position governor guide vane
q : Flow

Additional block shown in the Figure3, representing the hydraulic sub model is the characteristic of the turbine. Net height and water flow are the inputs for the shell curve of the turbine, for which the data were provided by the manufacturer. For each stationary q (water flow) and h_N (net height) information about the values for net power of the turbine (p_T) and efficiency of the turbine ηT. In our model, we use the option to get power of the turbine. The function is included in the model as 3D lookup Function block as shown in Figure 4.

Figure 4: Characteristics of the turbine, derived from the shell curve.

The other block shown in the Figure 3 is the function between the wicked gate position and gross section area.

- **Speed and Power Control Model**

The main purpose of the site visit was to analyze the performance of the governor that was implemented in the ABB control system during the course of the control system rehabilitation project of Ataturk HPP (14 Units) as shown in Figure 5.

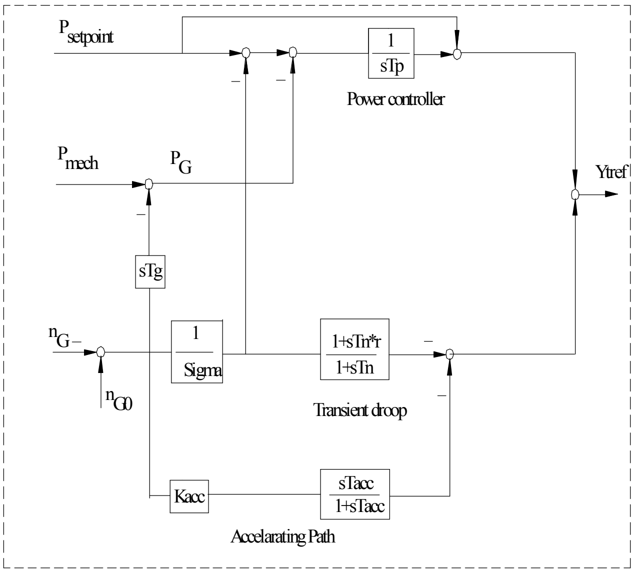

Figure 5: Speed and power control structure

Where ;

Psetpoint : Power setpoint

P_m : Mechanical power

P_G : Generation power

n_G : rated frequency,

n_{G0} : Frequency setpoint,

Tp : Integral time constant

Tg : Mechanical time constant

Sigma : Speed droop

Kacc : Accelerating input gain

Tacc : Accelerating time

r : Transient gain

Tn : Transient time

Ytref. : Setpoint position governor guide vane

5. SIMULATION

The model made in described manner was verified after connection of the sub models in one complete power plant model.

Here, some comparisons of the simulations and measured signals are presented.

- **Test 1 (change on load set point with step 10% till 100% load).**

In one of such measurement (the command is given in sense of increasing active power of the unit in small steps 10-20 MW and then decreasing active power of the unit in small steps 10-20 MW). Figure 6 shows the comparison between simulation (red) and measured signals (blue), for output power and wicked gate position.

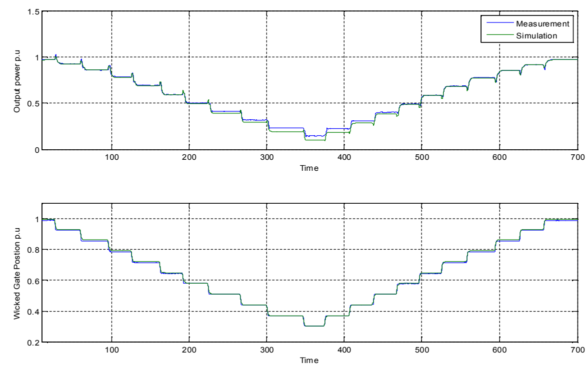

Figure 6: Output power and wicked gate position.

- **Connection Mode**

The power controller on for step (-/+200 mHz), 30 and 7 second periods. The parameters set on unit 1 for grid are listed in Table 1.

Table 1: Parameters for the grid

Pn	P0	Tw	Tp	r	Tn	Tacc	Kacc	Sigma
300	258	3 s	25s	0.12	100s	0.3s	4	0.08

- **Test 2 (-200mHz and +200mHz step at 258MWs)**

Figure 7 illustrates the response of Unit 1 to -200 mHz step frequency deviation 4% change and response of Unit to +200 mHz change in frequency 4.2% change (back to initial operating point).

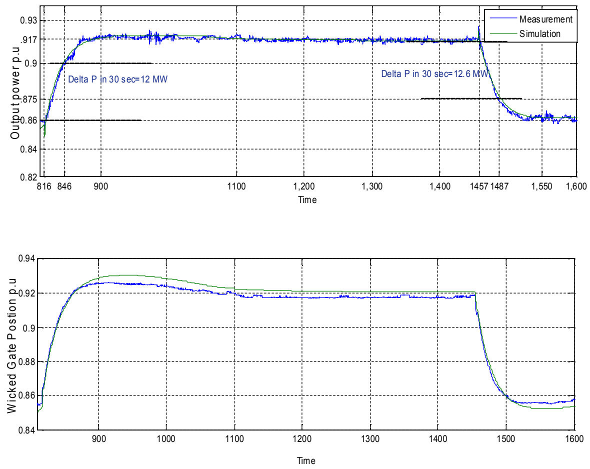

Figure 7: Response of Unit to -+200 mHz step.

The Figure shows the comparison between simulation (red) and measured signals (blue), for output power and wicked gate position.

- **Test 3 (30 and 7 second periods,100 mHz peak)**

Figure 8 illustrates the response of Unit 1to 30 and 7 second period sinusoidal changes in frequency. Peak to Peak power demand dictated by permanent droop is 15 MW (5%) and no observable response of the unit to these changes for 7 sec. period.

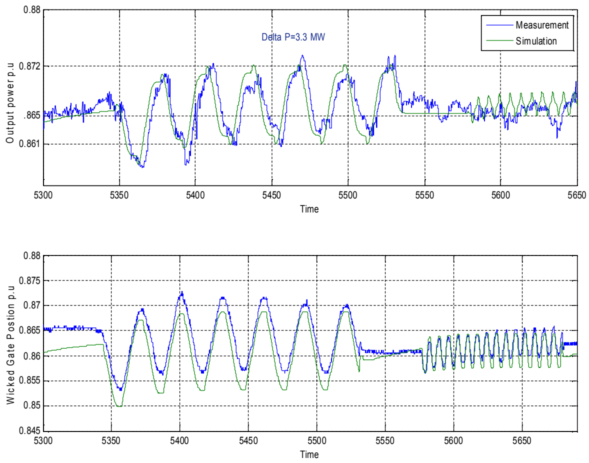

Figure 8: Response of Unit to 30 and 7 sec. periods.

The Figure shows the comparison between simulation (red) and measured signals (blue), for output power and wicked gate position.

- **Test 4 (operating in island mode)**

Simulated island mode test was realized per IEC-60308 which was also programmed in the software prior. Figure 9 illustrates the frequency behavior in an island mode. The initial load 261 MW (0.87 p.u. on the MVA base) an additional load of 0.044 p.u. is applied at time 4487.8 seconds. In this test the power controller off and the parameters set on Unit 1 for island operation are listed in Table 2.

Table 2: Parameters for Island Operation

Pn	P0	Tw	Tp	r	Tn	Tacc	Kacc	Sigma	ΔPL
300	261	3 s	25s	0.12	60s	0.3s	4	0.08	0.044

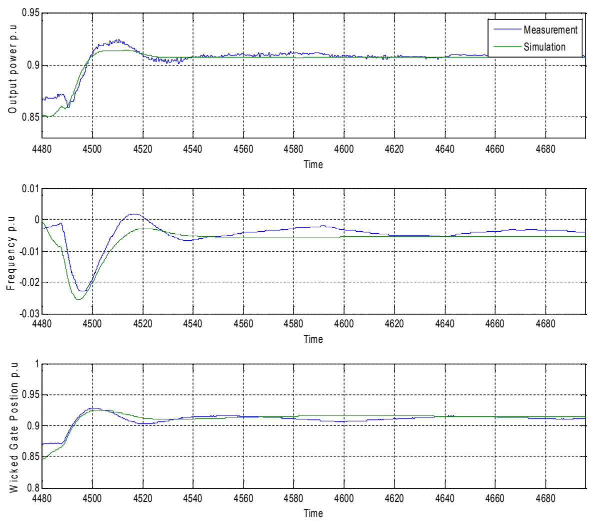

Figure 9: Response of Unit to 30 and 7 sec. periods.

The Figure shows the comparison between simulation (red) and measured signals (blue), for output power, frequency and wicked gate position.

CONCLUSION

As a result of the test that was carried out on newly refurbished Unit 1 governor of 8 x 300 MW Ataturk hydro power plants. These models have to be reliable for all operating working points of the system from zero to full operation.

The set of control parameters was reached taking into account:

- The requirements for UCTE,
- The requirements peculiar to Turkish Power System before and after interconnection,
- Extents of the physical realities of Ataturk hydro power plant.

For interconnected grid:

- The step of -200 mHz should result in 15 MW within 30 seconds
- For 30 sec period of grid frequency the simulation was stable
- For 7 sec period of grid frequency the unit did not response

The set of parameters was obtained giving the priority to the island operation stability which is a main requirement of Turkey's UCTE interconnection working group from hydro power plants to improve system stability.

In the end, the performance of the governor implemented in this control system rehabilitation project is capable of satisfying the UCTE requirements for the realization of Turkey's UCTE interconnection.

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BIOGRAPHIES

Ibrahim A. Nassar (1976) was born in El-Beheria, Egypt. He received the B.Sc. and M.Sc. degrees in electrical engineering from Al Azhar University, Egypt in 1999 and 2004, respectively. Since 2001, he has been with the Power Engineering and Electrical Machines Department, Faculty of Engineering, University of Al Azhar, Egypt. He started his Ph.D. in the University of Rostock, Germany in 2007 supported by an Egyptian government scholarship.

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