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"No. 1028"

AORC Technical meeting 2014

Examination of Frequency Step Response Test for Primary Frequency Control System of the Generating Units in Nam Ngum 2 Hydro Power Plant

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SUMMARY

This paper presents the examination of frequency step response test for the primary frequency control system of the generating units in the Nam Ngum 2 Hydro Power Plant. The test was conducted corresponding to the specific requirements under the Power Purchase Agreement (PPA) by injecting the step frequency signal of +/- 0.15 Hz into the frequency input of the speed governor control system without governor deadband and measuring the active power output at the 35 seconds after such step frequency injection. To comply with the regulations under the PPA, the measured active power output after the frequency deviation must be correspond to the governor permanent speed droop at 4 percent. The test results show the response of the primary control system of each generating unit during each simulated frequency excursion and provide the actual active output compliance with the PPA requirement in every test condition. The figure of test results also shown that the inverse response can be found in the transient period of the measured active power output. This paper also investigate the modeling of Nam Ngum 2 generating unit 1 and demonstrate the model simulation result under the same condition as in the actual test and comparison are made between simulation result and actual test data. The model provides the accurate result within its necessary and it can further be developed and implemented to all other units in Nam Ngum 2 Hydro Power Plant.

KEYWORDS

Nam Ngum 2 Hydro Power Plant – Primary Frequency Control – Step Frequency Response

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1. Introduction

The 615MW Nam Ngum 2 Hydro Power Plant is located 90 km north of the Lao People's Democratic Republic's capital city, Vientiane. As the one of four foreign independent power producers in the Lao PDR, this project consists of three 205 MW generating units, with vertical shaft Francis turbines. The power plant is connected to a double circuit of 230 kV transmission line to Nabong substation in Vientiane and Udon Thani 3 Substation in Northeast Thailand. A Concrete-Face Rock-fill Dam that spans across the Nam Ngum River, it contains an approximate 2,994 MCM effective storage reservoir. This project was originated under the Power Purchase Agreement between SouthEast Asia Energy Limited (and later novated to Nam Ngum 2 Power Company Limited) and the Electricity Generating Authority of Thailand in order to supply the electricity to Thailand.

In each year, an Annual Test, with the purpose of examining the actual operating characteristics and confirming the ability to maintain the power system stability of the power plant, must be performed under the Nam Ngum 2 obligations to the PPA. Items for testing include primary control frequency response of each unit. In particular, during the system frequency excursion, the unit primary control response must be activated in order to bring the system frequency back to normal conditions or it would otherwise lead to system instability. This is an important issue to the generator control that needs to be accurately performed and monitored. This paper presents the examination of frequency step response test for the primary frequency control system of Nam Ngum 2 Hydro Power Plant. The test was conducted corresponding to the specific requirements under the PPA by injecting the step frequency signal of +/- 0.15 Hz into the frequency input of the speed governor control system and measuring the active power output at the 35 seconds after such step frequency injection. For the Nam Ngum 2 Hydro Power Plant to comply with the obligation under its PPA, the measured active power output after the frequency injection must be correspond to the governor permanent speed droop at 4 percent.

In addition, this paper also examines the modeling of the primary frequency control system of the generating unit 1 in the Nam Ngum 2 Hydro Power Plant. The model is based on reference [1-5]. The parameters in the primary frequency control system model were obtained from the actual data of the generating unit. The simulation for unit 1 frequency step response test was performed under the same condition as in the actual test and measures the active power output at the steady state condition after the frequency deviation. In addition, the modeling of the primary control response can be used to perform the parameters tuning for the better performance of its control system if necessary.

2. Background Theory

Governor Speed Droop

$$Speed-droop(\%) = \frac{\Delta f / f_n}{\Delta P / \mathrm{P}_n} \times 100$$

Where Δf = Steady-state frequency deviation (Hz)

f_n = Rated frequency (Hz)

ΔP = Change in active power output due to frequency deviation (MW)

P_n = Rated power output (MW)

Water Starting Time

$$T_w = \frac{LQ_N}{gAH_s}$$

Where L = Penstock Length (m)
Q = Water flow rate (m^3/s)
g = Gravitational acceleration (m/s^2)
A = Penstock cross-section area (m^2)
H_s = Static head water level (m)

Hydro Turbine Governor Model

This paper demonstrates the behavior of the Nam Ngum 2 step-frequency response using the Electro-hydraulic governor model with classical linear model for turbine conduit [1]. The block diagram used in the simulation is shown in figure 1.

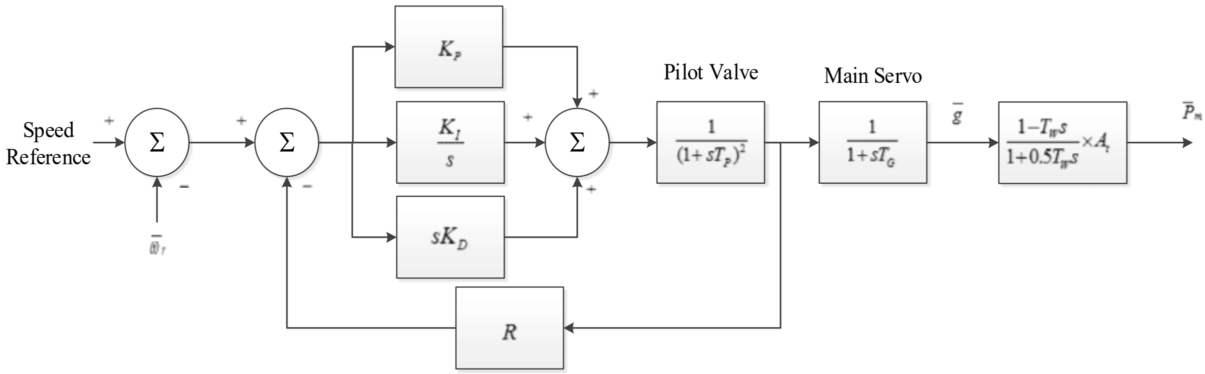

Fig. 1 Electro-hydraulic Governor turbine block diagram

Where R = Permanent droop = 0.04
K_P = Proportional gain = 6
$1/K_I$ = Integral time constant = 0.2
K_D = Differential gain = 0
T_P = Pilot valve time constant = 0.05
T_G = Servo time constant = 0.2
T_W = Water time constant = 2.41
A_t = Turbine gain = 1.11

3. Test Procedure and Results

The frequency step response test for the primary frequency control system was conducted by applying the simulated frequency change of $\pm$ 0.15 Hz deviated from nominal system frequency at 50 Hz to the input of the speed governor as illustrated in Figure 2. The active power output which is measured at 35 seconds after applying the step signal must be corresponding to speed droop at 4 percent. The rated active power output is computed based on the water level of the test date.

Unit 1

The unit 1 was tested during 3:30 p.m.-4:00 p.m. of May 2, 2013. The test conditions of the unit are at operating water level 362.47 mASL and rated active power output was 190.14 MW. To comply with speed droop at 4 percent, the change in active power output must exceed $\pm$ 14.26 MW. Test results are shown in Table 1 and the response data are plotted and illustrated in Figure 3 and 4.

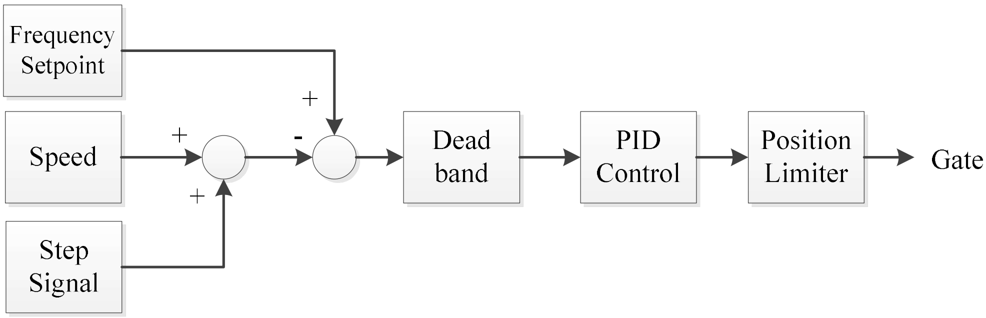

Fig. 2 Block diagram for Nam Ngum 2 primary frequency control system step-response test

Table 1. Actual unit 1 primary control system step frequency response

Frequency Deviation (Hz)	Stabilization Time (Sec)	Actual Unit Primary Response (MW)
+0.15	35	+19.08
-0.15	35	-22.16

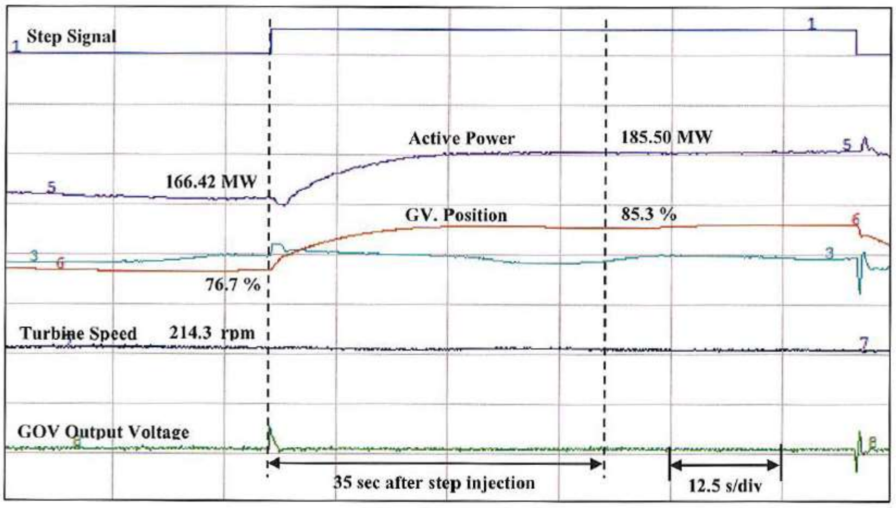

Fig. 3 Actual Unit 1 +0.15 Hz step-response

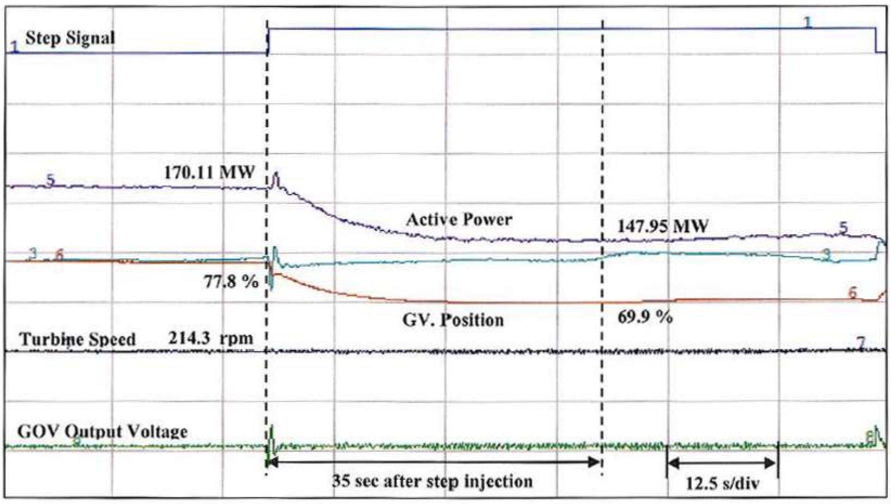

Fig. 4 Actual Unit 1 -0.15 Hz step-response

Unit 2
The test for unit 2 was performed on May 3, 2013 during 11:00 a.m.-11:30 a.m. The test conditions of this unit are at operating water level 362.21 mASL and rated active power output at 189.62 MW. The change in active power output must exceed ± 14.22 MW based on speed droop at 4 percent. Test results are shown in Table 2 and the response data are plotted and illustrated in Figure 5 and 6.

Table 2. Actual unit 2 primary control system step frequency response

Frequency Deviation (Hz)	Stabilization Time (Sec)	Actual Unit Primary Response (MW)
+0.15	35	+16.42
-0.15	35	-23.39

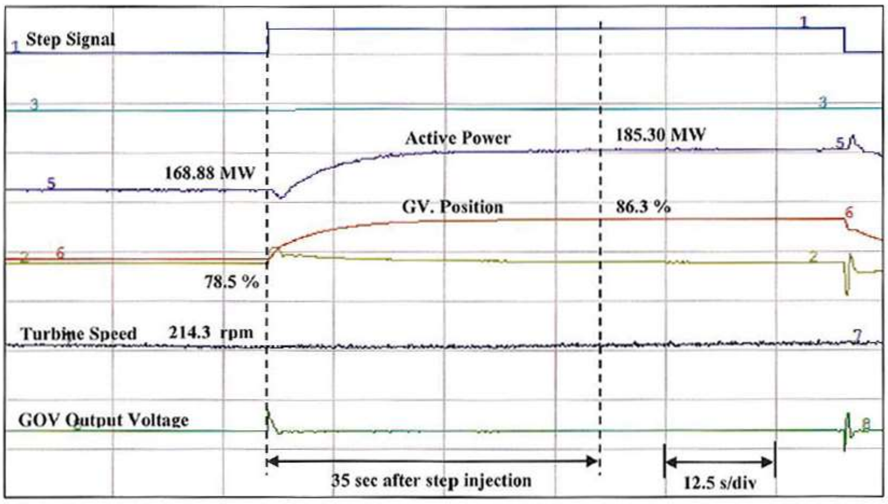

Fig. 5 Actual unit 2 +0.15 Hz step-response

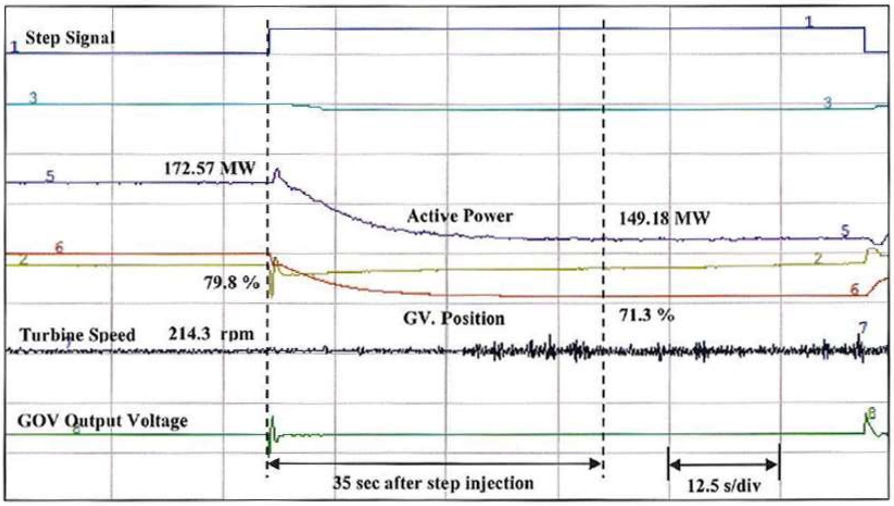

Fig. 6 Actual unit 2 -0.15 Hz step-response

Unit 3
The test for unit 3 was conducted on May 3, 2013 during 11:00 a.m.-11:30 a.m. The test conditions of this unit are at operating water level 361.90 mASL and rated active power output was 189 MW. The active power response must exceed ± 14.18 MW. Test results are shown in Table 3 and the response data are plotted and illustrated in Figure 7 and 8.

Table 3. Actual unit 3 primary control system step frequency response

Frequency Deviation (Hz)	Stabilization Time (Sec)	Actual Unit Primary Response (MW)
+0.15	35	+19.08
-0.15	35	-22.16

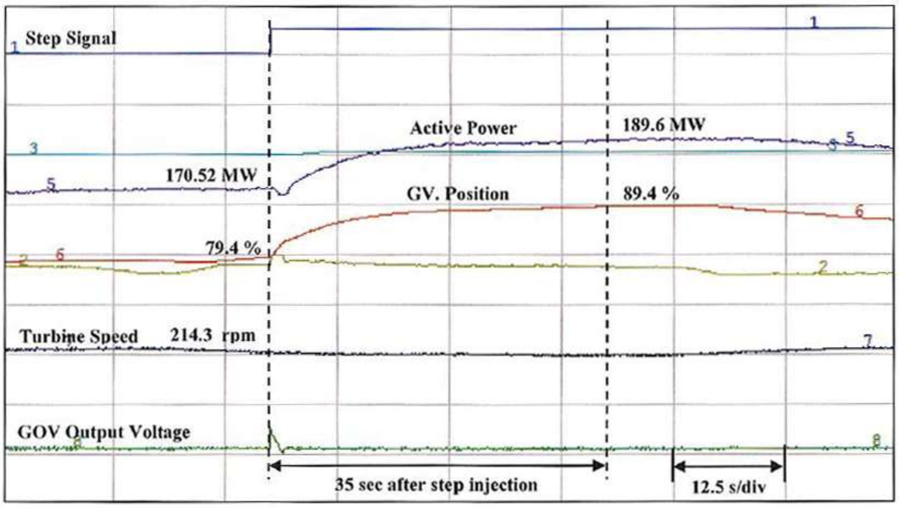

Fig. 7 Actual unit 3 +0.15 Hz step-response

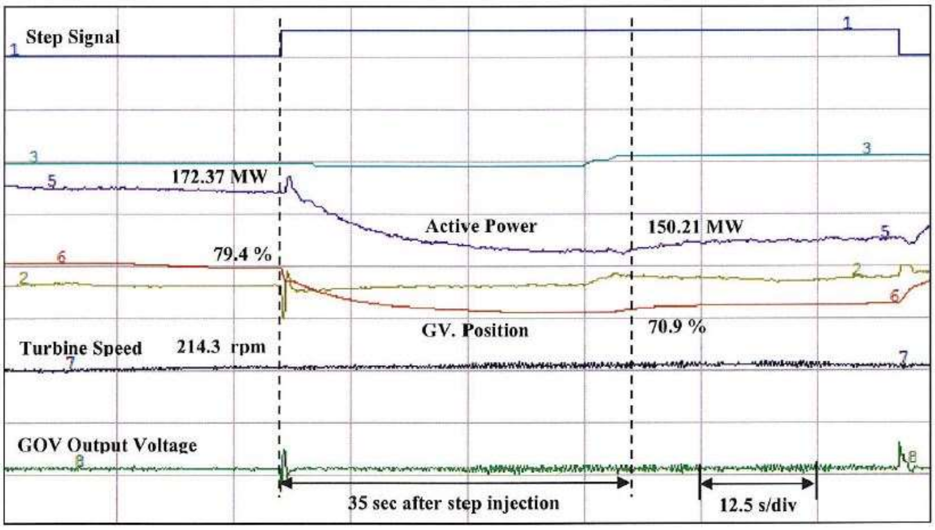

Fig. 8 Actual unit 3 -0.15 Hz step-response

Simulation

The model simulation was performed using MATLAB Simulink under the same condition as in the unit 1 actual test with rated active power output 190.14 MW. The block diagram is shown in Figure 1. The step function is applied to the speed signal at simulation time 10 second and measures the active power output at time 45 second. The results of the simulation are shown in Figure 9 and 10 and the comparison between simulated and actual step-response of unit 1 is shown in table 4. The inverse response of the actual result in Figure 3 and 4 are approximately 4 and 6 MW respectively comparing with the simulation result in Figure 9 and 10 which equal to 5.25 and 5.24 MW respectively.

Table 4. Comparison between actual and simulated unit 1 step frequency response

Frequency Deviation (Hz)	Actual Primary Response (MW)	Simulated Primary Response (MW)	Difference (MW)
+0.15	+19.08	+18.89	0.19
-0.15	-22.16	-18.90	3.26

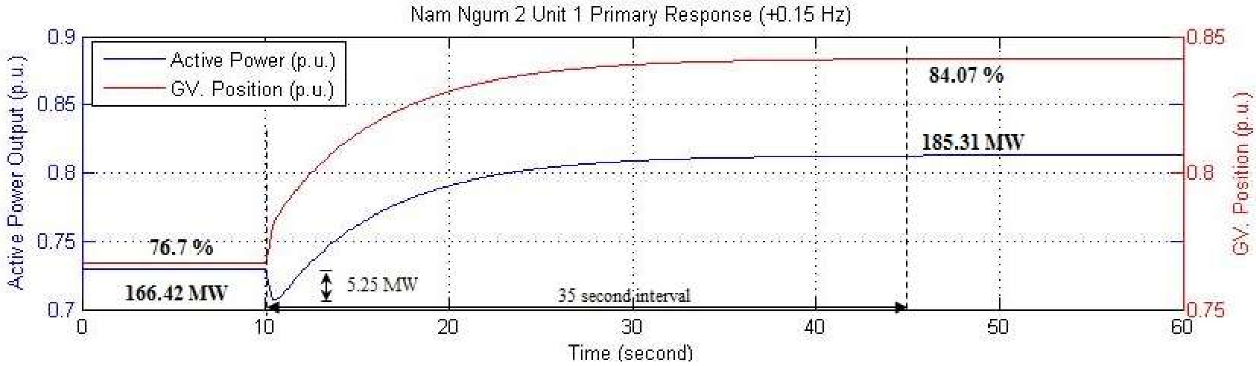

Fig. 9 Simulation result of +0.15 Hz step-response

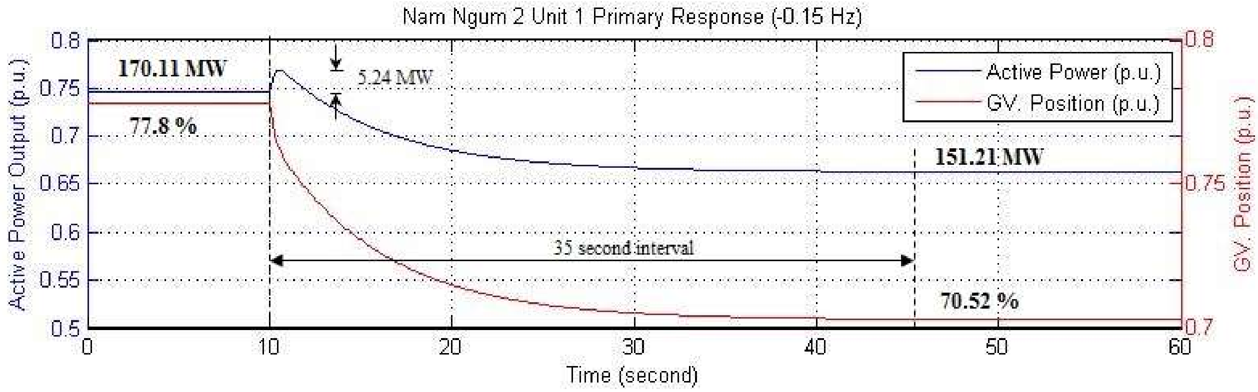

Fig. 10 Simulation result of +0.15 Hz step-response

4. Conclusion

This paper presents the examination of frequency step response test for primary frequency control in Nam Ngum 2 hydro power plant. The test results show that all of the generating units are complied with the obligation in the PPA by providing the active power response at 35 second after frequency deviation corresponding with the governor speed droop at 4 percent. The figure of test results also shown that the inverse response can be found in the transient period of the measured active power output. The investigation of modeling of generating unit in Nam Ngum 2 power plant was performed and presented. The model was tested with frequency step-response simulation and a comparison was made between the actual frequency response and the simulated frequency response. The result shows that this model provides the accurate result as seen in the error of active power output equal to 0.1% and 2.2% in +0.15 and -0.15 Hz step-response test respectively. It can then further be developed and implemented to all other units in Nam Ngum 2 Hydro Power Plant.

BIBLIOGRAPHY

[1] IEEE Working Group on Prime Mover and Energy Supply Models for System Dynamic Performance Studies, Hydraulic Turbine and Turbine Control Models for System Dynamic Studies, IEEE Transactions on Power Systems Vol.7 No.1, February 1992, pp.167-179.
[2] Tor, O.B., Karaagac, U. and Benlier, E., Step-Response Tests of a Unit at Ataturk Hydro Power Plant and Investigation of the Simple Representation of Unit Control System, 36th IEEE PES North American Power Symposium, University of Idaho, Moscow, USA, August 2004.
[3] Naghizadeh, R.A., Jazebi, S. and Vahidi, B., Modeling Hydro Power Plant and Tuning Hydro Governor as an Educational Guideline, International Review on Modelling and Simulations Vol.5 No.4, August 2012, pp.1780-1790.
[4] Zoby, M.R.G. and Yanagihara, J.I., Analysis of the Primary Control System of a Hydropower Plant in Isolated Model, J. Braz. Soc. Mech. Sci. & Eng. Vol.31 No.1, Jan.-Mar. 2009.
[5] Weber, H. and Prillwitz, F., Simulation Models of the Hydro Power Plants in Macedonia and Yugoslavia, IEEE Bologna Power Tech 2003, Bologna, Italy, June 2003.