Process Modelling for Load Frequency Control in Power Systems

S. St. Iliescu, I. Fagarasan, C. Soare, D. Ilisiu, F. Biliboaca

***Abstract*-- Underlining first the principle of Load Frequency Control (LFC) according to the UCTE regulations this paper also presents simple continuous time models identified for the main hydro and thermal power generation units used by the LFC in Romanian Power System. Different models were proposed in previous articles but they are very complex for LFC studies. An experimental identification procedure based on deterministic methods with rectangular pulse sample signal is proposed to estimate the values of models parameters. These models can be used for tuning LFC systems as well as for building and setting up a real-time simulator for dispatcher training.**

***Index Terms*-- Load frequency control, thermal and hydro power generation unit model, system identification.**

I. INTRODUCTION

MANY designed controllers for Load Frequency Control (LFC) in power system are based on advanced knowledge of power system. Mathematical models of power system used for simulations consists in interconnected control areas represented by thermal or hydro power generation units because the most units used in LFC are these types [1].

Power system is modelled as continuous while control signal is sent to the power plants via transmission networks in discrete time.

Different models have been proposed in previous articles but they are very complex for LFC studies ([2], [3], [4]) or the time constants of the models are too fast compared with the LFC execution time ([5], [6], [7]).

This paper presents in next section (II) the principle of LFC method for interconnected power systems and in section III it is described the method and obtained results for identification of mathematical models for power system represented by main active power units used by LFC in Romanian power system. These models can be used for tuning LFC systems as well as for building and setting up a real-time simulator for dispatcher training. In section IV a simulator is presented in order to test and validate a load frequency control diagram.

II. LOAD FREQUENCY CONTROL METHOD FOR INTERCONNECTED POWER SYSTEMS

The main objectives of the Load Frequency Control (LFC) are to balance the power generation and the load consumption in the control area in order to maintain the system frequency inside the required ranges and to keep the power exchange between areas at the scheduled values. LFC is three level control system [8], [9], [10]:

- ***Primary control*** is performed by the speed governors of the dedicated power generation units that vary their load when a frequency changes occur, in order to keep instantaneous balance between power production and consumption. With primary control a variation in system frequency greater than the dead band of the speed generator will result in a change in unit power generation. Generators are required to participate in this control by setting the droop according to specifications by the TSO (Transmission System Operator). Transients of primary control are in the time scale of seconds.
- ***Secondary control*** restores system frequency to a reference value and also maintains the power interchanges between areas in the systems with several control areas. It adjusts the load set-point of the generators. Transients of secondary control are in the order of minutes.
- ***Tertiary control*** is a dispatch action used to restore the secondary reserve. Tertiary control is an automatic action performed every 15 min or a manual change performed by the TSO after activation of secondary control to free up the secondary reserve.

The Automatic Generation Control (AGC) system represents an interesting scheme (Figure 1) for controlling the power balance and distributing the imbalance between units that are direct linked to the secondary controller.

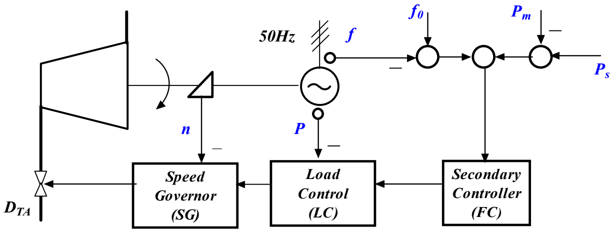

Fig. 1. Structural diagram of AGC (D_{TA} – steam flow trough turbine; n – turbine speed; f – system frequency; f_0 – reference system frequency; P_m – tie line measured power; P_s – scheduled power)

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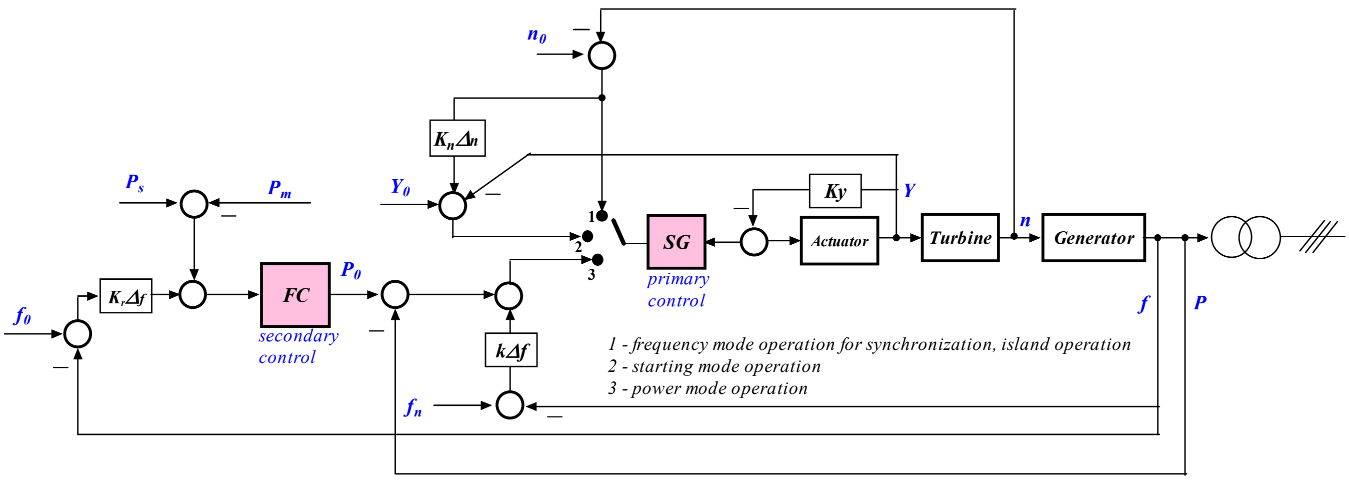

Fig. 2. Control block AGC diagram
Note: Y – valve opening position; n – turbine speed; f – system frequency; f_n- nominal value frequency, P – unit power; P_m – measured power; P_s- scheduled power (index 0 stands for reference values)

The AGC introduces a cascade control feedback loop based on load control loop leaded by the secondary controller for restoring frequency (FC) and on local frequency loops coordinated by the speed governors (SG) based on primary control that can be found in most units and a lot of others specific loops of the units.

The control block AGC diagram that considers different operation modes (starting mode, synchronization, island or power mode operation) for a generation unit that is directly linked to the secondary controller is depicted by Figure 2.

In order to explain the LFC in interconnected power systems, two power generation units (boiler-turbine-generator units) that operates in parallel as outputs are considered with two different droops and different unload operating speed (n_{01}, n_{02}). The fixed coupling in parallel at the two units' outputs imposes identical signals at the speed governors' outputs.

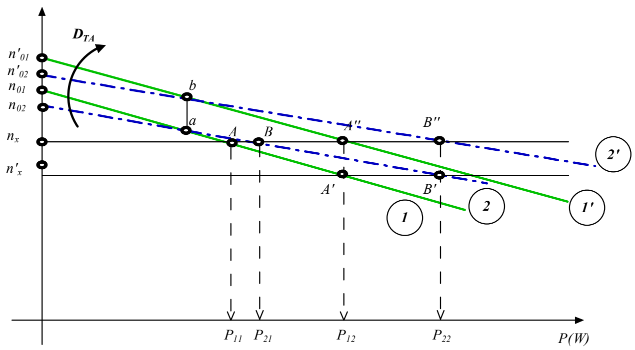

Fig. 3. LFC principle

Figure 3 helps to underline the LFC system principle. The static characteristics1 and 2 in figure 2 correspond to the two different power generation units. The normal operation of the power system is characterized by the reference speed n_x and the points A and B from the static characteristics of the unit 1 and 2. These units assure a total active power $P_1=P_{11}+P_{21}$.

If the total active power is increasing with $\Delta P = P_2 - P_1$ and the speed, respectively the frequency, are decreasing under the auto-control phenomena. Then a new power distribution is settled $P_2=P_{12}+P_{22}$ but at a new speed $n_x' < n_x$ that could generate unacceptable frequency deviations or errors in the system.

In order to achieve the initial frequency n_x and to maintain the actual power P_2, the static characteristics of the power generation units must be translated simultaneous with the same value *ab*, trough points A'' and B'' in figure 2 (characteristics 1' and 2'). The unload operation speeds are modified n'_{01}, n'_{02}.

In consequence maintaining the same active power repartition on power generation units inside the power system, after a frequency deviation as consequence of the total power deviation, the frequency is resettled at its reference value trough translation of all units' characteristics, in parallel and with equal quantities. The translation must be done at once in order to avoid undesired power circulations in power system.

III. MODELLING OF THE GENERATION UNITS TROUGH EXPERIMENTAL IDENTIFICATION

The model presented in this paper has been developed to be used for secondary control purposes and therefore the model's time constant are grated than several seconds.

A detailed study of data from different unit responses has been done to find an appropriate model for each thermal generation unit or hydro generation unit.

Data from 15th different units (11 hydro units and 4 thermal units) have been studied, using both step response tests and historical data from real operation.

A. *Experimental Identification Procedure*

The model identification was proceded on experimental data from plants, obtained as responses to a rectangular signal. The positive curve was selected to identify the model and the negative one to validate it.

For each unit the recorded signals were P_{cons}, the power requested from the unit from AGC control, the reference, and

P_{mas}, the output power generated by the unit.

An example of a set of data for a hydro generation unit is presented in figure 4 and for a thermal generation unit in figure 5. Based on this type of experimental data several models were identified trough deterministic identification methods with rectangular sample signal.

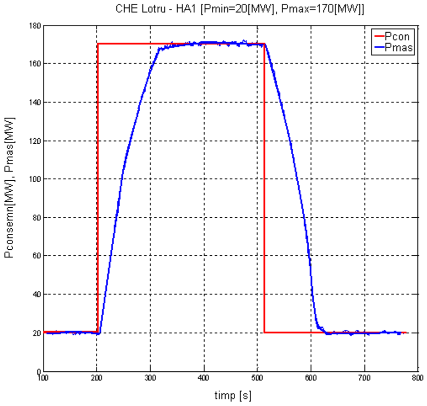

Fig. 4. Experimental data for a hydro generation unit (HA1 Lotru)

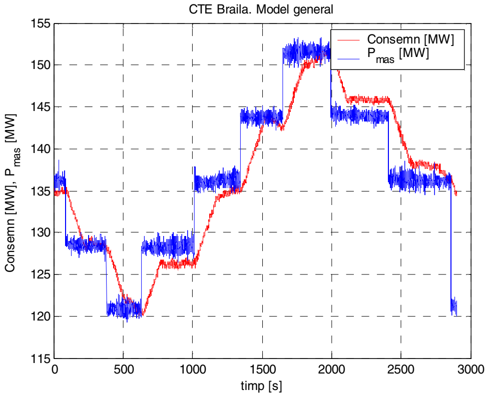

Fig. 5. Experimental data for a thermo generation unit (TA1 Braila)

Based on this type of experimental data, discrete signals for step responses are obtained as $y_i(t_i)+\eta_i$ where η_i represents sampled values for inherent noise present in any measurement.

An approximation of the real signal is proposed as $\tilde{y}_i(t_i,a,b,c,d)$ where *(a,b,c,d)* represents the model parameters.

The approximation error between the real signal and the approximated one is: $\varepsilon_i = y_i(t_i)+\eta_i-\tilde{y}_i(t_i,a,b,c)$.

A quality criterion is proposed as $J=\sum_{i=1}^{N}\varepsilon_i^2$ and applying a nonlinear optimization algorithm, the optimal model parameters are searching $(a_{opt},b_{opt},c_{opt})=\arg\min J$.

If the description of the problem seams to be simple the application of it meets serious difficulties as:

- The quality function is not a convex function in order to assure the convergence of the optimisation algorithm;
- Even the minimisation algorithm is convergent, it is possible that a given solution is a local minimum value and not the searched solution;
- The problem solution is strongly dependent from initializing point and from the imposed searching domain.

In this context several approximation models were tested for the experimental data as in figure 4.

Two different models are presented in this paper for identification of real measured data: a fist order model $\tilde{y}_{1i}(t_i,a,c)=a(1-e^{-ct_i})$ and a second order model $\tilde{y}_{1i}(t_i,a,b,c,d)=a+be^{-ct_i}-(a+b)e^{-dt_i}$, where a is the stationary value of the step response. For these models a Trust Region Algorithm (with 95% trust level) gives for the model's parameters the values in Table I.

Figure 6 shows the comparison between the real measurements and the two identified models, as well as the approximation errors. In this case the second order model is chose to be used for Lotru generation unit.

Similar procedures was used to identified the others power generation units.

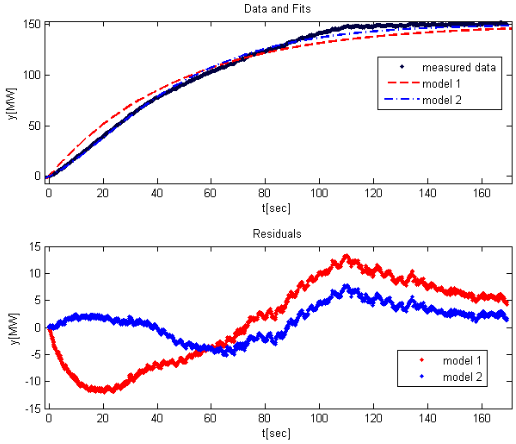

Fig. 6. Experimental Identification response for hydro generation unit (HA1 Lotru)

B. *Generation Units Models*

The units' responses can be modelled as first or second order transfer function or integrative element with time delay.

Therefore three types of models were identified for the studied units:

$$H_1(s)=e^{-\tau_1 s}K_1\frac{1}{T_1 s+1} \qquad (1)$$

$$H_2(s)=e^{-\tau_2 s}K_2\frac{T_{21}s+1}{T_{22}^2 s^2+2\xi T_{22}s+1} \qquad (2)$$

$$H_I(s)=e^{-\tau_I s}K_I\frac{1}{s} \qquad (3)$$

Every model block is completed by a load change rate limiter, a dead band and an offset.

The load change rate limiter in service in every generation unit acts as follows: if the input gradient in lower than the rate limiter's value, the output is equal to the input; if it is higher the output is a ramp of gradient equal to the rate limiter's value.

In addition, a dead band is usually present, either because of noise filter or due to speed governors.

A constant offset is added to the output of the transfer function to obtain the output power of the model.

The simulation diagram in figure 7 was used to compare the real and model's approximated response.

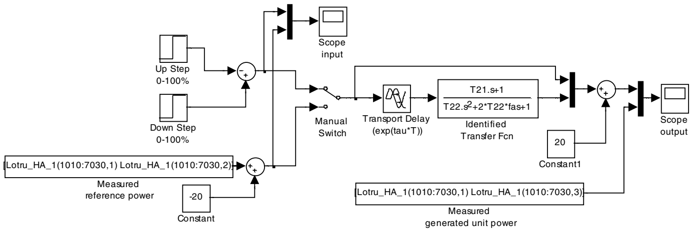

Fig. 7. Simulation diagram of HA1 Lotru

The rectangular response was simulated as two step inputs with contrary signs and with a time delay that settled the rectangular impulse period.

Through simulation of identified first and second models for hydro generation unit in Table I, by applying an input signal identically as the one applied to real plant, the responses in figure 8 are obtained.

TABLE I
MODEL PARAMETERS' VALUES OBTAINED FOR HA1 LOTRU

Model Type	Time Response	Parameters	Transfer function
1 st order	$y(t)=150\cdot$ $\cdot\left(1-e^{-0.0206\cdot t}\right)$	K1=1 T1= 48.6	$H(s)=\dfrac{0.0206}{s+0.0206}$
2 nd order	$y(t)=150+$ $+4505\cdot e^{-0.03963\cdot t}$ $-4655\cdot e^{-0.03853\cdot t}$	K2=1 T21= 3.7 T22=25.65 ξ =1.0046	$H(s)=$ $\dfrac{5.5\cdot s+1.5}{1000\bullet s^2+78.2\cdot s+1.5}$

It could be observed that the second order model approximation is more precise than the firs order approximation model and in conclusion for this unit the second order model will be used.

The identified model type for several studied units that represents the main active units for LFC in Romanian power system is resumed in Table II.

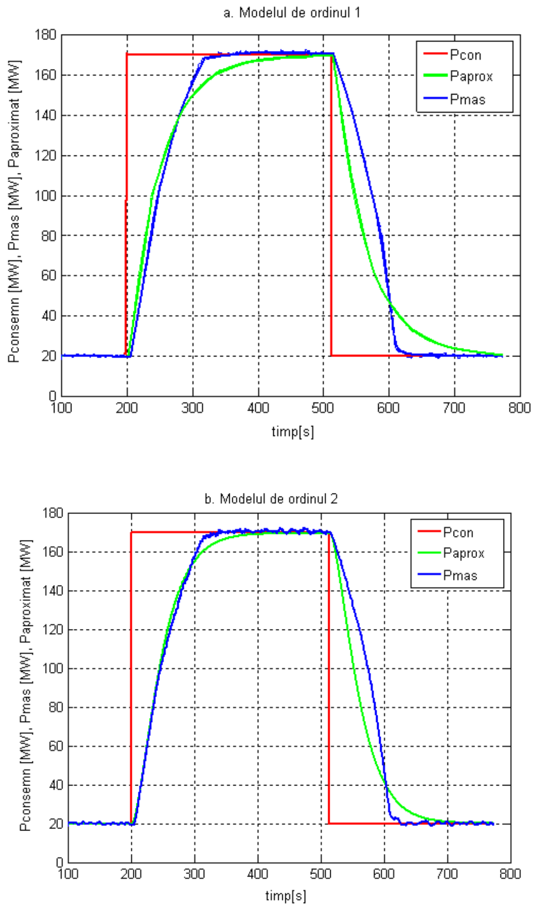

Fig. 8. Comparison between experimental measured data (Pmas) and approximated data by simulation (Paprox) - HA1 Lotru

TABLE II
MODEL TYPE FOR MAIN LFC ACTIVE UNITS

Generation Unit (GU) CHE – hydro GU CTE – thermal GU	***1st order model with time delay***	***2nd order model with time delay***	***integrative model with time delay***
CHE Lotru		X	
CHE Mariselu	X		
CHE Vidraru		X	
CHE Galceag	X		
CHE Sugag	X		
CHE Portile de Fier I			X
CTE Braila			X
CTE Iernut			X

IV. LOAD FREQUENCY CONTROL SIMULATOR

Based on the developed generation units models a simulator was build in Matlab/Simulink, in order to test a secondary control diagram with a PI controller for restoring frequency.

The simulator in figure 9 considers different generation units (e.g. 1 thermal unit and 2 hydro units). The thermal unit is modelled as integrative elements with saturation. The hydro units are 1st order models with time delay.

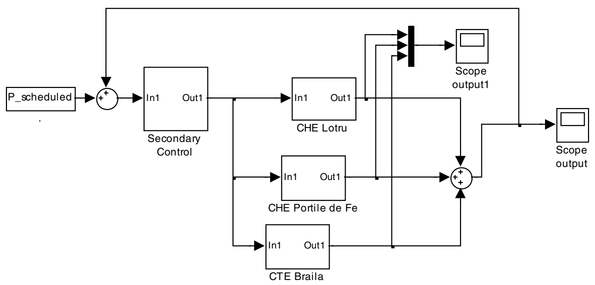

Fig. 9. Simulation diagram

The PI controller in equation (4) is completed with several elements in order to adapt it to the real operation conditions (figure 10). Therefore some coefficients are needed: K_1 for time conversion in seconds and K_2 for limiting the control command in a demanded interval (e.g.[-1,1]).

$$H_{FC}(s) = K_P + \frac{K_i}{s} \tag{4}$$

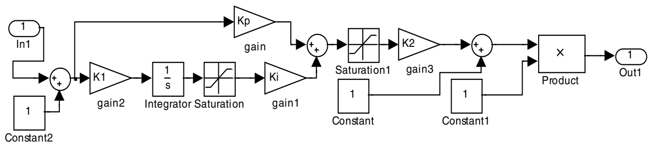

Fig. 10. Simulation diagram for the controller

The controller output signal must be adapt for each type of power plant depending on the assigned control band (BR_i).

The saturation value is set at $\sum_{i=1}^{n} BR_i$, where n represents the number of the controlled units. The gain is set for $1/\sum_{i=1}^{n} BR_i$, so that the controller's output is commanded in the limit [-1,1].

The secondary control diagram was tested based on a three unit's scenario with different control bands and different charge speeds (CS_i) as in Table III.

TABLE III
THE THREE SELECTED UNITS LOAD PARAMETERS

	Lotru	Portile de Fier	Braila
BR_i[MW]	150	260	60
CS_i[MW/min]	-	75	4

Using the simulator in figure 9 the control command corresponding to a 200 MW load is represented in figure 11 and the output load for each generation unit is shown in figure 12.

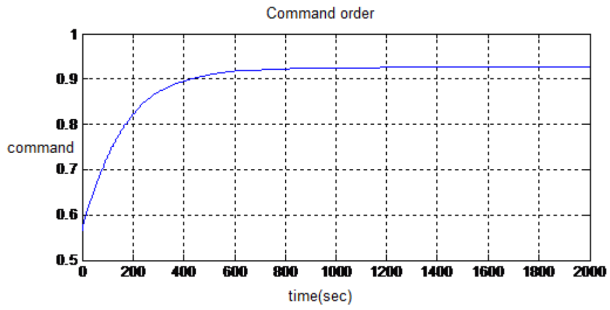

Fig. 11. Load command: order

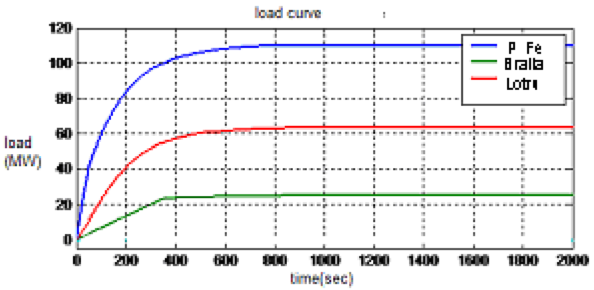

Fig. 12. Load curve output for each generation unit

V. CONCLUSION

Different models that can be used to represent a thermal or hydro power generation unit for AGC purpose have been developed. These models have been obtained after analyzing the real response of 15 power generation units.

The models consist of a rate limiter, a dead band, a first or second order transfer function or an integrative element and an offset.

The experimental identification procedure based on the rectangular sample signal was used to estimate the values of the model's parameters.

The developed models for power generation units can be used for tuning LFC systems as well as for building and setting up a real-time simulator for dispatcher training.

In this paper the models was used to build up a simulator for a secondary control diagram. The simulator was developed and tested in order to fit real operation conditions. The considered secondary controller was a PI controller with a specific adjustment block.

The power response was obtained stable for different control bands and different change speeds of the generation units.

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VII. BIOGRAPHIES

Sergiu Stelian ILIESCU has received the M.S. (1965) degree from the Power System Faculty, Automatic Control Department and Ph. D. (1979) degree in Computers- Electronics from University Politehnica of Bucharest (UPB). He was starting his professional activity in execution and implementation of automatic control equipments and systems, within the Automatic Control System Execution Company (IMIA). The next step was to work as design engineer within Power Systems Studies and Design Institute (ISPE).

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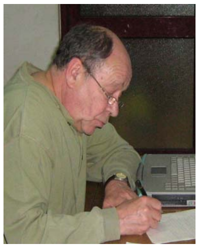

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