Modeling and Parameter Estimation of a Nuclear Power Plant

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***Abstract*— A simple dynamic model in physical coordinates and the corresponding parameter estimation procedure for the primary circuit dynamics and premodeling studies of the secondary circuit of VVER-type pressurized water reactors are presented in this paper. The primary uses of the model are control oriented dynamic model analysis and high level controller design. Therefore, the model should contain the minimal possible number of differential equations and it should be capable of describing important dynamic phenomena such as load change transients between day and night periods. Furthermore, the estimated parameter values should fall into physically meaningful ranges. The parameter estimation method of the primary circuit is an optimization based numerical method using the decomposed and the entire primary circuit model. The partial verification of the models of parts of the secondary circuit has also been completed using badly sampled measurments. The constructed model satisfies the predefined requirements and its response shows good fit to the measurement data that were obtained from three units of the Paks Nuclear Power Plant in Hungary.**

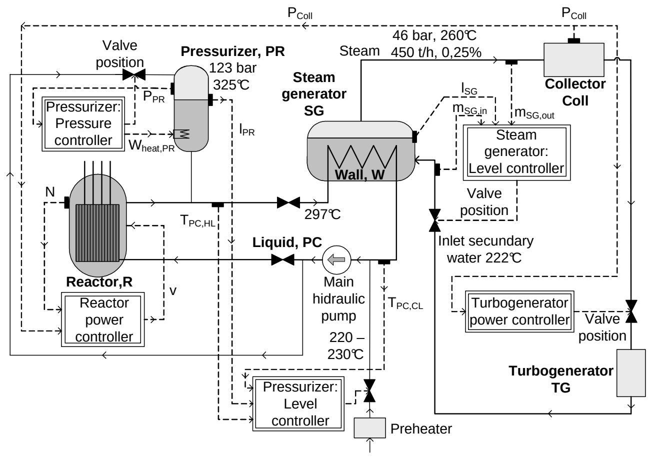

Fig. 1. Process flowsheet with the operating units of the simplified model. (R - reactor, PC - liquid in the primary circuit, PR - pressurizer, SG - steam generator, W - tube-wall, Coll - collector and TG - turbogenerator)

I. INTRODUCTION

The physical and moral lifetime of instruments and controls installed in electricity generating plants is generally shorter than the expected service time of the power generating unit itself. This fact often necessitates the re-tuning or the review of different subsystems in nuclear power plants (NPP). This requirement of re-tuning or review is strengthened by the gradually changing operating requirements, the ever stringent regulations related to performance, effectiveness and safety. These important tasks are supported by the improving quantity and quality of dynamic measurements as a result of developing hardware-software environment and modern sensor devices. It is well known from theory and engineering practice that the application of advanced feedback control can dramatically improve dynamical system properties often without the need to introduce significant changes in the technology.

Majority of the model analysis and controller design methods require that the original mathematical model of the system is in the form of (a preferably low number of) ordinary differential equations while the traditionally available and commonly used dynamic models for nuclear power plants (e.g. [6], [10]) are much too complex and detailed for control purposes. Relatively few publications can be found in the literature about the dynamic identification of simplified physical NPP models [2].

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Therefore, the aims of this paper are to present such a simple dynamic model for the primary and secondary circuit of a VVER-type (pressurized water reactors) NPP in physical coordinates, and to describe the parameter estimation procedure for the model. The intended use of the model is control oriented system analysis and controller design. The domain of the model includes the dynamic behavior in normal operating mode together with the load changes between the day and night periods.

The primary circuit model presented here is published in [5] and it is a modified version of the one that was described in [3], [4] where the detailed description can be found.

II. MODEL OF THE PRIMARY CIRCUIT

A. Modeling setup and assumptions

The set of operating units considered in our simple dynamic model includes the reactor (R), the primary circuit liquid (PC), the pressurizer (PR), the steam generator (SG) and the tube-wall in the steam generator (W) with their abbreviations between parentheses (see in Fig. 1). Their dynamic models are derived from simplified mass, energy and neutron balances constructed for a single balance volume that corresponds to the individual unit. Each balance volume is considered a spatially homogeneous lumped parameter system. The considered controllers are the pressure controller, the level controller of the pressurizer, the level controller in the steam generator and the power controller of the reactor, the dynamics of which has been neglected.

The reactor model is a time-dependent, single-group neutron diffusion equation [7] model, with a single type of delayed neutron emitting nuclei whose concentration is in a quasi steady-state. The dependence of the nuclear physical mechanisms on the temperature is neglected, but the effect of the control rod position on the reactivity is approximated by a quadratic function.

The liquid in the primary circuit is assumed to be pure water, whose density depends on the temperature described by a second order polynomial, and its dependence on the pressure is neglected. The heat transferred from the primary circuit to the tube wall of the steam generator depends polynomially on the temperature difference between the average temperature of primary circuit liquid and the temperature of the tube-wall.

The dynamics of the primary side of the steam generators and the dynamics of the secondary side vapor phase are very quick compared to the dynamics of secondary water mass and temperature, therefore they are assumed to be in a quasi steady state. Moreover, an equilibrium is assumed between the secondary liquid and the vapor phases. The heat transferred from the tube-wall of the steam generator to the secondary circuit water depends polynomially on the temperature difference between the temperature of the tube-wall and the temperature of the secondary liquid.

The liquid in the pressurizer is assumed to be pure water, and it is assumed to be part of the liquid in the primary circuit. The liquid mass in the pressurizer is computed as an excess to a nominal mass in the primary circuit. The density of the liquid is assumed to depend on its temperature according to a second order polynomial, and its dependence on the pressure is neglected.

The energy losses of operating units are supposed to be linear functions of their respective temperatures, except for the pressurizer where it is considered constant. The pressure in an operating unit is assumed to depend quadratically on the temperature in the operating unit.

B. State-Space Model

With the above simplifying modeling assumptions, the nonlinear state equations of the simple primary circuit dynamics are the following:

$$\frac{dN}{dt} = \frac{p_1 v^2 + p_2 v + p_3}{\Lambda} N + S \quad (1)$$

$$\frac{dM_{PC}}{dt} = m_{in} - m_{out} \quad (2)$$

$$\begin{aligned}\frac{dT_{PC}}{dt} &= \frac{1}{c_{p,PC} M_{PC}} \big[c_{p,PC} m_{in} \left(T_{PC,I} - T_{PC} \right) + W_R + \\ &+ c_{p,PC} m_{out} 15 - 6 \cdot K_{T,SG,1} \left(T_{PC} - T_W \right)^a - \\ &- K_{loss,PC} \left(T_{PC} - T_{out,PC} \right) \big] \end{aligned} \quad (3)$$

$$\frac{dM_{SG}}{dt} = m_{SG,in} - m_{SG,out} \quad (4)$$

$$\begin{aligned}\frac{dT_{SG}}{dt} &= \frac{1}{c^L_{p,SG} M_{SG}} \big[c^L_{p,SG} m_{SG,in} \left(T_{SGSW} - T_{SG} \right) + \\ &+ c^L_{p,SG} m_{SG,out} T_{SG} - m_{SG,out} E_{evap,SG} + \\ &+ K_{T,SG,2} \left(T_W - T_{SG} \right)^b - \\ &- K_{loss,SG} \left(T_{SG} - T_{out,SG} \right) \big] \end{aligned} \quad (5)$$

$$\begin{aligned}\frac{dT_W}{dt} &= \frac{1}{c_{p,W} M_W} \Big[K_{T,SG,1} \left(T_{PC} - T_W \right)^a - \\ &- K_{T,SG,2} \left(T_W - T_{SG} \right)^b \Big] \end{aligned} \quad (6)$$

$$\begin{aligned}\frac{dT_{PR}}{dt} &= \frac{1}{c_{p,PR} M_{PR}} \big[\chi_{m_{PR}>0} c_{p,PC} m_{PR} T_{PC,HL} + \\ &+ \chi_{m_{PR}<0} c_{p,PR} m_{PR} T_{PR} - W_{loss,PR} + \\ &+ W_{heat,PR} - c_{p,PR} m_{PR} T_{PR} \big] \end{aligned} \quad (7)$$

The output equations are as follows

$$W_R = c_\Psi N \quad (8)$$

$$p_{SG} = p^T_*(T_{SG}) \quad (9)$$

$$\ell_{PR} = \frac{1}{A_{PR}} \left(\frac{M_{PC}}{\varphi(T_{PC})} - V^0_{PC} \right) \quad (10)$$

$$p_{PR} = p^T_*(T_{PR}) \quad (11)$$

Note that the output variables determined by the above equations are the principal measured variables characterizing the state of the primary circuit: the reactor power W_R, the pressure in the steam generator p_{SG}, together with the level of and the pressure in the pressurizer (ℓ_{PR} and p_{PR}, respectively).

Other constitutive equations are:

$$\varphi(T_.) = c_{\varphi,0} + c_{\varphi,1} T_. + c_{\varphi,2} T_.^2 \quad (12)$$

$$\begin{aligned} m_{PR} &= \frac{dM_{PR}}{dt} = m_{in} - m_{out} - \\ &- V^0_{PC} \left(c_{\varphi,1} + 2 c_{\varphi,2} T_{PC} \right) \frac{dT_{PC}}{dt} \end{aligned} \quad (13)$$

where $\varphi(T_.)$ is the density of the liquid and $.$ stands for PC or PR. These equations determine the mass flow rate m_{PR} between the pressurizer and the primary circuit that is induced by the variation of the density of the primary circuit liquid caused by the changes in the primary circuit temperature. It is important to note, that the change in the flow direction, i.e. the change in the sign of m_{PR} makes the model exhibit a state-switching type hybrid behavior.

The definition of the variables and the parameters can be seen in Tables I and II, respectively.

From a physical point of view, neglecting the reactivity dependency on the temperatures is a serious over-simplification that may significantly influence the system dynamics. The main reason for this neglect is to obtain a dynamic model with the simplest possible algebraic structure and a minimum number of parameters to be estimated. This approximation will cause a difference between the measured and the model predicted neutron flux and primary circuit water temperature values, but this is still an acceptable simplification of reality in the investigated operating region (see Fig. 2).

The model is realized in MATLAB/SIMULINK.

C. Parameter estimation

The parameter estimation has been performed in two main steps (see details in [5]). In the first step, three subsystems of the overall model - the reactor, the main thermo-hydraulic part of the circuit and the pressurizer - have been identified

TABLE I

VARIABLES WITH TYPE (STATE, INPUT, OUTPUT, DISTURBANCE).

Identifier	**Variable**	**Type**
N	R neutron flux	s
v	R control rod position	i
W_R	R reactor power	o
m_{in}	PC inlet mass flow rate	i
m_{out}	PC purge mass flow rate	d
M_{PC}	PC liquid mass	s
$T_{PC,I}$	PC inlet temperature	d
T_{PC}	PC temperature	s
M_{PR}	PR liquid mass	o
p_{PR}	PR pressure	o
T_{PR}	PR temperature	s
ℓ_{PR}	PR liquid level	o
$W_{heat,PR}$	PR heating power	i
M_{SG}	SG water mass	s
T_{SG}	SG steam generator temperature	s
$m_{SG,in}$	SG inlet mass flow rate	i
$m_{SG,out}$	SG steam mass flow rate	d
T_{SGSW}	SG inlet water temperature	d
p_{SG}	SG steam pressure	o
T_W	W temperature of the wall	s

TABLE II

ESTIMATED PARAMETERS OF THE PRIMARY CIRCUIT MODEL

Notation	**Definition**	**Op. unit**
(p_1, p_2, p_3)	Rod's parameters	R
S	Neutron source	R
$c_{p,PC}$	Specific heat	PC
$K_{T,SG,1}$	Heat transfer coefficient	PC
$K_{T,SG,2}$	Heat transfer coefficient	SG
$K_{loss,PC}$	Energy loss coefficient	PC
$K_{loss,SG}$	Energy loss coefficient	SG
a, b	Powers of heat transfer	-
$c^L_{p,SG}$	Specific heat of water	SG
$c_{p,W} \cdot M_W$	Specific heat and mass	W
$c_{p,PR}$	Specific heat	PR
$W_{loss,PR}$	Heat loss	PR
V^0_{PC}	Volume of primary circuit	PR
$E_{evap,SG}$	Evaporation heat (not estimated)	SG

separately and sequentially. For each subsystem, the measured variables were classified as manipulated inputs, non-manipulable disturbances and outputs. The objective function (f_{obj}) of the identification measured the fit between the model simulated and measured output.

In the second step, the whole system model described by equations (1)-(7) was put together and identified using the parameter values obtained in the previous step as initial estimates. The final output for the objective function of the whole model is composed as a linear combination of the outputs corresponding to the subsystems in the first step.

The parameter estimation problem is basically an optimization problem which is bound constrained to keep the

TABLE III

ESTIMATED PARAMETERS OF THE INTEGRATED PRIMARY CIRCUIT MODEL. TS MEANS TIME SPAN.

Parameter	**Unit**	unit 1 TS: 4h	unit 3 TS: 2.5h	unit 4 TS: 2.5h
$-p_1$	m^{-2}	$1.36 \cdot 10^{-4}$	$1.23 \cdot 10^{-4}$	$1.32 \cdot 10^{-4}$
$-p_2$	m^{-1}	$6.05 \cdot 10^{-5}$	$5.46 \cdot 10^{-5}$	$6.68 \cdot 10^{-5}$
$-p_3$	1	$2.88 \cdot 10^{-4}$	$1.97 \cdot 10^{-4}$	$2.88 \cdot 10^{-4}$
S	$\%/s$	2884.4	1954.3	2901
$c_{p,PC}$	$J/kg/K$	5281	5093.8	5043.1
$K_{T,SG,1}$	W/K	$9.19 \cdot 10^6$	$8.86 \cdot 10^6$	$9.80 \cdot 10^6$
$K_{loss,PC}$	W/K	$3.00 \cdot 10^6$	$2.40 \cdot 10^6$	$3.33 \cdot 10^6$
a	$-$	1.097	1.073	1.112
$M_{SG}(0)$	kg	31810	31688	30788
$c^L_{p,SG}$	$J/kg/K$	4651.1	4669.7	4681.9
$K_{loss,SG}$	W	$1.52 \cdot 10^8$	$1.92 \cdot 10^8$	$1.15 \cdot 10^8$
$K_{T,SG,2}$	W/K	$3.30 \cdot 10^6$	$2.33 \cdot 10^6$	$2.48 \cdot 10^6$
b	$-$	2.004	2.688	1.806
$c_{p,W} \cdot M_W$	J/K	$2.031 \cdot 10^7$	$1.666 \cdot 10^7$	$1.93 \cdot 10^7$
$T_W(0)$	^oC	267.9	266.09	269.76
$c_{p,PR}$	$J/kg/K$	5895.4	5903.3	5896.4
$W_{loss,PR}$	W	$1.48 \cdot 10^5$	$1.72 \cdot 10^5$	$1.73 \cdot 10^5$

estimated parameter values in a physically meaningful range. Since the model equations (1)-(7) are nonlinear functions of certain parameters (e.g. a and b in Eq. (6)) and the existence of the bound constraints, the classical least squares (LS) method cannot be applied for identification.

For the evaluation of f_{obj}, the simulation of the system dynamics with some parameter vector θ is required which is a computationally expensive operation. This means that the numerical approximation and evaluation of the gradient of f_{obj} requires much computational effort and moreover, it can often be unreliable because of the noise of some measurements. These facts motivated us to choose a simple yet effective numerical optimization method that does not need the computation of the gradient of the objective function. The *Nelder-Mead simplex search method* [8] is a well-known direct search algorithm [9] for multidimensional optimization without derivatives. Since the ranges of the model parameters were relatively well-known from plant documentation, the proper selection of initial parameter values was possible.

The final result of the parameter estimation can be seen in the Table III and fitting of simulated and measured signals can be seen in Fig. 2.

III. MODEL OF THE SECONDARY CIRCUIT

A. *The model of the turbogenerator*

From the measured data, a static relation can be established between the thermal power of the reactor and the net effective electric power of the two turbogenerators of the unit (see Fig. 3):

- Unit 3: $P_E^{unit} = 5,166 \cdot 10^6 \cdot P_R - 6,836 \cdot 10^7$
- Unit 4: $P_E^{unit} = 5,882 \cdot 10^6 \cdot P_R - 7,366 \cdot 10^7$

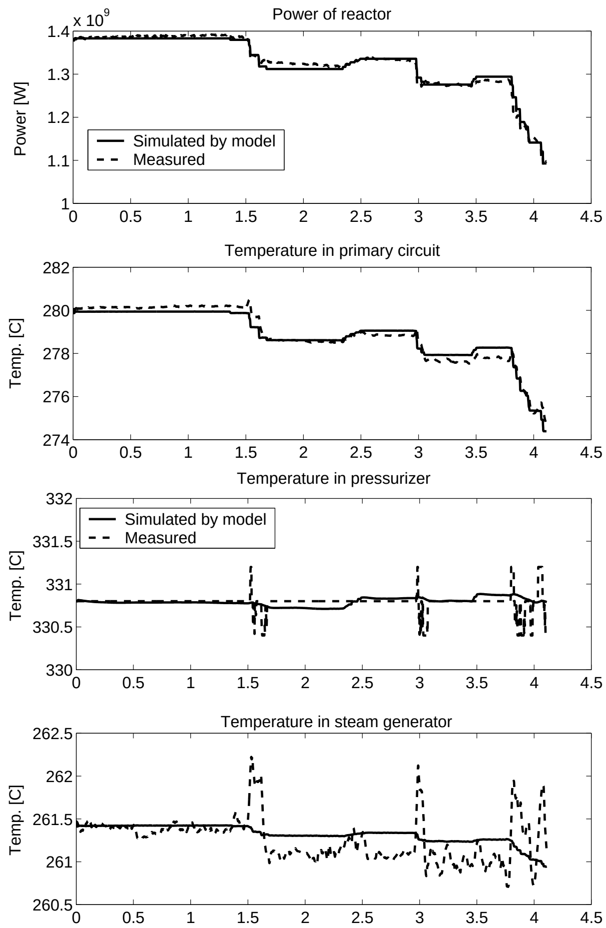

Fig. 2. Fitting of the neutronflux and the temperature signals after the parameter estimation.

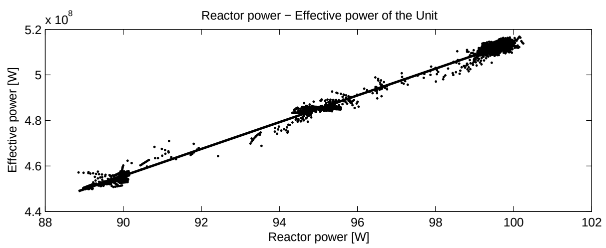

Fig. 3. The unit effective power as a function of the reactor power in case of unit 4.

where P_E^{unit} $[W]$ is the net effective power of the two turbogenerators of the unit and P_R $[\%]$ is the thermal power of the reactor in the per cent of its maximal thermal power.

B. The model of the fresh steam collector

The collector of the fresh steam plays a crucial rule in the operation of the Paks NPP. The pressure of the steam in the collector has to be held constant in all operating modes. This pressure can be controlled by the power of the reactor or by the inlet steam flowrate of the turbogenerator.

Therefore, the purpose of the modeling of the collector of the fresh steam is to describe its dynamics from controller design point of view.

The steam generator (SG) generates saturated steam. Its physical properties are different from the unsaturated steam (ideal gas): the pressure of saturated steam depends on its temperature and is independent from its volume. However, the steam in the collector become unsaturated a little because its volume has been increased during the flow from the SG to the collector. This flow is driven passively by the pressure difference between the SG and the collector. In Paks NPP three SGs feed one collector.

1) Modeling assumptions:

C1 Energy balance is described.
C2 The heat loss of the collector is constant.
C3 The specific heat of steam in the collector can be considered to be constant because the temperature of the steam can be changed a little only.
C4 The mass of the steam in the collector can be considered to be constant (i.e. the mass of the steam is much more than the inlet and the outlet steam flowrates).
C5 The pressure of the steam in the collector can be calculated by an algebraic expression from its temperature.
C6 The temperature of the inlet steam is the same as the temperature of the steam generated in the SG.

2) Balance equations: According to the assumption C4

$$M_{Coll} = konst \tag{14}$$

where M_{Coll} $[kg]$ is the mass of the steam in the collector.

Energy balance is described according to assumption C1:

$$\begin{aligned} \frac{dU_{Coll}}{dt} &= c_{Coll} m_{Coll,in} T_{Coll,in} - \\ &- c_{Coll} m_{Coll,out} T_{Coll} - W_{Coll,loss} \end{aligned} \tag{15}$$

where U_{Coll} $[J]$ is the inner energy of the steam in the collector, c_{Coll} $[J/K/kg]$ is the specific heat of the steam at temperature $258\ ^oC$, (the specific heat of the inlet and the outlet steam is the same based on the assumption C3), $m_{Coll,in}$ $[kg/s]$ is the inlet steam flowrate, $m_{Coll,out}$ $[kg/s]$ is the outlet steam flowrate, $T_{Coll,in}$ $[K]$ is the temperature of the inlet steam, T_{Coll} $[K]$ is the temperature of the steam in the collector and $W_{Coll,loss}$ $[J/s]$ is the heat loss of the collector (it is a constant based on the assumption C2).

To develop the differential equation of the temperature of the steam in the collector the expression $U_{Coll} = c_{Coll} M_{Coll} T_{Coll}$ is derivated according to time and rearranged, then the Eq. (15) is substituted into it and the assumption C6 is applied, and finally we get the expression

$$\begin{aligned} \frac{dT_{Coll}}{dt} &= \frac{1}{c_{Coll} M_{Coll}} \big(c_{Coll} m_{Coll,in} T_{SG} - \\ &- c_{Coll} m_{Coll,out} T_{Coll} - W_{Coll,loss} \big) \end{aligned} \tag{16}$$

3) Constitutive equations: Based on the assumption C5

$$p_{Coll} = f_1 \left(T_{Coll} \right) \tag{17}$$

where p_{Coll} $[Pa]$ is the pressure of the steam in the collector. The function $f_1 \left(T_{Coll} \right)$ is not known but some possible forms of it are as follows:

- If the steam in the collector can be considered to be unsaturated, then according to the law of Gay-Lussac: $p_{Coll} = a \cdot T_{Coll}$, where a $[Pa/K]$ is a constant.
- Linear function: $p_{Coll} = c \cdot T_{Coll} + d$, where c $[Pa/K]$ and d $[Pa]$ are constants.
- The steam of the collector can be considered to be a mixture of saturated and unsaturated steam, then: $p_{Coll} = b \cdot e^{f_2(T_{Coll})} + (1 - b) \cdot a \cdot T_{Coll}$, where b $[-]$ is a constant giving the partial mass rate of the saturated steam in the mixture. The function $e^{f_2(T_{Coll})}$ is the pressure-temperature function of the saturated steam known from steam tables.

C. Connection between the two circuits

1) Retroaction of the collector to the steam generator: So far, we considered that the temperature of the steam in the SG (T_{SG}) is independent from the pressure of the steam in the collector (p_{Coll}) (see Eq. (5), section II). However, there is a direct, physical connection between the SG and the collector: the steam flow. Therefore, the pressure of the steam in the SG can be influenced by the pressure of the steam in the collector. The SG contains saturated steam then its temperature is influenced by its pressure. We consider that this connection can be described by the application of a new, additive expression in the Eq. (5), i.e.

$$\begin{aligned}\frac{dT_{SG}}{dt} = & \frac{1}{c^L_{p,SG} M_{SG}} \left[c^L_{p,SG} m_{SG,in} \left(T_{SGSW} - T_{SG} \right) + \right. \\ & + c^L_{p,SG} m_{SG,out} T_{SG} - m_{SG,out} E_{evap,SG} + \\ & + K_{T,SG,2} \left(T_W - T_{SG} \right)^b - \\ & \left. - K_{loss,SG} \left(T_{SG} - T_{out,SG} \right) \right] + g \left(p_{Coll} \right)\end{aligned} \quad (18)$$

where $g(p_{Coll})$ is the function of the retroaction. The exact expression of $g(p_{Coll})$ is currently unknown.

2) Steam flow from the steam generator to the collector: A passive mass flow rate driven by pressure difference can be described by $m_{SG,out} = \sqrt{D_1 \rho \left(p_{SG} - p_{Coll} \right)}$, where D_1 $[kg \cdot m^3/s^2/Pa]$ is a constant and ρ $[kg/m^3]$ is the density of the steam [1]. If the density is constant, then

$$m_{SG,out} = \sqrt{D \cdot \left(p_{SG} - p_{Coll} \right)} \quad (19)$$

where D $[kg^2/s^2/Pa]$ is a constant and $D = D_1 \cdot \rho$.

D. Partial verification of the models

So far, we do not have appropriate measured signals for the verification of the model of the secondary circuit. Therefore, only a partial and static verification has been completed.

The models are realized in MATLAB/SIMULINK environment. Measured signals are received from the Paks NPP during normal operation mode and load changes, but the sampling times of these measurements are very high.

1) Verification of the collector model: In Fig. 2 there is $0.3 - 0.7$ K temperature difference between the simulated and the measured T_{SG} during the power decrease (e.g. at the 1.5^{th} hour). We assume that this difference is caused by the pressure and temperature growth in the collector. Therefore, we try to reconstruct this temperature growth using the collector model during the verification.

Since the measured signals are badly sampled, artificial signals are applied that are similar to the measured ones. The inlet and outlet steam flowrate are the same piecewise linear functions but there is a time offset between them. T_{SG} is held constants. The values of the parameters are similar to their value during the normal operation mode.

The inputs and the resulting output of this verification can be seen in Fig. 4. The dynamics of temperature matches well to the expected dynamics.

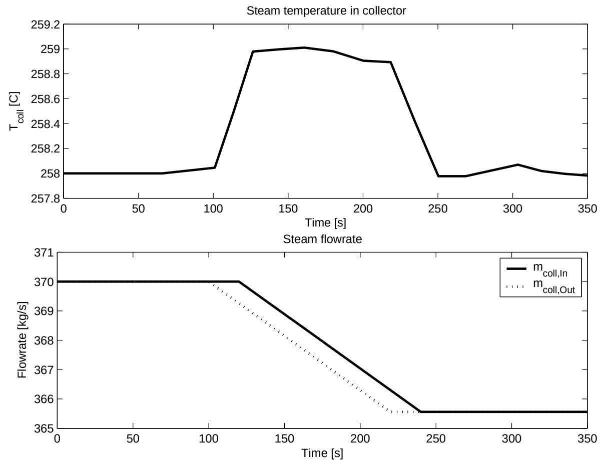

Fig. 4. Result of the verification of the collector model. Upper plot shows the inputs of the model, while the plot bellow shows the simulated output.

TABLE IV
PARAMETERS OF EQ. $m_{SG,out} = \sqrt{d_1 \cdot (p_{SG} - p_{Coll}) + d_2}$

SG number	d_1 **[$kg^2/s^2/Pa$]**	d_2 **[kg^2/s^2]**
1	0.094827	11891.4836
2	0.10729	10304.0694
3	0.079273	13354.4143
4	0.22286	8249.165
5	0.14278	5857.2293
6	0.21571	11134.8455

2) Verification of the steam flow model: The verification of Eq. (19) is based on the badly sampled measurements.

We could not estimate the value of parameter D in Eq. (19) such that the measured and simulated values of $m_{SG,out}$ fit well. However, if we rewrite the Eq. (19) in form

$$m_{SG,out} = \sqrt{d_1 \cdot \left(p_{SG} - p_{Coll} \right) + d_2} \quad (20)$$

then the simulated and the measured values of $m_{SG,out}$ fit well. The LS method is applied to fit the measured and simulated values. The resulting fit can be seen in Fig. 5 and the estimated parameter values can be seen in Table IV.

3) Retroaction of the collector to the SG: This verification is based on the badly sampled measurements.

The dynamics of the temperature in the SG as a function of the power of the reactor can be seen in Fig. 6. At the 3^{rd} hour, there is a power decrease. It causes a "jump" in the pressure of the steam in the collector and in the temperature of the SG. This phenomena is the retroaction. An opposite

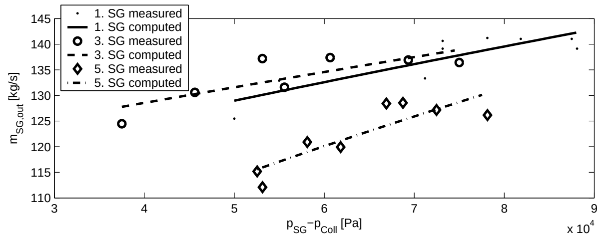

Fig. 5. Examples for the fit of the measured and the simulated values of $m_{SG,out}$ applying Eq. (20).

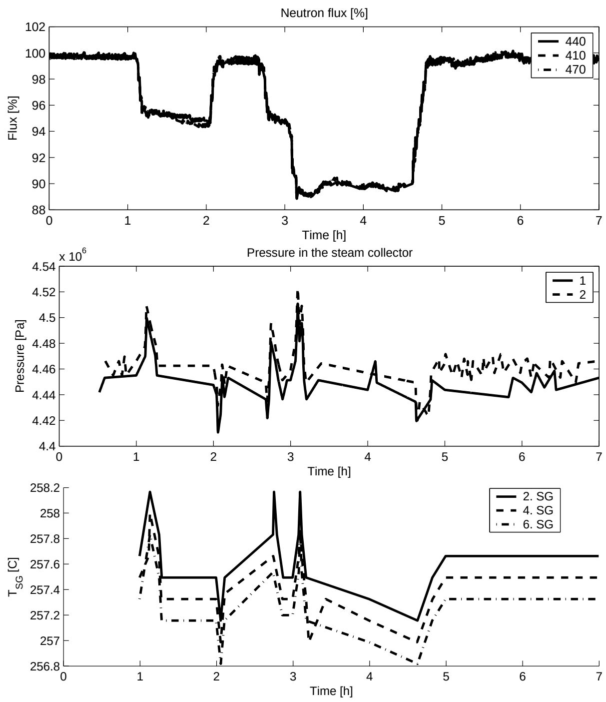

Fig. 6. Examples for T_{SG} as a function of the power of the reactor.

phenomena can be seen at the power increase before the 5^{th} hour.

Based on Fig. 6 we can describe the expression

$$\Delta T_{SG} = C_1 \Delta p_{Coll} \quad (21)$$

However, the measurement is badly sampled therefore, we cannot describe that $\frac{dT_{SG}}{dt} = C_1 \frac{dp_{Coll}}{dt}$, i.e. we cannot state that the expression $g(p_{Coll}) = C \frac{dp_{Coll}}{dt}$ is valid.

IV. CONCLUSIONS AND FUTURE WORK

A. Conclusions

The modeling and the parameter estimation procedure of a pressurized water NPP has been described in this paper. The result is a low dimensional nonlinear dynamic model with physically meaningful structure that is suitable for controller design, and describes the most important dynamic phenomena in a NPP, such as load changes between day and night periods. To complete the parameter estimation, the primary circuit has been decomposed to subsystems based on a system and control theoretical point of view taking into consideration the present controller configuration, too. Then the integrated model has been estimated. The parameters have been estimated using a quadratic error function and a nonlinear optimization algorithm. The necessary measurement data were collected from three units of the Paks NPP, located in Hungary. A static model of the turbogenerator and the dynamics models of the most important parts of the secondary circuit have been also developed and their partial verifications using badly sampled measured data have been achieved. The identified model shows good fit to the measurements and it will probably serve as a basis for the integrated re-design of the controllers in the near future. The model is not suitable for describing dynamics under non-standard operating conditions, such as faults.

B. Future Work

The new measurements of the primary and secondary circuit variables are expected from the Paks NPP. Applying these new signals the parameter estimation of the secondary circuit and the validation of the connected primary and secondary models will be carried on. Then, the recommendations of the new controllers, the controller structure and the supervisory controller will be developed.

V. ACKNOWLEDGMENTS

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