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Evolved Fuzzy Control System for a Steam Generator

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1. Introduction

Poor control of steam generator water level is the main cause of unexpected shutdowns in nuclear power plants. Such shutdowns are caused by violation of safety limits on the water level and are common at low operating power where the plant exhibits strong non-minimum phase characteristics. In addition, the steam generator is a highly complex, nonlinear and time-varying system and its parameters vary with operating conditions. Therefore, there is a need to systematically investigate the problem of controlling the water level in the steam generator in order to prevent reactor shutdowns.

Difficulties on designing a steam generator (SG) level controller arise from the following factors:

- *nonlinear plant characteristics*. The plant dynamics are highly nonlinear. This is reflected by the fact that the linearized plant model shows significant variation with operating power.
- *nonminimum-phase plant characteristics*. The plant exhibits strong inverse response behavior, particularly at low operating power due to the so-called “swell and shrink” effects.
- dynamics uncertainties,
- corrupted feed-water flow measurement signal with biased noises.

At low loads (less than 15% of full power) the non-minimum phase behavior is much more pronounced.

Various approaches have been reported in the literature: an adaptive PID level controller using a linear parameter varying model to describe the process dynamics over the entire operating power range (Irving et al. 1980); a model of the steam generator water level process in the form of a transfer function, determined based on first-principles analysis and expert experience has been presented in (Zhao et al., 2000); LQG controllers with “gain-scheduling” to cover the entire operating range (Menon & Parlos, 1992); a hybrid fuzzy-PI adaptive control of drum level, a model predictive controller to identify the operating point at each sampling time and use the plant model corresponding to this operating point as the prediction model (Kothare et al., 2000). Paper (Park & Seong, 1997) presents a self organizing fuzzy logic controller for the water level control of a steam generator. A

nonlinear physical model with a complexity that is suitable for model-based control has been presented by Astrom and Bell (Åstrom & Bell, 2000). The model describes the behavior of the system over a wide operating range.

With the advent of the current generation of high-speed computers, more advanced control strategies not limited to PI/PID, can be applied (Hirota, 1993), (Pedrycz & Gomide, 2007), (Yen et al., 1995), (Ross, 2004).

Model predictive control (MPC) design technique has gained wide acceptance in process control applications. Model predictive control has three basic steps: output prediction, control calculation and closing the feedback loop (Camacho & Bordons, 2004), (Demircioglu & Karasu, 2000), (Morari & Lee, 1999).

In this chapter, we apply MPC techniques to develop a framework for systematically addressing the various issues in the SG level control problem.

Fuzzy models have become one of the most well established approaches to non-linear system modeling since they are universal approximations which can deal with both quantitative and qualitative (linguistic) forms of information (Dubois & Prade, 1997), (Zadeh, 2005), (Zadeh, 1989) This chapter deals with Takagi-Sugeno (T-S) fuzzy models because this type of model provides efficient and computationally attractive solutions to a wide range of modeling problems capable to approximate nonlinear dynamics, multiple operating modes and significant parameter and structure variations (Kiriakidis, 1999), (Yager & Zadeh, 1992), (Ying, 2000). Takagi-Sugeno (T-S) fuzzy models have a good capability for prediction and can be easily used to design model-based predictive controllers for nonlinear systems (Espinosa et al., 1999).

The objective of this chapter is to design, evaluate and implement a water level controller for steam generators based on a fuzzy model predictive control approach. The chapter includes simulations of typical operating transients in the SG. A new concept of modular advanced control system designed for a seamless and gradual integration into the target systems is presented. The system is designed in such a way to improve the quality of monitoring and control of the whole system. The project targets the large scale distributed advanced control systems with optimum granularity architecture.

2. Fuzzy model

Fuzzy models can be divided into three classes: Linguistic Models (Mamdani Models), Fuzzy Relational Models, and Takagi-Sugeno (TS) Models. Both linguistic and fuzzy relational models are linguistically interpretable and can incorporate prior qualitative knowledge provided by experts (Zadeh, 2008). TS models are able to accurately represent a wide class of nonlinear systems using a relatively small number of parameters. TS models perform an interpolation of local models, usually linear, by means of a fuzzy inference mechanism. Their functional rule base structure is well-known to be intrinsically favorable for control applications.

This chapter deals with Takagi-Sugeno (T-S) fuzzy models because of their capability to approximate a large class of static and dynamic nonlinear systems. In T-S modeling

methodology, a nonlinear system is divided into a number of linear or nearly linear subsystems. A quasi-linear empirical model is developed by means of fuzzy logic for each subsystem. The whole process behavior is characterized by a weighted sum of the outputs from all quasi-linear fuzzy implication. The methodology facilitates the development of a nonlinear model that is essentially a collection of a number of quasi-linear models regulated by fuzzy logic. It also provides an opportunity to simplify the design of model predictive control. In such a model, the cause-effect relationship between control u and output y at the sampling time n is established in a discrete time representation. Each fuzzy implication is generated based on a system *step response* (Andone&Hossu, 2004), (Hossu et al., 2010) , (Huang et al. 2000).

$$\begin{aligned}
 & \text{IF } y(n) \text{ is } A_0^i, y(n-1) \text{ is } A_1^i, \dots, y(n-m+1) \text{ is } A_{m-1}^i, \\
 & \text{and } u(n) \text{ is } B_0^i, u(n-1) \text{ is } B_1^i, \dots, u(n-l+1) \text{ is } B_{l-1}^i \\
 & \text{THEN } y^i(n+1) = y(n) + \sum_{j=1}^T h_j^i \Delta u(n+1-j)
 \end{aligned} \tag{1}$$

where:

- A_j^i fuzzy set corresponding to output $y(n-j)$ in the i^{th} fuzzy implication
- B_j^i fuzzy set corresponding to input $u(n-j)$ in the i^{th} fuzzy implication
- h_j^i impulse response coefficient in the i^{th} fuzzy implication
- T model horizon
- $\Delta u(n)$ difference between $u(n)$ and $u(n-1)$

A complete fuzzy model for the system consists of p fuzzy implications. The system output $y(n+1)$ is inferred as a weighted average value of the outputs estimated by all fuzzy implications.

$$y(n+1) = \frac{\sum_{j=1}^p \mu^j y^j(n+1)}{\sum_{j=1}^p \mu^j} \tag{2}$$

where

$$\mu^j = \bigwedge_i A_i^j \bigwedge_k B_k^j \tag{3}$$

considering

$$\omega^j = \frac{\mu^j}{\sum_{j=1}^p \mu^j} \tag{4}$$

then

$$y(n+1) = \sum_{j=1}^p \omega^j y^j(n+1) \quad (5)$$

3. Fuzzy model predictive control

3.1 Problem formulation

The goal in this chapter is to study the use of the feed-water flow-rate as a manipulated variable to maintain the SG water level within allowable limits, in the face of the changing steam demand resulting from a change in the electrical power demand. The design goal of an FMPC is to minimize the predictive error between an output and a given reference trajectory in the next N_y steps through the selection of N_u step optimal control policies.

The optimization problem can be formulated as

$$\min_{\Delta u(n), \Delta u(n+1), \dots, \Delta u(n+N_u)} J(n) \quad (6)$$

$$J(n) = \sum_{i=1}^{N_y} \mu_i (\hat{y}(n+i) - y^r(n+i))^2 + \sum_{i=1}^{N_u} \nu_i \Delta u(n+i)^2 \quad (7)$$

where:

- μ_i and ν_i are the weighting factors for the prediction error and control energy;
- $\hat{y}(n+i)$ i^{th} step output prediction;
- $y^r(n+i)$ i^{th} step reference trajectory;
- $\Delta u(n+i)$ i^{th} step control action.

The weighted sum of the local control policies gives the overall control policy:

$$\Delta u(n+i) = \sum_{j=1}^p \omega^j \Delta u^j(n+i) \quad (8)$$

Substituting (2) and (8) into (7) yields (9)

$$J(n) = \sum_{i=1}^{N_y} \mu_i \left(\sum_{j=1}^p \left(\omega^j (\hat{y}^j(n+i) - y^r(n+i)) \right) \right)^2 + \sum_{i=0}^{N_u-1} \nu_i \left(\sum_{j=1}^p \omega^j \Delta u^j(n+i) \right)^2 \quad (9)$$

To simplify the computation, an alternative objective function is proposed as a satisfactory approximation of (9) (Huang et al., 2000).

$$\tilde{J}(n) = \sum_{j=1}^p \left((\omega^j)^2 \left(\sum_{i=1}^{N_y} \mu_i (\hat{y}(n+i) - y^r(n+i))^2 + \sum_{i=0}^{N_u-1} v_i \Delta u^j(n+i)^2 \right) \right) \tag{10}$$

The optimization problem can be defined as:

$$\min_{\Delta u(n), \Delta u(n+1), \dots, \Delta u(n+N_u-1)} \tilde{J}(n) = \min_{\Delta u(n), \Delta u(n+1), \dots, \Delta u(n+N_u-1)} \sum_{j=1}^p (\omega^j)^2 \tilde{J}^j(n) \tag{11}$$

$$\tilde{J}^j(n) = \sum_{i=1}^{N_y} \mu_i (\hat{y}^j(n+i) - y^r(n+i))^2 + \sum_{i=0}^{N_u-1} v_i (\Delta u^j(n+i))^2 \tag{12}$$

Using the alternative objective function (12), we can derive a controller by a hierarchical control design approach.

3.2 Controller design

1. *Lower Layer Design:* For the j^{th} subsystem, the optimization problem is defined as follows:

$$\min_{\Delta u(n), \Delta u(n+1), \dots, \Delta u(n+N_u-1)} \tilde{J}^j(n) \tag{13}$$

$$\begin{aligned} & \text{IF } y(n+k-1) \text{ is } A_0^j, \dots, y(n+k-m) \text{ is } A_{m-1}^j \\ \text{R}_j: & \text{ THEN } y^j(n+k) = y^j(n+k-1) + \sum_{i=1}^T h_i^j \Delta u(n+k-i) + \varepsilon^j(n+k-1) \end{aligned} \tag{14}$$

where $\varepsilon^j(n+k-1)$ serves for system coordination and it is determined at the upper layer.

2. *Upper Layer Design:* The upper layer coordination targets the identification of globally optimal control policies through coordinating $\varepsilon^j(n+k-1)$ for each local subsystem.
3. *System Coordination:* The controller is designed through a hierarchical control design (Figure 1). From the lower layer, the local information of output and control is transmitted to the upper layer. The whole design is decomposed into the derivation of p local controllers. The subsystems regulated by those local controllers will be coordinated to derive a globally optimal control policy.

The objective function defined in (11) can be rewritten in a matrix form:

$$\begin{aligned} \text{R}_j: \tilde{J}^j(n) &= (\hat{Y}_+^j(n) - Y^r(n))^T W_1^j (\hat{Y}_+^j(n) - Y^r(n)) + \\ &+ (\Delta U_+^j(n))^T W_2^j (\Delta U_+^j(n)) \end{aligned} \tag{15}$$

where:

$$\hat{Y}_+^j(n) = (\hat{y}^j(n+1) \hat{y}^j(n+2) \dots \hat{y}^j(n+N_y))^T \tag{16}$$

$$Y^r(n) = (y^r(n+1) y^r(n+2) \dots y^r(n+N_y))^T \tag{17}$$

$$\Delta U_+^j(n) = (\Delta u^j(n) \Delta u^j(n+1) \dots \Delta u^j(n+N_u-1))^T \tag{18}$$

$$W_1^j = \text{diag}\{\mu_1^j, \mu_2^j, \dots, \mu_{N_y}^j\} \tag{19}$$

$$W_2^j = \text{diag}\{v_1^j, v_2^j, \dots, v_{N_u}^j\} \tag{20}$$

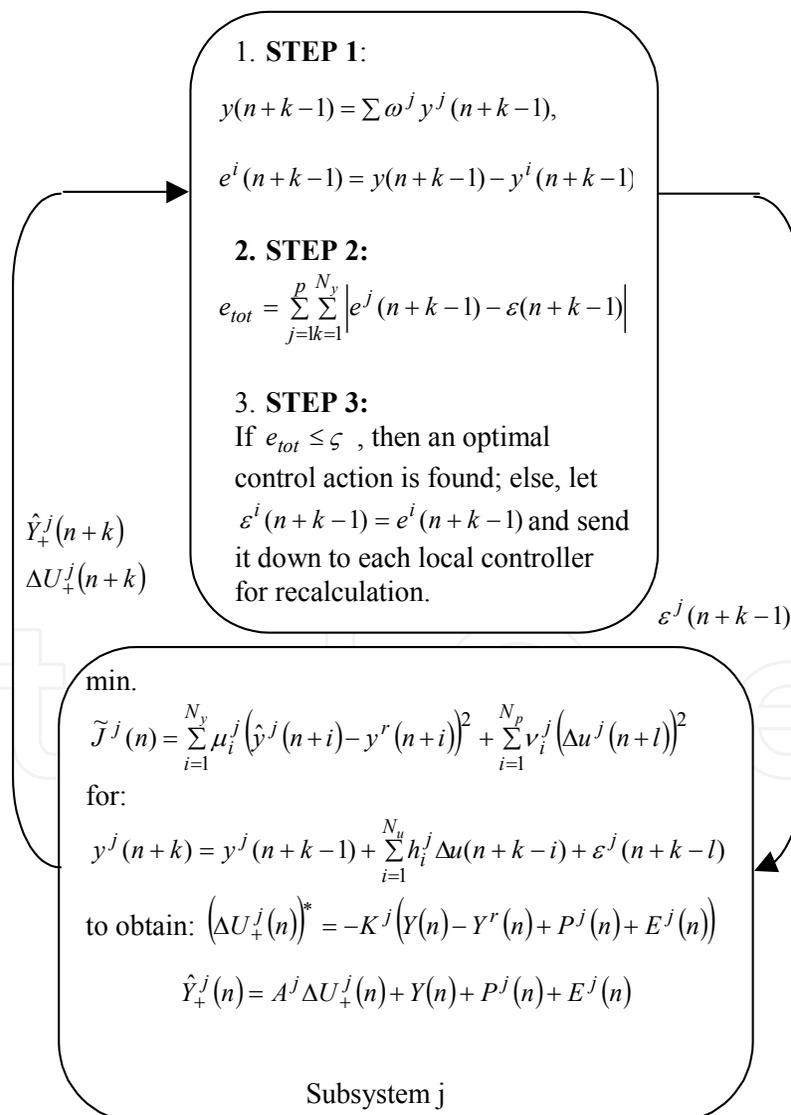


Fig. 1. Hierarchical controller design

The N_y - step prediction of the output by the j^{th} FI can be rewritten as follows:

$$\hat{Y}_+^j(n) = A^j \Delta U_+^j(n) + Y(n) + P^j(n) + E_+^j(n) \tag{21}$$

where:

$$A^j = \begin{bmatrix} a_1^j & 0 & 0 & \dots & 0 \\ a_2^j & a_1^j & 0 & & 0 \\ a_3^j & a_2^j & a_1^j & & 0 \\ \vdots & & & & \vdots \\ a_{N_y}^j & a_{N_y-1}^j & a_{N_y-2}^j & \dots & a_{N_y-N_u+1}^j \end{bmatrix} \tag{22}$$

$$a_i^j = \sum_{k=1}^i h_k^j \tag{23}$$

$$Y(n) = \left(y_{D_{al}}(n) \ y_{D_{al}}(n) \ \dots \ y(n)_{D_{al}} \right)^T \tag{24}$$

$$P^j(n) = \left(P_1^j(n) \ P_2^j(n) \ \dots \ P_{N_y}^j(n) \right)^T \tag{25}$$

$$E_+^j(n) = \left(0 \ \sum_{k=1}^2 \varepsilon^j(n+k-1) \ \dots \ \sum_{k=1}^{N_y} \varepsilon^j(n+k-1) \right)^T \tag{26}$$

$$P_i^j(n) = \sum_{k=1}^i \sum_{l=k+1}^T h_l^j \Delta u(n+k-l) \tag{27}$$

The resulting control policy for the j^{th} subsystem can be derived as

$$\begin{aligned} \tilde{J}^j(n) = & \left(\Delta U_+^j(n) \right)^T \left(A^{jT} W_1^j A + W_2^j \right) \Delta U_+^j(n) + \\ & + \left(\Delta U_+^j(n) \right)^T A^{jT} W_1^j Z^j(n) + \\ & + \left(Z^j(n) \right)^T W_1^j A^j \Delta U_+^j(n) + \left(Z^j(n) \right)^T W_1^j Z^j(n) \end{aligned} \tag{28}$$

where:

$$Z^j(n) = Y(n) - Y^r(n) + P^j(n) + E_+^j(n) \tag{29}$$

Minimizing (26) yields

$$\begin{aligned} \frac{\delta \tilde{J}^j(n)}{\delta \Delta U_+^j(n)} = & 2 \left(A^{jT} W_1^j A + W_2^j \right) \Delta U_+^j(n) + \\ & + 2 A^{jT} W_1^j Z^j(n) = 0 \end{aligned} \tag{30}$$

The control law by the j^{th} FI can be identified as

$$\left(\Delta U_+^j(n)\right)^* = -K^j Z^j(n) \quad (31)$$

$$K^j = \left(A^{jT} W_1^j A^j + W_2^j\right)^{-1} A^{jT} W_1^j \quad (32)$$

The optimal global control policies can be derived at the upper layer.

$$\Delta U_+(n) = \left(\Delta u(n) \Delta u(n+1) \cdots \Delta u(n+N_u-1)\right)^T \quad (33)$$

3.3 Parameter tuning

In controller design, the difficulty encountered is how to quickly minimize the upper bound of the objective function so that the control actions can force a process to track a specified trajectory as close as possible.

There has no rigorous solution to the selection of optimal control horizon (N_u) and prediction horizon (N_y).

The model horizon is selected so that $T\Delta t \geq$ open loop settling time.

The ranges of weighting factors W_1^j and W_2^j can be very wide, the importance is their relative magnitudes. The following procedure to tune the weighting factors is proposed:

- Select a value for W_1 and assign it to all local controllers. Determine W_2^j independently for each local controller in order to minimize the objective function for that subsystem
- Identify the largest W_2 and assign it to all subsystems.

Examine the system's closed-loop dynamic performance. Reduce the value of W_2 gradually until the desirable dynamic performance is identified.

3.4 Simulations

Process Modeling: The main problem in setting up a signal flow diagram for a level controlled system in a SG can be found in the inhomogeneous contents of the SG.

The filling consists of water at boiling temperature, pervaded by steam bubbles.

Since the volume fraction of the steam bubbles is quite considerable, the mean specific weight of the contents is very strongly dependent on the proportion of steam.

This, of course, means that the steam content also strongly influences the level in the SG. The steam content itself depends, in turn, on the load factor, on the changes in feed-water flow, and on feed-water temperature.

The presence of steam below the liquid level in the SG causes the *shrink-and-swell* phenomenon that in spite of an increased supply of water, the water level initially falls. Figure 2 shows responses of the water level to steps in feed-water and steam flow-rates at different operating power levels (Irving et al., 1980).

Particularly it is difficult to control automatically a steam generator water level during transient period or at low power less than 15% of full power because of its dynamic characteristics.

The inverse response behavior of the water level is most severe at low power (5%).

The changing process dynamics and the inverse response behavior significantly complicate the design of an effective water level control system.

A solution to this problem is to design local linear controllers at different points in the operating regime and then applies gain-scheduling techniques to schedule these controllers to obtain a globally applicable controller.

Consider a step in feed-water flow rate at 5% operating power. For this system, a fuzzy convolution model consisting of four fuzzy implications is developed as follows:

For $j=1$ to 4:

$$R^j : \text{if } y_{D_{al}}(n) \text{ is } A^j$$

$$\text{then } y_{D_{al}}^j(n+1) = y_{D_{al}}^j(n) + \sum_{i=1}^{200} h_{-D_{al}}^j u(n+1-i) \tag{34}$$

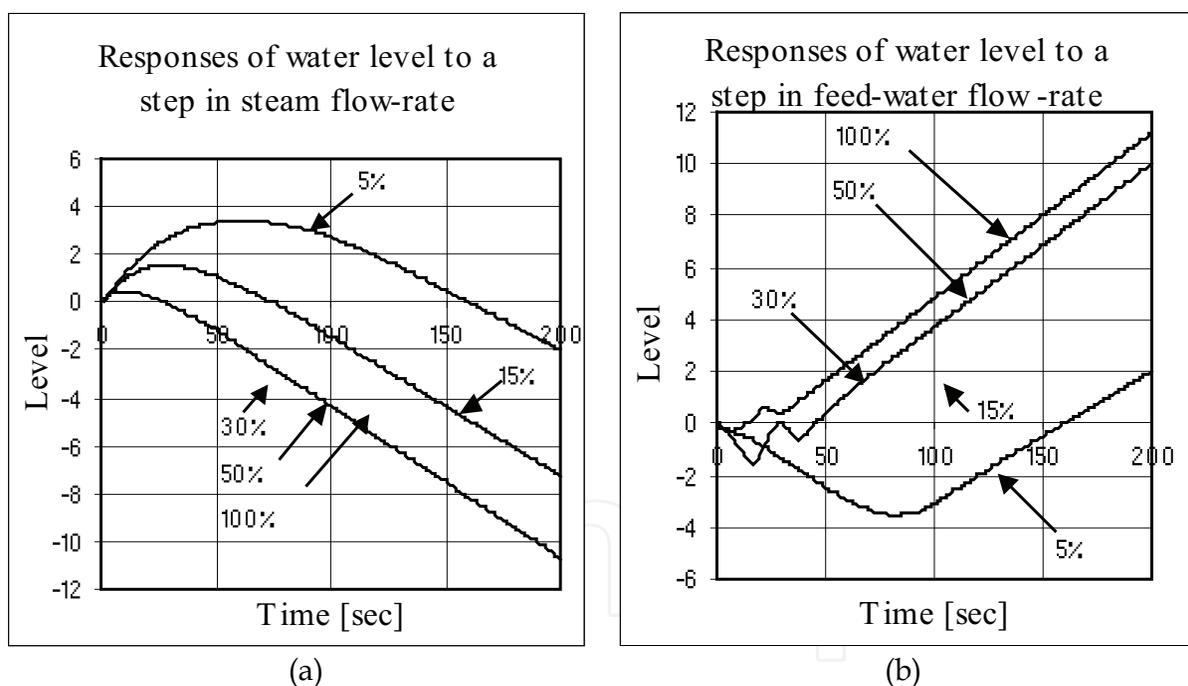


Fig. 2. Responses of water level at different operating power (indicated by %) to (a) a step in feed-water flow -rate. (b) a step in steam flow-rate.

Figure 3. shows the response of water level at 5% operating power to a step in feed-water flow -rate. In Figure 4 the system is decomposed into 4 subsystems: $y_{D_{al}}^1, y_{D_{al}}^2, y_{D_{al}}^3, y_{D_{al}}^4$.

Figure 5 shows the impulse response coefficients for $y_{D_{al}}^1, y_{D_{al}}^2, y_{D_{al}}^3, y_{D_{al}}^4$ subsystems and Figure 6 shows the definition of fuzzy sets A^1, A^2, A^3 and A^4 . Consider a step in steam flow rate at 5% operating power.

For this system, a fuzzy convolution model consisting of four fuzzy implications is developed as follows:

For $j=1$ to 4:

R^j : if $y_{D_0}(n)$ is A^j

$$\text{then } y_{D_0}^j(n+1) = y_{D_0}^j(n) + \sum_{i=1}^{200} h_{-D_0_i}^j u(n+1-i) \tag{35}$$

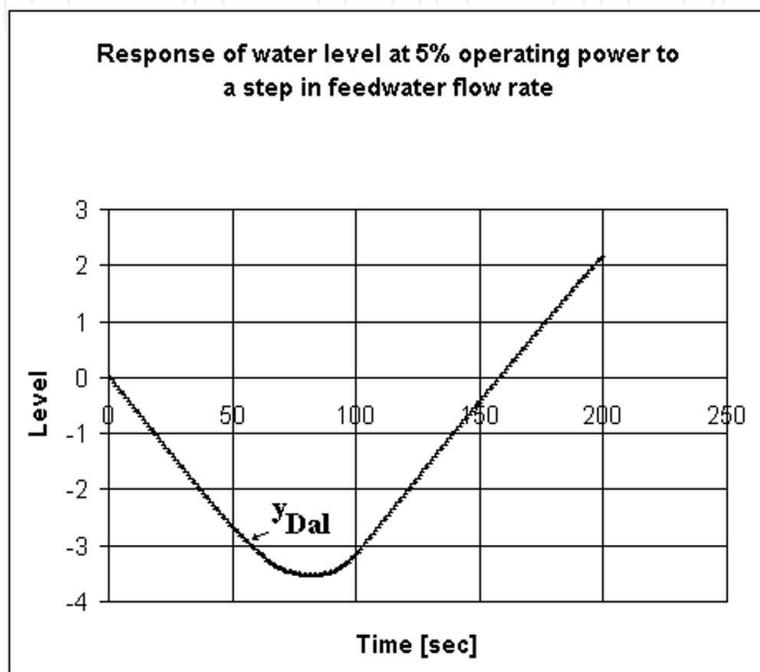


Fig. 3. Response of water level at 5% operating power to a step in feed-water flow -rate

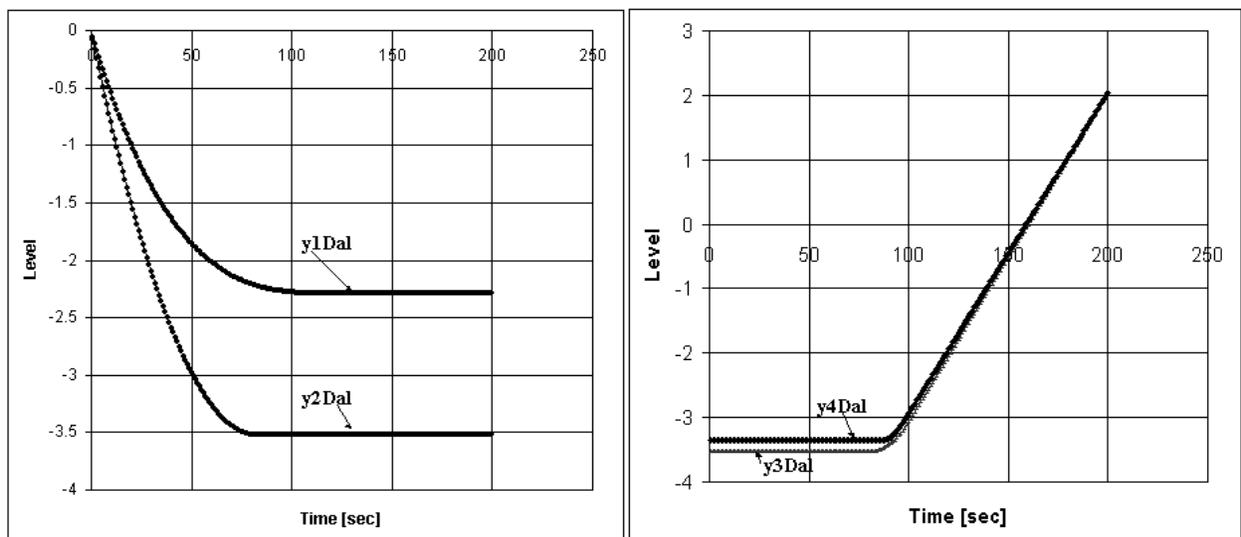


Fig. 4. The system is decomposed into 4 subsystems: $y_{D_{al}}^1$, $y_{D_{al}}^2$, $y_{D_{al}}^3$, $y_{D_{al}}^4$

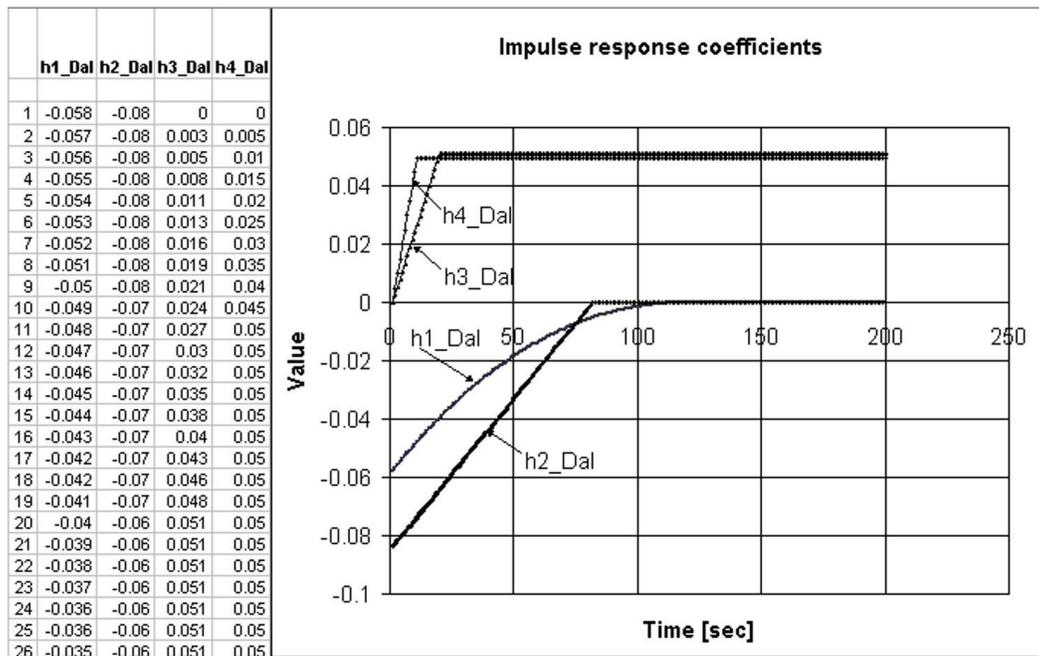


Fig. 5. The impulse response coefficients for $y_{Dal}^1, y_{Dal}^2, y_{Dal}^3, y_{Dal}^4$ subsystems

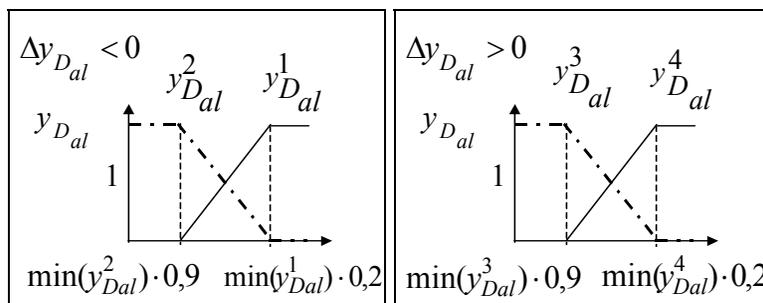


Fig. 6. Definition of fuzzy sets A^1, A^2, A^3 and A^4 for FI R^1, R^2, R^3 and R^4 respectively.

Figure 7 shows the response of water level at 5% operating power to a step in steam flow -rate.

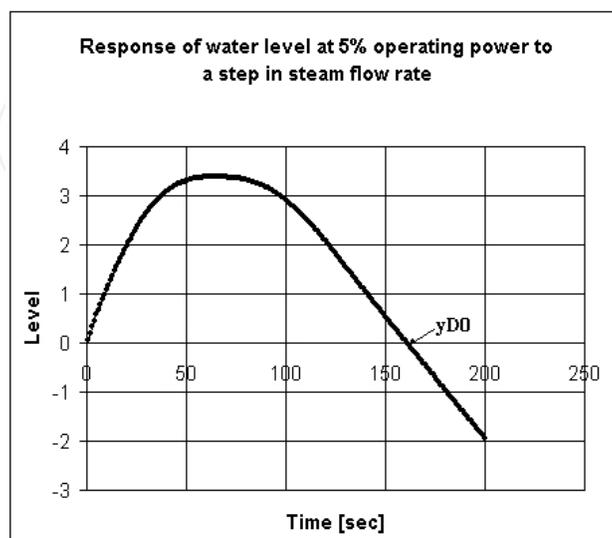


Fig. 7. Response of water level at 5% operating power to a step in steam flow -rate;

In Figure 8 the system is decomposed into 4 subsystems: $y_{D_0}^1, y_{D_0}^2, y_{D_0}^3, y_{D_0}^4$.

Figure 9 shows the impulse response coefficients for $y_{D_0}^1, y_{D_0}^2, y_{D_0}^3, y_{D_0}^4$ subsystems, Figure 10 shows the definition of fuzzy sets A^1, A^2, A^3 and A^4 .

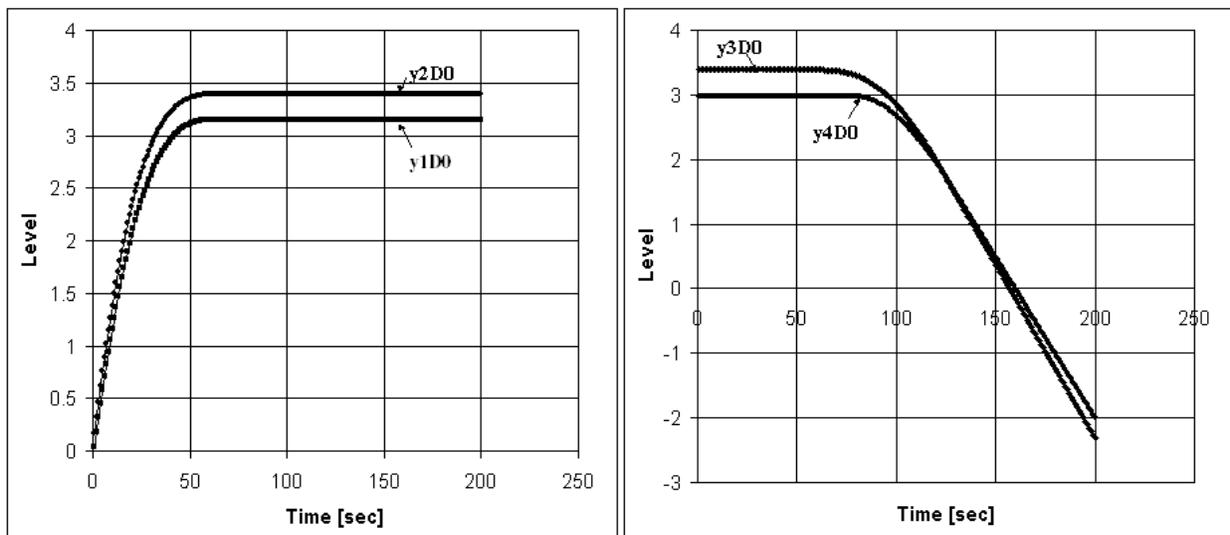


Fig. 8. The system is decomposed into 4 subsystems: $y_{D_0}^1, y_{D_0}^2, y_{D_0}^3, y_{D_0}^4$.

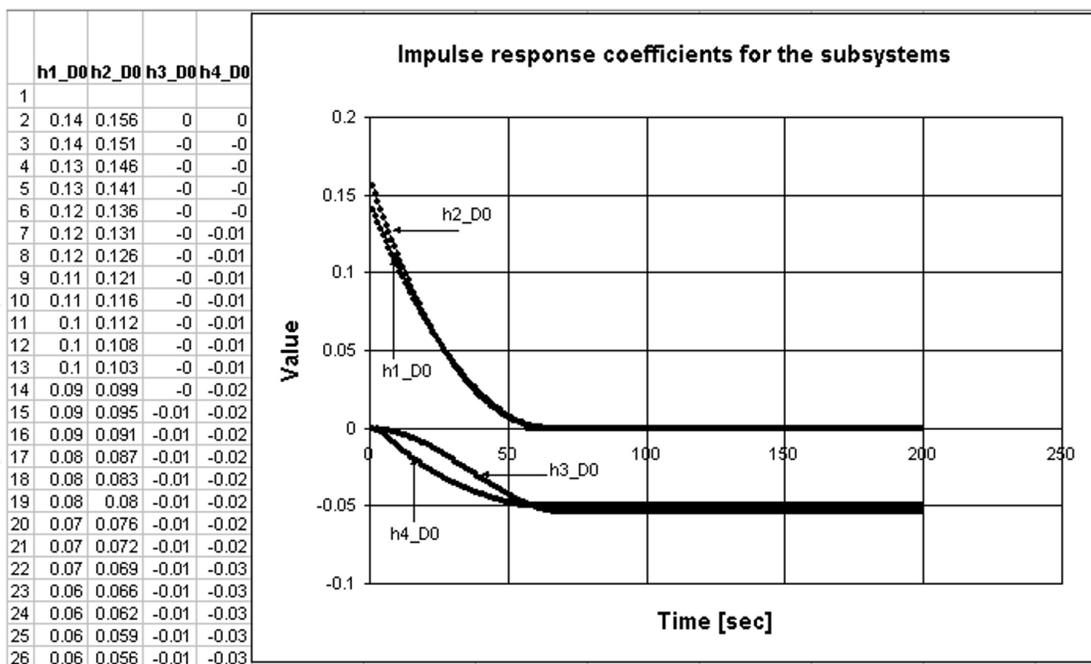


Fig. 9. The impulse response coefficients for $y_{D_0}^1, y_{D_0}^2, y_{D_0}^3, y_{D_0}^4$ subsystems

Controller Design: The goal is to study the use of the feed-water flow-rate as a manipulated variable to maintain the SG water level within allowable limits, in the face of the changing steam demand resulting from a change in the electrical power demand.

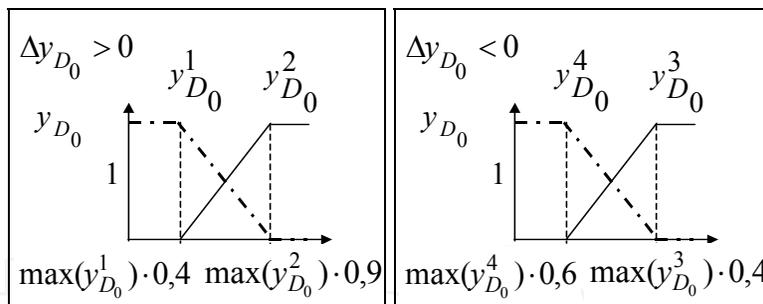


Fig. 10. Definition of fuzzy sets A^1, A^2, A^3 and A^4 for FI R^1, R^2, R^3 and R^4 respectively .

The simulations are organized around two different power transients:

- a step-up in power from 5% to 10% (Figure 11);
- a ramp-up in power from 5% to 10% (Figure 12)

The model horizon is $T=200$. Increasing N_y results in a more conservative control action that has a stabilizing effect but also increases the computational effort.

The computational effort increases as N_u is increased. A small value of N_u leads to a robust controller.

For both power transients the controller responses are very satisfactory and not very sensitive to changes in tuning parameters.

We can see that the performance is not strongly affected by the presence of the feed-water inverse response, only a slight oscillation is visible in the water level response.

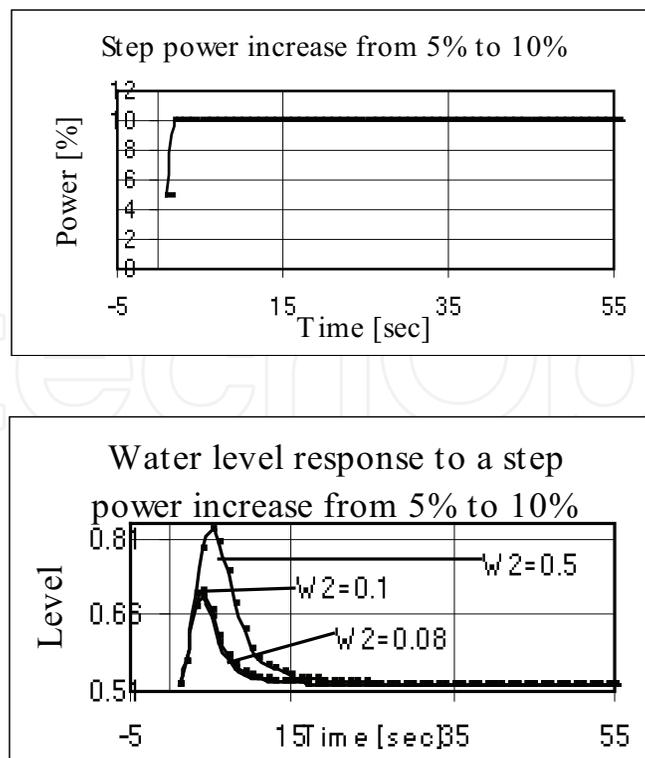


Fig. 11. Water level response to a step power increase from 5% to 10% ($N_u=2, N_y=3, W_1=1$)

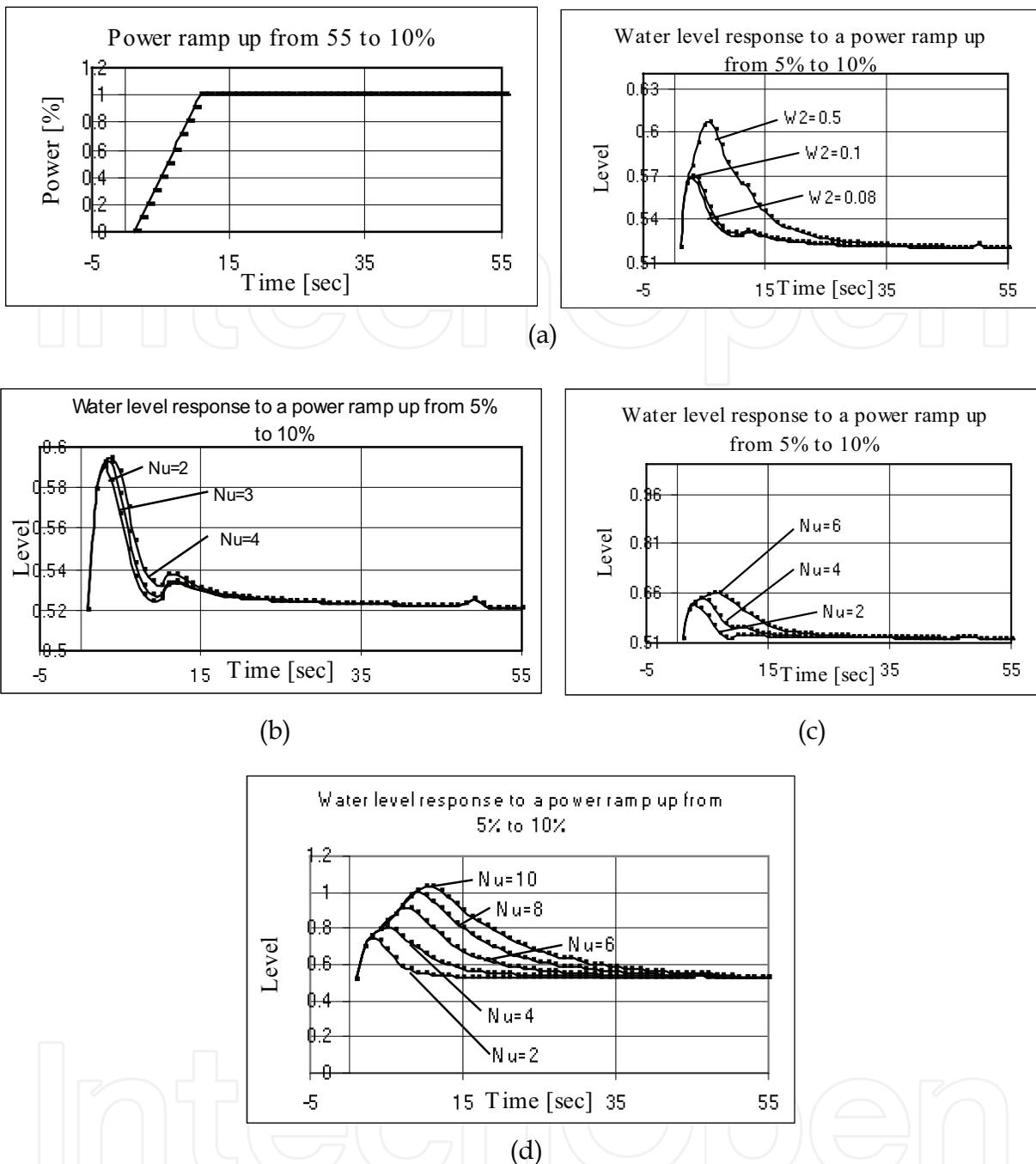


Fig. 12. Water level response. a) to power ramp up from 5% to 10% ($Nu=2$, $Ny=3$, $W_1=1$); b) to power ramp up from 5% to 10% ($W_2=0.1$, $Ny=3$, $W_1=1$); c) to power ramp up from 5% to 10% ($W_2=0.1$, $Ny=7$, $W_1=1$); d) to power ramp up from 5% to 10% ($W_2=0.1$, $Ny=11$, $W_1=1$).

3.5 Evolved controller client/server architecture

An original concept of modular *evolved* control system, seamless and with gradual integration into the *primary* control system is proposed.

The aim of the application is to integrate the concepts of *evolved control algorithms*, *portability of software modules*, *real time characteristics of the application*.

The target systems are the *large scale distributed control systems with optimum granularity architecture*.

The first part of the life cycle phases of the new control system, from conception to validation stage, the new control system lives “hiding in the shadow” of the control system it will replace, and after validation the old system will be replaced by the new one.

The identification, modeling, control and validation stages of the life cycle of the system, will be done *on-line* (the new system uses a real image of the I/O process data), without affecting the existing control system.

Because of high level of *interconnectivity between system components*, it is necessary to provide the *highest independence between communication modules on one-hand and the control modules on the other hand*. In order to obtain high ability of integration, the communication modules have to cover the widest possible area of industrial communication interfaces and protocols.

One item of the application is to offer a *unified API of extended generality and extendibility in order to unify access and information retrieval from various wireless and wired technology and communication interfaces* (RS 232, RS 485, fieldbus: Profibus / Interbus, Ethernet IP, TCP/IP, etc).

Applications could properly adapt to changes in the network connections.

The design and implementation of a solution to *hide the embedded communication network problems from the application system programmers* is included.

One of the main objectives of the application is to supply an *integrated solution of systems, which should support all the phases of the life cycle: modeling, simulation, development and implementation*.

For *parameter tuning, for validation and also for embedding a large number of industrial communication protocols, multi-disciplinary simulation environments are developed which generate instruments for control, I/O data consistency check, and defect detection*.

In the end, real-time advanced control applications are developed, with seamless and gradual integration into the existing distributed control system.

A software package for *evolved control* includes a method based on *fuzzy model predictive control*.

By using the basic concept of decomposition-coordination in a large-scale system theory, the *fuzzy model predictive controller design* can be accomplished through a *two-layer iterative design process*.

The design is decomposed into the derivation of local controllers. The subsystems regulated by those local controllers will be coordinated to derive a *globally optimal control policy*.

In order to provide the real-time characteristic, we choose a multitasking environment for the application (WINDOWS Operating System).

From structural point of view we propose a Client / Server architecture for fuzzy Controller (FC) (Andone et al., 2006):

Client - is a Windows application representing the implementation of the graphical user interface (GUI). The Client enables the operator to control the system in two modes:

manual/automatic, to monitor the system response, etc. The Client has also the ability to connect and communicate with the Server application.

Server - is an ActiveX EXE application containing the implementation of the Fuzzy Controller (FC) kernel.

The Server includes a collection of objects, these objects cover the tasks of both data processing and the communication between dedicated applications for input and output data.

The Client application will have a thread pool architecture.

The Server application will have a real multithreading architecture (each active object having assigned its own execution thread).

The Server have also a multi-layer structure: at the higher level are implemented upper FC and the communication classes (using different transmission mechanisms - DDE, OPC, HLI, ActiveX, Winsocket, Pipes), at the lower level are implemented the controllers for the subsystems corresponding to the low level FC.

The Server's application as real multithreading architecture, provides the FC Kernel the real-time response characteristic, required for the industrial process control.

4. Conclusions

Control of SG water level strongly affects nuclear power plant availability.

The control task is difficult for a number of reasons, the most important among them being the nonlinear plant dynamics and the non-minimum phase plant characteristics.

There has been a special interest in this problem during low power transients because of the dominant reverse thermal dynamic effects known as shrink and swell.

The SG level control problem was viewed as a single input/single output control problem with the feed-water as the manipulated variable, the level as the controlled variable and the turbine steam demand as disturbance.

It has been shown that in the case of nonlinear processes, the approach using fuzzy predictive control gives very promising results.

The process non-linearity was addressed by scheduling the model (and the controller) with the power level.

The SG system is modeled by Takagi-Sugeno's fuzzy modeling methodology, where the system output is estimated based on gradient. The complex shrink and swell phenomena associated with the SG water level are well captured by the model.

The predictive controller based on fuzzy model is designed in a hierarchical control design.

An original concept of modular evolved control system, seamless and gradual integration into the existing distributed control system is proposed in the chapter.

A unified API of extended generality and extendibility in order to unify access and information retrieval from various wireless and wired technology and communication interfaces is developed in order to ensure independence between communication and control modules of the designed systems.

A Client / Server architecture for evolved controller that runs on the Windows environment, with real-time characteristics is proposed.

5. Acknowledgment

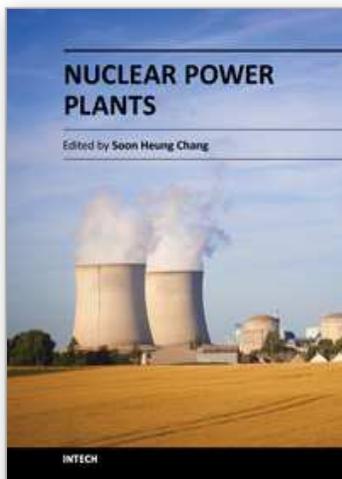
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