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Implementation of an MRAC_{nn} System on a FBR Building Block Type Simulator

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ABSTRACT

This report presents the implementation of a model reference adaptive control system based on the artificial neural network technique (MRAC_{nn}) in a fast breeder reactor (FBR) building block type (BBT) simulator representing the Monju prototype reactor. The purpose of this report is to improve the control of the outlet steam temperature of the three evaporators of the Monju prototype reactor. The connection between the MRAC_{nn} system and the BBT simulator is achieved through an external shared memory accessible by both systems. The MRAC_{nn} system calculates the demand for the position of the feedwater valve replacing the signal of a PID controller collocated inside the heat transport system model of the Monju prototype reactor. Two series of simulation tests have been performed, one with one loop connected to the MRAC_{nn} system (leaving the remaining two connected to the original PID controller), and the other with three loops connected to the MRAC_{nn} system. In both simulation tests the MRAC_{nn} system performed better than the PID controller, keeping the outlet steam temperature of the evaporators closer to the required set point value through all the transients.

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* PNC International Fellowship Awardee

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ニューラルネットワークを応用したモデル適応制御システムのFBRビルディングブロックタイプシミュレータへの実装

ウゴリーニ, ダニエレ*、　吉川　信治、　小澤　健二

要旨

本報告書は、ニューラルネットワークに基づいたモデル適応制御システム(MRACnn)の、高速増殖炉用ビルディングブロックタイプ(BBT)シミュレータへの実装について述べる。本報告の目的は、この制御手法が高速増殖炉もんじゅの３基の蒸発器の出口蒸気温度の制御性能をなお一層向上させることを、BBTシミュレータを用いて示すことである。MRACnnシステムとBBTシミュレータは、外部共有メモリを両者がアクセスすることにより結合された。その上で、MRACnnシステムは、BBTシミュレータで構築されたもんじゅプラント内のPID制御システムに替わって給水調整弁の開度を算出して蒸発器を制御している。MRACnnは2種類の実験を通じて評価された。その１つは、１ループの蒸発器のみをMRACnnで制御して他の２基の蒸発器は従来のPIDシステムによって制御する実験であり、他方は３基の蒸発器全てをMRACnnで制御する実験である。双方の実験で、対象とした全ての過渡条件下で、MRACnnが蒸発器の蒸気出口温度をPIDよりも設定値に近く保つことが確認された。

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1. INTRODUCTION

During the last few years the continuous appearance of faster computers endowed with fancy graphic features and a variety of useful devices has provided a powerful boost to all the engineering fields. Within a computer work-station the functional behavior and the performance of large process and production plants can be simulated down to each single component and several operation and accident scenarios as well as new advanced control and diagnosis systems can be reproduced, validated, and carefully analyzed.

In the Frontier Technology Section of the Oarai Engineering Center, an FBR building block type (BBT) simulator[1] representing to the minimum detail the component configuration and control system distribution of the Monju prototype reactor has been installed within a computer work-station.

This report describes the implementation and performance testing of an artificial neural network (ANN) based model reference adaptive control ($MRAC_{nn}$) system[2] in the FBR BBT simulator. The $MRAC_{nn}$ system has been tuned to control the outlet steam temperature of the evaporator.

This report is the prosecution of two reports previously presented. In the PNC-ZN9410-94-069 report the development of an $MRAC_{nn}$ system to control the outlet steam temperature of a stand alone model of an FBR evaporator was described. The report focused on the adaptive properties of the ANN technique and on showing that the $MRAC_{nn}$ system outperformed traditional PID controllers. In the PNC-ZN9410-95-210 report, the possibility of improving the control mechanism of the $MRAC_{nn}$ system was investigated. An anticipatory and a predictive control algorithms based on the ANN technique were developed. Embedding the two algorithms in the $MRAC_{nn}$ system resulted in a considerable improvement of the control action particularly toward the beginning and the end of transients.

The remainder of the report is organized as follow. A concise description of the characteristics and features of the FBR BBT simulator together with the connecting structural architecture that links it to the $MRAC_{nn}$ system is presented in section 2. In the following section the implementation of the $MRAC_{nn}$ system in the FBR BBT simulator is delineated. Simulation results are presented and discussed in section 4. In section 5 some conclusive remarks are proposed. A brief acknowledgment concludes this report.

2. FBR BUILDING BLOCK TYPE SIMULATOR

The FBR BBT simulator, whose simplified schematic functional structure is shown in Figure 1, mathematically simulates the operation behavior, based on specification and design data, of the Monju prototype reactor.

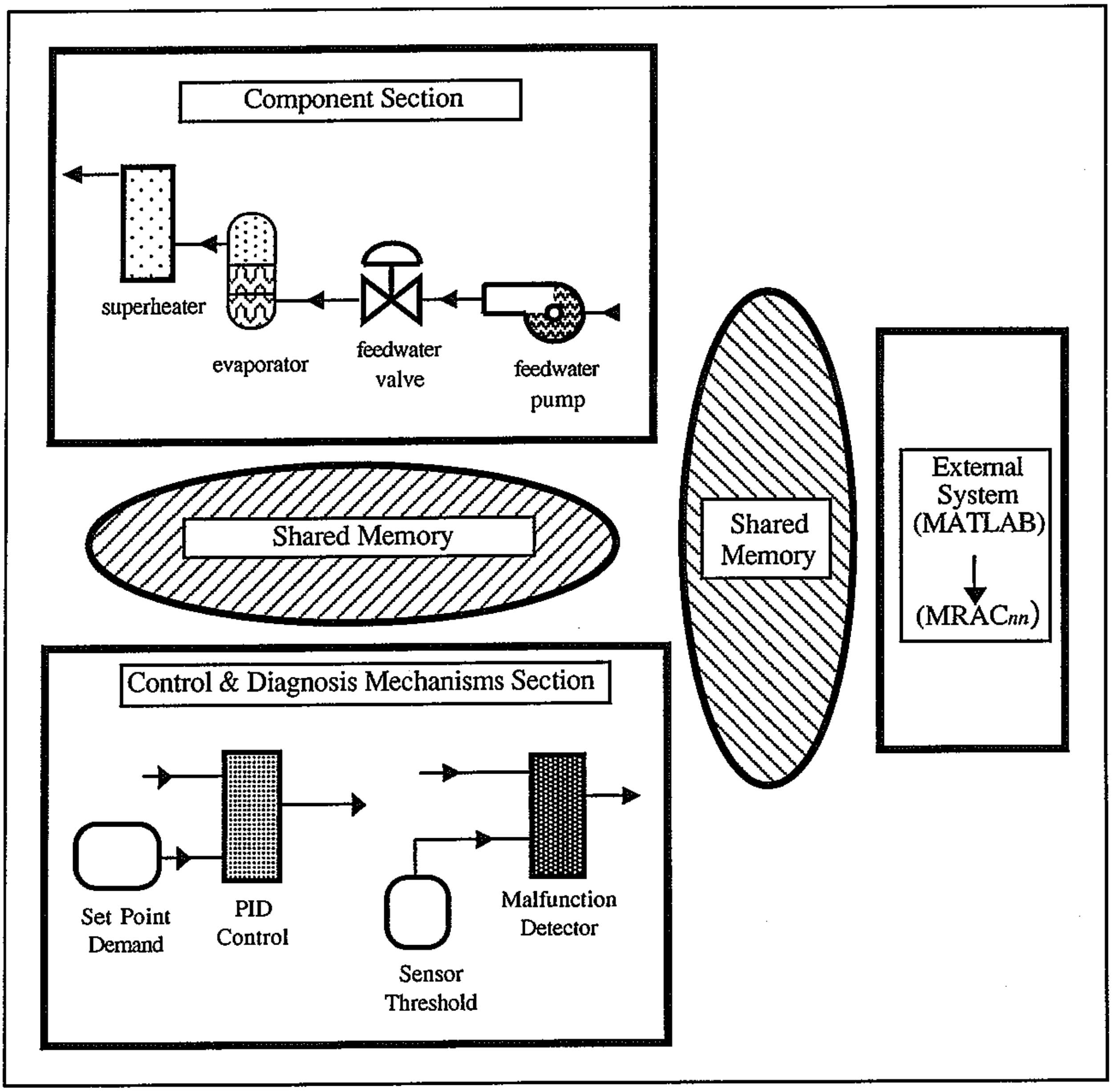

Figure 1. Schematic representation of the FBR BBT simulator component and control and diagnosis mechanisms with shared memory for internal and external data communication.

The simulator is structured in a node-junction architecture that can be constructed by arranging and connecting, using linking junctions, components and control and diagnosis mechanisms represented by icons. Underneath each icon there is a nodal mathematical representation of the component whose complexity (i.e. number of nodes) depends on the function and on the intrinsic characteristics of the component itself. For example more nodes are required to describe the evaporator than the superheater.

The component, and the diagnosis and control structure of the FBR are grouped in two separated sections. The two sections are connected through an internal shared memory where data flowing from both sides, such as state variables from the components, and control action and alarm signal from the control and diagnosis mechanisms, are stored. An external shared memory is provided to connect the FBR BBT simulator with external systems and functions. The purpose of the external shared memory is two-fold: to allow the utilization and analysis of data coming from the FBR BBT simulator, and to provide a gateway for modifying and comparing the performances of internal program routines, such as control and diagnosis systems, with external ones.

The FBR BBT simulator physical variables and parameters are calculated and, at the same time, upgraded inside the internal shared memory every .15 seconds. On the other hand data are stored and upgraded in the external shared memory only every second. At the same pace data coming from external systems are transferred from the external shared memory to the internal one.

Since the FBR BBT simulator performs in real-time, the intercurrent time between its mathematical calculations (.15 seconds) and the data entering from external systems (1 second) may introduce some undesired oscillations specifically when the external system acts as an on-line controller.

In this report the external system connected to the FBR BBT simulator is the MATLAB numerical computation software environment[3] within which the $MRAC_{nn}$ system has been developed. A detailed representation of the communication mechanism linking the FBR BBT simulator to MATLAB is shown in Figure 2.

The two systems run independently one each other within the same workstation. Each time the FBR BBT simulator stores the data in the external shared memory the desired variables are selected by the receive module.

Subsequently the receive module writes them in a file that can be accessed by the MRAC$_{nn}$ system. After the MRAC$_{nn}$ system has performed its calculations, it calls a special program that transforms the data in a format readable by the external shared memory and activates a send module. The send module reads the data previously stored in the external shared memory and send them to the FBR BBT simulator.

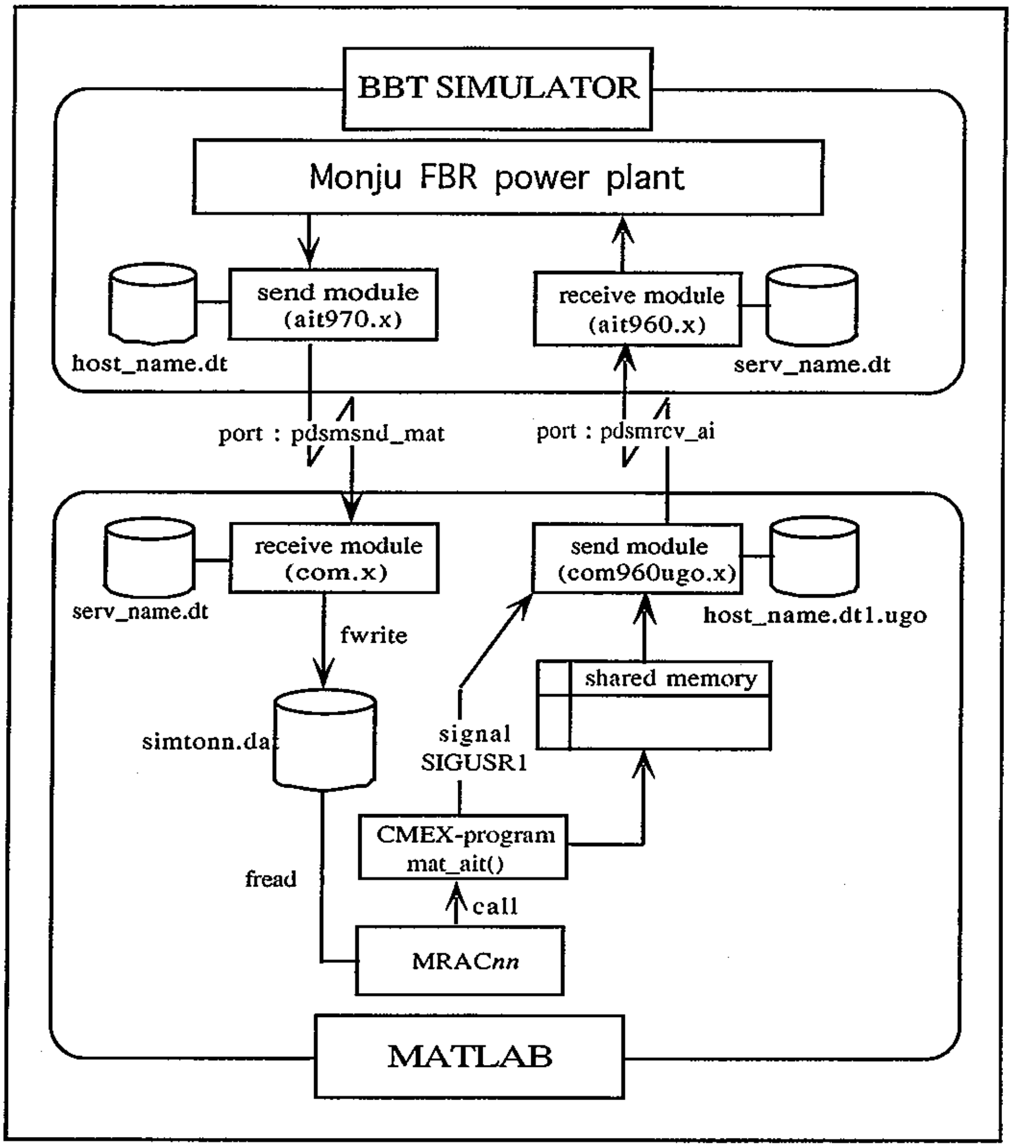

Figure 2. Communication system connecting the FBR BBT simulator and the MATLAB numerical computation software environment (external system).

3. CONNECTING THE MRAC$_{nn}$ SYSTEM TO THE FBR BBT SIMULATOR

The MRAC$_{nn}$ system has been connected to the PID control system that determines the position of the feedwater valve regulating the flow entering the evaporator. A logical switch module has been placed after the PID control system in each one of the three loops of the FBR simulator. The output of the PID control system and the output of the MRAC$_{nn}$ system are fed as input to the logical switch modules that select the output command according to the logical signal.

Due to the limitation on the utilization of MATLAB only one MRAC$_{nn}$ system could be implemented. Consequently the control action calculated by the MRAC$_{nn}$ system was equally transmitted to all the three loops. This simplification did not affect the testing of the performance of the MRAC$_{nn}$ system but it limited the range of possible transients that could be tested. In other words it was not possible to test transients involving only one or two specific loops.

The ANN used in the MRAC$_{nn}$ is multilayer with one input, one hidden, and one output layer with, respectively, seven, ten and four nodes. In the simulation tests performed on the stand alone model of the evaporator seven input data were used by the MRAC$_{nn}$, the outlet steam pressure, enthalpy, and temperature, the feedwater flow rate, the inlet and outlet sodium temperature and the intermediate heat exchanger outlet sodium temperature. This set of data, except for the outlet steam enthalpy that is calculated as function of pressure and temperature, are transferred from the FBR BBT simulator to the MRAC$_{nn}$ system together with the pressure and the feedwater temperature, the outlet steam temperature set point, the feedwater valve position and its inlet and outlet pressure, and the simulation time.

The MRAC$_{nn}$ system returns the demand for the feedwater valve position to the FBR BBT simulator.

3.1 Development of Valve Model for the MRAC$_{nn}$ System

The MRAC$_{nn}$ system was originally developed to calculate the feedwater flow demand for the evaporator. Since the $MRAC_{nn}$ has been connected to the feedwater valve position it was necessary to develop a model of a valve that determined the feedwater valve position given the desired flow. Initially a traditional mathematical model of a valve calculating the flow given the valve position was designed based on the data available from the FBR BBT simulator. Then the model has been inverted in order to have the valve position as output variable.

The valve position Yvlv is given by the absolute value of,

$$\mathrm{Yvlv} = \sqrt{\frac{\mathrm{Cvlv}}{\dfrac{2 \times A^2 \times \rho \times \left(\Delta P - \rho \times gr \times \Delta h\right)}{\mathrm{Wfw}^2} - \mathrm{Kfc} - 1}} \qquad (1)$$

where,

Cvlv = valve conductance,
A = valve cross section area,
ρ = feedwater density,
gr = gravity acceleration,
Δh = elevation drop,
ΔP = feedwater pressure drop in the valve,
Kfc = friction coefficient, and
Wfw = feedwater flow rate demand.

It was necessary to retrain the connecting weights of the ANN of the $MRAC_{nn}$ system. However since the ANN had been trained on a stand alone model with specification and performance data of the Monju evaporator the new set of connecting weights resulted very similar to the old one.

4. SIMULATION RESULTS AND DISCUSSION

Two types of simulation tests have been performed, a) connecting one loop, and b) connecting three loops of the FBR BBT simulator to the $MRAC_{nn}$ system. All the tests have been performed starting with the reactor at nearly 100% full nominal power by inducing ramp transients of 5% per minute rate in the reactor power itself.

4.1 Results with one-loop connection to the $MRAC_{nn}$

Three transients are presented to describe the performance of the $MRAC_{nn}$ system for a one-loop connection.

Figure 3, 4 and 5 show the trend of the outlet steam temperature of the loop controlled by the $MRAC_{nn}$ and of the remaining two loops, controlled by a PID controller for a reactor download ramp power from 100% to 90%, 80% and 70% respectively.

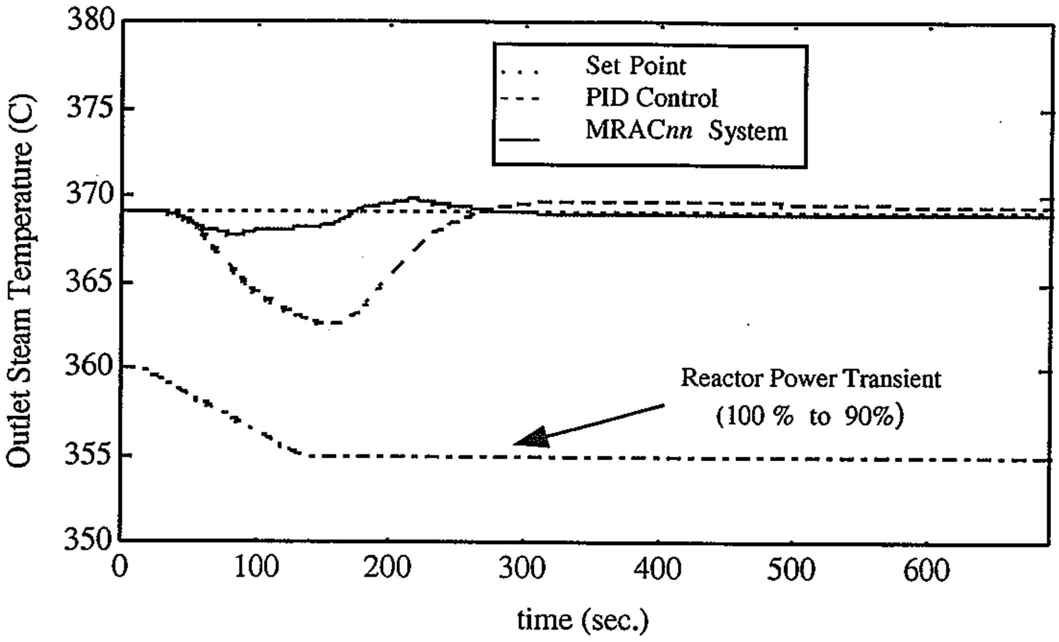

Figure 3. Outlet steam temperature trend of the PID controlled loops and of the $MRAC_{nn}$ controlled loop for 10% decrease in reactor power.

The $MRAC_{nn}$ performs better than the PID controller in all the transients. However the performance of the $MRAC_{nn}$ slightly decreases when the magnitude of the reactor power ramp transient increases. It is believed that two causes could be responsible for this behavior, the time delay existing between the two systems ($MRAC_{nn}$ and FBR BBT simulator), and the training of the ANN in the $MRAC_{nn}$ system. The ANN was trained on a stand alone model of an evaporator by inducing random variations to its inlet sodium temperature and feedwater flow rate. Although the stand alone model was designed based on the specification of the Monju evaporator, and a large range of operability scenarios could be covered, it is believed that the

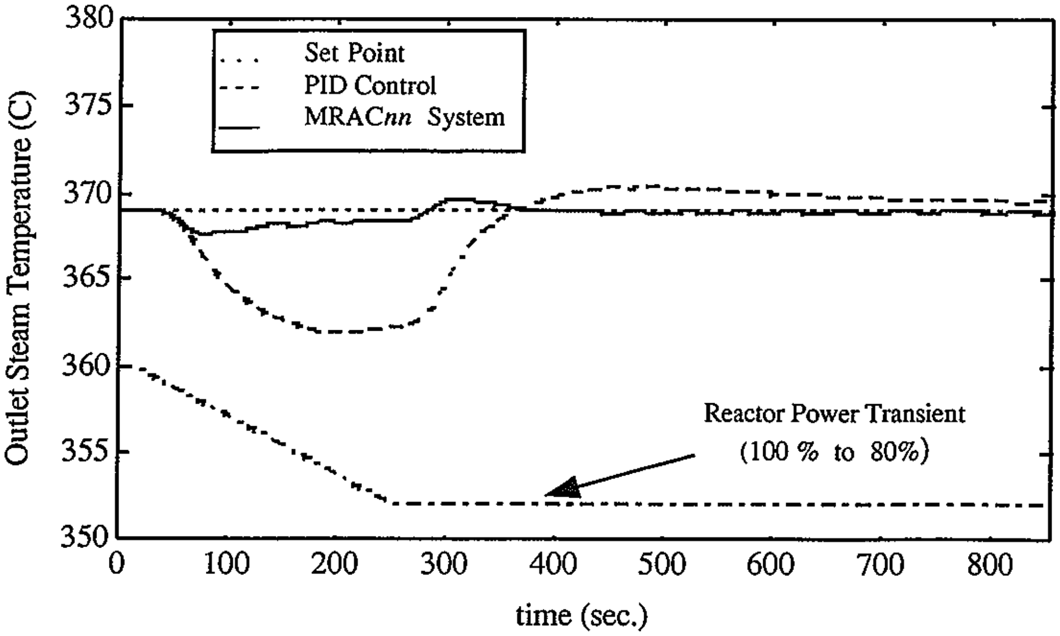

Figure 4. Outlet steam temperature trend of the PID controlled loops and of the MRAC_{nn} controlled loop for 20% decrease in reactor power.

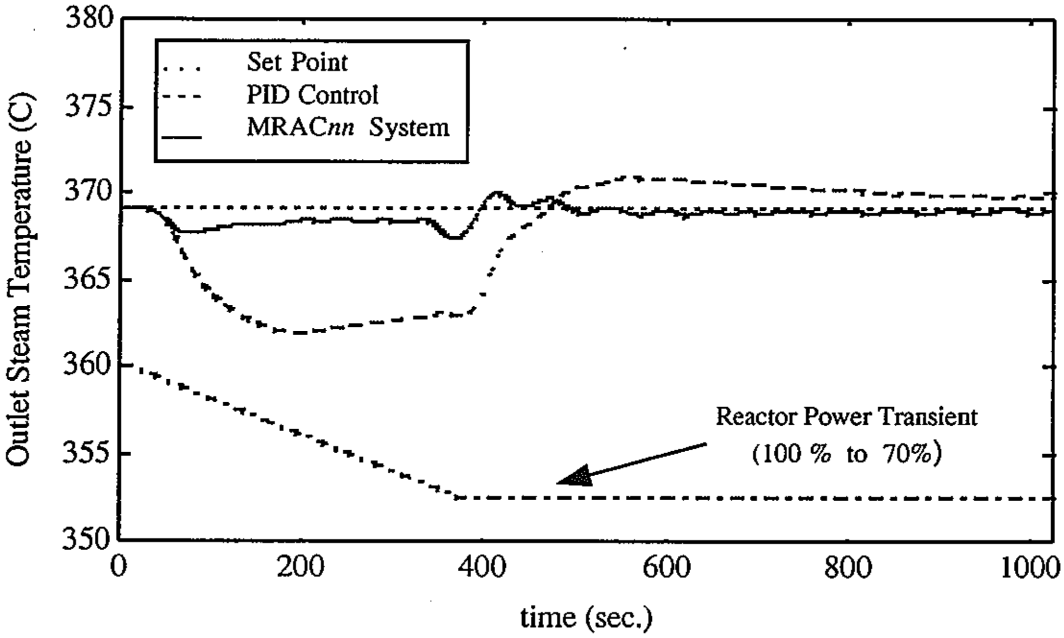

Figure 5. Outlet steam temperature trend of the PID controlled loops and of the MRAC_{nn} controlled loop for 30% decrease in reactor power.

behavior of the secondary sodium loop, and, consequently the variations of the input variables of the evaporator during large reactor power transients could not be simulated accurately. The mismatch between the two sets of input variables could introduce an unbalanced behavior in the control action of the $MRAC_{nn}$.

4.2 Results with three-loop connection to the $MRAC_{nn}$

Three transients are presented to describe the performance of the $MRAC_{nn}$ system for a three-loop connection.

Figure 6, 8 and 10 show the trend of the outlet steam temperature when the three evaporators are controlled by the $MRAC_{nn}$ and when they are controlled by a PID controller for a reactor download ramp power from 100% to 90%, 80% and 50% respectively. Analogously, the related feedwater valve percentage opening positions are presented in Figure 7, 9 and 11, respectively.

Since the three loops have an identical behavior throughout the simulation test, the trends of only one loop are represented in the following figures.

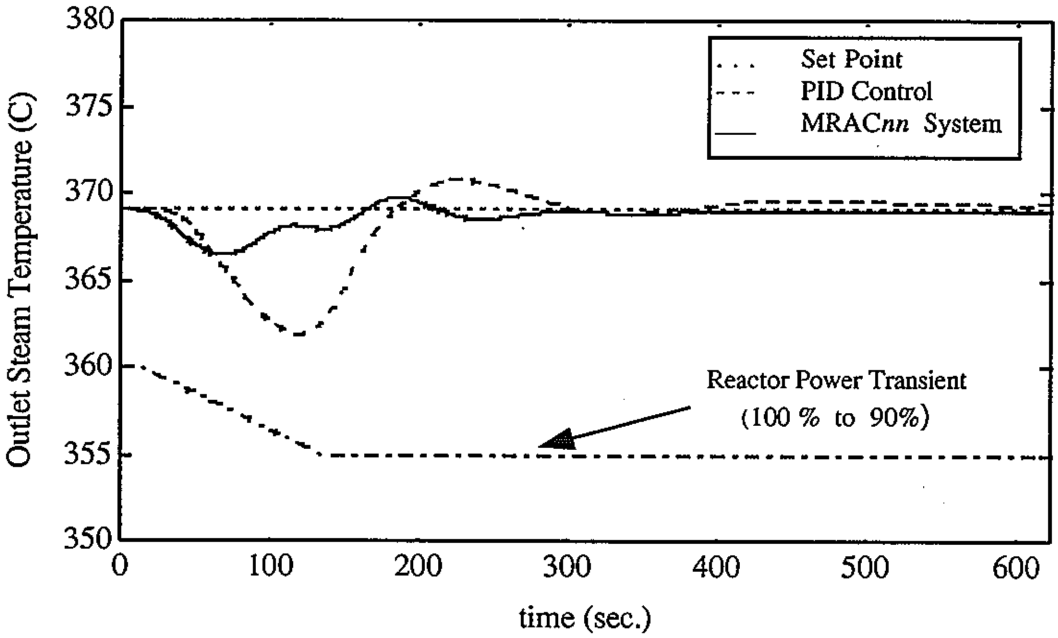

Figure 6. PID and $MRAC_{nn}$ system controlled outlet steam temperature trend for 10% decrease in reactor power.

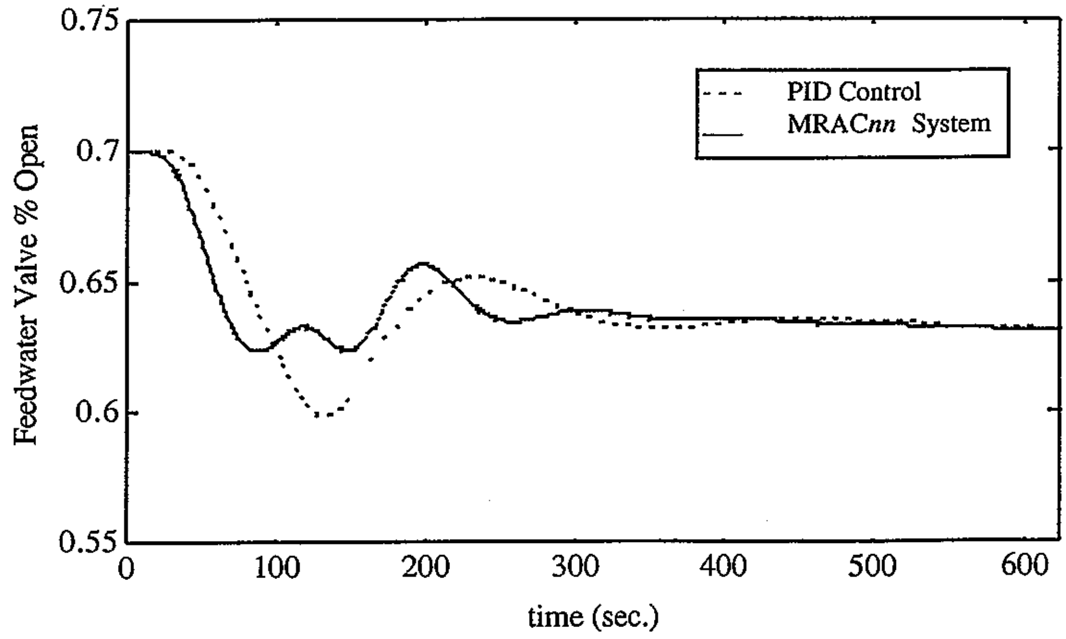

Figure 7. PID and the MRAC$_{nn}$ system controlled feedwater valve percentage opening position for 10% decrease in reactor power.

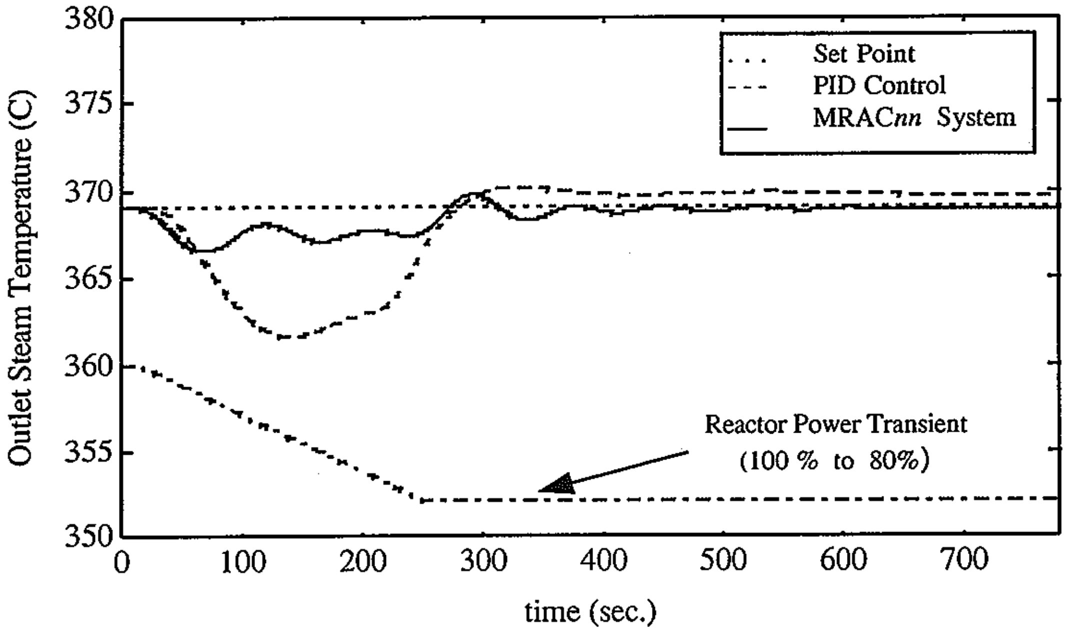

Figure 8. PID and MRAC$_{nn}$ system controlled outlet steam temperature trend for 20% decrease in reactor power.

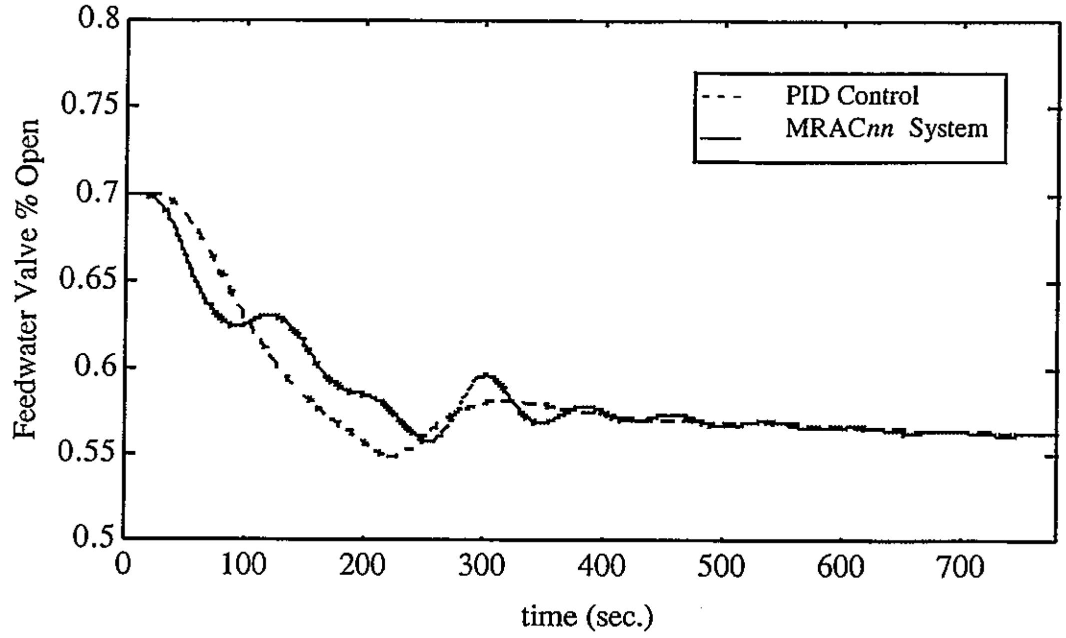

Figure 9. PID and the MRAC$_{nn}$ system controlled feedwater valve percentage opening position for 20% decrease in reactor power.

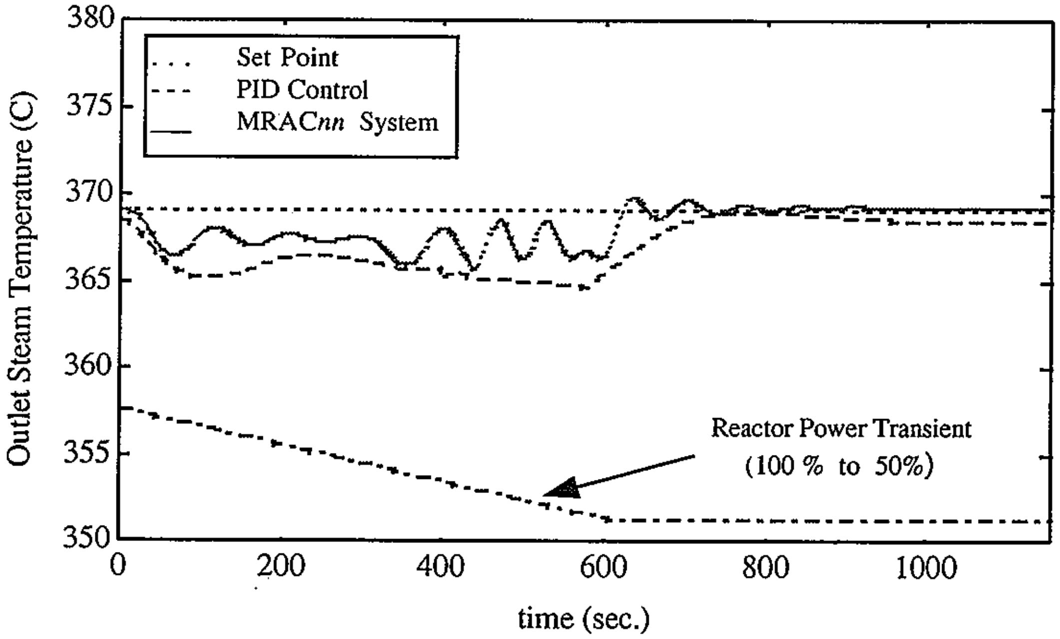

Figure 10. PID and MRAC$_{nn}$ system controlled outlet steam temperature trend for 50% decrease in reactor power.

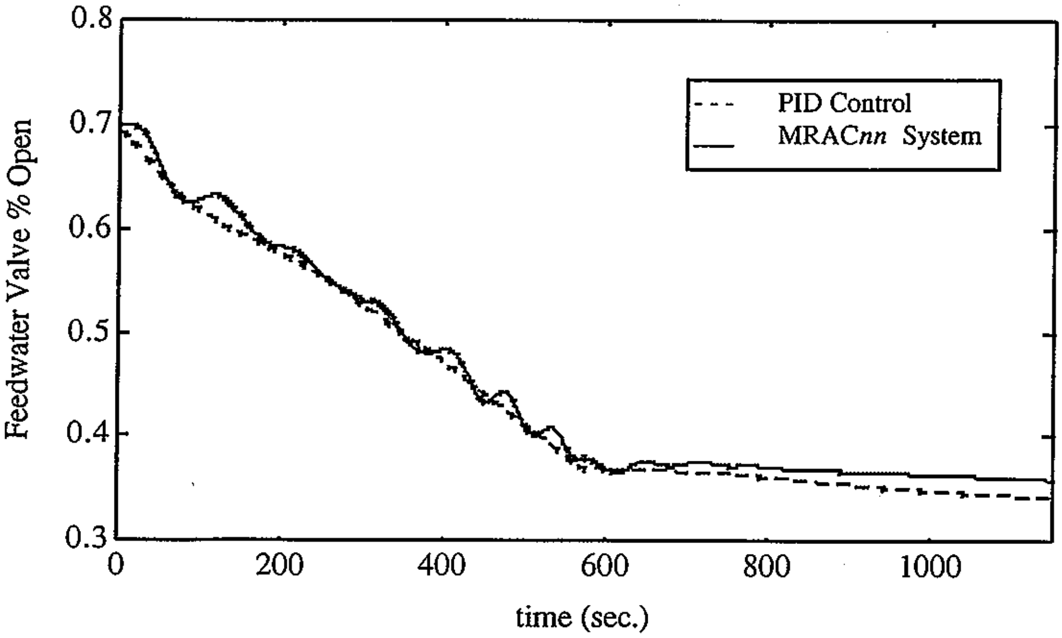

Figure 11. PID and the MRAC_{nn} system controlled feedwater valve percentage opening position for 50% decrease in reactor power.

The MRAC_{nn} performs better than the PID controller in all the transients. However, the performance of the MRAC_{nn} decreases, as already noticed in the one-loop connection case, when the magnitude of the reactor power ramp transient increases. As in the previous case the time delay between the two systems and the ANN training procedure are thought to be the causes of the oscillations observable in the control action of the MRAC_{nn} system.

It is also possible to notice that the MRAC_{nn} system performs better in the one-loop connection tests. At a first sight this could seem an anomalous situation, instead it evidences the time delay problems explained previously. Since the three loops of the reactor are connected each other in the upper and lower plenum of the core, when only one loop is controlled by the MRAC_{nn} system, the PID controller controlling the remaining two loops act as a smoothing factor reducing the oscillations generated by the MRAC_{nn} system.

5. CONCLUSIONS

The implementation of the $MRAC_{nn}$ system on the FBR BBT simulator has been successfully achieved. The $MRAC_{nn}$ system performs better than the PID controller installed inside the FBR BBT simulator even if the presence of a time delay between the two systems affects its efficacy when large ramp decrease transients of the reactor power are executed.

It is believed that by using an $MRAC_{nn}$ with an ANN trained on data originated by the FBR BBT simulator, and by embedding it inside the structure of the simulator a better control action capable to cover any kind of transient scenarios could be achieved.

6. ACKNOWLEDGEMENTS

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