

A THEORETICAL MODEL FOR THE IPEN RESEARCH REACTOR IEA-R1

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ABSTRACT

This work presents the Ipen research reactor IEA-R1 model. The model was developed using the Matlab GUIDE toolbox that consists of a set of functions designed to create interfaces in an easy and fast way. The system model equations are based in the IEA-R1 mass and energy inventory balance and physical as well as operational aspects are taken into consideration. The interface layout looks like a process flowchart. The user can see the variables and set values for temperatures, flow rate and nuclear power. After the establishment of the input variables values by pressing the calculate pushbutton, the program determines the values of thermal power and temperatures. Besides the normal operation conditions, there is the possibility to choose a faulty variable from a list. The program also allows the user to set the noise level for the input variables. Using the model, data were generated for different operational conditions, both under normal and faulty conditions with different noise levels added to the input variables. Data generated by the model were compared with real reactor data showing a good agreement. The IEA-R1 reactor theoretical model results are being used for the development of a *Monitoring and Fault Detection System* for the Ipen reactor. Besides, due to the widespread use of the Matlab platform, the reactor model can be easily adapted to be use in other studies.

1. INTRODUCTION

The Ipen nuclear research reactor IEA-R1 is a pool type reactor using water for the cooling and moderation functions and graphite and beryllium as reflector. Its first criticality was in September 16th, 1957. Since then, its nominal operation power is 2 MW. In 1997 a modernization process was performed to increase the power to 5 MW, in a full cycle operation time of 120 hours, in order to improve its radioisotope production capacity. In order to increase the reactor reliability and safety, a *Monitoring and Fault Detection System (MFDS)* is under development as part of an ageing management program. The monitoring and fault detection system will use the *GMDH (Group Method of Data Handling) methodology*. The *GMDH* is an algebraic algorithm to predict system state variables. It creates a set of equations that give a desired output as a function of a subset of inputs from successive polynomial approximation [1]. The developed methodology was first implemented and tested in a heat exchanger model, a simple thermodynamic system. Then the methodology was applied to a theoretical model of the IEA-R1 reactor.

The objective of this present model is to be a tool that generates data in different reactor operation conditions, allowing flexibility in situations where it is not possible to obtain data experimentally because of restrictions due to the nature of a nuclear reactor operation. Using the model, data were generated both under normal and faulty conditions. The IEA-R1 reactor

theoretical model results were used as a database for the development of the *MFDS* system using *GMDH* methodology. The IEA-R1 theoretical model performs the following tasks:

- Generation of data in different reactor operation conditions
- Setting the input variable values in an easy and fast way using a graphic interface
- Setting the noise level for the input variables
- Selecting a faulty variable from a list
- Visualization of the results in a dynamical way

2. THE IPEN RESEARCH REACTOR IEA-R1

Figure 1 shows a flowchart diagram of the Ipen nuclear research reactor IEA-R1.

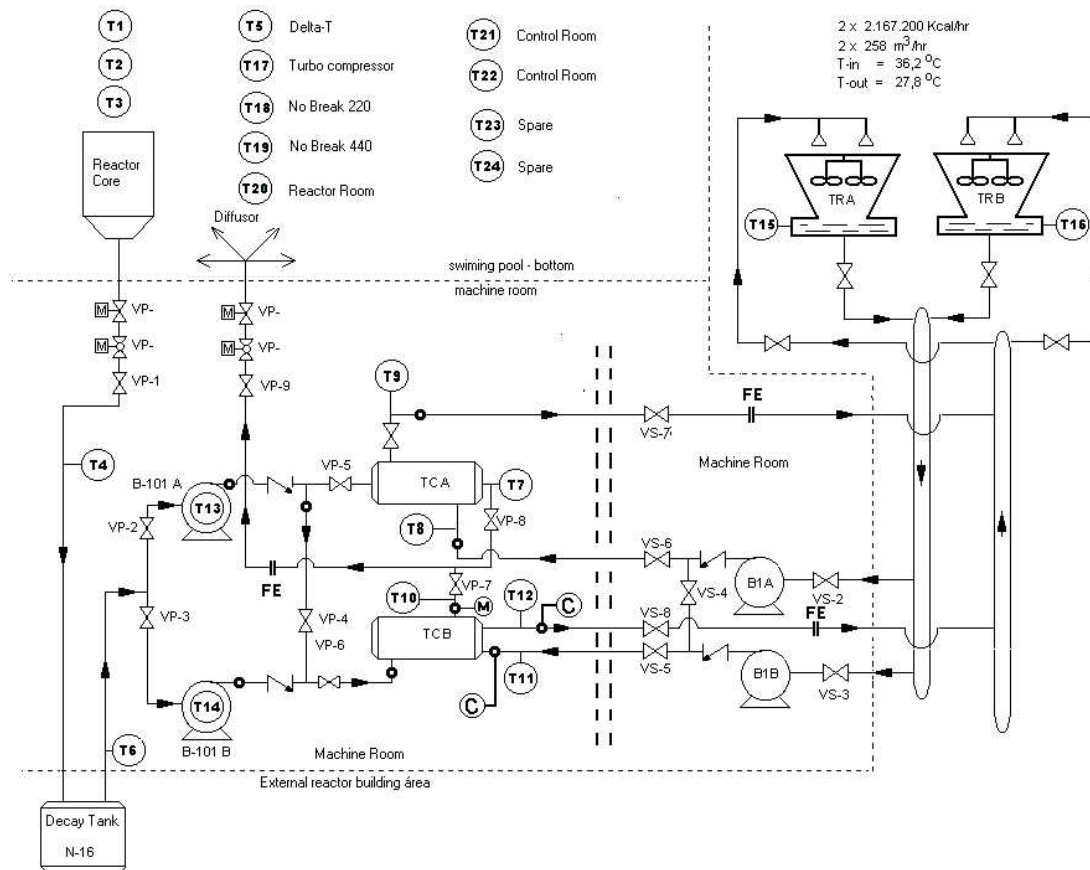


Figure 1. IEA-R1 experimental reactor schematic diagram

The model represents the basic relationships between the different process variables. The system process equations are based on the IEA-R1 mass and energy inventory balance [2] and [3], and the physical and operational parameters, such as pipe length and diameter, relationships between the flow rate, temperatures and pressure drop are taken into consideration.

3. RESEARCH REACTOR MODEL

The Ipen research reactor model was built using the Matlab GUIDE toolbox [4]. The GUIDE (Graphical User Interface Development Environment) toolbox is a set of functions designed to develop interfaces in an easy and fast way. One can add plots, sliders, frames, editable texts and push buttons that are related to other Matlab functions.

The interface layout was built to look like the reactor process flowchart. Figure 2 shows the program interface. The reactor core is represented immersed in the water pool. The temperatures T1, T2 and T3 are the temperatures above the core near the pool surface, at mid high and close to the core, respectively. The nuclear power is an input data and a nuclear power of 100% corresponds to the maximum operation power of 5 MW.

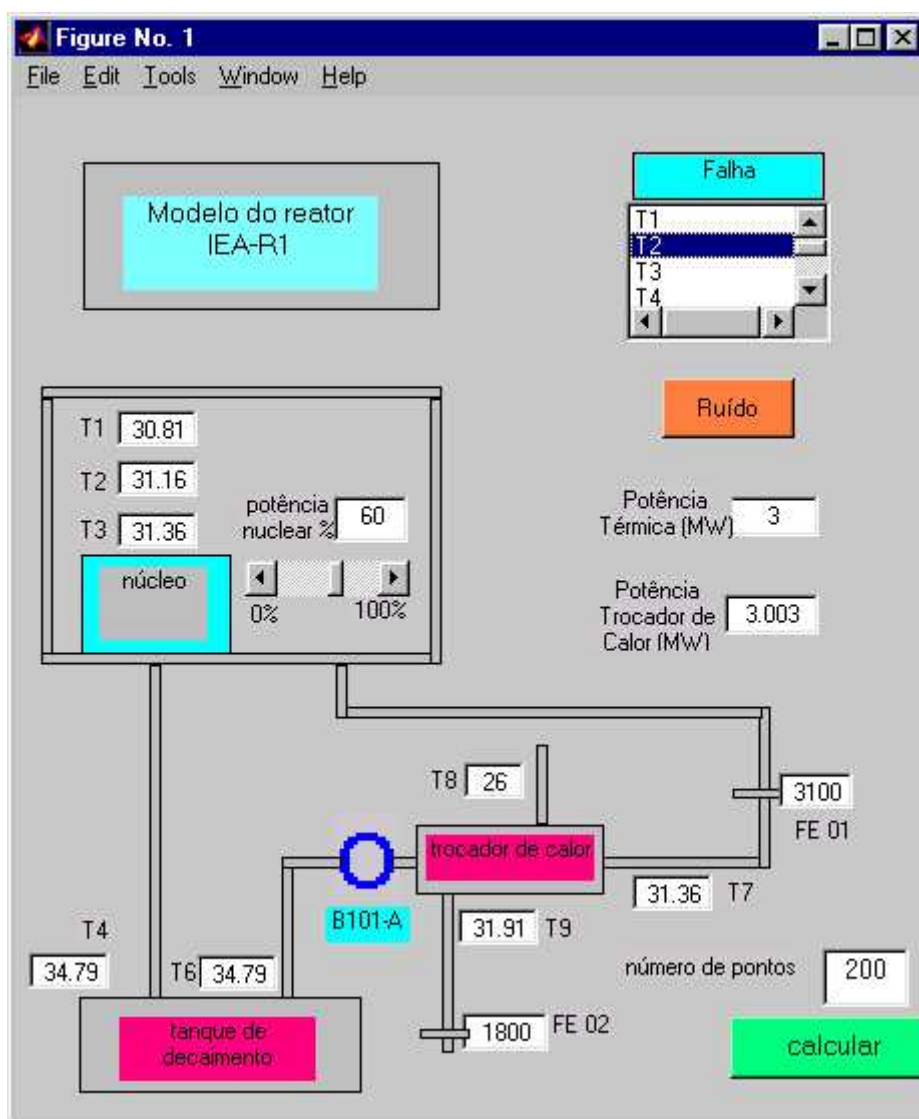


Figure 2. Program interface developed to compute the IEA-R1 nuclear reactor model variables.

The reactor coolant system is represented in the interface. The primary loop water flows through the reactor fuel elements and leaves the pool through a nozzle under the core. Then, the water passes through the decay tank: T4 is the decay tank inlet temperature and T6 is the outlet temperature. B101-A is the primary loop pump. The heat exchanger is also represented. T7 is the heat exchanger outlet temperature (primary loop side). FE 01 is the primary loop flowmeter. The primary water loop flows out of the heat exchanger and then returns to the pool. The secondary loop is partially represented by the secondary side of the heat exchanger. The pump in the secondary side and the cooling towers are not represented. T8 is the inlet temperature of the heat exchanger secondary side, and T9 is its outlet temperature. The secondary loop flow is measured by the FE 02 flowmeter. The units of temperature and flow are the same used in the reactor data acquisition system that is Celsius degrees and gallons per minute.

The interface shows the reactor thermal power (MW) computed from the nuclear power and from the heat exchanger primary side heat balance.

The developed model allows the user to add a fault to a variable by selecting the faulty variable from a list of all the model variables. The first option of the list is "no fault", that means normal operation condition. This option is used to simulate a faulty instrument such as a drifting temperature sensor or a valve actuator, which is faulty.

The input variables noise level can also be set. Choosing this option a new window will be open where one can specify the noise level in % for the variables T3 (core inlet temperature), T8 (heat exchanger inlet temperature – secondary loop), primary and secondary loop flow rates. As the other temperature values are calculated from the input variables, the resulting noise of the others variables are consequences of the input variables noise. This option can be used to simulate malfunction and faults in the instrumentation channel electronics as well as noisy environments.

The user can define the time interval by defining the total number of points and the time step where the variables are to be calculated by the model for a given operational condition. In this case the program calculates for one point, refreshes the values and restarts the computation for the next point.

The user defines the desired variable values for the temperatures, flow rate or nuclear power directly in the interface editable dialog box. After entering the variable values, the noise level, the fault condition and the number of data points, pressing the button *calculate* initiates the program, which calculates the thermal power according to the mass and energy inventory balance equations.

The function *calculate* performs the following tasks:

- read and load the variables values on the screen;
- verify which variable contains fault;
- add noise to the variables T3, T8 and primary and secondary flow rate according to the defined values;
- calculate the thermal power given by the reactor core, using the T3, T4 and primary loop flow rate values;
- calculates the heat exchanger thermal power in the primary and secondary sides;
- refresh the calculated values on the screen;

- places all the values in a data matrix, where the columns are the variable values T1, T2, T3, T4, T6, T7, T8, T9, FE02, FE01, nuclear power and thermal power, and the lines corresponding to the number of data points;
- creates a plot showing the data generated.

4. RESULTS

Using the IEA-R1 theoretical model, data was generated for many operation conditions both under normal or faulty condition. The normal operation conditions generate a database for the development of the GMDH algorithm for variable predictions. The faulty data were saved in Matlab files and then used in the developed monitoring program.

4.1 Comparison between data generated by the model and real operation data.

The IEA-R1 model was used to generate data at the same reactor operation conditions of the first week of April 2004. Figure 4 shows the difference % between model data temperatures and real operation data temperatures.

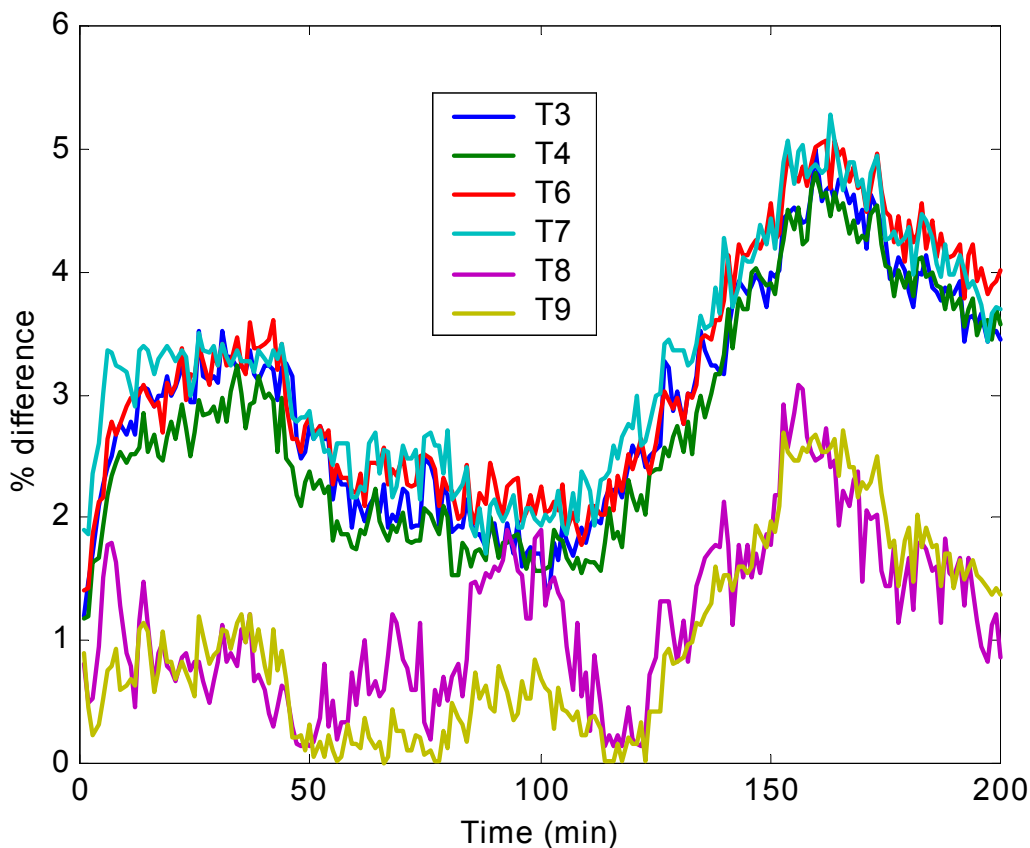


Figure 4. Difference between IEA-R1 reactor model and real reactor operation temperatures.

CONCLUSIONS

This work we presented the Ipen research reactor theoretical model. The model was developed using the Matlab toolbox GUIDE that consists of a set of functions designed to create interfaces in an easy and fast way. The system process equations are based in the IEA-R1 mass and energy inventory balance and the physical and operational aspects such as length, pipe diameter, flow rate, temperature and pressure drop, are taken into account.

The interface layout looks like the reactor process flowchart. Using the model, data were generated for different operational conditions, both under normal and faulty conditions with different noise levels added to the input variables. These data were used to perform an exhaustive *GMDH* methodology study.

Despite the simplicity of the model, the results showed a good agreement when compared to real operation data. This simplicity can however be translated into a robust and real time model for future applications. The IEA-R1 reactor theoretical model results showed to be very useful for the development of the *Monitoring and Fault Detection System*. Besides, due to the full use of the Matlab platform, this reactor model can be easily adapted to be used in other studies.

ACKNOWLEDGMENTS

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