

# DEVELOPMENT OF A FAULT TEST EXPERIMENTAL FACILITY MODEL USING MATLAB

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## ABSTRACT

The Fault Test Experimental Facility was developed to simulate a PWR nuclear power plant and is instrumented with temperature, level and pressure sensors. The Fault Test Experimental Facility can be operated to generate normal and fault data, and these failures can be added initially small, and their magnitude being increasing gradually. This work presents the Fault Test Experimental Facility model developed using the Matlab GUIDE (Graphical User Interface Development Environment) toolbox that consists of a set of functions designed to create interfaces in an easy and fast way. The system model is based on the mass and energy inventory balance equations. Physical as well as operational aspects are taken into consideration. The interface layout looks like a process flowchart and the user can set the input variables. 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 fault conditions with different noise levels added to the input variables. Data generated by the model will be compared with Fault Test Experimental Facility data. The Fault Test Experimental Facility theoretical model results will be used for the development of a Monitoring and Fault Detection System.

## 1. INTRODUCTION

Automated control systems are becoming more complex and the control algorithms more and more sophisticated. Consequently, there is a growing demand for fault tolerance which can be achieved not only by improving the individual reliabilities of the functional units but also by an efficient fault detection, isolation and accommodation (FDIA) concept [1].

Over the last two decades, the basic research on FDI (Fault Detection and Isolation) has gained increasing consideration world-wide. This development was mainly stimulated by the above-mentioned trend of automation towards more complexity and the corresponding growing demand for higher availability and security of control systems. However, a strong impetus also comes from the side of modern control theory that has brought forth powerful techniques of mathematical modelling, state estimation and parameter identification that have been made feasible by the spectacular progresses of modern computer technology. In the course of this development a novel philosophy for the FDI methodology has emerged and is increasingly discussed. It is based on the use of *analytical* (i.e. *functional*) rather than *physical* redundancy. This implies that the inherent redundancy contained in the static and

dynamic relationships among the system inputs and measured outputs is exploited for FDI. In other words, one makes use of a *mathematical model* of the system or of parts of it.

Model-based FDI is built upon a number of idealized assumptions, one of which is that the mathematical model used is a faithful replica of the plant dynamics. This is, of course, not possible in practice, as an accurate and complete mathematical description of a process is never available. Sometimes the mathematical structure of the dynamic system is not fully known. For other applications, the parameters of the system may not be fully known, or may only be known over a limited range of the plant's operation. There is therefore always a "model-reality mismatch" between the plant dynamics and the model used for FDI. [2]

This work presents the Fault Test Experimental Facility and a model 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 is based in the mass and energy inventory balance equations. Physical as well as operational aspects are taken into consideration. The interface layout looks like a process flowchart and the user can set the input variables. The program also allows the user to set the noise level for the input variables. Using the model, data can be generated for different operational conditions, both under normal and fault conditions with different noise levels added to the input variables. Data generated by the model will be compared with Fault Test Experimental Facility data. The Fault Test Experimental Facility theoretical model results will be used for the development of a Monitoring and Fault Detection System.

Moreover, the test rig provides data for future applications in diagnosis and monitoring systems that employ artificial intelligence techniques. The Artificial Intelligence techniques are also being widely used in monitoring systems and fault detection, standing out among them using knowledge-based systems such as fuzzy logic (fuzzy logic) and artificial neural networks. These, in particular, have been extensively used in a multitude of different areas [2] [3] [4] [5] [6] [7] [8].

## **2. DESCRIPTION OF THE EXPERIMENTAL FACILITY**

Fig. 1 shows the flowchart of Engineering PWR Power Reactor Plant Experimental Facility. The plant is comprised of elements that simulate the pressure vessel control behavior, steam generator, the primary and secondary loop pumps, an additional tank for heat exchange. Also, the Experimental Facility will be well instrumented with sensor and actuator technology, or digital network connectivity utilizing a Fieldbus system [9] signal processing devices (Programmable Logic Controllers), electronics assembly of the whole system as well as the mechanical structure of carbon steel, steel and aluminum plates.

The information system will allow studying the details of the temporal analysis of process variables of a power reactor (PWR type). In a second level of communication, the communication system in a reactor, allows an effective way to have security status of sensors and actuators, and makes effective system maintenance. Also, the application of an analytical system life of the main sensors and actuators allows tracking of lifespan by storing the information in a database.

Data will interface with the plant supervisory system, which is a SCADA (Supervisory Control and Data Acquisition) [10] and this, provide the data through standard interface. SCADA system is a software interface that performs processes and / or machines of various industrial sectors.

The system developed for graphics generation will bring the following benefits to the system:

- Registration and temporal analysis of process variables pressure, level, temperature and flow in the pressure vessel;
- Registration and temporal analysis of process variables pressure, level, temperature and flow in the steam generator;
- Analysis and storage of more than 40 electrical variables considering the pressure vessel and a steam generator;
- Lifespan of Analysis and predictive maintenance of sensors and actuators;
- SCADA supervisory system application for remote monitoring via web of control systems, through the variable I / O.

As for monitoring and interaction temperature variable, it will be implemented a system to the proportional action of the signal through a PWM system. The control device will send a signal 4-20 mA and this will be converted to a lot 0-220 VAC to act on electrical resistance.

Pressure measurement will be made at the following points:

- After the pump B1 (primary loop)
- At the exit of B2 pump (secondary loop)

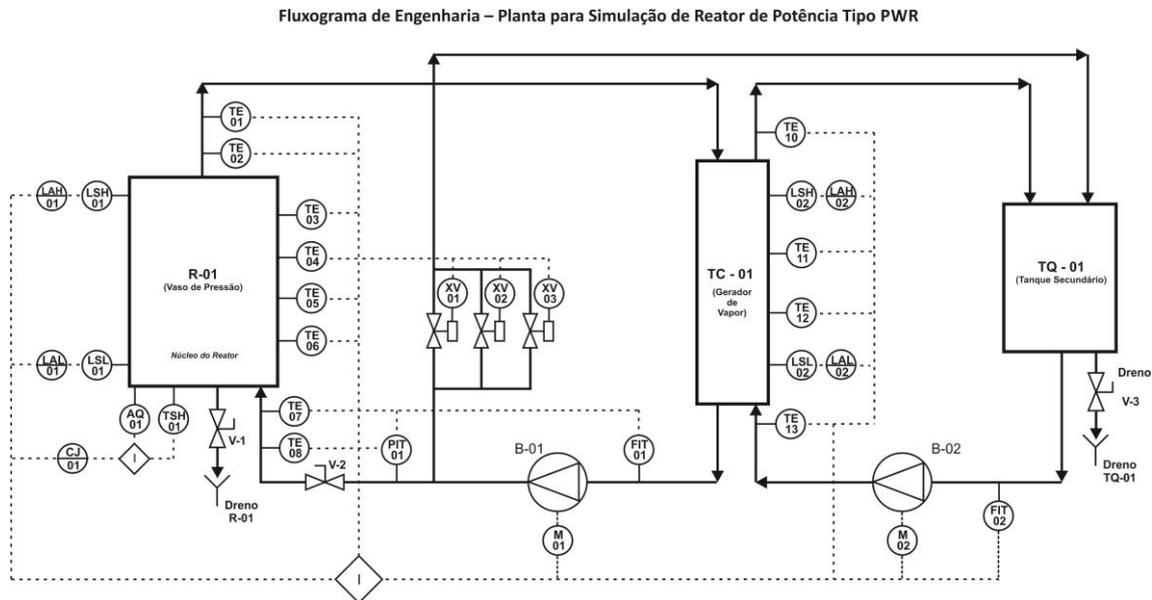
Level is measured using capacitive sensors and level switch in all tanks, including the secondary tank, TQ-01. A flow measurement will take place before the B-01 pump and also before the sign of the B-02 pump.

For the electrical parameters, it will be taken 44 parameters recorded in the monitoring system that will allow the analysis of the phase-to-phase, phase-to-neutral, three-phase voltage, current per phase and three-phase current, frequency, potential active, reactive and apparent power per phase and three-phase, power factor by phase and three phase, THD (Total Harmonic Distortion) per phase voltage and current, up to the 31<sup>st</sup> order, active and apparent demand (average and maximum for all demands), active and reactive energy (positive and negative) and maximum points (voltage and current).

In any circumstances, whether, measurement and / or control level, flow, temperature or pressure, the time domain analysis of all the aforementioned electrical variables will be possible to fully understand the behavior of these, under different operating conditions (electro-electronic variables of the whole system).

As this is a process control plan that provides all the data through standard Windows interface (SCADA) [10], all objects of study will be available at the institution for further application of research and development applied to energy efficiency, mechanical efficiency, as well as extension control algorithms strategies applied to the reactor.

This is possible because all points of I / O are available through connectors that allows the exchange of microprocessor control devices. For example, the development of means of dedicated logical and dedicated systems, such as systems with microcontrollers and / or microprocessors using any technology for the development of logic.



**Figure 1: Flowchart Plant Engineering - Power Reactor PWR Experimental Facility.**

Initially, the database will be divided as follows:

- Pressure data storage for Pressure Vessel, considering instant and accumulated storage;
- Flow of Data Storage of the primary loop and secondary loop through the pressure vessel and steam generator, considering that this storage will occur instantly and cumulatively;
- Data storage of all temperature measurement points for the Reactor Pressure Vessel, considering that this storage will occur instantly and cumulatively;
- Storage of data for all temperature measurement points for the Steam Generator, considering that this storage will occur instantly and cumulatively;
- Storage of 44 electrical parameters measured during the experiments;
- The whole system behavior storage, compared to mechanical disturbances generated, or electrically;

The control systems can occur by any of the variables, including pressure, level, temperature and flow. Let's examine each of them:

- Temperature: Through all the measuring elements installed on Pressure Vessel and Steam Generator, it becomes possible to control the temperature. In the case of Pressure Vessel, acting to control development will occur through PWM power controller.
- Pressure: The measurement of pressure will occur through the PIT-01, located between the pressure vessel inlet and the pump. The pressure setting in the system is possible through the speed variation of the B-01 pump.
- Level: Both in Pressure Vessel and the Steam Generator will be installed taken high and low level measurement through LSH-01 devices, LSL-01, LSH-02 and LSL-02. The performance will be possible through the pumps pumping B-01 and B-02.
- Flow: The flow is measured at two points in the primary circuit and the secondary circuit. In the primary circuit, the measurement will occur through the FIT-01 meter and the secondary circuit through the FIT-02 meter.
- Electrical parameters Measurements: it will be installed a meter of electrical measurements that will allow the collection of more than 40 electrical parameters of the entire system. This meter will display the data to be stored or not, depending on the practical study and / or research to be developed.

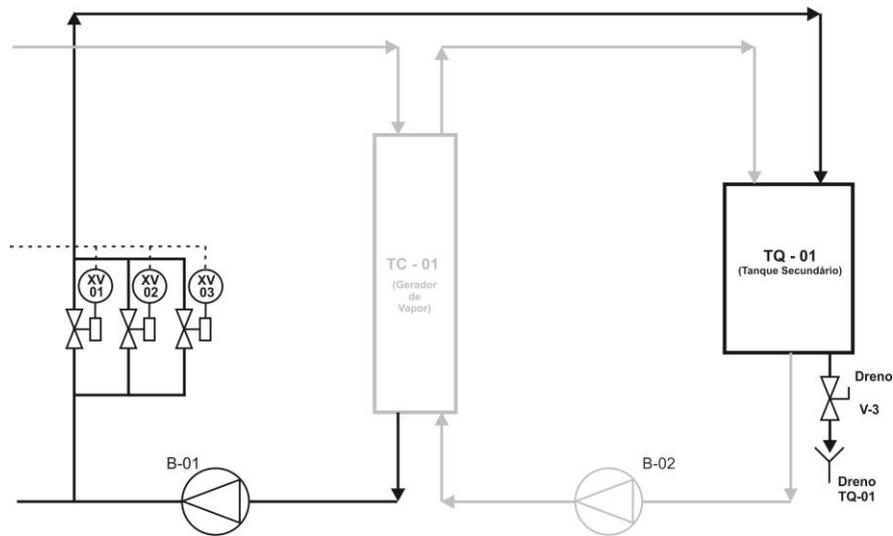
For all variables the supervision system will allow several options for the generation of instantaneous temporal graphics or measurements or accumulated. This will allow to compare data on various conditions x control system operation, including the insertion of faults in incipient cases and / or critical in the reactor.

## **2.1 Troubleshooting Analysis**

The system will allow the insertion failures in incipient cases for simulation and / or critical. In both cases, you can survey the temporal data, as well as its storage in a database. For insertion of faults, SCADA System [10] will provide a module that can be opened or closed valves, namely, the whole process of inserting malfunctions, may be accomplished by software.

As the temperature is a very important variable in a reactor, the system will provide the manual insertion temperature signal failures. This including Pressure Vessel and Steam Generator.

It will also provide fault in the pump drive command B-01, located in the primary loop and sensors of high and low level indication Pressure Vessel (LSH-01 and LSL-01) and the high level sensor Steam Generator (LSH-02).



**Figure 2: Highlight of the Fault Insertion System.**

Valves XV-01, XV-02 and XV-03 (highlighted in Fig. 2) together and / or separately can be opened depending on the type of failure to be entered into the system. The fact that one or more valves open, causes the fluid pressure being generated by the B-01 pump in the primary loop decreases.

With the insertion of one or more faults, as described above, the Experimental Facility will simulate a kind of fault known as LOCA (Loss of Coolant Accident) which is an important consideration in nuclear power reactor design criteria.

### 3. MATLAB MODEL USING GUIDE

The Experimental Test Facility model was built using the Matlab GUIDE toolbox [11]. 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. Using the GUIDE Layout Editor, you can graphically design your User Interface. GUIDE then automatically generates the MATLAB code for constructing the UI, which you can modify to program the behavior of your application.

The developed model calculates the flow rates, temperatures and pressure values according to the mass balance inventory equations and system power. For this purpose, they are used as input parameters the geometric dimensions (diameter and length of the pipes), material characteristics used (material of pipes and reservoirs), and operating characteristics. Due to the fact that the Experimental Facility is still in the design phase, these values are not known exactly. Therefore, estimates were used, which will be easily corrected in the final model after the construction of the Experimental Facility.

The interface layout was built to look like the Experimental Facility flowchart (see Fig. 2). Fig. 3 shows the program interface, with all process variables displayed. Some variables can be set, and others are calculated from the program.

The interface shows the reactor thermal power adjusted from the heater level and also computed for the Steam Generator primary side.

The developed model allows adding 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.

The input variables noise level can be set. Choosing this option a new window will be open where one can specify the noise level in % for the temperatures variables, and for the primary and secondary loop flowrates. Some temperature values are calculated from the input variables, and the resulting noise of the others variables are consequences of the input variables noise.

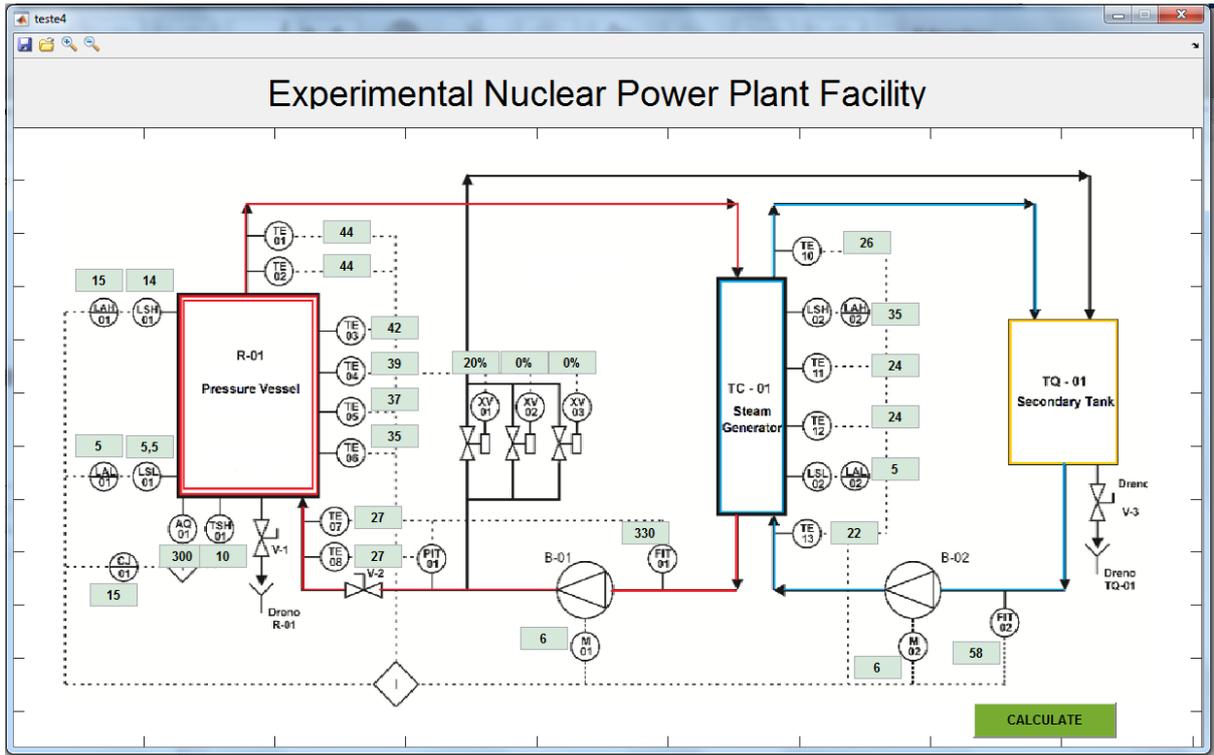
Finally one can set the total number of points to be generated by the model for the set operation condition. In this case the program calculates for one point, refreshes the values and restarts the computation for the next point.

The user set the desired variable values of temperatures, flow rate or nuclear power direct in the interface editable box. After the input variables, the noise level, fault condition and number of data points were chosen, pressing the button *calculate*, and the program calculates the thermal power according to the mass and energy inventory balance equations.

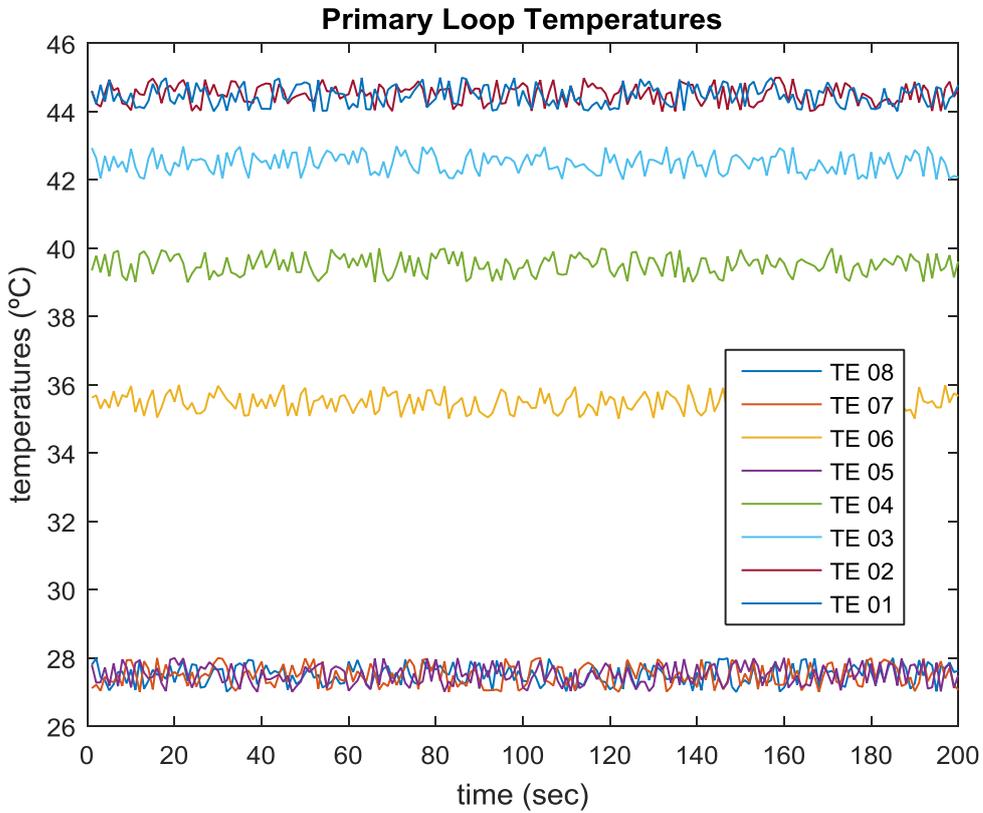
The function *calculate* performs the following tasks:

- read and load the variables values on the screen;
- verify which variable contains fault;
- add noise to the variables selected;
- calculate the thermal power given by the reactor core, using inlet and outlet nuclear core temperatures and primary loop flow rate values;
- calculates the heat exchanger thermal power in the primary and secondary side;
- refresh the calculates values on the screen;
- put all the values in a data matrix, where the columns are the variable values, and the lines corresponds to the number of data points;
- create a plot showing the data generated.

The test rig is still under construction, and therefore the exact values of their dimensions and material characteristics are not yet available. To use the theoretical model were estimated initial values, which will be adjusted accordingly when the construction of the test rig is ready. Figure 4 shows the calculated values of primary loop temperatures, with a noise value of 4%.



**Figure 3: User Guide Interface developed to model the Test Experimental Facility.**



**Figure 4: Primary loop temperatures.**

### 3. CONCLUSIONS

This work presented the design of an experimental facility for simulation of a nuclear power plant PWR type. Albeit on a small scale, this facility will have as main advantage the fact that very well instrumented with sensors and state-of-art actuators. Moreover, the proposal is that all the sensor's data reading and data storage are made in a conventional way and so remotely.

The experimental facility is a powerful data generation tool that will be used for the study and development of monitoring and diagnostic systems, as well as sensors and actuators fault detection, using artificial intelligence techniques.

A mathematical model of the test rig was started, and this will be updated according to the construction of it. As the experimental facility is ready, the theoretical data provided by the model will be properly compared with the actual data counter operation. This theoretical model can be refined based on the results.

The developed test rig can be used for various other experiments and studies involving sensors studies and other electronics measurement as well as new techniques of artificial intelligence to be arising in the future.

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