

## MATLAB Simulation for Loss of Flow (LOF) in Reactor TRIGA Puspati (RTP)

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### Abstract

*TRIGA Puspati Reactor is a nuclear reactor situated at Malaysia Nuclear Agency, Bangi. The reactor has gone to emergency shutdown when there is a fault. However, the pattern of the fault can be recognized and be diagnosed in the early stages before leading to shut down that can helpful for repairing and future maintenance. This project modelled the plant system based on real data, and to investigate its behaviour in identifying the fault by obtaining residual. The project explores the way of modelling using system identification and a plant with a compensator model to achieve the required results. Data are obtained from the Malaysia Nuclear Agency based on the actual reactor. Two separate data sets, one set of data as validation and the other is used to form the transfer function. Once the normal condition model is done, by using the same specifications fault model is developed with the same number of poles and zeroes. The residual is found by subtracting the output of the normal model with the fault model where it can form a pattern of fault. The fault created in the simulation by allowing the valve opening of water flow to the reactor by 25%, 50% and 75% at the cooling system of the reactor. It was found that the residual for 25% valve opening is the largest due to lower water flows from the heat exchanger lead to increase of temperature and pressure. For 50% valve opening, it is a middle-class fault and the residual created is smaller than the 25% valve opening but the value of temperature and pressure is still considerably high. So, the residual is still large but smaller than the residual for 25%. As for 75% valve opening the system output have longer oscillation. The temperature output is not that large compared to normal operation, but the system is observed to be still rising which means it has not reached a steady state yet. In this project, the residual value for these three different faults is observed and able to identify the severity of fault due to valve opening.*

**Keywords:** Prediction model, Fault diagnosing, Residual analysis.

## 1. Introduction

The software used for the modeling of TRIGA Puspati Reactor is MATLAB. The system identification toolbox in MATLAB is used for the modeling of the reactor where in that toolbox the transfer function is estimated given a set of input and output data. Reactor TRIGA Puspati (RTP) is a 1 MW research reactor at the

Malaysian Nuclear Agency, Bangi, Malaysia, which was installed in 1982. RTP core is a cylindrical core with 127 core locations designated to accommodate fuel elements and other non-fuel elements such as control rods and irradiation facilities [1]. The current mechanism applied in Nuclear Reactor TRIGA PUSPATI during abnormal situation is to go to shutdown where the rod that controls the fuels will

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detecting  
 s cause  
 to read  
 quickly  
 compared doing it in manually. This will help in reducing the analysing time and can help it reduce the losses.

It will be useful if the fault can be identified or detected earlier so that preventive measures can be taken before the reactor shutdown [2]. Previously used analog machine for analysis are now evolving into digital versions running on personal computers (referred to as Digital Reactivity Computers, or DRC) [3]. The fault is defined as an unwanted change of at least one aspect property of a process of the system from the desirable, acceptable, normal, standard condition [4]. The architecture of the Triga Puspati Reactor is made up of a cylindrical core which consists of fuel elements from solid Uranium Zirconium-Hydride (UZrH1.6) with 8.5wt. %, 12.0 wt. %, and 20.0 wt. % of uranium fuel (U) and 19.7% of Uranium-235 enrichment. There are 4 boron carbide (B4C) control rods whereby one of them is an air follower type and the rest are fuel follower type with B4C absorber on top of fuel section. The core is surrounded with graphite as reflector and cooled by natural convection. As for protecting purposes, the core biological shield is made of high-density concrete of 2.5m thick wall to attenuate radiation and shield its surrounding from radiological contamination [5].

There are generally three types of modelling white-box modelling, grey box modelling, and black-box modelling. In black-box modelling, the equation and the relationship between the input-output are not known clearly so the modelling focus will be on the empirical data value on the input and output to derive the relationship equation. In grey box modelling the equation and the properties of the system are partially known. So, it is combined with the operation data to create the model that best describes the system. In white box modelling, the equation of relationship is known prior and can be derived using chemical, biology, or physics knowledge. For this project, black box type modelling is used. LR model which is short for Linear Regression model is an example of a black-box model. The model stands for empirical relationships directly between input variables and storage temperature and can be the simplest black-box model possible with good accuracy [6]. The mathematical model derived for the system can be in the form of a transfer function (continuous or discrete), state-space model and Autoregressive models (ARX, ARMAX) [7]. The plate heat exchanger is used in different fields including food processing, petroleum refineries, chemical industries, power stations and steel mills due to their superior ability of heat transfer, compact build and ease of cleaning [8]. The heat exchanger used in reactor TRIGA Puspati is also one of them.

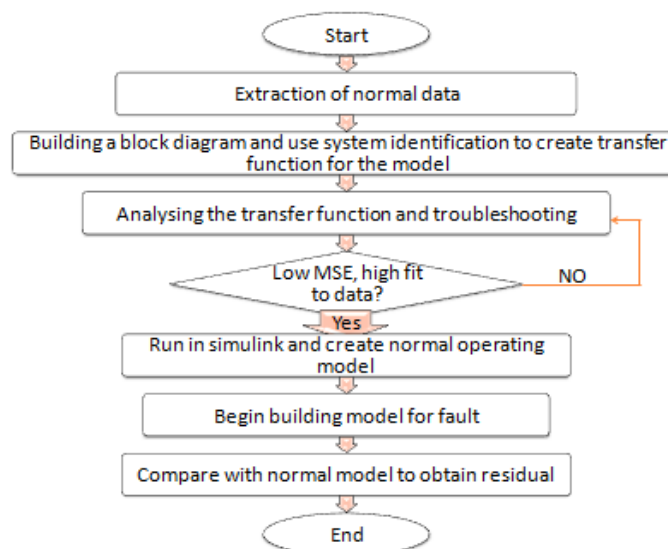
In many analysing study on the impact of the loss of flow toward the system, fault detection and diagnosing model was applied. The idea in identifying the fault, is by

obtaining residual value in order to understand fault pattern. Residual selection is an important factor in model-based diagnosis system, however, there are often more candidate residual generators than what is required. One method of residual selection approach, a convex optimization problem is formulated, using both structural information on the various residuals and training data from different fault scenarios [9]. Aside from model-based fault detection, there is data-based fault detection as well. The most commonly used method is, the Hotelling's  $T^2$  statistic and the Q statistic, which is also known as the squared prediction error, are used for fault detection [10]. Online data-driven fault detection strategy is intriguingly used to handle non-Gaussian electrical drive systems by combining two nonlinear coordinate projections. Experiments under unknown noise level of the electrical drive system are performed to demonstrate its effectiveness. PCA can be used because of its multivariate statistical analysis fundamentality [11].

System identification also one of the method that can be used in dealing with fault detection and diagnosing as other researchers also have been applied it. Even though there are many new method exists, system identification approach is still viable. Thus the research focused on to understand the capability of system identification in fault detection and diagnosing. Other researchers studied the nonlinear system identification and fault detection are studied by other researchers by implementing the hierarchical clustering analysis and local linear model. The author X. Wang and V.L. Syrmos applies the nonlinear autoregressive to approximate the system dynamics. The proposed system identification able to capture the nonlinear system dynamic and correctly detect the faults [12]. Another research is on heating, ventilation and air conditioning (HVAC) equipment. From the research, the approach has advantages for computationally efficient while not required detailed building [13]. Based on these researches, in order to know its capability, we applied the system identification approach to the reactor cooling system.

## 2. Methodology

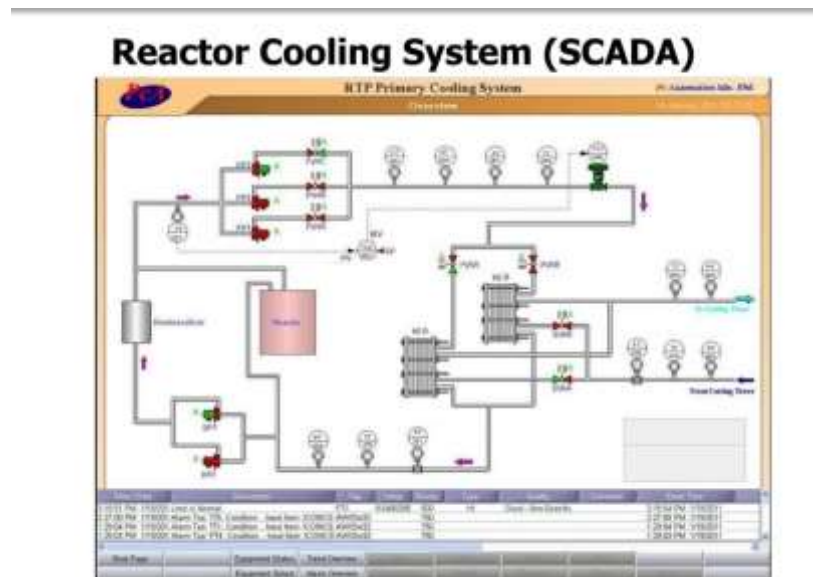
The process of modeling the Triga Puspati Reactor involves a few important steps, as outlined in the flow chart in Figure 1.



### Figure 1. Project Flowchart

The reactor at focus here is a TRIGA MARK – II pool-type reactor. The reactor is a pool water reactor type where the water for cooling will be channelled into the reactor after going through the heat exchanger. The water from the cooling system is circulated to the reactor and the heat exchanger. There are one auxiliary heat exchanger and one auxiliary pump in between the heat exchanger and the reactor. Each pipe lining either from heat exchangers to the reactor or from the reactor to the cooling system has sensors and meters installed to it.

There are flowrate (FT), temperature (TT), and pressure (PT), sensors for each main pipelining. Before these sensors are valves that open and close when that line of flow is operational. Figure 2 shows the full schematic of the system provided by the Malaysia Nuclear Agency (MNA). There are two main steps in this project which is the modelling and residual analysis.

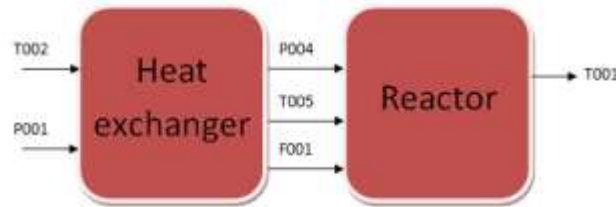


**Figure 2. Full schematic of the system provided by the Malaysia Nuclear Agency (MNA).**

### 2.1. Modeling

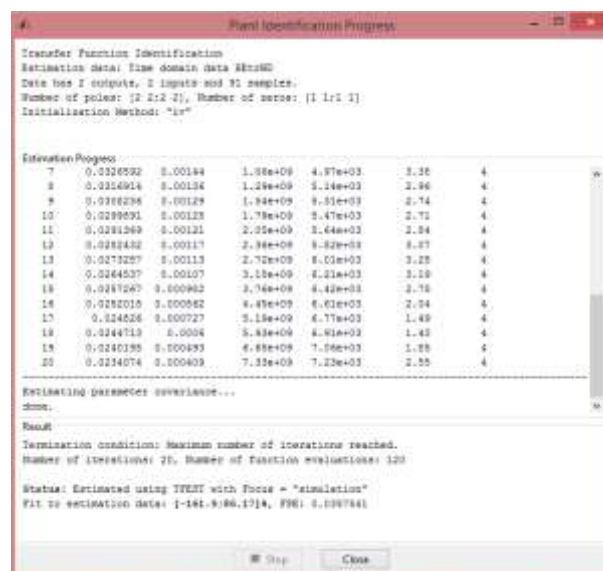
The modeling is done in MATLAB using system identification toolbox. It can be observed from Figure 2 that the system has two main blocks the heat exchanger and the reactor. The cooling tower effect on the system can be ignored due to the flow from the cooling tower does not mix with the primary flow in the heat exchanger but the cooling of water is done merely via heat transfer. So, the temperature and flow of water going out from heat exchanger to the cooling tower is also ignored for the sake of simplification. Once the required subsystem for modelling is identified the input-output characteristics of the subsystem is identified and the block diagram is built. The corresponding block diagram is shown in Figure 3. A data object is created by defining in code the input-output relationship between data obtained from the real reactor. The data is sampled for every 60 seconds. Once the data object

is created it is put inside system identification toolbox to create and estimate the transfer function. The data set is divided into two and one is used to generate the transfer function and the other set is used for validation data.



**Figure 3. Block diagram of the cooling system of the Reactor TRIGA Puspati**

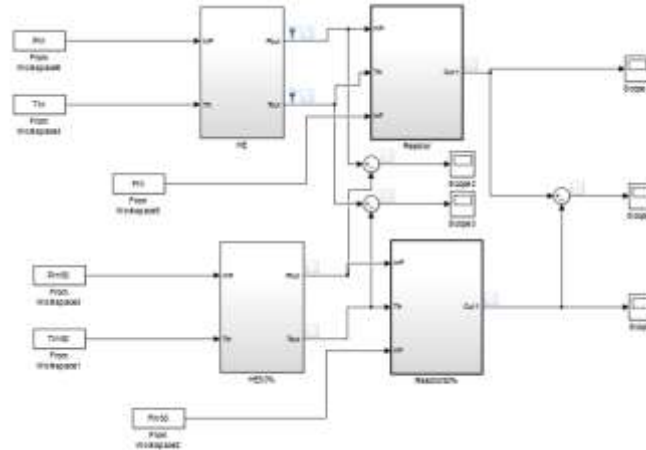
It can be seen the data from sensor temperature sensor (T002) and Pressure sensor (P001) is the input for heat exchanger. Pressure and temperature sensor P004 and T005, as well as flow sensor (F001), becomes the input for the reactor subsystem meanwhile temperature measured by T001 sensor is the output. The imported variables can be seen in the MATLAB workspace. Then, referring to the block diagram the coding for modelling is done by defining a data object for the Multi-Input Multi-Output (MIMO) system. The data object is used for modelling in system identification toolbox. Once the entire required data object is imported into system identification, the modelling begins when the mathematical model is created by specifying the validation data and working data and estimating the transfer function. Once the transfer function is obtained it is put inside SIMULINK and simulated. The modelling begins when the mathematical model is created by specifying the validation data, working data and estimating transfer function. The estimation is done through the iteration process as shown in figure 4.



**Figure 4. Estimation in MATLAB**

## 2.2. Residual Analysis

Once the normal operational model is created then the model for fault is created. Here the fault in concern is the fault of valve flow restriction as much as 75%, 50%, and 25%. Once the fault model is done using the same specifications as the normal operation model, the model output is subtracted with the general outlook is as shown in Figure 5. The residual for each fault type is compared.



**Figure 5. SIMULINK general outlook for fault residual calculation**

The theory behind it is that the flow is restricted due to a faulty valve, broken pipeline or leakage in the pipeline. Table 3.1 shows the list of faults simulated in MATLAB.

Fault	Fault Injection Type	Fault Location
25% Restricted Flow	Making the opening of the valve to be 25%	The valve after the pump (PV4C, PV4B, PV4A)
50% Restricted Flow	Making the opening of the valve to be 50%	
75% Restricted Flow	Making the opening of the valve to be 75%	

**Table 1. List of faults simulated in MATLAB**

### 3. Discussions

The results obtained from normal and fault model are compared. The output response is determined based on offset or steady-state error, percentage overshoot, rise time and 2% settling time. It was observed that the transfer function obtained has fit to estimation data that is viable for one parameter which is the temperature around 86.17% but for pressure the fit is not acceptable which is around -161.9%.

So, corrective action must be taken by adding poles and zeroes as a compensator design to obtain better fit of estimation data. It was observed that the system for the Pressure variable performed better with 4 poles and 4 zeroes on the transfer function with 85.52% fit to estimation data. The temperature parameter had better performance when the transfer function is estimated with 3 poles and 3 zeroes with 94.89% fit to estimated data. For the reactor, the same method is done and the transfer function with the best fit is obtained. Once the transfer function with the best fit is obtained it is entered SIMULINK and simulated. Figure 6 and figure 7 shows the block diagram and the transfer function of Heat exchanger subsystem and reactor subsystem respectively.

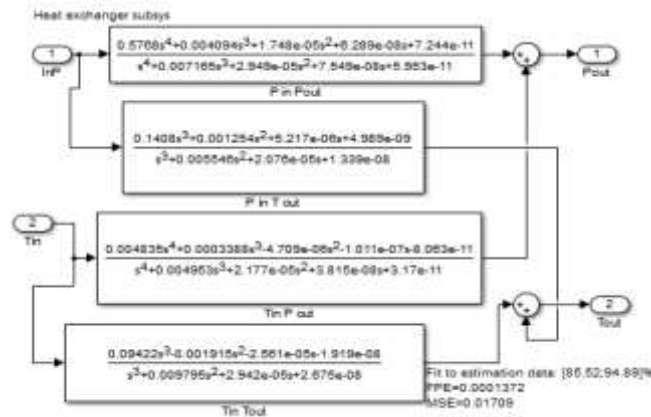


Figure 6. Heat exchanger model and transfer function

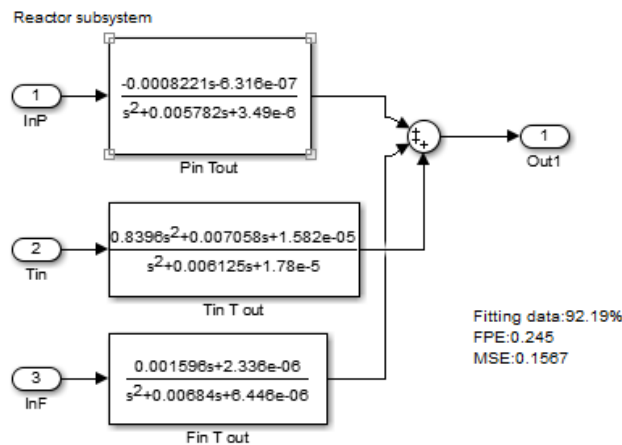


Figure 7. Reactor subsystem normal operation model

The simulated output from the reactor is 44 °C as in the real operation data. Figure 8 represents the reactor temperature during the process.



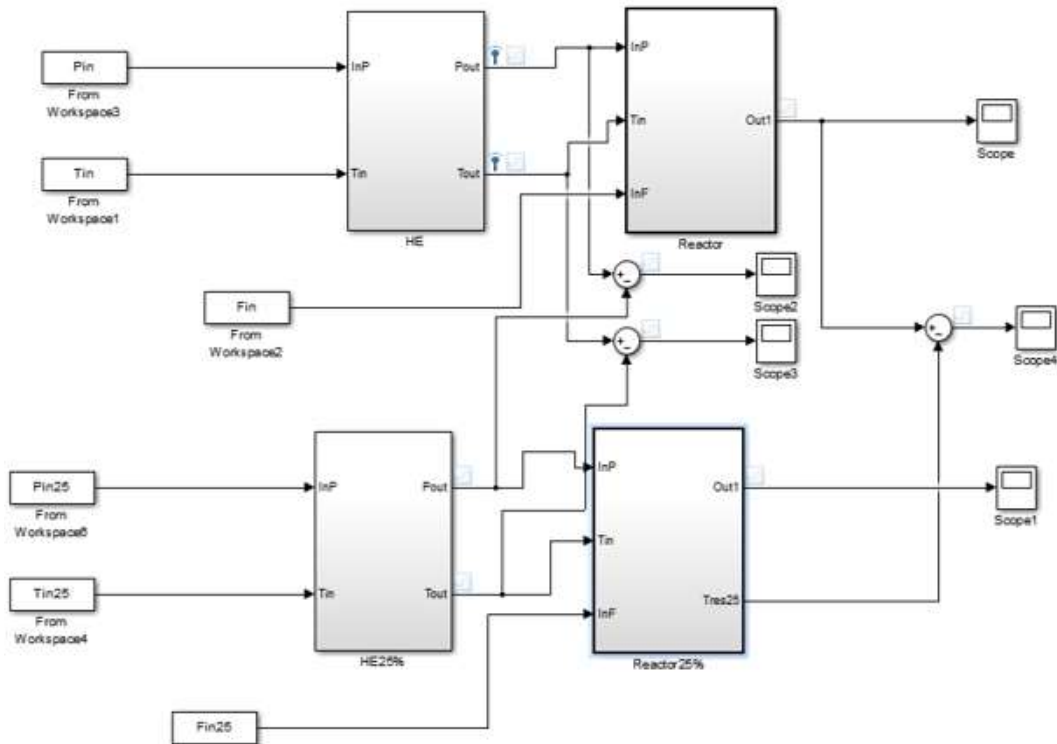
**Figure 8. Simulated Reactor Temperature**

The plant for normal operation able to achieve the steady-state response at the range that is close to the operation point of the real reactor. This allows the model able to represent the reactor and thus allow it to compare them with the fault condition. Fault are developed are based on the valve opening to the reactor, as such 25%, 50% and 75% valve opening are used.

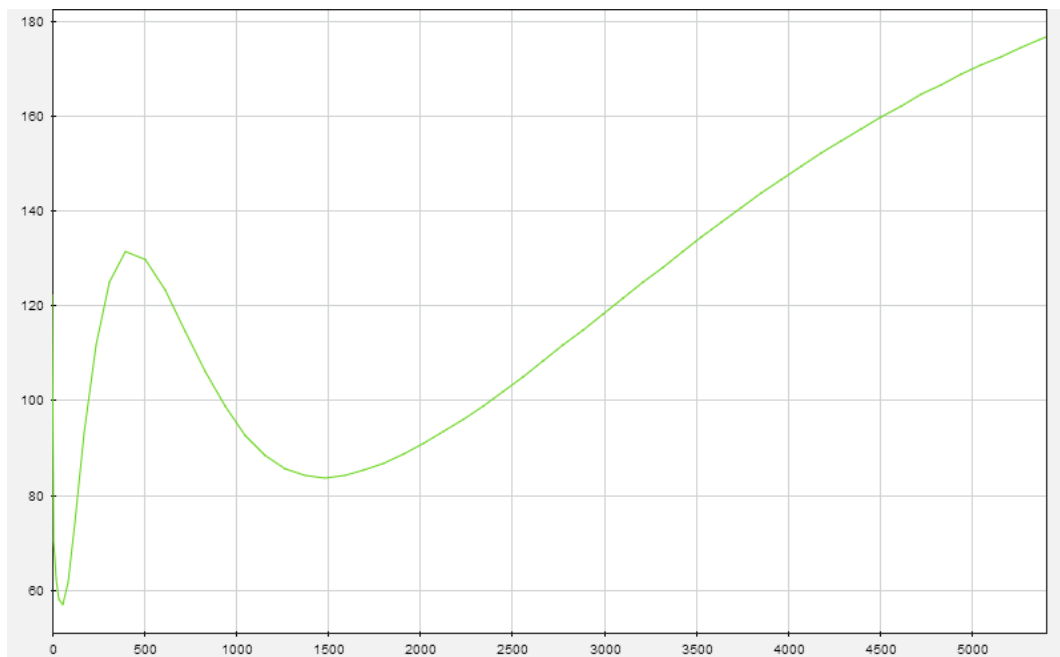
#### 4. Results

After getting the right plant model for actual operation and fault condition the fault residual is calculated by subtracting the fault model output with the normal operation model output. The schematic outlook for the operation is shown in Figure 4. The result of this research based on 3 different valves opening that is at 25%, 50%, and 75%. The reactor system and the fault reactor system are included to calculate the residual respectively. Figure 9 represents the overall model to calculate residual. The model includes the normal and fault stage during the 25% valve opening. Two different models are developed to compare the 50% and 75% valve opening. Figure 10 shows the temperature of the reactor during the 25% valve opening. The graph shows a sharp increase in the early stage to indicate the model is beginning to start and follow up by declination of temperature as the valve opened. With such small valve opening the model were not able to obtain a steady result and began to show a steady increase of temperature.





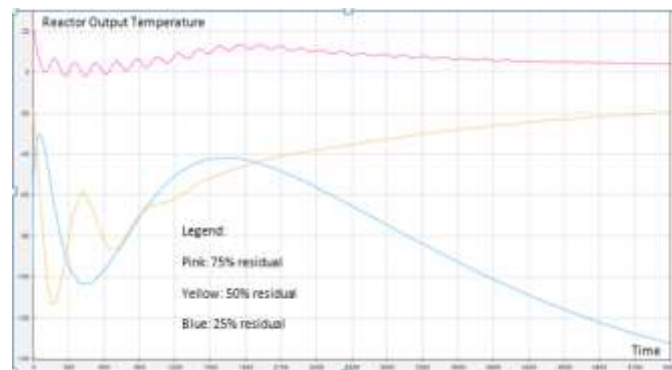
**Figure 9. Overall system outlook to calculating residual for 25% opening.**



**Figure 10 Reactor temperature for 25% valve opening**

The output residual for the temperature of the reactor for different valve opening is shown in Figure 11. Between the three different valves opening, the 25% valve opening shows the highest residual difference in comparison to the normal opening. The residual can achieve up to 130 residual difference. Meanwhile, for 75% valve

opening the residual value are high at the beginning of the process but able to reduce below 10 residual value in the end. This leads to a lower residual point when compared to another model.



**Figure 11. Residual output temperature of the reactor**

The system for the fault of 75% the system is oscillatory from start till the end. But the error is small because the fault of 75% valve is the smallest in loss of flow. The residual for the other two flow restriction is huge. Although it can be seen the system oscillates at first then it stops after a certain period. After it stops oscillating for 25% flow the temperature is still increasing because the residual is going to more negative so the temperature for the 25% flow is still increasing and it is the highest and this fits the estimated scenario. This is due to when there is less water going to the reactor to cool it down the reactor temperature will be higher. For 50% valve opening the reactor stabilizes at -20 this is a big error to be considered as well. 50% flow restriction is the middle-class fault, but the effect is still significant for the plant reactor.

## 5. Conclusion

The modelling for the normal operation of the model is done successfully. The validation is done by having the equation with highest fit with (85.52%, 94.89%) for heat exchanger subsystem and 92.19% fit for reactor subsystem. Having low Mean Square Error (MSE) is another criterion that is observed for validating the model. The model had low MSE which is 0.01709 for heat exchanger subsystem and 0.1567 for reactor subsystem. Another method of validation is done by using the transfer function in SIMULINK to model the reactor and if the result obtained is the same as the normal operating condition of the plant then the modelling is successful. Then the specification that is used for modelling the normal operation of the plant is used to model the fault operation data. Fault operation is focused on flow factor and it is controlled by the valve opening. The residual is obtained by subtracting the output of normal condition model with fault condition model. The Residual for 25% valve opening and 50 % valve opening is large.

The residual for 75% valve opening is smaller compared to the other fault. This is because the system output seems to oscillate, and it takes too long a time to reach a larger value for its temperature parameter. This project is up until finding the residual pattern for flow parameter only. With obtaining the fault pattern it can

improve performance and efficiency for maintenance purposes as it help reduce work to analyse the fault of the reactor.

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