# Model Based Sensor Parameter Estimation and Smart Calibration Scheme

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**Abstract:** For online estimation of calibration related sensor parameters, a composite model is proposed by considering a cascade of the plant and sensor as one system. Online parameter estimation is carried out by comparing the system response with the response of an estimated parameter model of the system. The difference between these outputs is minimized by adjusting the estimated parameters according to adaptive laws. If the actual values of the sensor calibration parameters drift with time, it will be tracked by the estimator and notified to the operator if it exceeds some preset bounds.
**Keyword:** Sensor Ageing, Adaptive Parameter Estimation, Smart Calibration

## 1 Introduction

Nuclear Power plants (NPPs) follow special safety standard building code to ensure its two key factors; safety and reliability. Today's modern era revolves around energy, it being the need of the hour. Hence the demand of nuclear power plants is ever increasing with a tradeoff between cost effectiveness and capacity-factor. In order to ensure availability, comprehensive preventive measures are required.

Failure is considered as a permanent disruption of a system's capability to execute a desired purpose with meticulous requirements. Different types of faults and failures can occur in instrument, equipment and process of NPP, which can have a significant effect on plant's performance [1][2]. For example drift in the steam Generator feed water flow sensor can result in the reduction of output reactor power by 3 % [3]. Over time the steady state enactment of an instrument can be degraded in NPP, ensuing in consequences such as drift and bias [4]. The current practice to overcome these issues is to periodically calibrate the instruments in NPPs. This often requires a system shutdown or takes the instrument out of service. However, operational experience shows that less than 5% of manual calibration is even necessary[5].Staff workload, radiation exposure and plant outage time increase due to the unnecessary calibrations. Moreover, manual intervention might have an adverse effect on the reliability of the instrument.

All sensors "age" and their response naturally changes over time. Sensor is only one component in the measurement system, all the other components which are associated with it in the measurement system are also subjected to the variability due to sensor ageing. The current practice to overcome the sensor ageing is to periodically re-calibrate the sensor. In spite of periodic calibration, it is necessary to adopt online methods of sensor health monitoring while the plant is in operation. Signal processing, fault detection schemes and parameter estimation could be employed for this purpose; however, an estimation of the parameters of the faulty sensor would be a much more useful metric for the operations and maintenance personnel. A key component in re-calibration is the accurate estimation of a sensor's output. Steady state performance of the sensor can be validated by comparing its actual output with the reference.

The work on the modeling and the identification of pressurizer of a VVER NPP has been carried out by different researchers for the purpose of controller design [6] simulation on pressurizer pressure systems [7]. In order to carry out model based parameter estimation of sensor, the model of pressurizer at the PAKS Nuclear Power Plant has been taken. The model is validated by simulating the mathematical model [8] deduced in this paper and the results are shown in Fig.1.

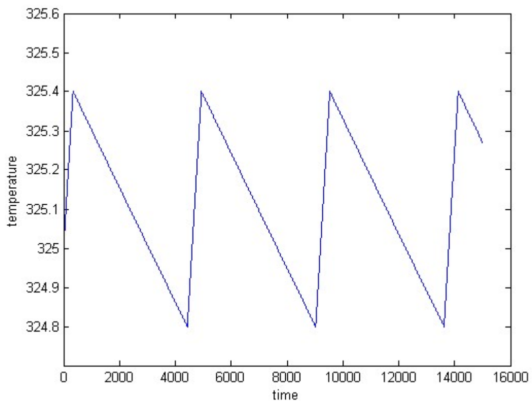


**Fig.1: Measured output of the system**

The mathematical model of the pressurizer is combined with the sensor model to make a composite model as shown in Fig.2. Input to this composite model is actuation of heaters, "Q" present at the bottom of the pressurizer and the output "$\boldsymbol{y}$" is the measured temperature from the temperature sensor. This "$\boldsymbol{y}$" and "Q" is input to the estimator as well, which estimates the output and required parameters.

This paper is organized as follows. Methodology of the proposed technique is discussed in section 2. Results and simulations are described in section 3 and conclusion is included in section 4. Nomenclature and References are mentioned at the end.

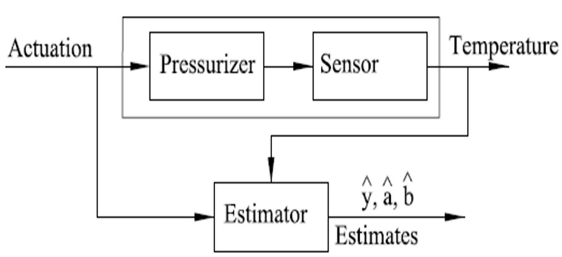


**Fig.2: Block Diagram of Proposed Strategy**

## 2 Methodology

In a PWR the pressure is maintained by a pressurizer which is a large vessel containing liquid water and steam. The regulation of the pressure is carried out by heaters and sprays which affect the temperature and thus the water level and pressure of the vessel. Therefore, the variable of interest is the temperature which is governed by the differential equations of the energy of the dynamical pressurizer system. The inlet water temperature and heater power are the enthalpy inputs to the system while the outlet temperature and wall heat loss are considered as the outputs. According to [8] the following differential equations represent the pressurizer.

$$\dot{U} = c_P m T_I - c_P m T + K_W (T_W - T) + Q \qquad (1)$$

$$\dot{U}_W = K_W (T_W - T) - W_{loss} \qquad (2)$$

$$U = c_P M T \qquad (3)$$

$$U_W = C_{PW} T_W \qquad (4)$$

Thus, the average temperature, in Laplace transform domain, can be written as the output of a system which has the energy of the heaters as its input.

$$T = \frac{Q(K_W - sC_{PW}) + c_P m T_I (K_W - sC_{PW}) + K_W W_{loss}}{s^2 c_P m C_{PW} - s(K_W c_P m - c_P m C_{PW} - K_W C_{PW}) - c_P m K_W} \qquad (5)$$

The sensor required to measure this temperature can be modeled as a first order system as follows.

$$\dot{y} = -ay + bT \qquad (6)$$

It is observed that the parameters of this sensor might vary with time due to wear and tear and exposure to unfavorable environments. This process is known as sensor aging and is a problem found in a variety of sensors across industries. The standard practice to handle this is to perform periodic calibrations. Instead of that, an online method is proposed here which aims to determine sensor parameters and evaluate its performance while the sensor is in operation. An adaptive online parameter estimation approach is applied here for this purpose.

The first order system in equation (6) can be rewritten as

$$y = \frac{1}{s + a_m}(a_m - a)y + bT \qquad (7)$$

Where $a_m > 0$ is an arbitrary constant value that can be chosen to obtain desirable transient behavior in the adaptation of the estimated variables.

The estimated output of the sensor, $\hat{y}$, may be written as:

$$\hat{y} = \frac{1}{s+a_m}(a_m - \hat{a})y + \hat{b}\hat{T} \tag{8}$$

$\hat{a}$ and $\hat{b}$ are estimates of $a$ and $b$ respectively and $\hat{T}$ may be calculated from the equation (5), as all the variables for that purpose are known.

For the adaptive laws the error is calculated as

$$e_1 = y - \hat{y} \tag{9}$$

The adaptive laws to calculate the rate of change of the estimated parameters are given as[9]:

$$\dot{\hat{a}} = -e_1 y \gamma_1, \dot{\hat{b}} = e_1 T \gamma_2 \tag{10}$$

Where $\gamma_1$, $\gamma_2 > 0$ are constant gains that can be adjusted to affect the rate of adaptation.

## 3 Results and Simulations

The pressurizer and sensor differential equations were implemented in MATLAB along with the adaptive estimator. To simulate the sensor drift, the parameters $\boldsymbol{a}$ and $\boldsymbol{b}$ started with correct values and were slightly changed at different times. The adaptive system successfully tracked these changes and minimized $\boldsymbol{e_1}$ as shown in Fig.2.Thus, the system may notify the operator when the parameters have drifted beyond a specified threshold.

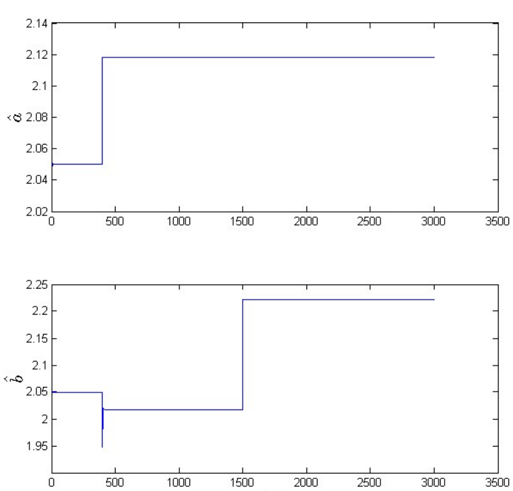


**Fig 3: The Estimated Parameters $\hat{a}$ and $\hat{b}$**

In Fig. 4 the faults can be observed at two distinct times when the sensor output suddenly changes. The estimated output in Fig. 5 closely mirrors the output of the faulty sensor showing the effectiveness of the estimation technique.

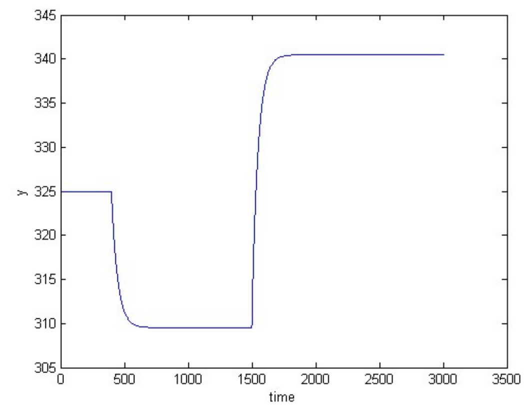


**Fig.4: Output of the Faulty Sensor**

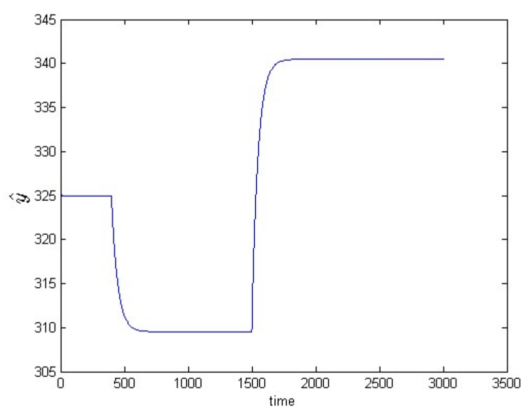


**Fig.5: Estimated Output of the Faulty Sensor**

## 4 Conclusion

In order to avoid the plant shutdown due to calibration related faults in sensors, a composite model of sensor and pressurizer is derived and simulated for online estimation of calibration related sensor parameters. The simulation results show that if the parameters of the sensor will be faulty it will be accurately estimated by the estimator, using adaptive laws, mentioned in the methodology of proposed technique. This will help the operator to take prompt action whenever the parameters of sensor will go out of bound and will increase the capacity factor of plant.

## Nomenclature

All the terminologies used in this paper are presented in Table1

**Table 1: Important Terminologies**

| | |
|---|---|
| $T_I$ | Inlet Water temperature |
| $T$ | Water temperature |
| $T_W$ | Tank wall temperature |
| $m$ | Mass flow rate of water |
| $M$ | Mass of water |
| $c_P$ | Specific heat of water |
| $K_W$ | Wall heat transfer coefficient |
| $Q$ | Power of electric heater |
| $W_{loss}$ | Heat loss of the system |
| $C_{PW}$ | Heat capacity of wall |
| $U$ | Internal energy of water |
| $U_W$ | Internal energy of wall |
| **NPP** | Nuclear Power plant |

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