

Process data validation in CCGT and nuclear power plants

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ABSTRACT

Process data validation is employed for monitoring and optimising processes in nuclear power plants, combined-cycle gas turbine power plants, coal-fired power plants, refuse incineration plants and gas power pools, as well as in the chemical and petrochemical industries. It is a method for determining a consistent process image, taking closed mass, energy and materials balances into account. It takes the place of:

- Cost-intensive acceptance and inspection measurements,
- Part of the instrumentation within the processes.

If it is installed online, it supplies a continuous stream of results, allowing impermissible developments during operation or in the plant to be quantitatively estimated. Data validation also yields information about operating states in non-instrumented or insufficiently instrumented parts of the plant. If data validation is integrated in the installation early on during the project planning phase, it is possible to reduce the number of measuring points compared with that considered necessary in the past. Since the saving per measuring point is approximately 15,000 EURO, this can represent a substantial reduction in the cost for investments in the plant. Depending on the type and size of the plant, as much as 125,000 EURO can be saved additionally every year because fewer key measuring points need to be calibrated.

This work describes experience with online process data validation in CCGT and nuclear power plants (boiling water and pressurised water reactors).

INTRODUCTION

Process data validation is a method for determining a consistent process image of data records containing mean measured values, taking closed mass, energy and materials balances into account. The method is based on a procedure for identifying the most probable process state in the mathematical-statistical sense. It is described in VDI 2048 [1].

When it comes to mapping a real process, this means that all available measured quantities, in other words including all redundant measured quantities, are combined in a single plant diagram. The overdetermined system of equations that results is solved using the Gaussian calculus of observations. The "true" values calculated with a probability greater than 95 % reflect the most likely physical state of the process. This method is particularly effective in connection with process monitoring and optimisation [2], [3], [4].

This work describes experience with online process data validation in:

- CCGT power plants, and
- Nuclear power plants (boiling water and pressurised water reactors)

The improvements in operating management efficiency and the potential calibration economies which are facilitated by online validation are quantified.

THEORETICAL BASIS

The theoretical basis of data validation is explained with the aid of an example. **Figure 1** shows a SPLITTER into which one mass flow enters and from which two mass flows exit. A mass flow rate of 500 t/h is measured for stream 1, while the value for stream 2 is 245 t/h and that for stream 3 is 250 t/h. The following condition must be fulfilled:

$$m_{\text{stream 1}} = m_{\text{stream 2}} + m_{\text{stream 3}} \quad (1)$$

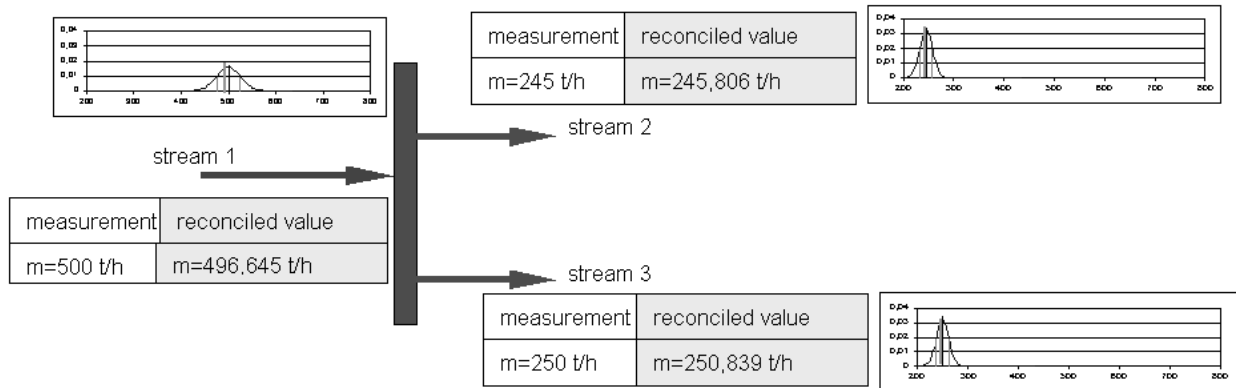


Fig. 1: Example

Each of the measured values is assigned a permissible standard deviation equivalent to 5 % (of the measured value), resulting in the Gaussian normal distribution shown in Figure 1 being allocated to each measurement. The simply overdetermined system is then solved by means of a calculus of observations taking a minimisation criteria into account.

The minimisation criteria (PENALTY function) is as follows:

$$\sum \left(\frac{\text{measurement} - \text{reconciled value}}{\text{standard deviation}} \right)^2 = \text{minimum} \quad (2)$$

A PENALTY-value of 0.0256 is calculated for this example. The results of the calculus of observations are also presented in Figure 1. The validated (reconciled) values now satisfy Eq. 1 (mass balance closed).

USE IN NUCLEAR POWER PLANTS

Process data validation with VALI III [5] is used in nuclear power plants in order to:

- Perform acceptance measurements
- Trace start-up activities in the plants
- Determine the mean coolant temperature more accurately
- Determine the thermal reactor output more accurately
- Use the validation results as a calibration standard
- Reduce the cost of calibrating measuring points

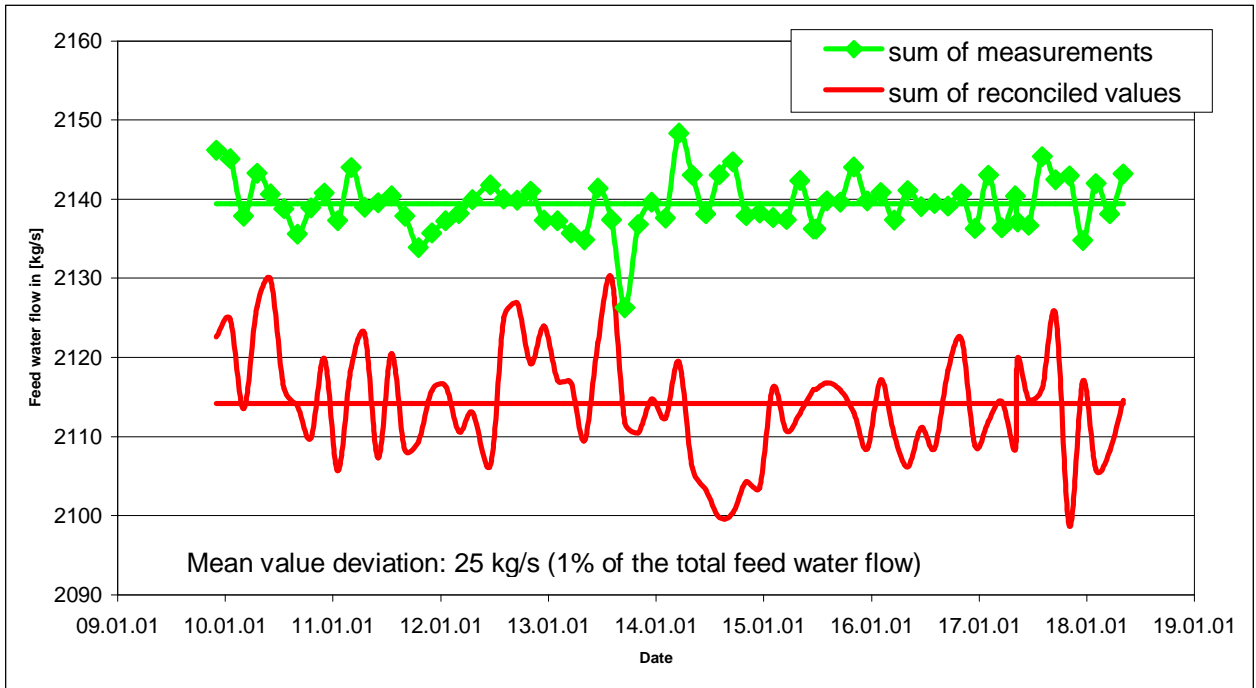


Fig. 4: Total feed water mass flow of the steam generator

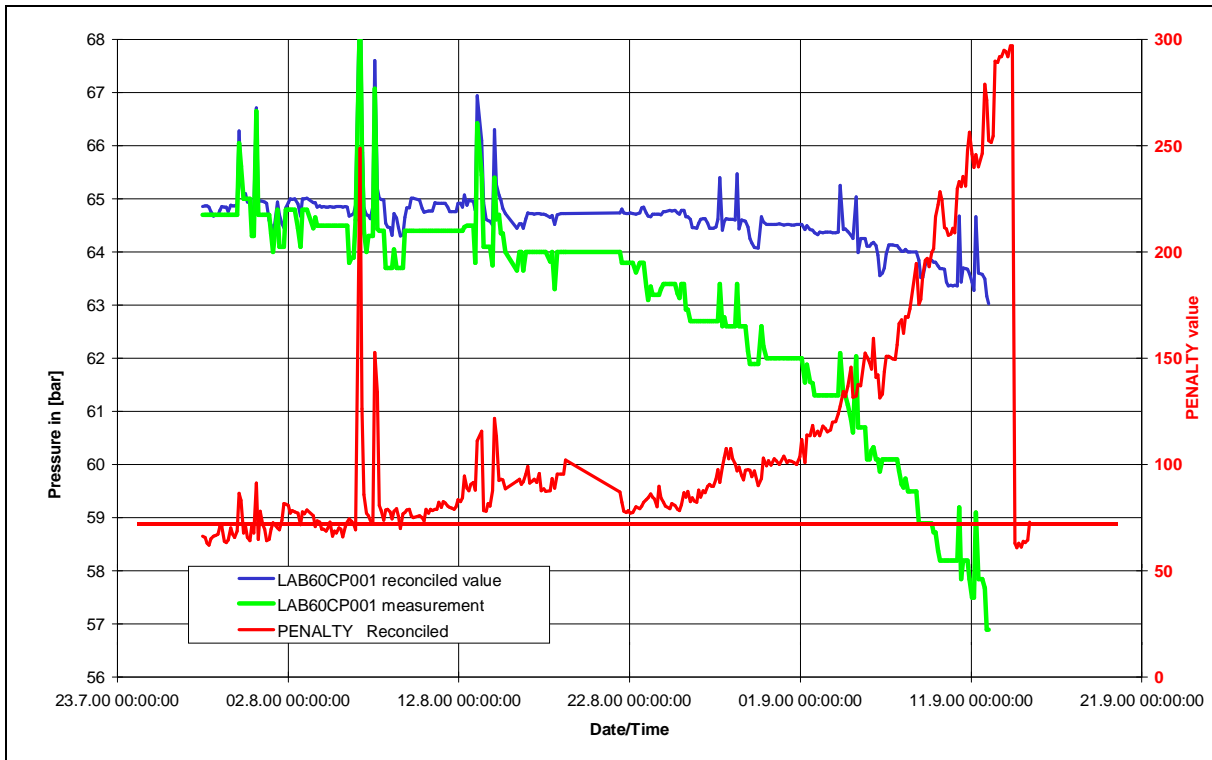


Fig. 5: Drifting measuring point

Figure 4 compares the feed water mass flow of the four steam generators with the reconciled values. The deviation between the measured feed water mass flow and the reconciled mass flow is 25 kg/s, equivalent to 1 % of the total mass flow (accuracy range of the measuring devices). The aim is to use the reconciled values as a calibration standard and to calibrate the measuring devices such that the measured values correspond to the reconciled values. Since the feed water mass flow measurement is relevant to the safety of the plant, the approval of the independent expert is required. This procedure has already been completed, i.e. the results of the validation can be used as a calibration standard. In the example described here, the electrical output is increased by 13 MW_{el}.

Figure 5 confirms how the feed water pressure measurement drifts upstream of one steam generator. The same graph also shows the PENALTY-function over the drift period. The PENALTY-function is the sum of all deviations of the model as a whole according to Eq. 2. During operation under 100 % load, the PENALTY-value for this nuclear power plant is 70. The measuring point drift causes the PENALTY-value to rise to 300. This is indicated by the system directly by means of a reference to the faulty measuring point that caused this increase. Data validation is thus an extremely effective instrument for monitoring processes, since it enables state-oriented calibration of measuring points. State-oriented calibration allows a nuclear power plant to economise 125,000 EURO per year. The investment costs for a data validation system are hence recuperated within just twelve months.

USE IN CCGT POWER PLANTS

The aim of data validation in **combined-cycle gas turbine power plants** is to:

- Perform acceptance tests much more precisely than is possible using conventional acceptance test methods
- Obtain closed mass and energy balances (important when supplying district heat)
- Monitor the process more efficiently
- Obtain more detailed information about the gas turbine
- Identify potential problems in the combustion chambers at an early stage
- Monitor wholesale purchases of natural gas and the heating energy billed by the supplier
- Reduce the cost of calibrating measuring points

Figure 6 shows a gas turbine on the VALI user interface.

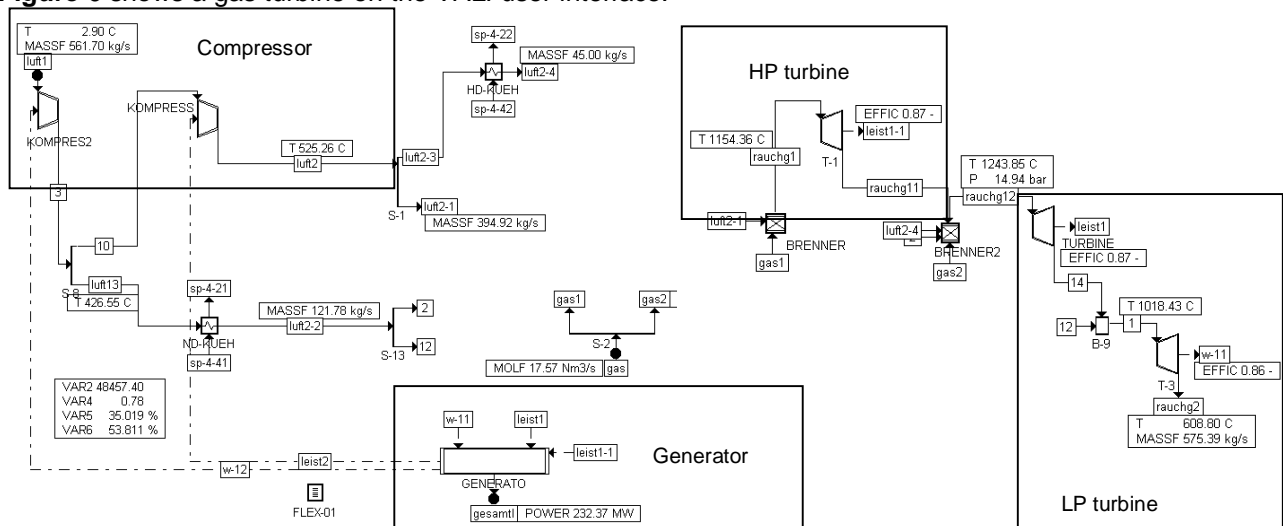


Fig. 6: Model of a gas turbine

A more detailed comparison of acceptance tests with and without data validation can be found in [6]. **Table 1** shows the considerable differences that exist between a conventional acceptance test and an acceptance test with data validation.

Table 1: Comparison of the results of a conventional acceptance test and an acceptance test with data validation

Description	Conventional acceptance test		Acceptance test with data validation	
	Value	Tolerance	Value	Tolerance
Guaranteed net electrical output	366.7 MW		366.7 MW	
Measured net electrical output	367 MW	+/- 0.929 MW	366.98 MW	+/- 0.573 MW
Guaranteed net heat consumption	6211.7 kJ/kWh		6211.7 kJ/kWh	
Measured net heat consumption	6195.4 kJ/kWh	+/- 146.5 kJ/kWh	6196.4 kJ/kWh	+/- 16.6 kJ/kWh

If only those measured quantities that are directly needed to calculate the end result are taken into account, the prospective additional consumption of heat amounts to 146.5 KJ/kWh. This represents an average annual financial loss to the customer of 1,648,250 EURO.

If a larger number of measured quantities over and above those directly needed for the calculation are used in conjunction with data validation, the number of uncertainties in the end results is significantly reduced. The prospective additional consumption of heat amounts instead to 16.6 kJ/kWh, equivalent to an annual financial loss to the customer of 186,700 EURO. The maximum value of 200,000 EURO laid down in the contract is thus adhered to.

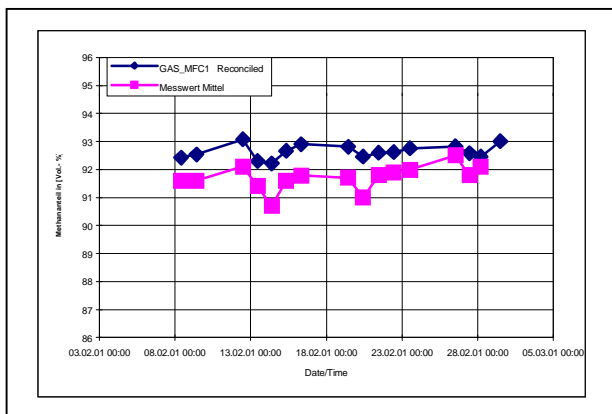


Fig. 7: Methane component analysed and reconciled

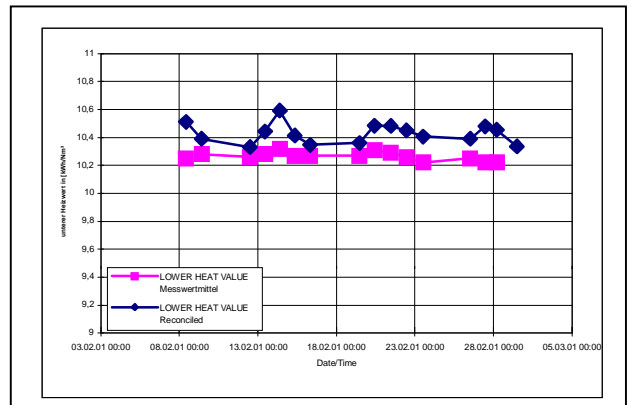


Fig. 8: Lower heating value analysed and reconciled

Figure 7 shows the analysed and reconciled methane components of the gas. **Figure 8** compares the lower heating value based on analysed values with the reconciled lower heating value. These values cannot be traced ONLINE without a validation because the results of the analysis are never available simultaneously.

Figure 9 shows the measured and reconciled main steam temperatures. The maximum measured temperature is up to 5 K higher than the reconciled temperature. This means that the plant is not being operated with its maximum efficiency. Reconciled data is required in order to establish this, however.

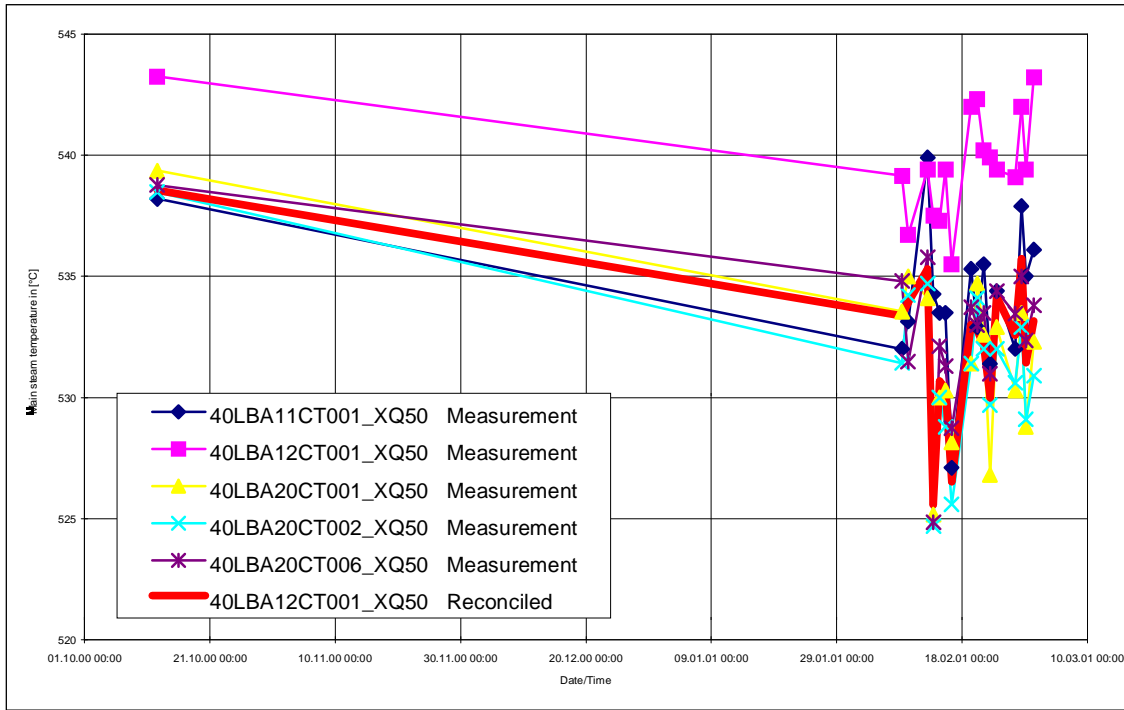


Fig. 9: Graph of the measured and reconciled main steam temperatures

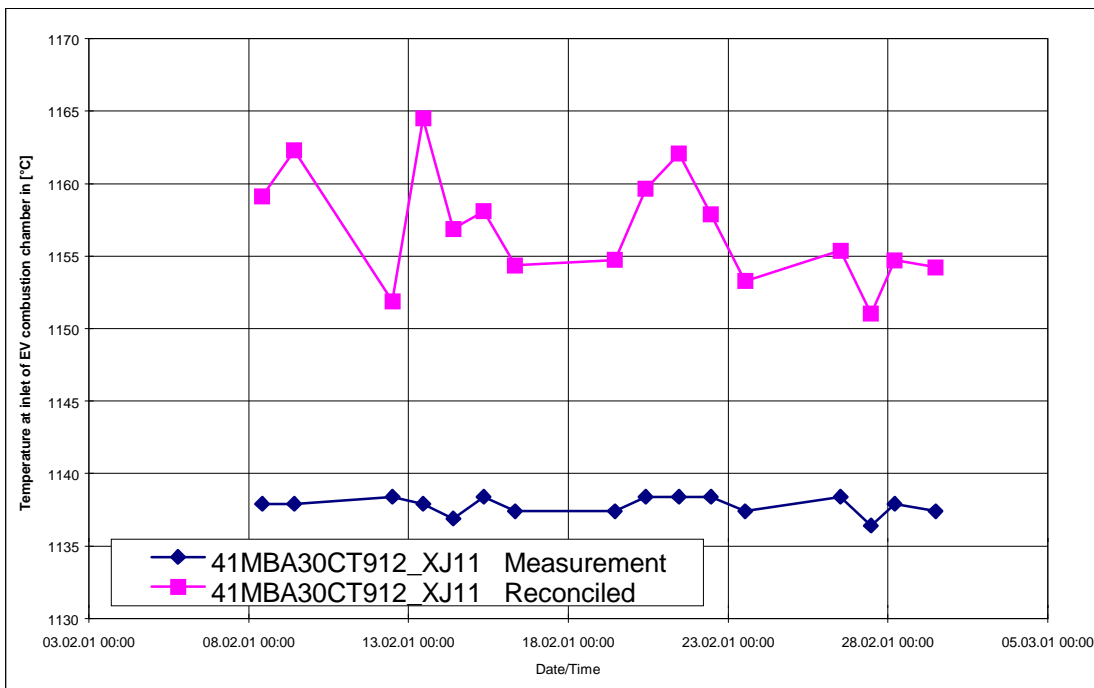


Fig. 10: Measured and reconciled EV combustion chamber temperatures

Figure 10 shows the measured and reconciled EV combustion chamber temperatures. The measured value is approximately 20 K lower than the reconciled value, corresponding to a 2 % deviation.

CONCLUSIONS

Process optimisation is only possible at all if detailed information about the complete set of process values is available. Particularly in the case of large power plants (nuclear: 1300 MW, CCGT: 500 MW), measured values inside the permissible ranges may result in considerable financial losses. Failure to exploit the full thermal reactor output over a period of several decades in the order of 40 MW_{th} can mean a loss of several hundred million euros in today's terms. Similar losses are likely to be incurred by a CCGT power plant if the operating regime is not optimised.

For this reason, all plant owners are urgently advised to implement continuous data validation in their process monitoring concept.

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