Highest Possible Reliability for Power Recovery in Nuclear Power Plants with Process Data Reconciliation According to VDI2048

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1. Abstract

The power output of a nuclear power plant can deviate from licensed level due to a variety of reasons – measurement errors, inner and outer leakages, component degradation (e.g. condenser), etc. The incurred "lost" MW cause substantial financial losses over time of up to $25 million. In order to minimize these costs and improve plant safety at the same time, a monitoring system is required to promptly indicate and localize the root cause in the plant process with high reliability. The state of the art monitoring tool, as recommended by EPRI [1], is process data reconciliation (PDR) according to the German guideline VDI 2048 [2,3].

PDR – as opposed to process simulation – considers all available (especially redundant) process information in a thermodynamic model and addresses uncertainties to each information/measurement. Under fulfilment of all boundary conditions (closed mass, energy and material balances), PDR calculates the most likely state of the process.

The quality of the model is measured by global and local criteria described in the VDI 2048 guideline. After these criteria are met after rigorous fine-tuning, the results are resilient and represent the "true" state of the process with the lowest available overall uncertainty.

PDR is the only methodology world-wide which is approved to be used for correction of input measurements in the thermal core power calculation, e.g. feedwater flow and temperature.

In general, the online PDR system can be used:

- as a basis for correction of feed water mass flow and feed water temperature measurements (recovery of lost MW).
- as a basis for correction of $T_{average}$ (T_{av}) (recovery of steam generator outlet pressure in PWRs).
- for maintaining the thermal core power and the feed water mass flow under continuous operation conditions.
- for automatic detection of erroneous measurements and measurement drift.
- for detection of inner leakages, non-condensable gases and system losses.
- for calculating non measured values (e.g. heat transfer coefficients, ΔT, preheater loads,…).
- as a monitoring system for the main thermodynamic process.
- for verifying warranty tests more accurate.
- as an application of condition-based maintenance and component monitoring.
- for What-if scenarios (simulation, not PDR)

This paper describes the methodology according to VDI 2048 (use of Gaussian correction principle and quality criteria). The benefits gained from the use of the online monitoring system are demonstrated.

2. Principle of Process Data Reconciliation Based on VDI 2048

2.1. Theoretical background

All measured values are subject to distortions caused by avoidable, systematic or random errors. For more than 200 years the Gaussian correction principle that is complemented by taking boundary conditions into account has been available as an estimation method in the statistical-mathematical sense that allows these measurement errors to be detected.

The basic idea of this method is to use not only the minimum quantity of measured variables required to obtain a solution but to record all accessible measured variables along with the respective variances and covariances. Additionally the true values of the measured variables must meet the boundary conditions:

- mass balances,
- energy balances and

- material balances (stoichiometric laws).

This method is described in VDI 2048 [2, 3] and is the best possible quality control method available to detect serious measurement errors. This methodology allows consistent estimations of the true values of the measured variables to be derived from conflicting measured values. The consistent estimated values thus obtained correspond to the true values with a 95% probability.

2.2. Consequences for the Nuclear Power Plant process

When process data reconciliation based on VDI 2048 is applied to the Primary and Secondary processes of a nuclear plant, the measured temperatures, mass flows and pressures lose their singular character. The physical relationships between the measured parameters generated via secondary conditions such as mass balance and energy balance result in a process image that corresponds to the physical basis of the process as closely as possible. The relationships thus generated can be represented via the correlation coefficients that result

3. Benefits for Nuclear Power Plants

The *online* PDR system is used in over 42 nuclear power plants units:

- as a basis for correction of feed water mass flow and feed water temperature measurements (recovery of lost Megawatts [4])
- as a basis for correction of Taverage (Tav), see **Figure 1** (recovery of steam generator outlet pressure in PWRs).

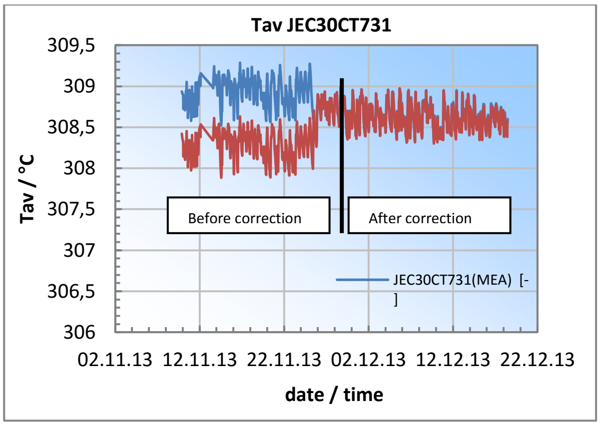

Figure 1: Correction of Tav in a NPP

The benefits for thermal performance engineers, plant operators and plant management are derived from early stage differentiation and detection of:

- erroneous measurements
- measurement drifts
- inner leakages of preheaters
- non-condensables
- condenser leakages
- condenser fouling

These are all events which have influence on power recovery, reactor thermal power calculation, safety, availability, reliability and performance of the plant.

3.1. Power Recovery

The accurate determination of feed water mass flow based on the reconciled values allows the application of correction factors to the instrument readings. These corrected values represent the most accurate values and result in recovery of "lost" megawatts, see **Figure 2**.

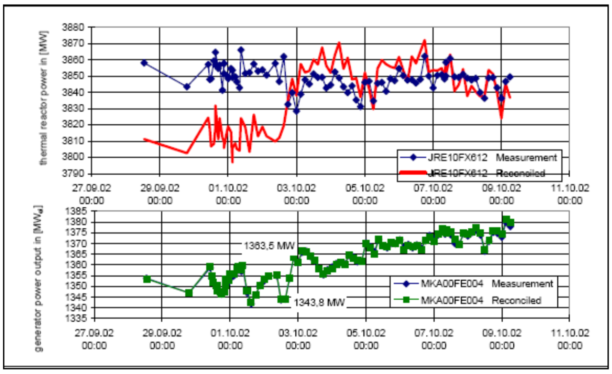

Figure 2: Introduction of reconciled correction factors

3.2. Reactor Thermal Power Calculation

The lower uncertainty of the reconciled values results in a lower uncertainty of the parameter used in the reactor thermal power calculation. With the appropriate licensing permissions a plant can take advantage of this reduced uncertainty to operate at reduced margin and uprated power, or measurement uncertainty recapture (MUR), see **Figure 3**.

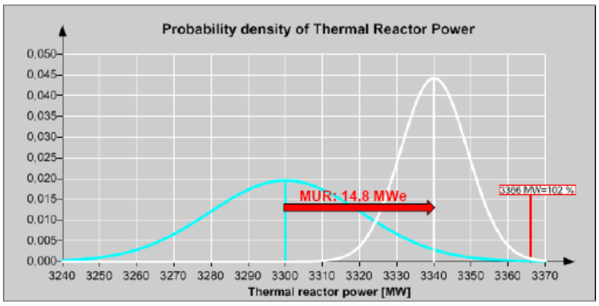

Figure 3: Realization of MUR potential with PDR

3.3. Safety

In the case of a feed water mass flow measurement drift on an erroneous measurement which has influence on the thermal reactor power calculation, the online system serves as a tool that detects a possible overpower event at a very early stage. In addition, the detection of non-condensables in boiling water reactors is also a safety related motivation for using this system. In the past, *the online system* has detected non-condensables in low pressure preheaters and in moisture separator reheaters (MSR). In this case, the MSR was taken out of operation.

3.4. Availability, reliability and performance

Inner leakages of preheaters, condenser leakages or condenser fouling lead to a decrease in plant reliability. For example, an inner leakage of a MSR was detected. The results of one reconciliation run (01/29/2007, 6 AM) without modelling an inner leakage in one MSR is shown in **Figure 4**.

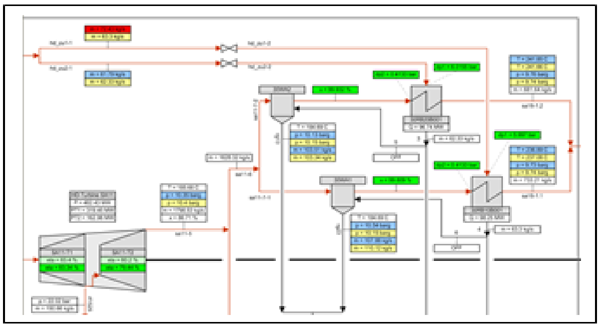

Figure 4: Results with basis model (01/29/2007)

The red highlighted value shows a suspected tag. The analysis of the thermal performance engineer shows, that the suspected tag is not triggered by an erroneous measurement. The reason must be an inner leakage of a MSR. In **Figure 5**, the results of the same measurement file from (01/29/2007, 6 AM) are shown with taking into account the inner leakage.

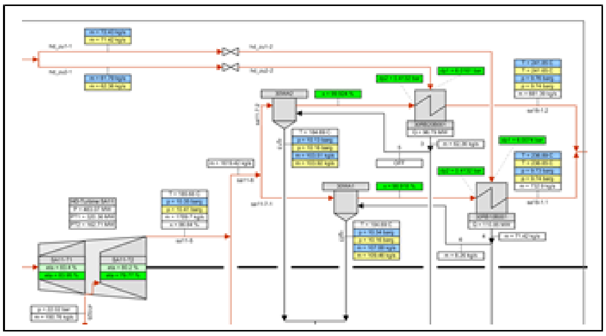

Figure 5: Results with modelled inner leakage (01/29/2007)

In the following outage the inner leakage was found and repaired. After start up, the performance of the MSR was considerably improved, see **Figure 6**. The preheating temperature after MSR1 increased from 236.9°C to 239.7°C. This led to an improved performance of the entire process.

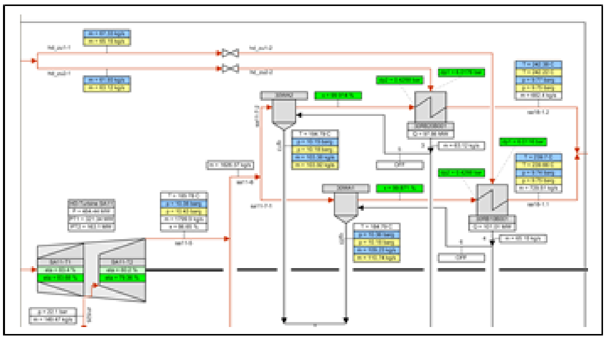

Figure 6: Results with basis model (12/01/2007, 12 AM))

4. Heat flow diagram

The heat flow diagram shows important thermodynamic values such as enthalpy or vapor fraction in detail. All of the values are based on reconciled process data which fulfill the mass and energy balance over the entire process. This information is displayed and can be automatically printed every hour.

5. Conclusion

Reconciled measurements based on VDI 2048 fulfill the mass, energy and material balances. Hence a more precise image of the process is available. This monitoring application facilitates early indication of process degradations and erroneous measurements (especially important for control variables). The improved accuracy of the reconciled values leads to a more accurate reactor thermal power calculation, resulting in realization of possible power recovery potentials and MUR.

References

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