THERMAL DIAGNOSTICS IN POWER PLANTS TO IMPROVE PERFORMANCE

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1. INTRODUCTION

From planning through operation, the global power industry is poised for tremendous growth and expansion over the next few years. Demand is surpassing capacity, forcing the construction of hundreds of new plants as well as dramatic *renovations* and expansion *of current facilities*. Industry sources estimate that global demand for electricity alone will require more than 1,700 gigawatts of new and replacement generating capacity over the next 20 years." IJPGC 1995 Minneapolis

All over the world there is a huge amount of power plants in the 150 to 600 MW range that have already been in operation for more than 25 years. Some of these units have already reached their "theoretical" life time and are still in quite good shape and therefore there is no need to tear them down or replace them. Sometimes there are good reasons not replace the units completely, but to replace components to improve performance and to get a few years of additional life time. Some of these reasons are :

- inancial (only smaller investments are feasible)
- licensing (at the present location a completely new unit would not be licensed)
- political (the planing of new units face a strong opposition by action groups)
- environmental (for new units the environmental requirements are extreme high)
- technical (material problems e.g. cracks in LP-rotors)
- etc.

When considering an improvement of an old unit, a detailed knowledge of the actual performance of the whole unit and its components (systems) is essential. Only this knowledge enables the planning engineer to find the best technical and commercial solution for an improvement. The return of investment can only be determined when the improvement in performance can be calculated with sufficient accuracy. The necessary tests and calculations need quite some experience and sophisticated calculation programs. Testing units with the existing plant instrumentation gives results that bear a large uncertainty and include a high risk to lead to the wrong decisions for improvements.

In the following the ABB. approach for the improvement of performance of old power plants is discussed under the special aspect of testing and the test equipment that is needed to get the necessary information.

2. DIAGNOSIS TESTING

2.1. Preparations for Thermal Testing

Before planning any testing to get data on the performance of the unit and its major components, the already available information has to be studied thoroughly. This information are the design data of the plant, results of former performance and routine tests and all other information that exists on the units.

The thorough study of these documents can save a lot of time, trouble and delay in the actions that are following.

The next step is an extensive inspection of the plant in respect of the available test connections. This takes normally at least two or three days and should be done together with experienced plant personnel. During this inspection the tightness of the water/steam cycle and the condenser has to be tested to detect obvious deficiencies that have to be fixed prior to any performance testing.

When planning the extend of a diagnosis test the following should be taken into consideration :

- are the existing thermowells-wells and pressure taps sufficient
- are the installed flow elements acceptable in respect of the desired accuracy
- is the installation of any additional test connections or flow devices necessary
- are the cycle losses in an acceptable range
- are internal leakage's detected
- are any deficiencies known that can be fixed prior to the testing
- what has to be done during an possible upcoming outage
- are there any restriction for testing due to operational or technical reasons
- how much personnel is needed
- what test equipment is needed
- how much money can be spend for testing

2.2. Conduction of Tests

A full diagnosis test on a fossil or nuclear unit is basically an expanded heat rate test. When conducting a heat rate test to proof the power output and heat rate of a unit, the main interest is laid on the values that determine the heat rate and power output directly and in the respect of applying the correction curves. For an fossil unit these values are :

- feed-water flow
- superheater- and reheater spray water flow
- final feed-water temperature
- main steam pressure and temperature
- hot and cold reheat pressure and temperature
- low pressure turbine exhaust pressure or
- cooling water inlet temperature (when the condenser is part of the contract)
- generator output
- power factor

for a nuclear unit this is even reduced to :

- feed-water flow
- final feed-water temperature
- main steam pressure and temperature
- low pressure turbine exhaust pressure or
- cooling water inlet temperature

- generator output
- power factor

The rest of the measurements is used to :

- check the measurement for plausibility
- check the operation of the single components (especially heaters and condenser)
- give feedback to the design department

For a full diagnosis test the possibility to calculate the efficiency / performance of all single components of the power plant is essential. Therefore all measuring points have to be equipped with high accuracy instruments to get the most accurate information. The more accurate the single values are, the better the single components and the overall performance can be calculated.

Only a high accuracy of the test values makes it possible to recalculate the turbine cycle with the design programs. These programs use iteration methods on the turbine expansion line and the extractions to the feed-water heaters. With inconsistent data from tests with poor accuracy these programs do not converge or delivery wrong results that can cause wrong conclusions on improvement activities.

2.3. Evaluation of Tests

The expanded heat rate test is usually evaluated with the standard methods using the original correction curves. The corrected heat rate and power output is compared with the design heat balance and if available with results from former heat rate or component tests.

This comparison gives usually already enough information to find the components that are performing poor and sometimes even no further investigations are necessary.

The single components of a power plant have to be evaluated in detail. For all these components the significant values are determined and compared with the design values. If the design values are not known, these measured values are compared with the present technical possible values. The significant values are for :

steam turbines

- efficiency of hp and ip turbines
- efficiency of lp turbines (has to be calculated by iteration due to the wet steam in the exhaust)
- turbine constants (swallowing capacity)

heat exchangers (feed-water heaters, feed-water tank)

- terminal temperature difference
- pressure drop in extraction lines
- pressure drop in heaters and pipe sections
- heat transfer coefficients
- sub-cooling
- wetness in extraction (nuclear)

condenser (main turbine, auxiliary turbine)

- steam, cooling water flow
- terminal temperature difference
- heat transfer coefficient
- sub-cooling

pumps (condensate, feed-water, heater drains, cooling water circulation)

- net positive suction heads of pumps
- enthalpy rises across pumps
- capacity of pumps
- power consumption of motor

moisture separators (reheat system)

- separation effectiveness
- separated water flow

flow elements (condensate, feed-water, fuel)

- flow coefficient
- accuracy

Remark : Care has to be taken when the test or design heat balance is calculated with an older version of the steam table. The present steam table (IFC formulation for industrial use) was introduced in 1967.

2.4. Additional Test Methods

In addition to the conventional methods used when testing nuclear or fossil units the use of non-standard test methods might be taken into consideration. The two methods briefly discussed below are methods to determine mass flows not by making use of any plant instrumentation like installed orifices or nozzles. These methods can be used when the mass flows determined with the installed flow device are questionable and/or this flow device cannot be inspected.

2.4.1 Tracer Testing

The tracer method is making use of either chemical or nuclear analyzing methods. The principle is to add a small flow with known concentration (tracer) to a large unknown flow (e.g. feed-water). After a sufficient mixture length samples are taken and analyzed. From concentration of the mixture the flow can be calculated. Depending on the test conditions (mixture length, flow ratio, etc.) an accuracy in the 0.5 % range is achievable. ABB uses both methods.

2.4.2 Ultrasonic Flow Measurement

Another method that can be used to measure mass flows in closed pipes is the ultrasonic method. This can be done without the installation of any equipment in the piping. Only the insulation has to removed. The accuracy of this method without special weld in sensors is about 2 %. With sensors that have to be welded into the existing pipe the accuracy can be increased to about 1 %. This is a very cost-effective method compared with the tracer method.

3. DATA ACQUISITION SYSTEMS FOR THERMAL TESTING

3.1. History

For the thermal testing of power plants ABB (BBC at that time), as well as some of its competitors, developed a computerized data acquisition system for the use especially in power plants (*UNI*versal *D*ata *A*cquisition *S*ystem). The reason to introduce such systems was the increasing cost of personnel and the wish to get more accurate data with "the press of a button".

The use of computerized systems for that purpose was started in the 1970's as soon as computers and computer controlled multiplexers and digital voltmeters (data acquisition systems) were sturdy enough to be used in the rough environment of a power plant. The first generation of these systems needed a complete trailer to store the computer and the rest of the data acquisition system. At that time the programs had to be developed individually. This was

the time of teletypes, punched cards and tapes and machine code programming. Due to the technology at that time all analog signals had to be wired to the trailer with the computer system. The temporary cabling system looked like a cobweb spreading all over the plant.
The "second generation" was based on smaller computer systems (DEC PDP11, HP1000 e.g.) and the data acquisition part of these systems were also smaller and could be placed outside the trailers in the plants. At that time the programs were written in BASIC and FORTRAN and the first professional programs were on the market.
With the upcoming of powerful personal computers (PCs based on the Intel 80386, 486, Pentium or comparable Motorola processors) and the progressive reduction of the size of data acquisition devices the volume of the necessary equipment as well as the necessary investments were drastically reduced. The price of a "simple screen with keyboard" of the second generation was as much as a 486D2 PC now a days. With the increasing market professional acquisition programs became an industrial standard.

3.2. ABB's UNIDAS II

After 13 years of operation of a system of the "second generation" even the best maintained system wears out and we had to look for a new system for our purposes. The experience with the former systems and a thorough study of the equipment available on the market let to the following philosophy for the UNIDAS II system that replaced our old system in 1994 :
Computer
- Standard "high performance" personal computer (80486 or better)
- no special interface for the standard application (RS232 standard)
- IEEE interface for special devices (power analyzer)

data acquisition (DA)
- 16 bit A/D conversion
- A/D conversion close to signal source (reduction potential disturbance)
- small DA units with high integrated intelligence (vs. "centralized system)
- up to 1000 test channels
- DA units connected via a "LAN" (RS 485)

data sampling rate in the 10 sec range for 400 channels
standard software must be available for the system
collected data must be portable to a standard "spread sheet program" (e.g. EXCEL)

3.3. Hard- and Software

The hardware consists of following components :

- Personal computers	notebook computers INTEL 80486 based
- docking station for the PCs	for special interfaces (IEEE)
- 8 / 16 channel DA modules	Measurement Systems datascan 7000 series
- pressure transmitters	Rosemount 3051 family
- differential pressure transmitters	Rosemount 3051 family
- RTDs for temperatures up to 600 °C	
- power analyzer	NORMA D5255
Data acquisition software	"from the shelf"
- Labtech Control	(V5.04)
Evaluation software	"home made" based on standard software

- EXCEL (V5.0)
- Steam Table (Add-in for MS-EXCEL)

3.4. Accuracy of the System

The accuracy of the overall system is determined on the following influences :
DA system
- accuracy of the A/D conversion
- temperature influence on the digital voltmeters and current sources
- long term stability

sensors
- accuracy of calibration
- long term stability
- temperature influence
- line pressure influence for differential pressure transducers

For pressure and differential pressure measurement ABB uses mainly standard industrial transducers that are specially taken care of. These pressure transmitters are calibrated in our own calibration laboratory with reference instruments that are traceable to the national standards and are only used for the purpose of guarantee and diagnosis testing. The differential pressure transducers are calibrated under the line pressure that is expected in the plant. If necessary (due to the applicable standards or contract) this calibrations can also be conducted on site.

The temperature sensors (ABB uses mostly RTDs) and the power analyzers as well as the DA system are calibrated at ABB central laboratory which has the status of a national accepted calibration lab.

Each transmitter and RTD or thermocouple has its own individual calibration formula in the computer system.

With the sensors, calibration system and calculation methods ABB is using, the following accuracy's of the measurements are expected :

- DA-system	0.03 %	
- pressure measurement	0.14 %	
- differential pressure measurement	0.14 %	
- temperature measurement	0.10 %	
- power measurement	0.10 %	(depending on the PT's and CT's)

This system is used for guarantee tests on steam turbines and whole fossil, nuclear and combined cycle units as well as for diagnostic test on this units. It has also been used and will be used in the future for prototype tests of ABB's gas turbines (GT11N2, GT13E2, GT24) with up to more than 800 test points (GT24).

3.5. Evaluation Programs

The data acquisition software stores all measured data as an ASCII-file on the computer disk. From there the data are transferred into a spreadsheet program where the basic statistics is done (averaging, standard deviation, minimum and maximum and fluctuations). These values have to be checked for obvious mistakes caused by the sensors and cabling system and to check the steady state operation of the unit.

The next step is the calculation of thermodynamic values (enthalpies, entropies, specific volume, saturation temperature etc.). From that state all the mass flows are calculated using the formulas according to the relevant standards (ISO, DIN, ASME etc.). Now the uncorrected heat rate and all the significant values of the single components are calculated. In the next step the correction curves are applied and this results in the corrected heat rate and power output that can be compared to former test results.

In an additional step the steam cycle and turbine design programs (ABB's HT005, HT452) can be used to recalculate the measured cycle. With these programs the influence of modifications to the cycle (e.g. replacement of a bad performing high pressure heater) can be calculated. These programs model the complete cycle including the geometry of the steam turbine. With this kind of program the water steam cycle is completely recalculated and all influences are taken care of. So the fact that an improvement on one side causes a deterioration on the other side should not happen. This gives also the possibility for a cost-benefit analysis based on the calculated heat rate improvement and the cost for material and labor for the replacement of components.

4. SUMMARY AND OUTLOOK

The improvement of older power plants by changing poor performing components is a cost effective method to increase the capacity of the units. The necessary information for the detection of components that are to be replaced can be obtained from heat rate and component tests with high accuracy instrumentation. The discussed methods and tools provided by ABB. were used with success in several power plants in Europe. These tools are in the process of permanent improvement and can be used in almost any type of power plant. We expect that due to the reasons discussed above, there is a high potential for improvement of a lot of power plants in the next decade.