EFFICIENCY AND ENVIRONMENTAL IMPROVEMENT PROGRAMME IN COMPOSTILLA POWER STATION

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Abstract

This paper presents the background, the developments and the results obtained to date with respect to the Performance Improvement Plan implemented by the Compostilla II Thermal Power Station (TPS) owned by Endesa. This power station has five pulverised coal generator sets which use coal with low volatile content and represent a total installed power of 1312 MWe.

The ultimate objective of the Programme is to increase the energy and economic performance of the power station, and at the same time to reduce the emission of contaminating substances, acting on the areas of greater potential for improvement; improvement in process monitoring, improvement of combustion conditions in the boiler, improvement of the turbine system and improvement in the operation of auxiliary systems.

The advances achieved in these areas include:

- The availability of determinations of fundamental parameters, such as mass coal flows to burners, mass air flow to furnace jets, local composition and temperature of gases in the burner flames and maps of the composition of gases and solid unburned substances at the exit from the boiler.
- On-line computer systems for quality assurance of coal analysis, quality assurance of plant measurements and calculation of specific consumption of the power station and the performance of the significant parts of the installation.
- Implementation in the boiler of non-conventional adjustments to combustion, achieving reductions of specific consumption of around 2%, and reductions of 30% in NOx emissions. Adjustments identified with the use of experimental programs rigorously designed to locate the optimum regulation of the combustion systems.
- The development of a computer system for advanced operational control, designed to display continuously to the operator the boiler adjustments necessary to achieve and maintain optimum performance and optimum NOx emissions.
- The execution of optimisation programs for the mills and the air feed system, with which reductions in energy consumption of 10% have already been achieved for the mills, with potential reductions in fan consumption of over 25%.
- The development of software and procedures for the optimum execution of turbine servicing, as well as the implementation of on-line turbine and cycle monitoring systems and the reduction of losses due to leaks and purges.

1. INTRODUCTION

The economic context of electricity generation of a thermal nature at present demands improved competitiveness. Given the cost of the fuel, which is from 50 to 70% of the total, one immediate way to achieve this is by increasing the energy efficiency of the installations.

With this scenario in mind, in 1995 the Performance Improvement Plan of the Compostilla TPS (Endesa) was begun. This Thermal Power Station has 5 thermal units (141, 141, 330, 350 and 350
MW). The fuel used is coal (anthracites and low volatile coals) from the Bierzo-Villablino basin, located in NW Spain.

1.1. General

The Sankey diagram of the Power Station shown in Fig. 1 shows energy loss produced in the transformation of chemical energy (from coal) into electrical energy in Compostilla during 1994. The net performance of 34.7% achieved indicates little by itself. Analysis must take into account certain limiting factors such as:

- Design values.
- Operating regime, including load regulation, stops, starts and associated transients.
- Degradation of equipment.
- Environmental restrictions, which almost always imply an increase in the heat rate.

Low design heat rates are of little use if the unit is not operated correctly. This requires means, motivation and criteria allowing centring and prioritisation of efforts to reduce controllable losses.

1.2. History

Concern over improving efficiency has always existed in Compostilla. However, initially, availability was the main priority. As unplanned unavailability was reduced from over 18% in the early 80s to the present values of less than 2%, more and more attention has been paid to performance. In 1981 a plan was drawn up to improve data collection for evaluating the efficiency of turbine and boiler. The importance of the automaticisation and dependability of data collection was stressed at that time. A basis was thus established for on-going energy accounting.

In 1983 a technical audit recommended daily monitoring, at similar load conditions, of the parameters with more influence on performance, the study of deviations from optimum values, and the systematisation of performance testing before and after overhauls.

Another audit during 1987 stressed the importance of inspection, monitoring and analysis of results for the achievement of correct operation and preventive maintenance.

In 1991 the first performance improvement plan was published, describing the actions carried out, together with a cost-profit analysis.

In mid-1993 The Performance Improvement Plan presented here was launched.

1.3. Justification for the Performance Improvement Plan

The most encouraging reasons were as follows:

- The conviction that performance could be improved. The differences between initial values and operational results, the awareness that the units were technologically improvable, and specific experiments carried out proved this.

- Knowledge of other experiences. Reports showed improvements of 2-3% after the application of similar plans.

- The competitive difficulties arising from the use of an expensive fuel, and the environmental demands, which required investments (de-sulfurisation of gases, injection of SO$_3$, environmental monitoring networks) and an increase in operating costs which had to be compensated for.

- The availability of many of the resources necessary (trained and motivated workforce, instrumentation and monitoring equipment available, etc.).

- The need for centralising efforts. Over and above individual efforts, what was necessary was
planning, with an overall view of the problem, firm support from Management, participation and teamwork.

2. THE STARTING POINT

Examining the 1994 results on the Sankey diagram in Figure 1, it can be seen that there are some losses which, in spite of their high value, are inevitable (i.e. those for cooling in the condenser); others, however, in spite of being small, can be largely reduced. The reduction of these latter values represents a significant reduction in operating costs. Let us see a few examples:

Net production during 1994 was 7277 Gwh. The net loss of heat in combustion gases was 244.9 therms/Mwh. At a cost of 2.2 Pta/therm, this gives a total of 3,920 Mpta (Million Pesetas). Part of this can be recovered in different ways, for example:

- Reducing the temperature of gases by increasing the surface area of heat exchange.
- Reducing the amount of gases, using less excess air.

Both methods are viable, but with different approaches. The first requires investment and a cost-profit analysis; in the second case, an improvement in operating procedures is required.

In the Performance Improvement Plan (PMR) both types of action should be taken into account, prioritising on the base of an objective analysis.

Other important losses were:

- Electrical consumption of auxiliary services ....... 1902 Mpta
- Unburned carbon in combustion residues ...... 1064 Mpta
- Consumption of steam in auxiliary services ....... 477 Mpta

In addition to the totals for the turbine cycle, which were 18214 Mpta. These losses only include the cost of coal. They should also include costs of transformation, maintenance, amortisation of plant and the industrial profit margin.

The sensitivity analysis carried out made it possible to identify the controllable operating parameters which had most effect on the losses, evaluating how far variations in their values contributed to the reduction of losses. The result was the quality map obtained. Four major improvement areas were identified, in the following order:

- Optimisation of combustion
- Optimisation of the turbine cycle
- Reduction of electricity use in auxiliary services
- Reduction of steam use in auxiliary services

Each has individual requirements in terms of investments required and potential improvements.

3. ACTIONS PRIOR TO IMPLEMENTATION OF THE PLAN

3.1. Improvement of Energy Accounting

On examination of the existing energy accounting system, it was verified that it was not operative as a feedback system for improving efficiency. In addition, it was very insensitive to the different operational modes of the plant and to maintenance activities. To overcome these defects, it was necessary to reduce the time base and to increase the sensitivity of the performance calculations. The performance improvement plan required, first of all, a precise way of measuring performance.

The first step was to change from monthly to daily based calculations, and several related activities were also carried out:
- Validation of calculation algorithms.
- Identification of valves which may produce leaks and re-circulation whose effect would modify performance and the calculation method. Establishment of periodic surveillance of these valves by means of thermovision.
- Equipment for the continuous measurement of carbon in ash.
- Individual measurement of several flows (e.g.: continuous blowdown, auxiliary and blowing steam, etc.).
- Portable equipment for comparison with fixed equipment (ultrasonic flowmeters, energy analysers, multiparameter gas analysers, IR pyrometers).
- Permanent use of precision nozzles to measure the feed water flow to the boiler, in the low pressure circuit.
- Improvements in measurements of temperature and \( \text{O}_2 \) in combustion gases at the exit of the boiler.

3.2. On-line Performance Monitoring

If the performance calculations are changed from daily to real time, the operator can see immediately the effect of his actions. This is a first step towards the optimisation and improvement of efficiency. It also helps in predicting the need for maintenance and for improving the economic performance of the units.

Its implementation requires the expansion and upgrading of existing instrumentation, particularly if the calculation system is to be sensitive. In this particular case the following actions have been taken:

- Measurement of steam flow in the extraction to the TBAA
- Measurement of circulating water flow
- Measurement of temperatures and pressures in the low pressure heaters
- Measurement of flow and temperature of the combustion gases
- Measurement of the degree of opening of the turbine regulation valves
- Measurement of the alternator hydrogen coolant flow
- Measurement of \( \text{O}_2 \) at the entrance and exit of the regenerative air preheaters
- Individual measurements for main consumers of electricity

3.3 Implementation of a Signal Quality Assurance System

Any performance calculation system fed with primary data of doubtful quality will produce “garbage” quality results, and lose credibility very quickly. It is therefore essential to make a prior effort to assure the quality of the data.

Action was taken, in this respect, on three fronts:

A) Audit of the quality of primary signals, evaluating whether each type of sensor, its location and installation, as well as the conversion and transmission of the signal, were the most appropriate for each case, including a review of the validity of the maintenance and calibration procedures of the instrumentation.
B) Provision of a computerised system for equipment maintenance and calibration.
C) Implementation in the performance monitoring software of a system for monitoring the quality of the primary signals. This system includes 3 validation filters:
   - By origin: verifying the fulfillment of the functional dependency relationships amongst the signals used, with a particular confidence level.
   - By consistency: verifying that the signals fulfill the rules imposed by the nature of the process (e.g.: decreasing pressures and temperatures, balance of materials and energy, etc.) within acceptable tolerances.
   - By recurrence, with the availability of redundant measurements for fundamental variables (e.g. circulating water, air, coal and gas flows, both measured and estimated).

3.4. Personnel Awareness
Improvements in efficiency depend on the development of skills and ability of the plant personnel. A PMR should be the goal of the whole plant. It should be, therefore, a tool for integrating and promoting teamwork. Thus the creation of multifunctional work teams should be promoted, each carrying out specific activities with pre-established time scales and attainable goals.

The plan should establish priorities for activities; that is, efforts should be directed towards those activities which offer the best chance of improvement, within the operational possibilities of the work teams.

No-one knows everything, and everyone has something to say. The dispersion of information and knowledge demands teamwork and an overall view of the performance improvement process.

In order to increase awareness, specific actions are planned, such as:

- The development of quality indicators reflecting the achievements of the different work teams in the improvement tasks assigned to them.
- The promotion of communication and feedback on different aspects of performance, indicators, etc.
- The establishment of goals, previously agreed upon, for the performance indicators, only achievable through the well focused efforts of the teams.
- Identification of the need for training in the area of performance.

3.5. Management Support

As in all new processes, the support of management is crucial for success. This support should be made evident:

- By backing actions designed to create awareness.
- By promoting the prior actions described above.
- By facilitating the provision of material resources and necessary personnel.
- By defining the structure of the plan, assigning responsibilities and ensuring an overall, integrating view of all activities.
- By promoting the creation of improvement groups.
- By controlling the degree of development of the plan and the achievement of the goals proposed.

4. IDENTIFICATION OF AREAS OF IMPROVEMENT

The quality map drawn up showed up the weak (and strong) points of Compostilla P.S., and their hierarchy. Some of the actions carried out are described briefly below. The inter-relation between them should be emphasised.

- **Improvements in the boiler system**
  - Organisation of combustion.
  - Adjustment of milling.
  - Control of fouling of the pre-heaters.

- **Improvements in the turbine system**
  - Actions carried out during overhauls.
  - Identification of malfunctions.

- **Reductions in electricity consumption in auxiliary services**

- **Reductions in water-steam consumption in auxiliary services**

5. ACTION PLAN

An exhaustive examination of the weak points encountered, their inter-relation and the resources
available, form a basis for their prioritisation. Actions are initially divided in two groups, depending on whether or not investment is required. In parallel, the technical and organisational actions have to be launched. Logically, those actions not requiring investment are developed first.

5.1 Optimisation of Combustion and Auxiliary Boiler Operations

On analysing the situation it is concluded that the greatest lack of information is related to the boiler environment and coal preparation. The boiler is like a black box for correct operation. For example, the flows of coal and air to each burner are unknown, as are the combustion conditions within the furnace. The scarce monitoring of the process indicates that the boilers do not operate at optimum levels. Improvements can be achieved by concentrating exclusively on the adjustment of their parameters, and the modification of the instructions for the regulating elements, if investment in monitoring is made. The potential improvements are estimated at 2% for the performance of the boiler, and a reduction in NOx emissions of between 25 and 50%.

Once the necessary measures have been identified and the necessary measurement systems implemented, tests can begin with different optimisation goals. In all of these the working methods should be strictly documented, so that it is possible to identify with certainty those conditions which produce real improvements, eliminating the constant and significant noise derived from the numerous parameters which are modified in an uncontrolled and undesirable way while the boiler is operating.

Depending on the monitoring level of the boiler and on the computerised development of the information evaluation systems, optimisation can evolve from being a specific, highly labour-intense activity to become an advanced system of on-line diagnostics.

5.1.1. Measurement and monitoring systems

Coal sampling
The diverse nature of the coal consumed in the Compostilla Power Station demands special attention, in all its aspects. In order to determine its precise analytic composition, a quality assurance system which has gained ENAC certification has been implemented. With respect to sampling, an automatic system of sampling from conveyor belts has been developed, tested and validated. This system complies with ISO-1988-1975 and ISO-9411-1.

In order to measure the flow of coal to the burners, a probe conforming to ISO-9931 has been developed and validated. This is an automatic isokinetic sampling probe which sweeps the whole pulverised coal duct during sampling. Its automation reduce significantly the duration of sampling, making it possible to carry out checks and adjustments of air-coal flow between burners, and at the same time it provides samples for granulometry. The Compostilla P.S. has carried out trails of on-line measurement of coal flow in feed chutes to the burners (laser, robotization of manual sampling) and participates in the Finecoal and Onlicoal projects financed by ECSC.

Sampling of fly ash
Initially samples were taken during tests in the ash silos, although the procedure was changed to continuous sampling. The idea arose after the detection of stratification in the unburned carbon content in the gas conducts at the exit of the boiler. Stratification could help to locate local malfunctions; thus, portable sampling equipment was used for ash in gas conducts. In order to obtain a representative sample of the globality of fly ash, another sampling equipment has been tested and validated for the sampling of ducts used for the pneumatic transport of ash to the silos.

Monitoring of gases at the exit from the boiler
The stratification detected in the content of unburned carbon in fly ash, together with that appearing in the composition of the gases during the preheater tests, were of great help in solving specific malfunctions of combustion. This gave rise to the idea of monitoring the space-time distribution of $O_2$-CO-NO and unburned in fly ash in the flue gas ducts at the exit of the boiler.

By means of exhaustive manual sampling for all of the operational alternatives which could affect these measurements, the centres of gravity (in number and location) representative of the different
combustion zones were found. An automatic system of sampling and sequential analysis of all points selected at the exit of the economiser, controlled from a PLC, was immediately developed.

**Monitoring of the air flow to the burners**

Although knowledge and control of each air flow to the burners is fundamental for the correct organisation of combustion, it is difficult, in general terms, to measure this. In the case of Compostilla, the geometric complexity of the combustion air circuit suggested the possibility of indirect measurement.

The selected method was that of 3-D modelling in fluid dynamic code. Thus, once the total flow and the position of the different regulating air dampers is known, the model gives the six different masic air flows corresponding to each of the 24 coal burners existing in this type of boiler.

**Monitoring of burners**

The obtaining of information on each of the 24 air-coal flows leaving the burners implies the complete measurement of the flow of coal to the burners using the probe described above. A quicker way of obtaining relevant information on the functioning of the burners is the specific determination of O₂, CO, NO and flame temperature in the region over each burner.

Although this specific determination is of help in locating possible anomalies in the organisation of combustion, it loses effectiveness with respect to solving problems by successive approximation. In this respect it is extremely useful to robotise the sampling. For this reason, at this time the construction of a prototype of an automatic probe system is being finalised (Opticom System) for the measurement of local conditions in the flames of burners, which will shortly be operational in Compostilla P.S. Figure 2 shows one of the monitoring and control screens of the Opticom System, developed within the framework of an ECSC project.

**Monitoring of stockpiles**

The introduction of more restrictive environmental legislation on emissions has made it necessary to improve the management of coal stockpiles. Bearing in mind the minimisation of internal transport as a limiting economic factor, a computerised system was implemented to determine at all times the analytic composition of coal stockpiles during their homogenisation. This in turn helps operators ensure that SO₂ emissions in later combustion gases do not exceed pre-established limits, which are in all case lower than current legal limits. The great variations in coal type from a total of 64 mines in the region motivated this action.

**5.1.2. NOx Reduction Project**

The aim is to determine which combustion conditions allow the reduction of NOx emissions without significantly penalising the boiler performance.

Although there is abundant bibliography on NOx control, this is not true in the case of coal with low content in volatile materials, as is the present case. For this reason the project obtained ECSC financing.

The fundamental activity was a global campaign of measures structured in five successive phases (Figure 3):

1. Identification of the fundamental process variables. Comparison of the instrumentation used (fixed and portable) to measure these variables.
2. Parametric tests of modifications to operating conditions. Matrix of factorial tests to determine the sensitivity of boiler and generator performance to modifications in operational variables.
Preliminary results are obtained.

3. Tendency confirmation tests. Repetition of the most significant of the previous tests, spaced in time to block the effect associated with overall changes in the state of the boiler.

4. Maximum improvement tests. Associating the modifications of variables with a positive effect on efficiency. Their aim is to evaluate the additive effects of the combination of operational modifications in order to find the optimum adjustment of combustion conditions.

5. Long term tests. To detect difficulties in maintaining optimum combustion conditions in the presence of unforeseen variations, and to consolidate definitive results.

After more than 200 tests, results clearly show that it is possible to reduce NOx emissions using primary measures exclusively, with no additional investment. The primary measures shown to be most effective were: reduction of excess oxygen; adjustment of the secondary air/tertiary air ratios and limited support of fuel-oil. Figure 4 show the results obtained in unit 4 of Compostilla Power Station.

Reductions were obtained of between 20 and 35% in NOx emissions, depending on the boiler concerned, and it was demonstrated that the implementation of these measures does not imply additional costs. In fact, costs were even reduced as a consequence of the greater knowledge of the combustion process, which permitted appropriate adjustment of the type of flame created. In addition, it was found that the most efficient actions differ depending on the different boiler designs existing in Compostilla Power Station.

Another activity derived from this project was the preparation of 3-D models in fluid-dynamic code for simulating the combustion and generation of NOx. For validation the information and results obtained during the project tests were used.

5.1.3. Combustion Optimisation Process

This project is a continuation of the previous project. During the tests for the previous project, it was evident that there was a possibility of substantially improving the performance of the boiler by means of adjustment of operational variables. In some cases, important reductions in NOx emissions were achieved at the same time.

The aim was to improve boiler performance by 1% by identifying the air and coal distribution which would enable a joint reduction of excess combustion air and carbon-in-ash.

The results and the methodological support of the previous project were used, and the aim proposed was achieved; at the same time non-conventional operating conditions were explored for enhancing the operating stability of the boilers.

5.1.4 Milling Optimisation Project

The aims are to evaluate the influence of the type of coating, load, type and granulometry of the milling balls on the granulometry of the coal and carbon-in-ash. In addition, a reduction of 9 GWh/year in the consumption of the mills was aimed at.

Within the group of activities requiring investment, the design, manufacture and assembly of adjustable classifiers able to vary the fineness and the flow of coal to the burners was carried out, and substantial improvements were obtained in the granulometry of pulverised coal (Figure 5).

As an extension of combustion optimisation, a series of evaluation and follow-up tests of the operation of the mills of three of the units in Compostilla Power Station was designed. A large proportion of these has currently been completed, and has permitted 10% reductions in energy consumption of the mills of two of the units analysed.

In addition, modifications in the fans and in the primary air regulation system of one of the units have managed to reduce the primary air power consumption by more than 50% with respect to design conditions.
This work is included in the ECSC Finecoal project.

5.1.5 Expert diagnostic aid system

This is the last step in combustion optimisation. Its objective is to develop simulation models and calculation programs for the evaluation of boiler functionality and the correlation between performance and foreseeable NOx emissions.

In short, the aim is simultaneous on-line optimisation of performance and NOx, for any given state of the boiler, by means of a self adapting expert system. It is supported by the advances in monitoring systems, the methodological experience gained in the previous projects, and the application of advanced optimisation, management and prediction techniques, such as genetic algorithms, expert systems and neural networks. (Figure 6).

This system is at present under development and has ECSC financing (Optinox Project). The final product is a boiler supervision module, with interactive communication with the operator and capable of being the support for unit optimisation processes, using predictive models and simulations of combustion and boiler behaviour, on an eminently empirical basis.

The Supervision System incorporates the following main functions:

* Optimisation function. By means of strategically pre-established criteria, the System provides a selection of optimum adjustments of manipulable boiler variables for a particular operating condition.

* Heat rate/NOx minimisation function. Provides, for a pre-established condition, the adjustments necessary to optimise heat rate or NOx, fulfilling pre-established instructions for the other variable.

* Predictive function. Determines heat rate and NOx emission foreseeable for a particular adjustment of the boiler.

* Sensitivity function. Provides an estimate of the relative influence on heat rate or NOx, acting on the instruction value of a particular variable. This function is designed for the evaluation of actions on instrumentation and/or controls.

* Reference generation function. Based on the variability observed for heat rate and NOx in pre-established conditions, the System determines the range of values corresponding to the current adjustment, as a reference for the correct functioning of the installation and/or instrumentation.

5.2. Actions in the Turbine Cycle

Although with respect to the boiler, correct operation is of decisive importance for performance, in the turbine the actions taken during overhauls are of key importance. The operational mission in this case is limited to minimising time drift of post-overhauls efficiency.

5.2.1. Audits during overhauls

Software has been developed for guiding personnel during assembling of the turbine rotor. The aim is to minimise energy loss through leaks. The system has all the data necessary to readjust all gaps after displacement of the rotor; evaluate deviations with respect to reference values; detect areas with unacceptable tolerances and reject movements which are in general out of limits. Encotech Inc's STPE software is also available for energy audits during overhauls.

Among the benefits derived from the use of these tools are; objective decision making with regard to actions to be accepted or rejected during overhauls, their scope, date limit and quality control of actions and compliance with specifications. In the Compostilla Power Station, it has been proved that with rational, low investment actions involving polishing, replacement of sealing teeps, adjustment of
clearances and cleaning during overhauls, important efficiency gains have been made without the need for investments.

Another line of action followed has been that of controlling and documenting cleaning during overhauls.

5.2.2. On-line monitoring

In addition to the utilities available in the on-line monitoring of performance (monitoring, detection and quantification of performance and leaks in the turbine and leaks and re-circulation in the cycle), the following have been developed:

- Improvement of the isolation of the cycle, implementing leak detection systems in valves and periodical inspections.
- Reduction of continuous blowdown from the boiler drum by optimisation of the cycle chemistry and the rapid detection and suppression of leaks in condensers.
- Minimisation of losses through lamination in regulation valves.
- Suppression of evaporative tanks.

6. OVERALL RESULTS AND CONCLUSIONS

The development at the Compostilla Power station of a solidly based and structured Performance Improvement Plan has shown the potential of this type of action, which tends to improve competitiveness in thermal power stations. This improvement is achieved through a more rational use of fuel, the cost of which is the major contributor to the final price of each kWh generated.

Heat rate improvements of greater than 2% have been documented for the units involved in this Plan, and both their availability and their environmental performance has increased, with reductions in NOx emissions of around 30%.

The actions undertaken were structured in four inter-related areas:

* Improvements in the boiler system.
* Improvements in the turbine system.
* Reductions in electricity consumption by auxiliary processes.
* Reductions in water-steam consumption of auxiliary processes.

The significant methodological advances of the performance Improvement Plan developed at Compostilla P.S., with respect to monitoring and to optimisation strategies for the different processes involved, allow us to affirm the tremendous profitability of ENDESA’s bet on this type of action.
Figure 1: Sankey diagram for Compostilla Power Station

Figure 2: Graphical interface of the OPTICOM system for in-furnace monitoring
Figure 3: Phases of the Projects for NO\textsubscript{x} reduction and heat rate improvement

Figure 4: Results obtained for NO\textsubscript{x} reduction (and heat rate improvement) in Compostilla Unit 4
Figure 5: Improvement of coal size distribution by the use of new adjustable classifiers

Figure 6: General scheme of the OPTINOX system for on-line combined optimisation of boiler efficiency and NOx emissions

Comments / Special Instructions
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