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Process Quality Optimization

Concepts, Success Factors, Experiences

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Abstract

Process quality optimisation: schemes, success factors, Experience

In light of the climate protection targets, rising energy source prices and increasingly tougher competition, the systematic optimization of process efficiency in fossil-fired power plants provides significant value leverage. Apart from plant-related retrofit measures, systematic monitoring and analysis of efficiency-relevant and often plant-individual key process indicators can lead to further improvement of the plant utilization ratios. A variety of online software solutions (so-called process quality monitoring systems, or PQM systems in short), most of which are independent of process I&C systems, are on offer for this purpose. Within the scope of a project, requirements for RWE Power's lignite-, hard coal- and gas-fired power plants regarding the design of PQM systems, their connection to the process I&C systems and process parameters to be monitored were defined and appropriate utilization and servicing schemes incl. an organisational structure for the sustainable optimization of efficiency in the power plants developed. The SR::EPOS software of the company Steag Energy Services GmbH was chosen as system solution for testing in the pilot units.

Pilot testing of the PQM system in the Ibbenbüren, Neurath D and Niederaußem G power plant units was recently completed, so that initial results obtained in the implementation and utilization phase are available. Currently the installation of the PQM system in up to 27 further power plant units of RWE Power is in progress.

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Introduction

In order to increase the economic efficiency of the power plant installations and to reach the climate protection goals, measures for optimizing the plant and process efficiencies are developed and implemented with a high priority at the RWE Power AG power plants. Besides implementing several new construction projects (Lignite-fired unit with optimized plant technology 2&3, Westfalen D/E, CCPP Lingen), the existing plants have been modernized continuously in recent years (e.g. by means of retrofit measures), and in parts their efficiencies have been raised by several percentage points.

Another approach is the continuous optimization of the process efficiencies as well as the rapid detection and elimination of causes of efficiency losses at the power plant. In contrast to the optimization of the plant technology, the point here is to adjust the mode of operation of the unit for an optimal efficiency considering the current condition of the unit (fouling, malfunctions, etc.) and to initiate countermeasures in the case of deviations from the nominal condition.

Thousands of analog and binary signals accumulate in the process control system of a power plant, which are used for the monitoring, control, and closed loop control of the plant. Here the primary task of control system is to ensure a safe plant operation complying with the defined operating parameters. Both the condition of the plant components (e.g. the heat transfer in a heat exchanger) and external boundary conditions (e.g. coal qualities, cooling water temperatures) are subject to constant change. If the plant is to be operated with an optimal efficiency under the current boundary conditions or if the changes limiting the efficiency are to be identified and remedied promptly, a deviation from the optimal efficiency possible in each case will have to be detected, the cause will have to be identified and the mode of operation adjusted.

Due to the high complexity of power plant technology as well as the energy conversion process, this process cannot be automated completely for the time being, although fully automated optimization controls customized for specific tasks do exist (e.g. modules for optimizing the on-site power at the cold end, fuzzy logic-optimized soot blower control, neural controllers in the area of the steam generator for optimizing the fuel/air ratios, etc.). Therefore it is necessary to provide the plant engineers (maintenance and operation) with a tool that, based on data from the process control system,

- allows for a transparent representation and assessment of the process status of the plant and the individual components, respectively,
- localizes weak spots in the process, malfunctions, and potentials for optimization regarding the process quality
- offers a fast economic assessment of maintenance measures relevant to the efficiency and of changes of the mode of operation, respectively, and
- allows to simulate modes of operation and component changes (e.g. shutdown of a pre-heater) in the back office without any effort and risk at the plant.

The introduction of such an IT tool represents a necessary, but not a sufficient condition for optimizing the process efficiencies. Only by providing the required staff resources, by defining and consistently implementing the utilization and maintenance concept and by building up system know-how on the operator side will it be possible to use the system efficiently.

To ensure this, requirements to the process quality monitoring system (scope of the components and characteristics to be monitored/assessed as well as requirements to the documentation, training, project flow when implementing the system) were defined by RWE, and a corresponding utilization concept was developed and an infrastructure for the testing and roll-out of the system created. In the context of a tender, a suitable PQO system was selected and the implementation of the system at the hard coal-fired power plant Ibbenbüren and at the lignite-fired power plants Niederaußem G and Neurath D were orderd for a pilot operation.

Below, the system concept, the schedule of the system introduction, the utilization concept and the required IT/process data processing infrastructure are described and experiences from the pilot utilization phase are introduced using the hard-coal-fired power plant of Ibbenbüren (794 MWn) as an example.

PQO system concept

For several years now, RWE Power has been using various system solutions for

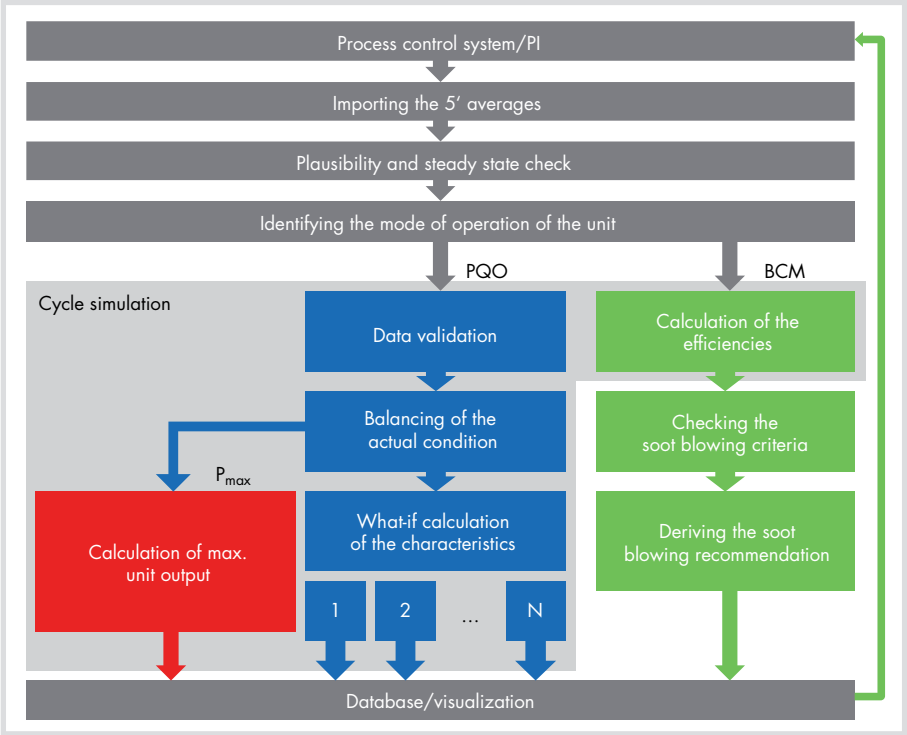

Fig. 1. Calculation process in SR::EPOS.

validating process data, for optimizing the use of soot blowers and water lance blowers as well as for the simulation and assessment of power plant processes. In the context of the PQO project, the experiences existing in the group as well as in the market were considered, and the PQO system solution SR::EPOS by Steag Energy Services – hereinafter called SES – based on the thermodynamic cycle simulation EBSILON®Professional was selected for a pilot application and possibly for later use in the fossil fuel power plants of RWE Power. Compliance with the following requirements was of particular importance for the selection:

- Online calculation of characteristics based on current measured data in a calculation sequence of five to 10 minutes
- Checking and improving the quality of the measured data by means of a data validation, certified according to the guideline VDI 2048, whereby the calculation of all characteristics has to be carried out based on the validated data.
- Calculation of realistic reference values for all assessed components (approx. 40 characteristics) for the entire load range, for all modes of operation that regularly occur and considering the current ambient conditions.
- Assessment of the deviation between the reference values and the actual values by quantifying the effects on the efficiency to be allocated in each case, and by specifying the corresponding additional and reduced costs, respectively.
- Possibility to adjust the calculation models in an appropriate time (e.g. for the purpose of considering small changes in the plant, running what-if analyses, or subsequent implementation of a further assessment of characteristics).
- Modular design of the system with the option to integrate proprietary or (closed loop) solutions for optimizing the soot blower and water lance blower use already installed at some power plant units, as well as for optimizing the on-site power at the cold end.
- Availability of a powerful and easily adjustable software for visualizing and analyzing calculation results.

A cycle simulation model of the power plant process (description of the energy balances, mass flow balances, and material balances of the power plant by a set of coupled algebraic equations) in EBSILON®Professional represents the calculation kernel of the PQO system SR::EPOS for all further assessments as well as for the data validation. The model comprises the thermodynamic image of the water and steam cycle, of the air and flue gas path, and of the boiler, including all measurements required for the balancing and data validation.

The essential advantage of using a cycle simulation is that not only all regularly occurring modes of operation of the unit as well as the behavior of each component in the entire load range between minimum and nominal load point can be considered, but that also the interaction between the individual components of the cycle is represented. The influence of a change of the thermodynamic properties of a component or a process parameter on the overall process thus becomes quantifiable.

Figure 1 shows a diagram of the modular design of the PQO system as well as the calculation process as implemented in the pilot unit Ibbenbüren. For the sake of completeness, the integration of the modules for optimized control of the soot blowers (Boiler cleaning management, BCM) and for determining the bottlenecks when reaching the maximum unit output (Pmax) implemented in Ibbenbüren on the basis of SR::EPOS are sketched in Fig. 1 as well. In Ibbenbüren, the following calculation process for the online assessment of the components and certain process parameters, respectively, was implemented using the PQO system:

Data plausibility check and steady state: Before the transfer of the current measured data from the process control system to the cycle simulation, these are condensed to five-minute averages and submitted to a plausibility check. This way, measured values with measuring range violations are detected and marked. If the unit is in steady state (which is checked, amongst others, using the live steam mass flow gradients), the balancing can be executed in the thermodynamic model.

Data validation (VDI 2048): All measurements are prone to measuring uncertainties, random and systematic measuring errors as a rule. For optimization potentials to become visible and quantifiable in the first place and for measuring errors to be detected reliably, a procedure for reducing the measuring uncertainties and for automatically detecting and, if applicable, correcting measuring errors is an integral part of a process quality monitoring system. Guideline VDI 2048 [1] describes a procedure for quantifying and reducing measuring uncertainties in thermal acceptance measurements. By linking the measured values via energy balances, mass balances, and material balances and by defining measuring uncertainties, additional information unavailable in the process control system is used and evaluated by means of mathematical methods (least squares) for each measured value. To do so, all five-minute averages checked for plausibility are first subjected to a data validation, and the quality of the validation result is checked according to the quality criteria defined in VDI 2048. In the event of a violation (RWE definition) of the quality criteria, the data record will be discarded and no further calculations will be carried out until the next five-minute average is present.

Determining the actual condition of the components and processes: If the data validation has been successful, the balancing of the actual condition of the power plant and the calculation of all actual values for components, process parameters, and efficiencies can be carried out in the cycle simulation based on validated measured values.

	Operating team	Plant engineers	System experts			
Task	Short-term optimization of the mode of operation of the unit	Monitoring of the component qualities	Trend evaluations for components and mode of operation	Deriving potentials for improvement	First level support and administration & further development	Evaluation of experiments and offline what-if analyses
Frequency	ongoing	regular	regular, monthly reports			
Type of use	local/unit-specific		central/across units			
Tool	GUI (client), process control system		GUI (client), EBSILON models			

Fig. 2. PQO system users and their tasks.

Determining the reference values and nominal/actual comparison: To determine the reference condition of a component or of a parameter to be assessed under the current boundary conditions, the thermodynamic behaviour in the model is determined by means of the characteristic lines defined during the system implementation phase (or directly by means of a data-based model) instead of by current measured values (e.g. temperatures and pressures at the component inlets and outlets). The subsequent determination of the overall process efficiency in the cycle simulation and the comparison with the efficiency from the actual balancing reveal which efficiency potential can be realized by the deviation of the respective process parameter from the reference value. This calculation is carried out for each component to be assessed and each process parameter to be assessed, respectively.

Visualization: Subsequently, a further condensation of the calculation results e.g. to performance factors (comparison of actual and reference condition) takes place. All calculation results and data validation results are stored in a database and can then be displayed in a client and evaluated.

PQO utilization concept

Figure 2 gives a concise overview of various users as well as their tasks. Basically, three distinct areas of activity can be defined according to the current concept:

- Using the PQO system for the short-term optimization of the mode of operation of the unit and for detecting sudden parameter changes of components
- Systematic evaluation of the PQO results (also across units) and deduction of process quality improvement potentials
- System administration and maintenance of system and hardware.

The short-term optimization of the mode of operation of the unit as well as the detection of and fast reaction to the sudden deterioration of components can only be effected taking into account all information concerning plant technology and operation and thus lie within the responsibility of the plant operator and the maintenance engineers, respectively.

For this, the PQO system provides an overview of all relevant component and process parameters with a significant influence on the power plant efficiency, as a juxtaposition of the current actual and reference values. To each process parameter deviation, a change of the process efficiency is allocated and financially assessed. This helps the plant operator by providing quantities for identifying optimization potentials and for assessing his intervention into the process. This information is available on a separate screen in the PQO system client (Figure 3, left) and is visualized on the shift supervisor's screen and, if possible according to the control room concept, on a separate screen in the operating and monitoring line. The maintenance engineers can use the client on their office PCs and retrieve all relevant process information (Figure 3, right) there.

A systematic analysis, unit-specific as well as across units, and preparation of the PQO system results, identification and assessment of improvement potentials, execution of what-if studies as well as detailed review of the technical feasibility at the sites is time-consuming. Besides knowledge of power plant process technology, it requires a deeper understanding of the models and assumptions the PQO system is based on. With regard to the high workload of the power plant engineers in their daily business, regional and central expert positions have thus been created for dealing with the above-mentioned tasks and for the introduction, standardization and the continuous support and administration of the PQO systems in the sectors of hard coal-fired and gas-fired power plants as well as lignite-fired power plants. For the support of the systems, the RWE experts are supported by the system supplier in the context of a maintenance contract that in particular ensures the basic maintenance of the systems as well as the debugging.

IT/process data processing connection of the PQO system

Due to the high performance requirements, one separate calculation server for carrying out PQO calculations is needed per power plant unit. As the power plant sites of the hard coal- and gas-fired power plant sector of RWE Power are distributed over the map, placing the calculation servers at the respective sites would result in a higher maintenance effort (in particular for the software maintenance) after the roll-out of the system. In addition, according to the utilization concept it should be possible to use the system from each office PC in the RWE Corporate Network (RCN).

A central demilitarized zone (DMZ) was created for the PQO calculation servers to comply with the requirements. As the respective PQO calculation servers have

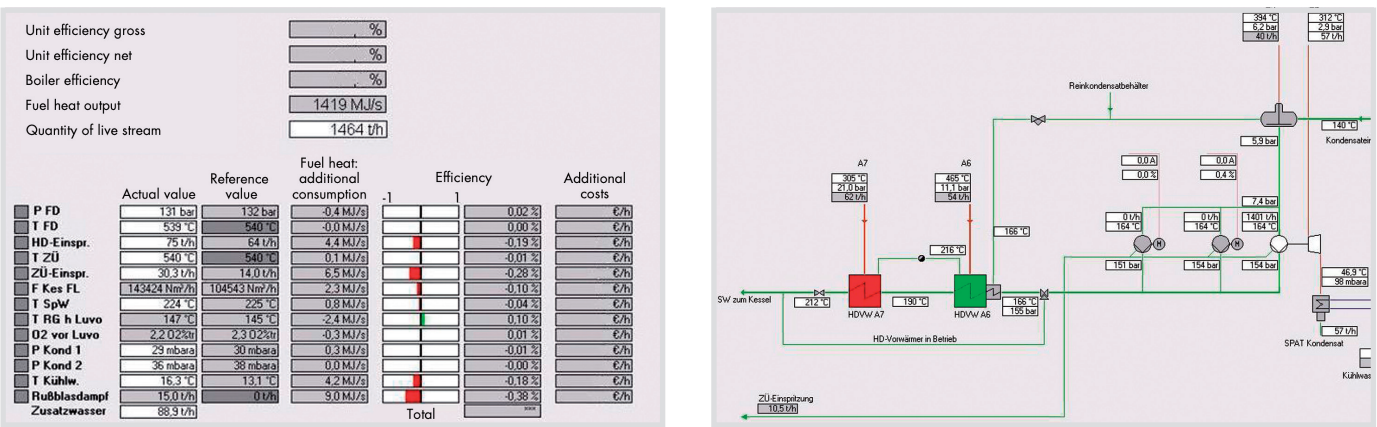

Fig. 3. Excerpt from PQO overview screen (left) and a process image (right) from the client.

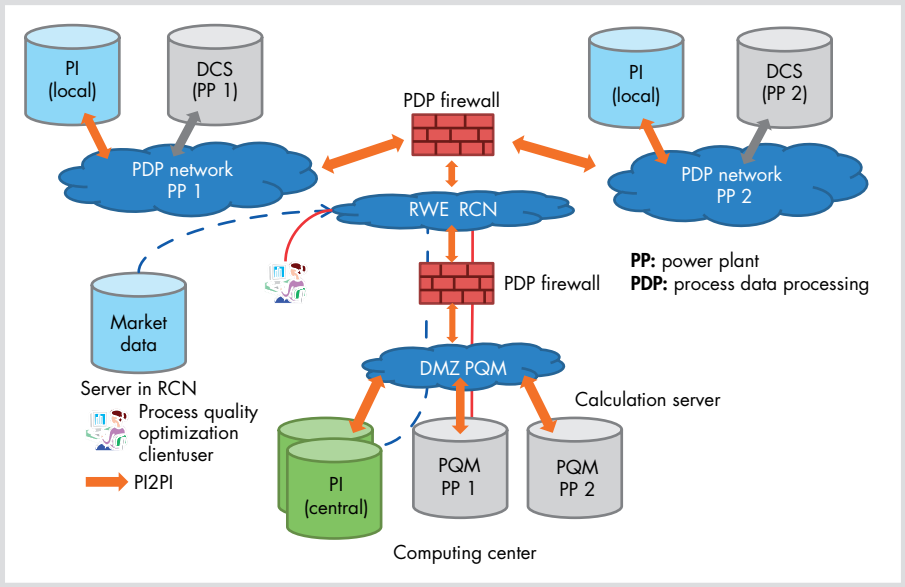

Fig. 4. IT/process data processing structure of a PQO system.

to access the process data network of the power plants not only in reading but also in writing mode (e.g. in the case of clearance of soot blowing requests of the soot blowing management module in automatic operation), the connection between the calculation servers in the DMZ and the respective process data networks of the power plants was implemented via a safe PI2PI connection. Here it was possible to share an existing PI infrastructure of the sites.

In addition, using a central infrastructure allows to provide the PQO system with secondary data stored in the central databases like e.g. current fuel properties or current fuel prices without major effort. Figure 4 shows a diagram of the IT/process data processing structure of the PQO system. First experiences from the pilot utilization phase at the Ibbenbüren power plant have shown that both the system performance and the system accessibility comply with the imposed requirements.

System implementation at the Ibbenbüren pilot power plant

In order to check the functional efficiency of the selected PQO system solution, of the utilization concept as well as the IT/process data processing structure during power plant operation, the system was first tested at the Ibbenbüren power plant and at the power plants Neurath Unit D and Niederaußem G. Below, the implementation process as well as first experiences will be illustrated using the pilot project at the Ibbenbüren power plant as an example.

The system implementation was carried out at Ibbenbüren by SES and took nine months including test operation. It comprised the creation and fine-tuning of the unit simulation, configuration of the data interfaces between the PQO system and the process control system, programming of modes of operation and characteristics, adjustments of the data validation as well as commissioning of the soot blowing module BCM. The company NIS was hired for setting up the IT/process data processing environment. Figure 5, left shows the chronological sequence of the pilot project. To ensure a high quality of the results and a high acceptance of the system from the beginning and to establish the coupling between the process control system and the PQO system, the contractor was intensively supported by an RWE Power project team consisting of the PQO system experts and several power plant engineers (Figure 5, right) as early as during the implementation phase.

The power plant was modeled based on available data sources (P&I diagrams, thermal flow diagrams, acceptance measurement reports, manufacturer characteristic fields, etc.) and was continuously adjusted and subjected to quality assurance by the contractor in the project team in the course of the creation of the model. Owing to this step, it was possible to make the assuptions the model was based on transparent for the subsequent users of the system and to improve the accuracy of the model in many instances by coordination with the know-how of the power plant engineers.

Just like the modeling of the cycle, also visualization screens, reference values, calculation rules for characteristics as well as the measuring points to be used for the modeling and assessments were defined and checked, respectively (e.g. by intensive use of the system by team members). This was done considering the operational particularities in the project team and in bilateral coordination between the contractor and the particular experts, respectively. The transfer of knowledge between the project team and the contractor was ensured by monthly project discussions and by the presence of an SES project engineer at the power plant (ca. two days per week). During this piloting phase, the system concept and in particular the calculation process and the calculation methodology of characteristics were adjusted to the requirements of RWE, and the utilization concept was refined. In addition, the methodical cooperation in the project team e.g. for the quality assurance of models regarding future projects was further optimized. Figure 6 shows an overview of organizational success factors for a successful implementation of PQO systems.

Altogether, it was possible to program and assess almost all the characteristics defined at the beginning of the project. Here the equipment with measuring points at the unit proved to be a limiting factor, whereby at critical points, unique sets of measurements had been carried out already during

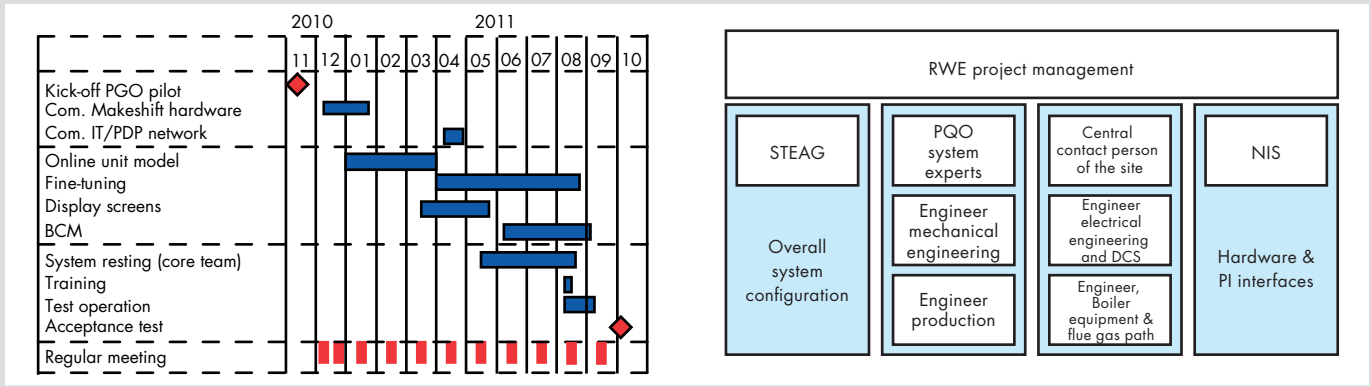

Fig. 5. Project schedule (left), structure of the introduction team in Ibbenbüren (right).

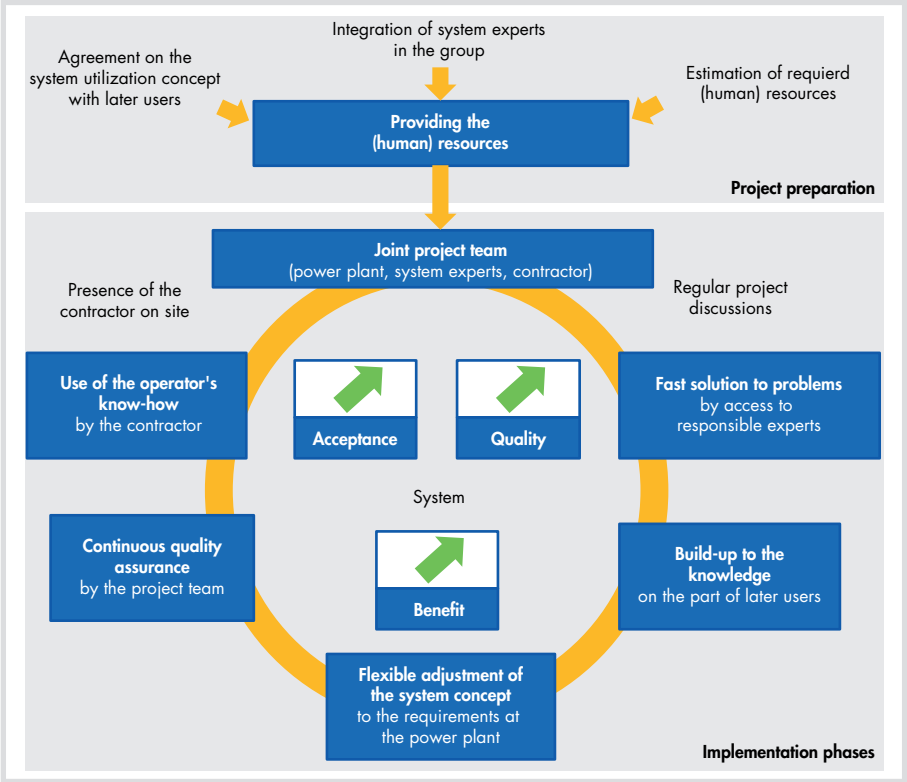

Fig. 6. Overview of organizational success factors.

the implementation phase. It turned out that although comprehensive documents had been provided, the sufficiently precise calculation of the reference values for some characteristics or components was only possible to a limited extent at the time of the system acceptance test. For example, there were no manufacturer characteristic lines for operation of the cooling tower in winter. Therefore in future PQO projects it is assumed that approximately a half year after implementation of the system, some reference values will have to be adjusted based on the operating values typically unavailable at the start of the project.

At the time of the system acceptance test, it was possible to establish an overall system availability (all periods of time with the unit in steady state were considered here) of over 90 percent. It is to be increased to ca. 94 percent in the phase after the project by optimizing the convergence behavior of the models and by expanding the models by modes of operation not yet considered or not tested during the system implementation.

The frequency of the data validation as well as the downstream assessment of the process qualities for more than 40 process parameters was implemented in Ibbenbüren in a 10-minute cycle, with ca. 15 minutes required per calculation process. In the test phase it turned out that the frequency of calculation as well as the delay time between the action at the power plant and the PQO evaluation result are sufficient for using the system to its full extent.

As early as during the implementation phase, several approaches for improving the process quality could be found by using the PQO system in Ibbenbüren. These ranged from the identification of faulty measuring points to the detection and remedying of sub-optimal modes of operation and malfunctions of components that otherwise would have led to efficiency losses. In this way, an increase in the otherwise unrecordable feedwater losses compared to the latest thermal acceptance measurement could be detected by means of the PQO system. Among other things, significant leakages of the boiler drain valves were found and remedied in the course of subsequent tests. The PQO system also reported that after starting up the unit, one cooling tower zone was not activated. As a result, this operating condition that would have caused a significant deterioration of the process efficiency could be remedied immediately. In addition to process quality monitoring, the system is currently used intensively for determining efficiency-optimal modes of operation of units at the minimum load point and for several plant retrofitting measures (pre-heater and cooling tower overhaul).

Summary

Altogether, the pilot projects were able to prove the technical fitness of the PQO system SR::EPOS for the use in hard coal-fired, gas-fired, and lignite-fired power plants according to the RWE specification, as well as the expectation to the beneficial effect of PQO systems, and the contractor's high expertise concerning process technology that is essential for implementing PQO systems. Therefore the system is now being implemented in 28 hard coal-fired, gas-fired, as well as lignite-fired units in total. By 2014, all lignite-fired, hard coal-fired, and combined cycle power plants of RWE Power including all newly constructed units are to be equipped with the PQO system, and the use of these systems is to be converted to permanent operation.

The comprehensive introduction of PQO systems at RWE Power represents another consistent step towards optimizing process efficiencies and thus saving emissions and increasing power generation efficiency.

References

[1] VDI 2048: Uncertainties of measurements at acceptance tests for energy conversion and power plants, Sheet 1-3, Beuth Verlag, 2000.