Solutions for the Flexible Operation of Power Plants

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1. ABSTRACT

In a scenario of an increasing use of renewable energies, the coal-fired power plants will be more and more forced to compensate for the volatility of the natural resources. Even huge coal-fired units which have been designed for base load operation will face an increased number of start-up/shut down cycles and the requirement for faster load changes.

The operation of power plants is highly complex. For the operating companies, managing a reliable plant operation with frequent start-up and shutdown procedures, different fuel qualities, and a high availability at maintenance costs as low as possible is both a challenge and a chance.

One reason for the changed boundary conditions is the addition of renewable energies. The objective is to be able to successfully meet the volatile requirements of the energy market with a flexible and economically efficient power plant operation in future.

The expert software solutions of STEAG Energy Services ensure an assessment of plants in procedural and technical terms. By continuously evaluating available performance values, the systems provide reliable information enabling an optimized mode of operation and condition-based maintenance of the plant and help to increase the plant's availability early on.

Information on the efficiency, load-independent performance factors, coal qualities, heat rates, and availabilities describes the quality of the operation and is available on site. Fouling and wear of the plant components, i.e. creep and fatigue, can thus be detected in a timely manner, and additional costs can be avoided.

This paper describes an integrated approach to benchmark the start-up performance. As a result, deviations from an intended mode of operation will be identified. Known margins for an increase in start-up speed and / or number of cycles are a precondition for a more flexible but safe plant operation. Thus the component fatigue, start-up duration and costs due to component degradation and fuel consumption are taken into account to evaluate the optimal start-up transient.

2. CHALLENGES FOR COAL-FIRED POWER PLANTS DUE TO AN INCREASING USE OF RENEWABLE ENERGIES

Due to the increasing share of renewable energies in power generation, lignite- and hard coal-fired power plants have to react more and more flexibly. In various parts of the plant, this leads to an increased wear of components due to faster load changes and a more frequent start-up and shutdown of the power plant units. It was not possible to consider the changed operation and load duty cycle at the time of the design of the base load plants. New methods for assessing the component condition are required to continue ensuring the plant safety. Optimal start-up procedures and condition-based inspection intervals are prerequisites for a flexible, safe, and economically efficient plant operation.

The following list shows the strategic and technical approaches to successfully meet the requirements of the current situation in Germany in terms of energy policy:

- Identification of component reserves to be able to use higher stresses for a flexible operation in future
- Implementation of higher start-up transients and/or more frequent start-up procedures than considered at the time of the design
- Minimizing the start-up costs to enable more frequent start-ups and shutdowns for an economically efficient use of the unit
- Economically efficient decrease of low load and minimum load to up to 15 percent for hard coal-fired power plants
- Implementation of primary and secondary control measures
- Application of modern DCS and performance monitoring systems to be able to operate with optimal start-up transients and to assess and thus optimize all steady-state load ranges
- Continuous transparency regarding external and internal boundary conditions to be able to implement an optimal marketing strategy (weather, merit order, fuel and wear costs, plant condition, energy prices)
- Condition-based maintenance strategy involving modern condition monitoring systems to ensure a safe continued operation at minimal maintenance costs

In what follows, the two subject areas “identification of reserves for a flexible operation” and the “determination of optimal start-up transients from a technical and economic point of view” will be presented.

3. SOLUTIONS

In the following chapters four solutions for a flexible operation of power plants are presented:

1. Identification of Reserves for a Flexible Operation
2. Start-up Costs: Determining Optimal Start-up Gradients
3. Smart Inspection Assessment for a Safe and Flexible Continued Operation
4. Smart Inspection Assessment for a Safe and Flexible Continued Operation

3.1. Identification of Reserves for a Flexible Operation

In the context of a technical inspection on a 700 MW hard coal-fired unit, the question was analyzed whether calculatorily there is enough potential for doubling the number of start-ups. Since the commissioning, the SR1 system has been monitoring selected thick-walled boiler and pipe components. In doing so, the calculatory creep damage and low cycle fatigue are determined according to DIN EN 12952. The results provide information on the actual stress of the components as well as on critical operating conditions. The SR1 system of STEAG Energy Services enables a realistic lifetime calculation and has been in use throughout the world since 1989.

In the present case, the superheater 3 outlet header has the highest calculatory lifetime consumption. In the SR1 online system, the mode of operation is assessed coherently. For the detailed analysis of the mode of operation, the start-up procedures were divided into cold, warm, and hot starts according to the criteria defined in Table 1. The downtime was most important here.

Start type	Min. cycle pressure	Min. cycle temperature	Downtime
Cold start	0 bar	>20 °C	>48h
Warm start	0 bar	>80 °C	<48h
Hot start	0 bar	>250 °C	<8h

Table 1: Criteria for the classification of cold, warm, and hot starts (downtime most important)

In 2014, the following load duty cycle was identified:

Start type	Number	dT_{max} [K]	$Sigma_{max}$ [N/mm²]
Cold start	4	-84	-502
Warm start	17	-121	-709
Hot start	3	-77	-436
Shutdown	24	111	804

Table 2: Load duty cycle in 2014 for the superheater 3 header

- dT_{max} = maximum temperature difference at the time of maximum total stress during the respective start-up or shutdown procedures
- $Sigma_{max}$ = maximum total stress according to DIN EN 12952-4:2011 Appendix B (equation. B.1) during the respective start-up or shutdown procedures

It becomes obvious that the warm starts cause the major part of the low cycle fatigue due to the high stress level and the high number of cycles. In 2014, the calculatory increase in the total lifetime consumption for the outlet header amounted to 3.77 percent and is distributed as follows:

Year	Hours of operation [h]	D_F [%]	D_C [%]	D_{TOTAL} [%]
2014	7,735	1.88	1.89	3.77

Table 3: Calculatory increase in the component fatigue of the superheater 3 header in 2014

- D_F = calculatory low cycle fatigue according to DIN EN 12952-4
- D_C = calculatory creep damage according to DIN EN 12952-4
- D_{TOTAL} = sum of DF and DC

To allow for a better evaluation of the results, the extrapolation of the lifetime consumption to 200,000 hours of operation is effected in a linear way on the basis of the calculatory stress identified in 2014.

Hours of operation [h]	D_f [%]	D_c [%]	D_{total} [%]
200,000h	48.6	48.9	97.5

Table 4: Linear extrapolation to 200,000h of the calculatory stress of the superheater 3 header determined in 2014

Based on the component fatigue determined in 2014, there is no potential for doubling the number of start-ups as the header has been highly stressed both by creep stress and cycling stress. Subsequently, a detailed analysis of the low cycle fatigue during the 17 warm starts and the previous shutdown procedures was carried out. Two load changes were identified that can be avoided in future by optimizing the mode of operation. This results in a significant savings potential that can be used for a flexible power plant operation.

Event	D_f [%]	**Number per year**	**Savings potential D_F per year** [%]
WS,max + shutdown,max	0.58	2	1.16

Table 5: Lifetime consumption by critical cycle (warm start + shutdown)

Hours of operation [h]	D_f [%]	D_{total} [%]	$D_{F,optimized}$ [%]	$D_{total, optimized}$ [%]
200,000h	48.6	97.5	18.6	67.5

Table 6: Linear extrapolation to 200,000h of the stress determined in 2014 (with and without consideration of an optimized mode of operation)

If such critical conditions are avoided, the number of start-ups can be doubled in future. The SR1 system provides a central basis of valuation for detecting such conditions and thus is a prerequisite for a both flexible and economically efficient continued operation.

3.2. Start-up Costs: Determining Optimal Start-up Gradients

The solutions by STEAG Energy Services enable an integrated start-up monitoring and are the basis for optimizing the processes. The central goal is to optimally design the start-up process from an economic and technical point of view to be able to develop ideal application strategies for the unit.

The following criteria are monitored per start-up procedure:

- Lifetime consumption of components and the related costs
- Fuel consumption
- Start-up time

Wear costs and fuel costs are compared in order to determine optimal start-up transients. The start-up monitoring identifies deviations from the ideal condition and points out savings potentials. It thus provides an important prerequisite for the decision support at the site – e.g. for new unit application strategies, an automation of start-up procedures or a prevention of faults.

The start-up heat consumption mainly depends on the previous downtime. The colder the plant, the more heat will be required for the start. The following example of a systematic analysis of start-up procedures shows that the applied fuel quantities and thus the fuel costs per start-up often differ significantly in spite of similar boundary conditions (downtime).

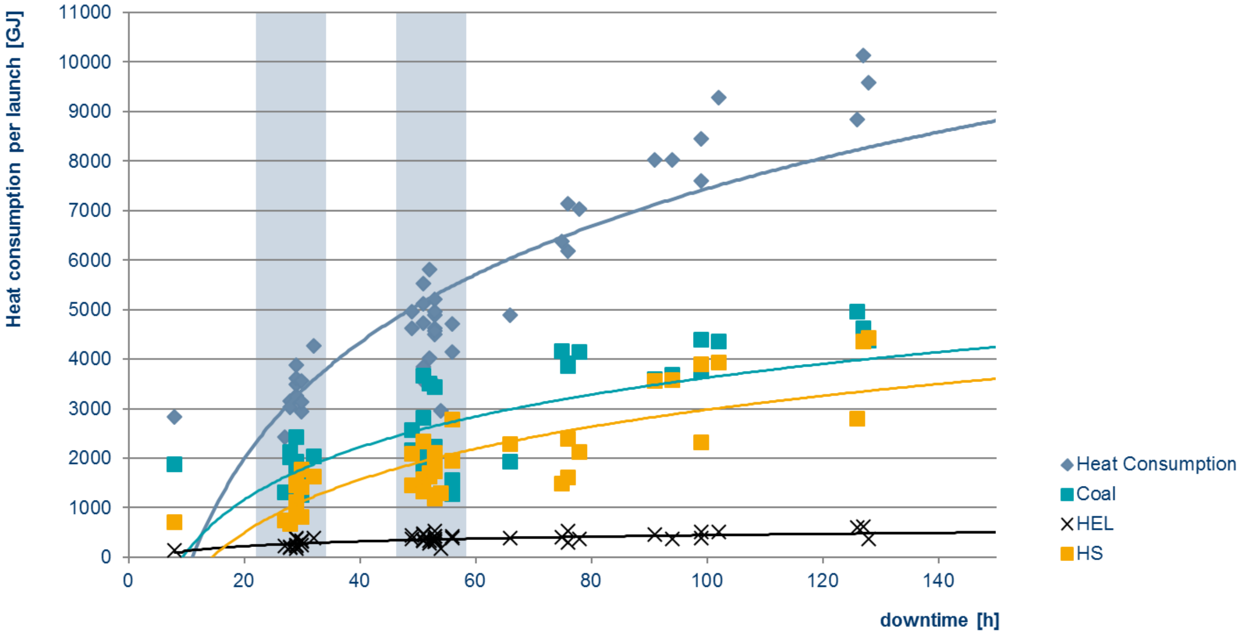


Fig. 1: Fuel and heat consumption for different start-up procedures as a function of the downtime

Thus the following savings potential results for two examined start-ups:

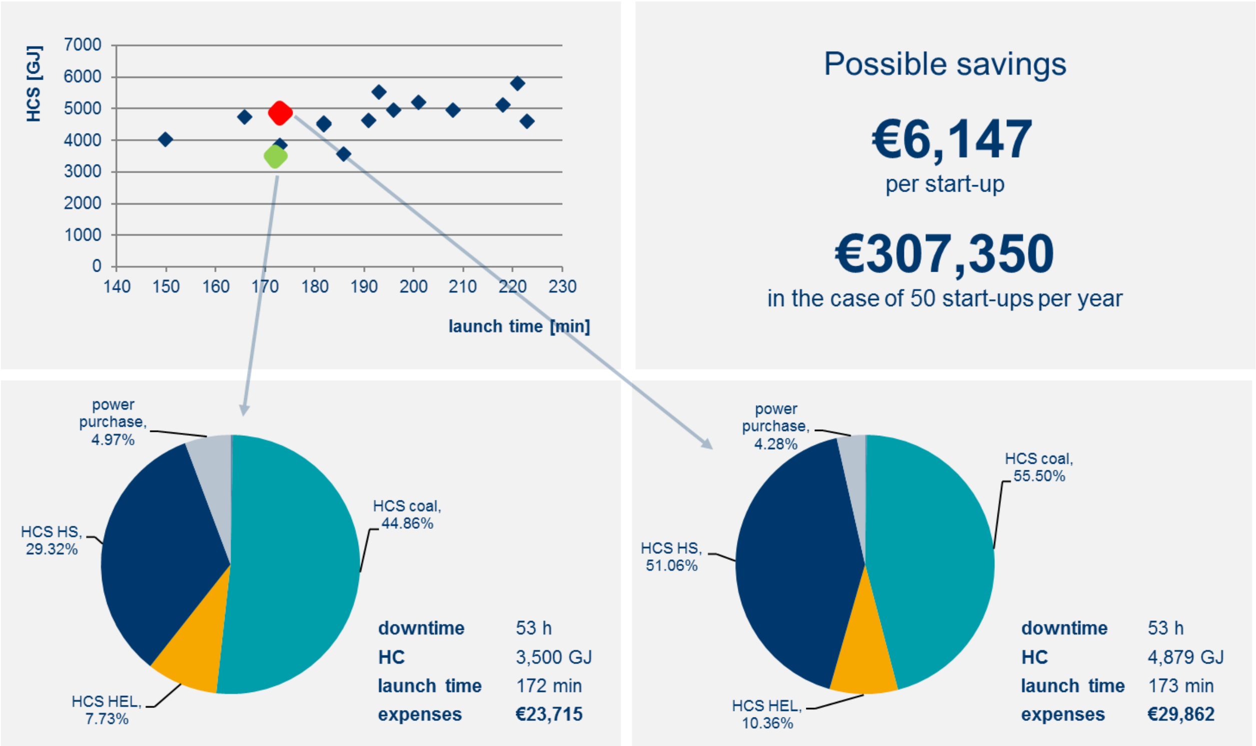


Fig. 2: Determining the savings potential for selected start-up procedures.

For an integrated assessment of the start-up costs, the wear costs due to low cycle fatigue for critical boiler and turbine components must be considered as well. The higher the temperature transient during the start-up, the higher the stress of thick-walled components. In the case of high start-up speeds, however, the fuel costs decrease as the phases when expensive secondary fuels (gas and oil) are required are shortened. Therefore the goal is to determine ideal start-up transients as the best compromise of fuel and wear costs.

For this, the total cost of a header was rated at €1 million (material, manufacture, delivery, mounting, inspections). The planned operating time is 200,000 hours.

The following diagram shows the interrelationship of fuel costs and wear costs as a function of the temperature gradient.

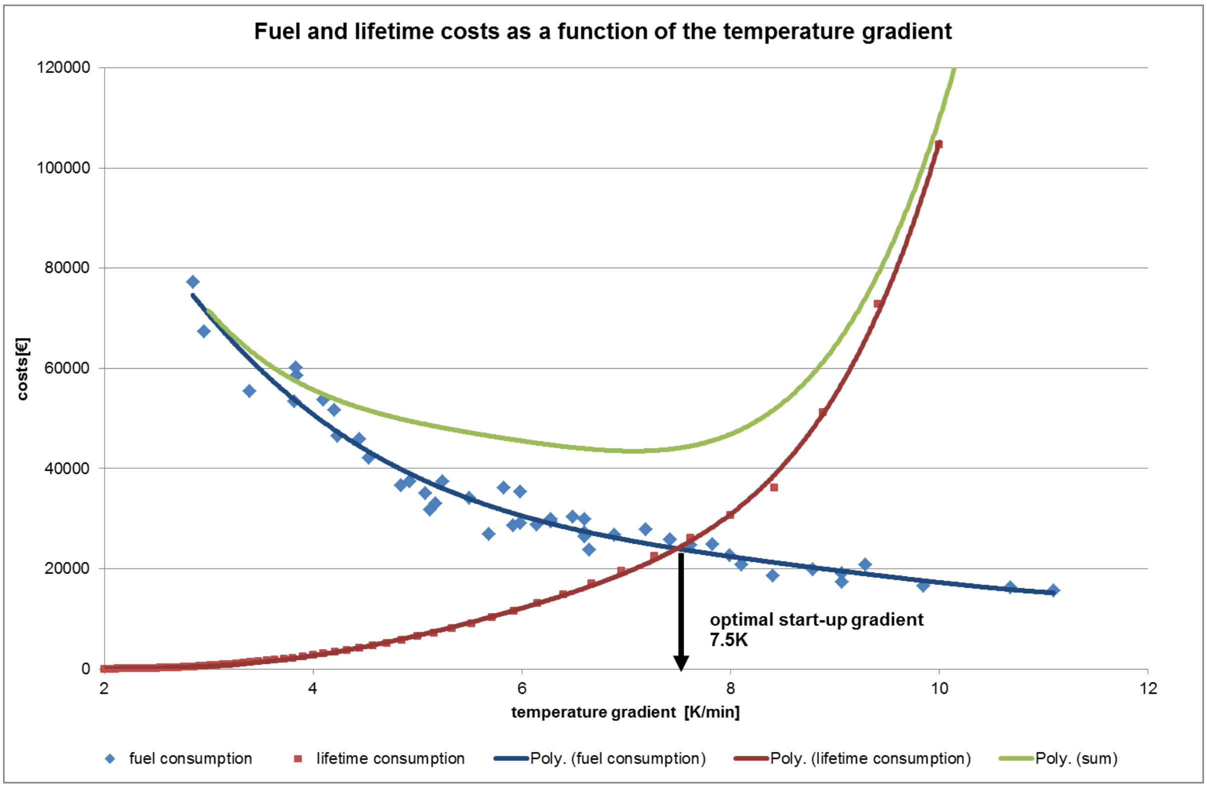


Fig. 3: Fuel and lifetime costs as a function of the temperature gradient

Thus the optimal temperature gradient is at 7.5 K/min.

By continuously determining and monitoring the fuel and wear costs, optimal start-up gradients can be derived, and the economically efficient operation can be ensured. Besides a precise recording of the fuel quantities per procedure, the integrated start-up monitoring of STEAG Energy Services also considers the low cycle fatigue of selected critical components. Thus all information for a systematic optimization of the start-ups is available.

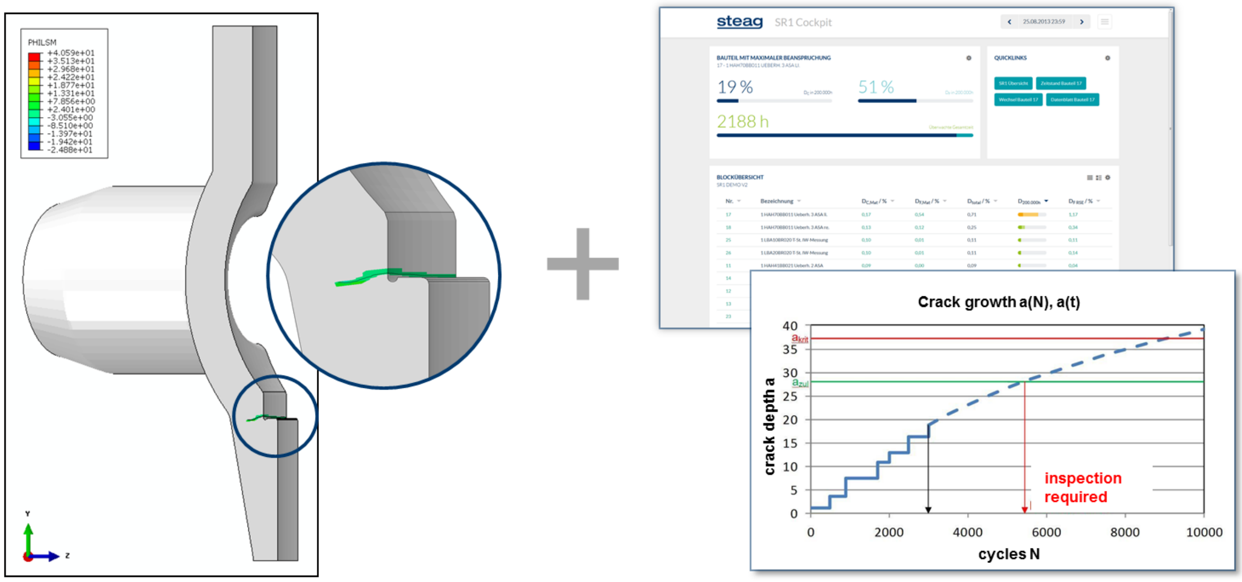
3.3. Smart Inspection Assessment for a Safe and Flexible Continued Operation

High load change velocities in combination with maximal and thus economically efficient test cycles can only be ensured if the component condition is known. The flexible operation of today's plants was not considered at the time of the design. Therefore it cannot be assumed that the component fatigue takes place as originally expected. In addition, inspections were mainly restricted to damages due to creep stress in the past. For a safe and flexible continued operation, the component condition in terms of low cycle fatigue must be determined.

Moreover, with SIA (Smart Inspection Assessment) STEAG Energy Services and TÜV NORD SysTec have developed a procedure that enables a substantiated acceleration of the start-ups and load changes. Here the highly flexible continued operation of the components is ensured on the basis of crack predictions – even if the operating history is unknown. With SIA, modern test and calculation methods are combined in a perfect way. A crack formation is assumed based on ultrasonic tests on undamaged components at first, and the further presumable crack growth is predicted online, taking into account the records on the mode of operation of the plant. The result: SIA allows to define condition-based inspection intervals in order to reduce the maintenance costs and ensure the continued operation.

Benefits of the solutions for a higher flexibilization of the unit operation:

- Mastering the balancing act between flexibility and wear by means of systematic condition assessments of highly stressed boiler components
- Identifying optimal start-up transients from an economic and technical point of view
- Identifying and making use of potentials for a flexible operation by means of online monitoring of thick-walled components
- Optimizing inspection cycles and reducing costs by means of condition-based maintenance intervals for ensuring the continued operation
- Keeping track of component conditions at all times by means of continuous trend predictions
- Unlocking component reserves by modern calculation methods
- Systematically planning the unit operation from an economic and technical point of view
- Reducing the maintenance costs by means of an improved prediction of the component condition



Trend projection

Examples of the operating scenarios “base load“ and “energy turnaround“ are shown below to contrast different modes of operation.

Both trend diagrams of the software SR::SPC (Fig. 4 and 5) show the extrapolation of the alternating low cycle over one year (projection period). The expected increase in fatigue in this time period amounts to 0.5 percent for both scenarios. In the scenario “energy turnaround”, steep transient operating procedures and frequent load changes lead to a higher stress of the superheater 4 header. After six months already, 0.5 percent alternating low cycle fatigue would be reached with a comparable mode of operation. For 30 years, the alternating stress would double from 15 to 30 percent. According to the damage accumulation [1], the fraction of the creep damage is to be added on top of this.

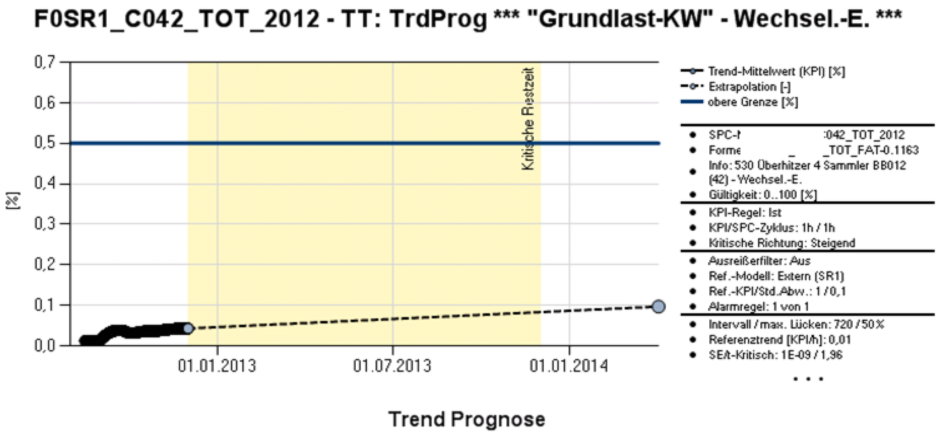


Figure 4: Continuous extrapolation of the alternating low cycle fatigue – scenario "base load"

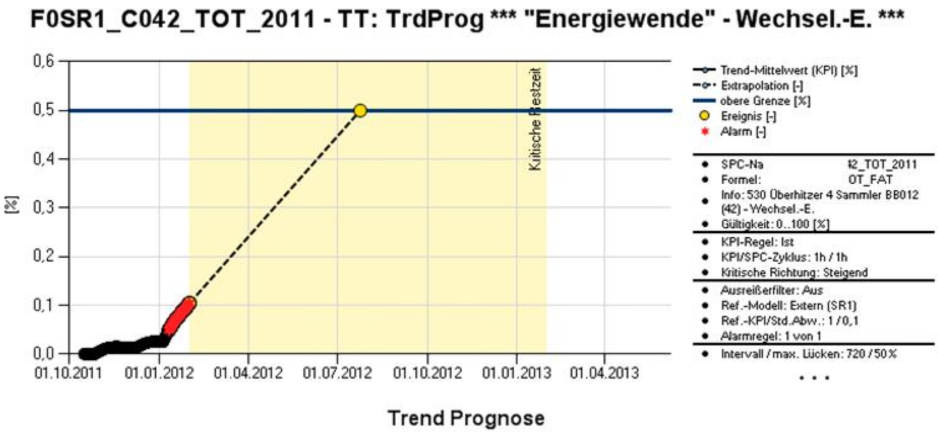


Figure 5: Continuous extrapolation of the alternating low cycle fatigue – scenario "energy turnaround"

4. SUMMARY

In future, online systems will make a large contribution to operation management and maintenance management. The more precisely the plant condition is recorded and assessed based on the modules mentioned above, the more precisely can the inspection methods, scopes, and intervals for the recurrent inspections be planned. [1] In the case of new plants or when changing components, the monitoring and thus the recording of critical modes of operation is recommended from the beginning in order to be able to argue for individual inspection intervals (extension or reduction) and to plan and reduce the maintenance effort. In the case of existing plants, a recalculation of the operating time elapsed so far is possible – provided that the required operating data are available.

If historical operating data for an assessment of the component condition are unavailable, the continuous operation and future inspection intervals can be determined with SIA in an economically particularly efficient way. The procedure perfectly combines modern test and calculation methods.

In addition, the continuous trend analysis monitors the stress of thick-walled components. If the expected fatigue is transgressed during the projection period due to the current mode of operation, one can react with a more moderate mode of operation, or the additional consumption can be economically assessed and tolerated if applicable.

A key aspect is the assessment and optimization of start-up procedures. For this, the costs are assessed in an integrated way, and optimal start-up transients are determined from an economic and technical point of view. In combination with a powerful start-up automation/control, the adherence to maximally admissible transients can be ensured in future.

5. REFERENCES

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