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Assessment of the rise in the turbine operation risk due to increased cyclicity of the power unit operation

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A B S T R A C T

The energy market liberalization and the increasing share of renewable energy sources, considered for environmental reasons to be a priority in electricity generation, necessitate a change in the operation strategy of coal-fired power units. Units that have so far operated as basic ones will more and more often have to function as regulation units. This involves a rise in their operation cyclicity and frequent changes in the power output. This paper presents an analysis of the impact of these new methods of operation on changes in the technical risk. A detailed analysis is made of the turbine rotors, whose damage may lead to severe consequences. It is proved that a rise in the operation cyclicity may raise the level of risk related to further operation. The risk growth effect is especially important for power units which have already been operated for a long time and whose components show a relatively large life consumption.

1. Introduction

The change in the structure of electricity generation sources observed in many European countries characterized by a growing share of renewable energy, wind energy in the first place, is first and foremost dictated by the environment protection reasons. At the same time, long-operated coal-fired power units are being replaced with new supercritical power plants with a capacity of the order of 1000 MW. Such power units are characterized by high electricity generation efficiency that exceeds 45% and allows a substantial reduction in carbon dioxide emissions per a unit of generated energy. At present, therefore, the structure of a typical power generation system comprises old coal-fired power plants, new supercritical coal-fired power units, renewable energy sources and, in many cases, nuclear power stations. Coal-fired power units have a special role to play in this structure because in many countries they are still the basis that ensures adequate power supplies. They have to satisfy in parallel the requirements of economic efficiency, environmental protection as well as those related to a much higher thermal flexibility. This last requirement is dictated by the priorities of electricity generation from renewable sources, wind farms in particular, in which changes in energy generation often have a stochastic nature. The shortages of power resulting from a smaller electricity generation from wind have to be compensated for by coal-fired power units. An essential problem that arises from this fact is the ability of these units for transition from basic to regulation operation, the opportunity to introduce rapid changes in loads and shortening of the start-up time. The following are examples of the power unit operation flexibility measures:

- the allowable range of changes in the power capacity and the ability to operate permanently with the maximum and minimum power,
- the ability for frequent shutdowns and start-ups and the rate of completion of start-up and shutdown processes,
- the allowable rate of changes in loads in small and large ranges of the power output.

If these criteria are satisfied, the system reliability is sufficient to ensure supplies of appropriate amounts of energy. However, this may also create a series of problems related to the power unit cyclic operation and the high frequency of changes in power. The effect of this operation pattern are essential changes in the thermal and strength states of the boiler and turbine elements, which has an impact on the durability and safety of the power unit operation.

The issues related to the increased cyclicity of the operation of coal-fired power units is now a subject of numerous studies. For example [1], evaluates the problems of damage to the power unit elements due to the cyclicity of thermal and mechanical stresses.

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Nomenclature

J	Rice integral
K_I	stress intensity factor
K_{IC}	material toughness
L	general load acting on the element
L_L	general limit load
M	coefficient dependent on the crack shape and location
N	number of start - ups
P_f	probability of failure
R	risk
R_e	yield point [MPa]
R_m	tensile strength [MPa]
T	temperature [°C]
Z	total life consumption
Z_N	fatigue life consumption
Z_t	creep life consumption
Z_c	critical value of life consumption
a	crack size [mm]
a_0	initial crack dimension [mm]
a_{cr}	critical crack dimension [mm]
g_1, g_2, g_3	performance functions
t	time [h, min]
$\Delta\varepsilon$	range of changes in total strains
ε_I, ε_{II}, ε_{III}	strain components
ε_{ref}	strain corresponding to stress σ_{ref}
σ	tensile stress [MPa]
σ_r, σ_a, σ_c, τ	stress components [MPa]
σ_{eqv}	equivalent stress [MPa]
σ_{ref}	reference stress [MPa]

The impact of thermal and mechanical fatigue of the superheater tubes on their residual life and the durability of the entire unit is estimated together with economic and ecological gains made due to improved flexibility of the power unit operation. The change in the conditions of the coal-fired power unit operation due to the development of renewable energy sources and market liberalization is also discussed in Ref. [2]. It is shown that a rise in the number of start-ups and changes in the power unit capacity necessitates a rise in the number and scope of maintenances. The economic effects of different strategies of the power unit operation and the impact thereof on the durability of the boiler elements are considered in Ref. [3]. The conclusions presented in the papers mentioned above indicate that it is possible to improve the power unit operation flexibility even though this type of operation involves certain costs [4]. It should also be emphasized that the papers focus primarily on the operation of boilers without an analysis of the turbine operation under new operating conditions. This paper presents an analysis of the impact of an increased number of the power unit start-ups on the technical risk of operation. Detailed considerations focus on an analysis of the turbine components, especially rotors. Failure of the rotor may have very serious consequences such as financial losses, but it may also present hazards to the life and health of the power station personnel. An assessment of the change in the risk related to a change in the turbine operation strategy should be the basis for a rational decision concerning an increase in the power unit operation cyclicity.

2. Operation-related risk analysis

2.1. Risk analysis procedure

The impact of a change in the operating conditions on the safety of operation of the power unit elements was estimated by comparing the change in the technical risk for different operation strategies. Technical risk is understood as the product of an unfavourable event occurrence probability and the event consequences. Denoting the risk as R, the following may be written:

$$R = \sum_i P_i \cdot C_i \tag{1}$$

where:

P_i – probability of occurrence of event "i",
C_i – consequences of occurrence of event "i".

The flowchart of the procedure for an analysis of risk defined in this way presented in Fig. 1 includes the following: definition of the analysed system and its elements, identification of hazards related to the operation of a given element, qualitative and quantitative risk estimation and risk assessment in the light of adopted criteria.

The first basic step in the risk analysis is to define the analysed system, its subsystems and main elements. In the case presented herein, the system is a power unit with the following main subsystems: the turbine, the boiler and the generator. The considerations are further focused on the risk analysis of the main components of the turbine.

The next step in the analysis is to identify hazardous scenarios. The basic stage of the risk analysis is to find out what bad may happen and what the potential situations and processes are that may lead to incorrect or dangerous operation of the elements and of the entire system. This means that identification of the scenarios requires very good knowledge of a wide range of aspects, both structural and operational. A good source of information about the possible scenarios of damage are the data concerning previous failures, experience gained from operation and maintenance/repair works as well as engineers and experts. The essential stage of the risk analysis procedure is the risk estimation. Depending on the specificity of the system under analysis, the availability of data, the expected accuracy of the estimation and the computational capacity, both qualitative and quantitative methods are used. The quantitative estimation result is the risk numerical value assigned to individual scenarios, elements and to the entire system. A prerequisite for the risk quantitative estimation is the calculation of the probability of the occurrence of hazardous events. Analytical and simulation methods are used for this purpose. Statistical

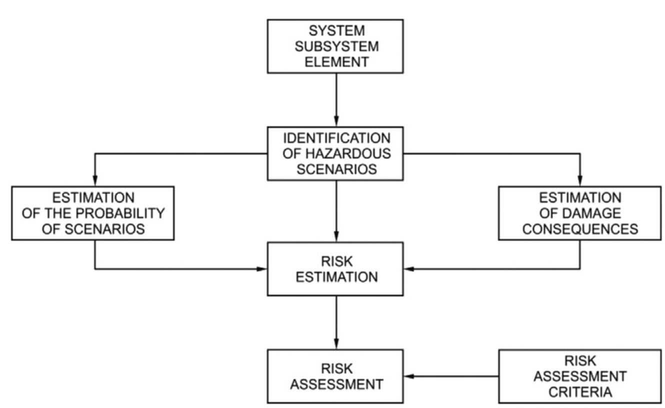

Fig. 1. Flowchart of the risk analysis procedure.