Adaptation of coal-fired units for further operation in the transitional period of transformation of the Polish energy sector

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Introduction

Poland, like other EU countries, is trying to transform its energy system by gradually increasing the share of generation from low- and zero-emission sources. For this purpose, investments have been carried out for many years to increase the participation of energy from renewable sources while limiting the use of fossil fuels. The phasing out of coal sources should be synchronized with the increase in renewable energy generation to ensure Poland's energy security and the competitiveness of its economy as well as the financial possibilities of its citizens.

Abandoning the operation of coal-fired units, similarly to other EU countries, should be properly synchronized with the launch of subsequent renewable energy sources, continuous safety verification, including updating forecasts of demand for energy and heat.

Among the coal-fired units still operated in the Polish power system, 200 MW class units deserve special attention. These units have been modernized many times, especially to reduce emissions and improve efficiency. Due to their number, design features and relatively cheap ability to extend the operation of the main thermomechanical devices and the life of the most important structural components, they can provide the Polish but also the European energy system with a significant volume of power and flexibility.

Modernizations of 200 MW class units were often carried out with the significant participation of Pro Novum, especially in terms of improving their safety, availability and flexibility. Using our knowledge and experience, we have developed "Guidelines for extending the life of thermomechanical devices in power units from 100 MW to 360 MW" [1] with the participation of the best specialists from Polish power plants. On their basis, technically advanced diagnostic systems have been created enabling online updates of technical condition assessments, verification of durability forecasts and archiving of information and knowledge, assuming that one of the most important conditions for safe operation and availability is maintaining technical competences, especially in the field of maintaining the technical condition [2].

We have equipped the latest versions of diagnostic systems with functions supporting the safety of not only 200 MW class units, which operate in an increasingly regulatory mode. Additionally, we have developed a method to improve the flexibility of 200 MW units based on the identification and use of reserves in durability and control systems [3]. We intend to offer our diagnostic surveillance systems in the LTDSA (Long Time Diagnostic Service Agreement) mode. We also equipped them with functions for monitoring the technical condition of units decommissioned, which will have the status of a strategic reserve for some time, i.e. they will be ready for "emergency" activation in the event of a threat to the security of the National Power System.

We strive to ensure that our solutions supporting the safety and availability of devices and power units are closely related to the needs of the Polish energy industry. We hope that, among others: with the support of our solutions, the transformation of the Polish power system will be carried out in a sustainable and rational way. In Polish conditions, this means the need to use existing sources of energy generation from coal and long-operated energy equipment in a way that will ensure the fastest possible increase in renewable energy generation, taking into account the fact that it is a very expensive process and still involves many technical, organizational and geopolitical risks.

The current state of the Polish power system

From the beginning of its existence, the Polish energy industry was mainly based on fossil fuels, such as coal and lignite. Since 2008,

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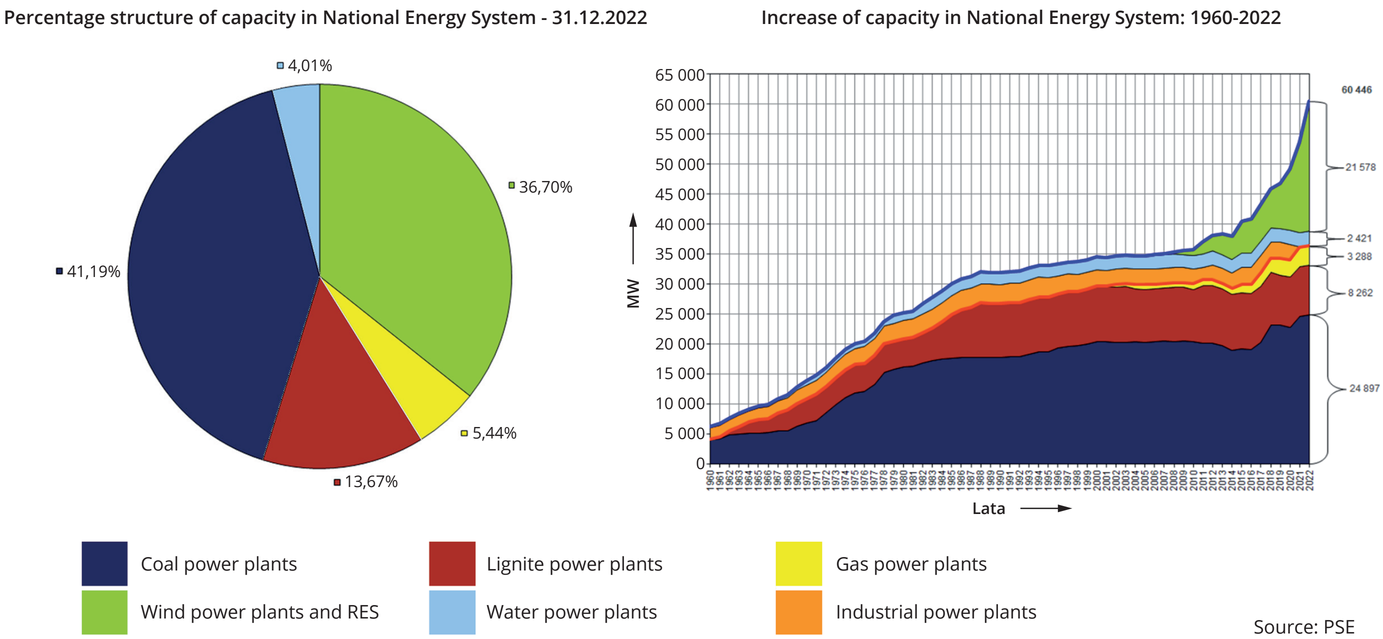

Fig. 1. Structure of electricity production in Poland (December 31, 2022) and its change over the period (1960 - 2022).

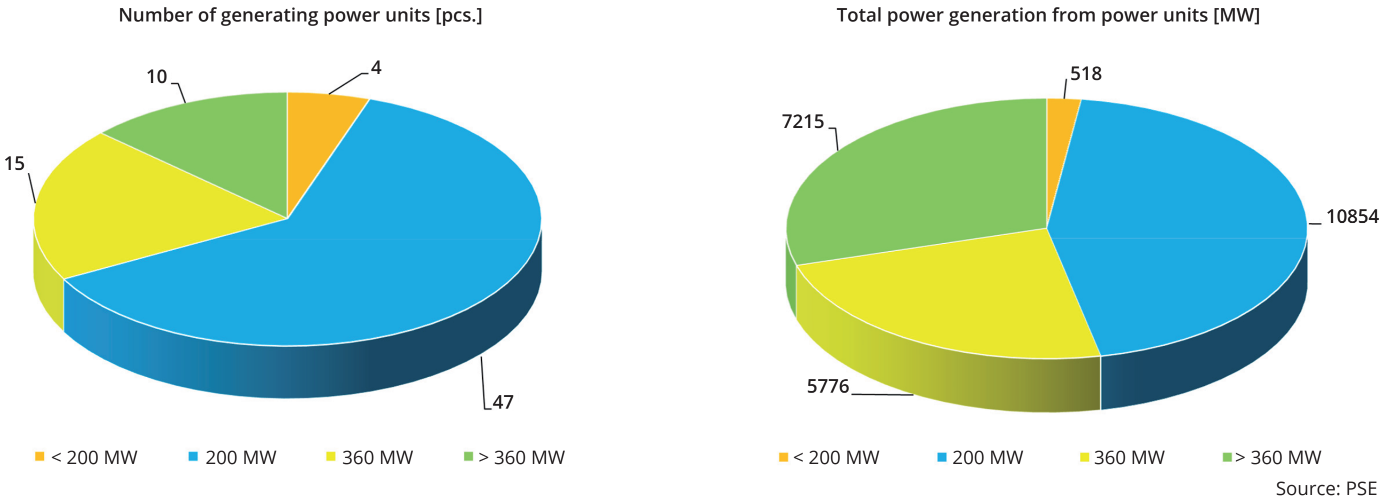

Fig. 2. Power of Generation Units with the status of Centrally Dispatched Units.

due to a large number of investments, the power generated from renewable sources has been growing at a high rate (Figure 1). Moreover, the Polish energy strategy assumes the launch of further large power plants using low-emission and renewable sources (e.g. nuclear power plants and large wind farms in the Baltic Sea). Unfortunately, a large amount of energy from renewable sources in the energy mix, apart from the obvious benefits, causes problems with the stability of the energy system. To prevent this, the construction of gas power plants was planned, but due to the current geopolitical situation, this raw material has become a dangerous, uncertain and expensive source of energy. For this reason, a scenario in which existing coal units will operate in an increasingly regulated mode is very likely. It is possible that some of them will have to increase their flexibility.

The most energy from coal, almost 50% of the available power of the National Power System, is generated by 200 MW units (Figure 2). The vast majority of them were created at a time when current methods of construction, calculations and diagnostics were not available, and a completely different approach to the operating time of devices was used than today. The devices were to work as long as possible and be repairable not only by their supplier. This created conditions for their numerous modernizations aimed at extending their operation, but also at improving their efficiency and adapting them to legal requirements, especially in terms of meeting pollutant emission limits. Pro Novum performed diagnostics on almost all of these units, and participated in their modernization in some of them, extending operation and improving safety and availability.

The units that in the past operated in the basic mode and were designed for such operating conditions currently operate in the regulatory mode, which forces a much higher frequency of startups, shutdowns and very frequent power changes in the range between the nominal power and the technical minimum, in some cases reduced compared to design (Figure 3). The 200 MW class units are most exposed to such work. Currently, some of them work periodically in a mode close to flexible, due to the reduced technical minimum and the large number of startups. For this reason, they are more often used to stabilize the system by the Polish operator.

Diagnostics as a source of knowledge to improve the flexibility of 200 MW units

Ten years ago, Pro Novum, anticipating the need to extend the operating time and increase the availability of 200 MW class coal-fired power units, developed the "Guidelines..." [1] for power plant specialists responsible for maintaining the technical condition of the power plant's production assets. Subsequently, the "Pro Novum Guidelines" [2] were extended to include issues of energy chemistry and 100 to 360 MW units. In our "Guidelines..." we use not only our own knowledge and experience

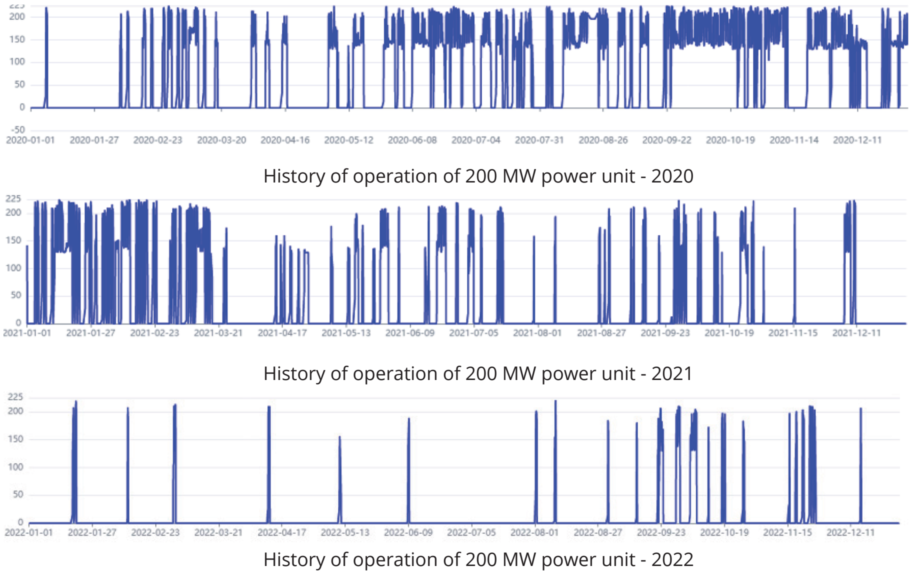

Fig. 3. Charts of power of coal-fired units – selected examples.

[3-7], but also state standards and documents, including the Office of Technical Inspection and foreign documents and studies, including VGBE [8].

The Pro Novum guidelines also have IT versions. Diagnostic systems in this form have been implemented in the Polish energy industry for many years. Their essence is to treat diagnostics as a process related to the operation of the power unit (Figure 4). This approach enables the use of all relevant information about operation (operation history, working conditions, failure states) and maintaining the technical condition of the facility (repairs, renovations, modernizations) and allows diagnostics to be performed remotely.

An important component of the Pro Novum Method to increase the flexibility of 200 MW units is the Virtual Diagnostic System (VDS), which is based on the digitization of processes and objects subject to diagnostics and communication between the real object and the diagnostic test environment (Figure 5). The basis of VDS operation is communication between the systems located in the power plant (measuring systems, DCS, etc.) and the Pro Novum expert environment in which diagnostic algorithms are implemented. In the Pro Novum environment, tests and calibrations of algorithms are performed, which are ultimately installed at engineering stations in the power plant – in order to increase the security of its infrastructure. Thanks to this, Pro Novum algorithms can be part of the unit control system (stored in operator logics), provide information for the operator (in real time) and asset maintenance specialists. The use of tools such as VDS allowed for the successful implementation of the Pro Novum Method to improve the flexibility of a 200 MW class unit. The success was due to, among others, limiting the number of tests on a real power unit.

The Pro Novum method of increasing the flexibility of 200 MW units is based on an advanced analysis of operational, design and process problems, as well as the identification and use of reserves in the strength and durability of devices as well as critical elements and reserves in the power unit control system (Figure 6). The proposed method does not require significant modernization or replacement of the unit equipment, which makes it low-cost and largely universal. The use of reserves in terms of strength and durability of devices is carried out using modern computing and IT technologies implemented in VDS. The temperature criteria were replaced with stress criteria, which was implemented in the so-called Durability Control Block.

The Pro Novum method was tested and verified as part of the Units 200+ project financed by the National Center for Research and Development. The aim of the project was to develop a method that could increase the flexibility of class 200 units and verify its assumptions on a reference (real) power unit. The project assumed making appropriate modifications to the power unit to enable lowering the technical minimum and accelerating the unit's startup from various thermal states. Many consortiums took part in the project, which was divided into 3 stages, and 3 companies reached the finals, including Pro Novum, which entered it from 1st place. The method we propose assumes the use of natural reserves of 200 MW class units in terms of the durability of the main components of the unit and the possibility of changes in the steam-water-fuel-exhaust gas process control system.

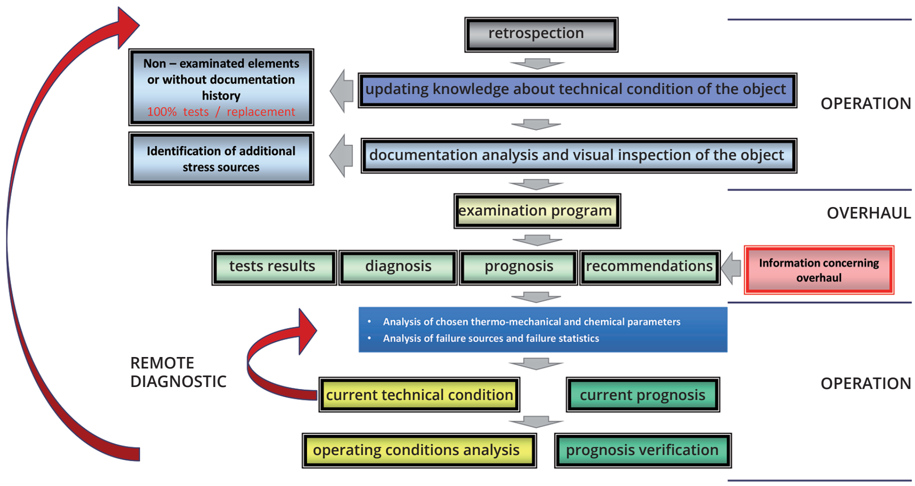

Fig. 4. Diagnostic system as a process integrated with the operation of the unit.

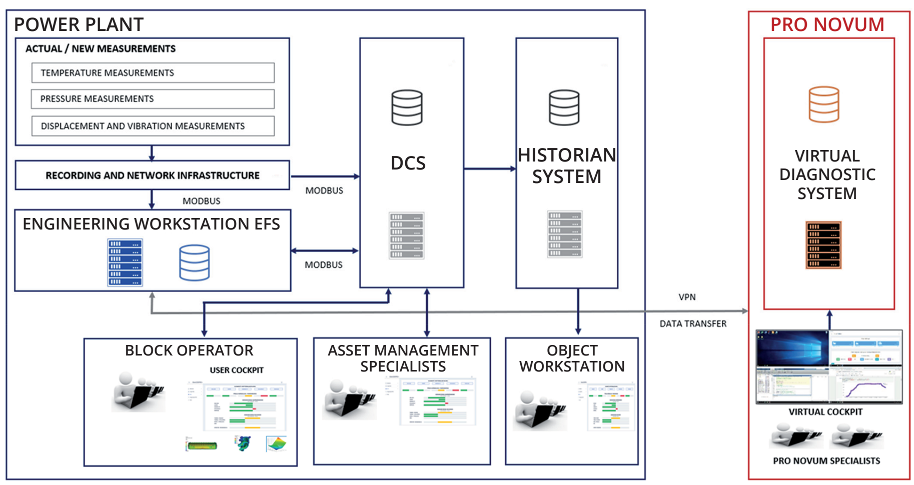

Fig. 5. Architecture of the Virtual Diagnostic Environment and its communication with the power unit on which the Pro Novum Method to increase flexibility was implemented.

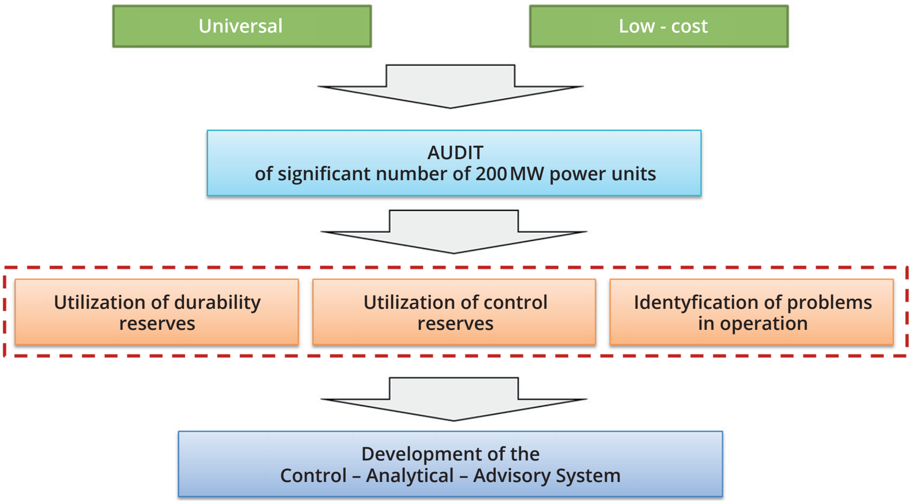

Fig. 6. Pro Novum Method concept – diagram of the process of improving the flexibility of a 200 MW class unit.

The use of reserves on the strength side is analysed by calculating stresses in the critical elements of the unit in real time. For this purpose, VDS uses the concept of a digital twin. Depending on the needs, we use reduced numerical models or response surfaces to model real objects. The model processed in this

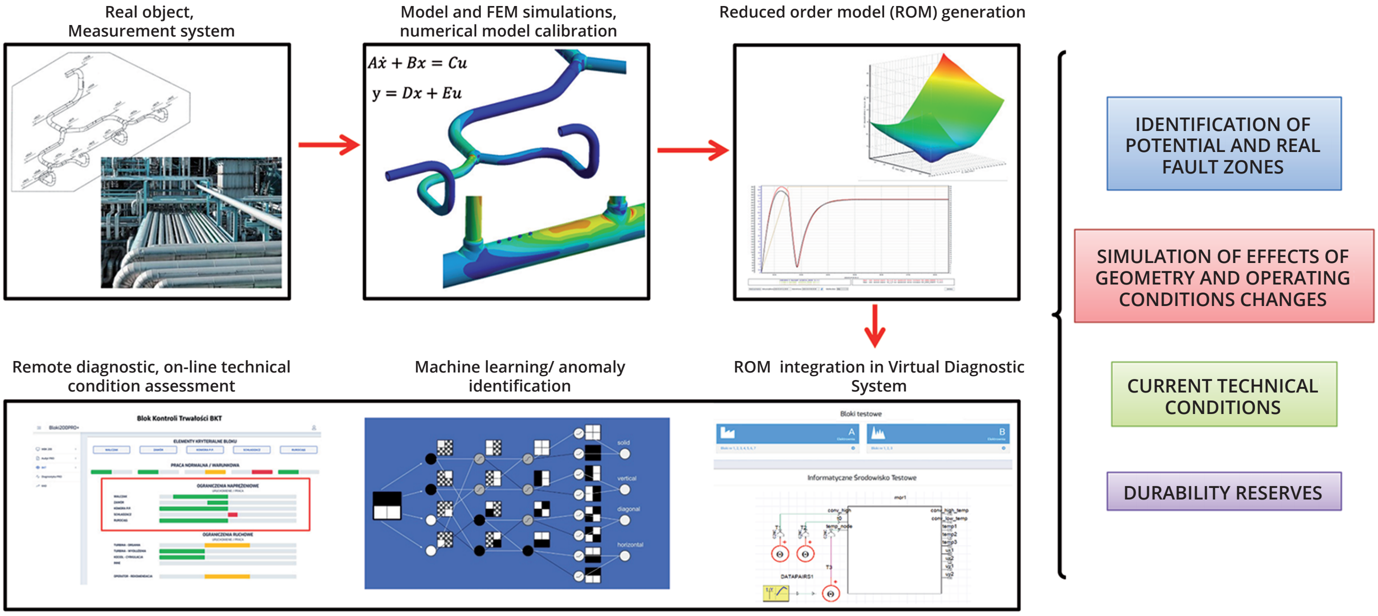

Fig. 7. The process of creating a digital twin, machine learning and integration with expert software.

way may generate data that is difficult or impossible to obtain on the basis of the measurement system (e.g. due to the lack of appropriate sensors). Models developed based on current documentation are calibrated based on retrospection, including the analysis of the history and operating conditions of devices/elements recorded in DCS, as well as the results of tests performed during device standstills. Information from the twin is processed by expert algorithms (Figure 7).

We use numerical models of real objects to create digital twins. We try to ensure that they are based on current material data (based on research), which is extremely important in the case of modelling long-term objects. Examples of models installed in the VDS system are turbine casings, chambers, pipelines, valves and drums (Figure 8). Part of the VDS is the Virtual Testing Environment, thanks to which we have the opportunity to test the behaviour of various design nodes (devices) under real and simulated operating conditions of the unit (e.g. accelerated startups, reduced technical minimum, faster power consumption, etc.). Thanks to it, we managed to significantly reduce the number of time- and labour-consuming tests on a real power unit.

VDS can also be used to determine the possibility of conditional operation of a damaged element (with a crack). An example of such an application was work on a steam boiler element (steam superheater outlet chamber), in which cracks were detected during renovation and could not be repaired due to their location (internal surface) and the prefabrication of a new element required several months. The use of VDS enabled continued safe operation of the chamber until it was replaced.

Summary

Taking into account the still large share of coal energy in the Polish energy mix, it is difficult to imagine that it could be completely abandoned in the next 20 years. It is also impossible to imagine the Polish power system without 200 MW class units in the next 10-15 years.

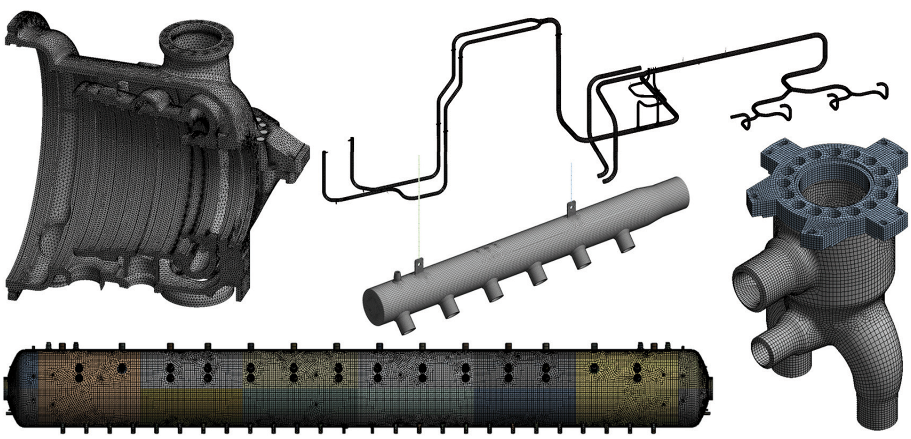

Fig. 8. Examples of numerical models of critical elements and installations used in diagnostic systems monitoring their current technical condition remotely.

Due to their design features, 200 MW class units allow their operation to be extended as long as there is sufficient technical competence to maintain their technical condition (not necessarily with equipment suppliers). These units can also significantly support the flexibility and security of the Polish energy system, as they can be adapted to regulatory operation at low cost.

However, it should be remembered that these units have been modernized many times. The more modernized the unit (the greater the number of new components), the more difficult it is to reach for reserves because the suppliers of new components have reduced them to a minimum. However, their individual flexibility does not have to be increased extremely, because their large number in the power system improves its flexibility to a significant extent. We assume that even if there are no funds for the modernization of 200 MW class units, there is a chance that much smaller funds will be found to adapt them to:

- extension of service life,
- improving flexibility to the most useful extent, e.g. reducing their technical minimum,
- co-combustion of biomass and/or alternative fuels.

The Pro Novum method can help meet the above-mentioned expectations in a low-cost way, by:

- identification of durability stocks and reserves on the side of controlling the course of basic processes in the unit,
- development of appropriate measurement, logical, analytical and IT infrastructure implementing the Method,
- supervision over the safe operation of the unit using the described infrastructure.

Extending the operation of coal-fired units and adapting them to new operating regimes, properly synchronized with increasing generation from low- and zero-emission sources, is a sine qua non condition for the successful transformation of the power system not only in Poland.

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Kurzfassung

Anpassung von kohlebefeuerten Blöcken für den weiteren Betrieb in der Übergangszeit der Transformation des polnischen Energiesektors

Wie andere EU-Länder versucht auch Polen, sein Energiesystem umzugestalten, indem es schrittweise den Anteil der Erzeugung aus emissionsarmen und emissionsfreien Quellen erhöht. Zu diesem Zweck werden seit vielen Jahren Investitionen getätigt, um den Anteil der Energie aus erneuerbaren Quellen zu erhöhen und gleichzeitig die Nutzung fossiler Brennstoffe einzuschränken. Der Ausstieg aus der Kohleverstromung sollte mit dem Ausbau der erneuerbaren Energien synchronisiert werden, um die Energiesicherheit Polens, die Wettbewerbsfähigkeit seiner Wirtschaft und die finanziellen Möglichkeiten seiner Bürger zu gewährleisten. Unter den kohlebefeuerten Blöcken, die noch im polnischen Stromnetz betrieben werden, verdienen die Blöcke der 200-MW-Klasse besondere Aufmerksamkeit. Diese Blöcke wurden mehrfach modernisiert, insbesondere um die Emissionen zu senken und den Wirkungsgrad zu verbessern. Aufgrund ihrer Anzahl, ihrer Konstruktionsmerkmale und der relativ kostengünstigen Möglichkeit, den Betrieb der wichtigsten thermomechanischen Vorrichtungen und die Lebensdauer der wichtigsten strukturellen Komponenten zu verlängern, können sie dem polnischen, aber auch dem europäischen Energiesystem eine beträchtliche Menge an Leistung und Flexibilität bieten.