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Environmentally friendly replacement of mature 200 MW coal-fired power blocks with 2 boilers working on one 500 MW class Steam Turbine Generator (2on1 unit concept)

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Abstract The paper covers problems of the owners of a fleet of long-operated conventional power plants that are going to be decommissioned soon in result of failing to achieve new admissible emissions levels or exceeding pressure elements design lifetime. Energoprojekt-Katowice SA, Siemens AG and Rafako SA presents their joint concept of the solution which is a 2on1 concept – replacing two unit by two ultra-supercritical boilers feeding one turbine. Polish market has been taken as an example.

Keywords: Coal fired power plant; Flexibility increasing; Old units replacement

Abreviations

AELs	–	admissible emission levels
BAT	–	best available technology
BREF	–	BAT reference documents
CCPP	–	combined cycle power plant
COSTART	–	parallel start of boiler and steam turbine

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EPK	–	Energoprojekt-Katowice SA
ESP	–	electrostatic precipitator
FGD	–	flue gas desulfurization
GCF	–	gross capacity factor
GDP	–	gross domestic product
HI	–	high-intermediate
HP	–	high pressure
IP	–	intermediate pressure
IRR	–	internal rate of return
LCP	–	large combustion plant
LP	–	low pressure
LUVO	–	Ljungstrom rotary air heater
NPVR	–	net present value ratio
OECD	–	Organisation for Economic Co-operation and Development
PSE	–	Polskie Sieci Elektroenergetyczne S.A. (Polish Power Grid Company)
PV	–	photovoltaic
RH	–	reheated
SCR	–	selective catalytic reduction
SPC	–	set point controller
SPP	–	steam power plant (coal fired power plant)
SPPA	–	Siemens Power Plant Automation
USC	–	ultra-supercritical

1 System power demand curve in Poland

Electric power is sometimes referred to as a commodity. Yet, even as a commodity, electricity has several unique features that distinguishes it from other commodities. The first important difference is that, unlike other goods, it is very difficult to store. Energy storage is very expensive, the storage price being comparable to the original generating cost. Under grid operating conditions, production must be instantly balanced against demand because electric power must be available on demand. Hence, a portion of power-generating assets must act as a reserve, i.e., electrical generating capacity that has to be available, but is normally not used. The second major difference is the importance of electric power to the economy, standing in direct correlation with a national gross domestic product. It is crucially important to securing reliability and stability of industry. One look at the elasticity of demand versus price provides a clear picture of just how important it is. If we combine these two distinguishing features we can conclude with relative certainty that surplus supply (power reserve) has to follow demand. Hence, it is the demand curve that determines what generating capacity is required.

The Polish Power Grid Company (PSE), is the public body responsible in Poland for maintaining the grid balance. It performs analyses and publishes data related to current and predicted power demand.

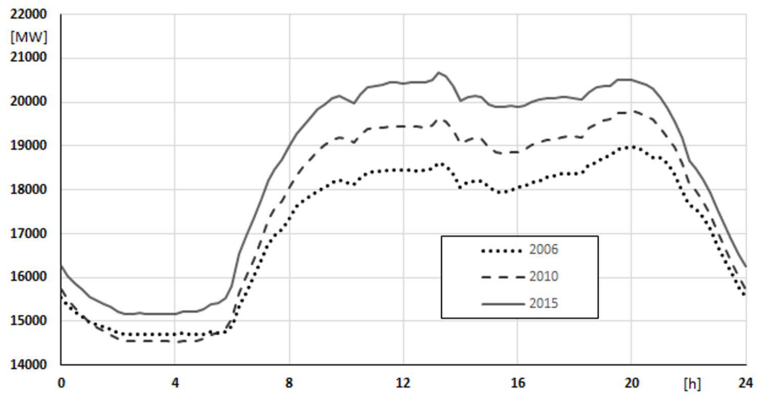

Figure 1: Poland - daily power demand profile in 2006, 2010 and 2015 [1].

As shown in Fig. 1 different unit loads (following demand) throughout the day are a consequence of the demand curve. In any economic analysis related to power generating units, the critical question arising is what will be the load percentage or, in energy industry terms, what will be the gross capacity factor (GCF). The answer to this question can be found in a monotonous curve of power demand. The curve in Fig. 2 was developed for units dispatched by PSE (centrally dispatched units).

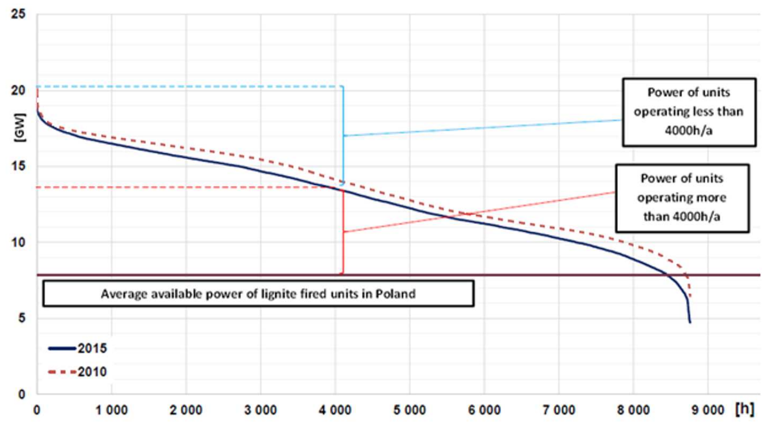

Figure 2: Poland – monotonous curve of power demand from centrally dispatched units in 2010 and 2015.

2 Future role of fossil fuel power generation and market segmentation

In electrical energy markets, a power generating unit's variable cost determines its average load and priority of operation. Thus, the lower a unit's generating costs, the more operating hours it will accumulate. By carefully analyzing the Fig. 2, three market segments can be distinguished:

- 10 GW market segment comprising base-load units, i.e., units with a generating potential exceeding 7000 h/a. This market segment should be occupied by the newest, most efficient power-generating units. However, they do not have to be particularly flexible.
- 5 GW market segment comprising units that operate at full load approximately 4000 h/a. Here, an efficiency versus flexibility tradeoff is expected.
- 5 GW market segment of peakers operating less than 2000 h/a. This market segment is occupied by flexible units whose efficiency is of secondary importance.

Additionally, cogeneration plants (approx. 10 GW) and renewable energy units (approx. 8 GW) have higher generation priority then centrally dispatched units (approx. 24 GW). It is noteworthy that grid dispatchers have limited control over cogeneration plants. It is even more important to understand that renewable energy sources, being intermittent and hardly predictable, can be a grid dispatcher's nightmare.

2.1 Power generation from renewable energy sources

In June 2016, the installed electrical generating capacity of renewable energy sources in Poland exceeded 8.2 GW. The growth of installed renewable capacity has been very rapid in recent years, as shown in Fig. 3. The authors' perspective on future growth in this sector is presented in Fig. 4. Under Polish climatic conditions, the generation capacity factors for onshore wind farms and photovoltaic (PV) plants are 2000 h/a and 1000 h/a, respectively.

2.1.1 Fossil fuel power plants – environmental protection

Fossil fuel power plants are currently under pressure to dramatically reduce their impact on the environment. In recent years, power production groups

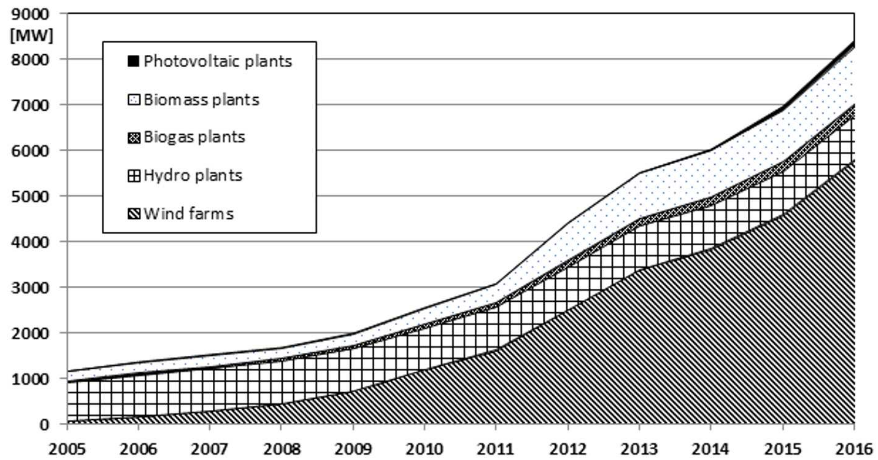

Figure 3: Diagram of installed renewable capacity growth in Poland [2].

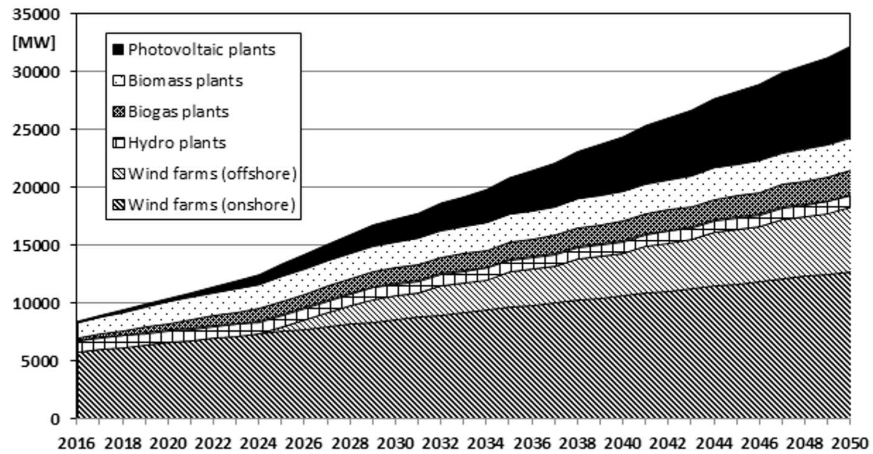

Figure 4: Diagram of projected installed renewable capacities in Poland.

have had to invest billions of euros to install dust collection, DeNO$_x$ and flue gas desulfurization (FGD) systems to meet the large combustion plant (LCP) emission limits. Nowadays, new best available technology (BAT) reference documents (BREF) must also be considered. What is more, it is predicted that prices for CO_2 emissions will rise which adds even more pressure to use only high-efficiency plants that operate at a low CO_2/kWh factor.

2.1.2 New BAT conclusions

On 31st July 2017 a resolution on the new LCP BAT was published which reduces the admissible emission levels (AELs) of existing and future power plants. The number of substances subject to emissions limits has increased: to NO_x and SO_x are now added Hg, NH_3, HCl and HF. Furthermore, a number of AELs have been stipulated for wastewater from flue gas treatment systems, and some AELs previously limited in scope have been tightened. The time allotted to adapt an installation will be four years.

2.1.3 OECD financing rules

The more stringent financing rules introduced by the Organisation for Economic Co-operation and Development (OECD) in November 2015 have strongly impacted the aforementioned methodology, requiring changes in the marketplace. The conditions of these new financing rules are summarized in Tab. 1. This implies that steam power plants built in future need to be supercritical or ultra-supercritical (USC) units in order to receive attractive financing.

Table 1: Framework conditions for OECD financing, depending on technology [3].

Maximum repayment terms

PLANT UNIT SIZE (gross installed capacity)	**Unit > 500 MW**	**Unit ≥300 to 500 MW**	**Unit < 300 MW**
Ultra-supercritical (*i.e.*, with a steam pressure >240 bar and ≥593°C steam temperature), OR Emissions < 750 g CO_2/kWh	12 years[1]	12 years[1]	12 years[1]
Supercritical (*i.e.*, with a steam pressure >221 bar and >550°C steam temperature), OR Emissions between 750 and 850 g CO_2/kWh	Ineligible	10 years, and only in IDA-eligible countries[1,2,3]	10 years, and only in IDA-eligible countries[1,2,3]
Subcritical (*i.e.*, with a steam pressure < 221 bar), OR Emissions > 850 g CO_2/kWh	Ineligible	Ineligible	10 years, and only in IDA-eligible countries[1,3]

3 Structure of current generating assets in Poland

The power generation industry in Poland is coal-based. Hard coal- and lignite-fired plants together account for 82% of the electric power generated in the country. A detailed structure is presented in the graph (Fig. 5).

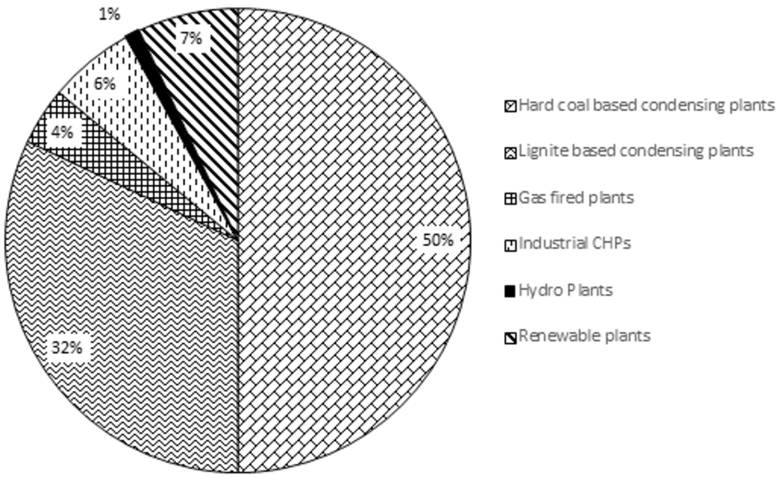

Figure 5: Poland. Structure of electric power generation by fuel in 2016.

Generating assets in Poland are aging. The average age of the centrally dispatched units is between 30 and 40 years, as presented in Fig. 6. Considering the fact that the design service life of a power plant is 40 years and for pressurized components 200 000 operating hours, it can be concluded that both construction of new units and rehabilitation projects will be necessary.

4 200 MW-class units in the Polish fleet – a weakness or opportunity?

Approximately forty percent of Polish power generating capacity is based on 200 MW-class units. The youngest units were commissioned in 1983, while the oldest have been in service 50 years. Most of these units have been modernized. In the case of Turow Power Plant, a rehabilitation project included installation of a completely new power train. Table 2 presents a detailed breakdown of the 200-MW-class units.

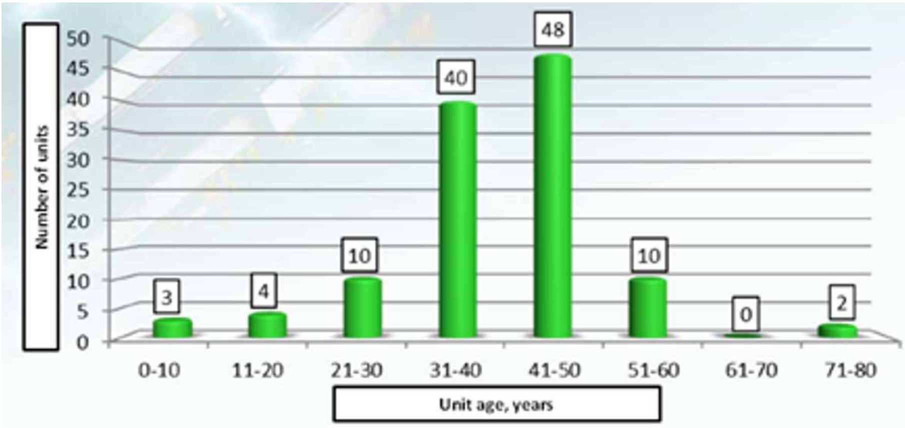

Figure 6: Centrally dispatched units in Poland – age structure.

Table 2: 200 MWe class units in Poland.

Power plant	Units and capacity	Total rated power, MW	Year of commissioning
Dolna Odra	3 x 222, 3 x 232	1362	1974–1977
Jaworzno III	5 x 225, 1 x 220	1345	1977–1979
Kozienice	3 x 228, 4 x 225, 1 x 215	1799	1972–1975
Łaziska	3 x 225, 1 x 230	905	1972
Ostrołęka	1 x 226, 1 x 221, 1 x 200	647	1972
Pątnów	5 x 200, 1 x 222	1222	1967–1969
Połaniec	2 x 225, 4 x 242, 1 x 239	1657	1979–1983
Rybnik	5 x 225, 2 x 215, 1 x 220	1775	1974–1978
Turów	3 x 235, 3 x 269	1488	1998–2005

The technical solutions applied in 200 MW units are very robust. Properly maintained units of this class can be operated much longer than their original design service life. Restrictions on operation arise either from the continually changing emissions standards or from relatively low efficiency (impacting capacity factor in the energy market).

Owners ultimately have to make decision to either decommission or modernize. If the decision is to modernize, then question is: what is the appropriate solution. It is the authors' opinion that there are two possible solutions: either improve environmental performance to comply with the standards in force and replace critical pressurized components, or replace the power train with an arrangement of 2 boilers serving 1 steam turbine (below referred to as the 'DuoBlock' design concept). In the case of the first of the above two options, the modernized unit will be a peaker (with a capacity factor of around 2000 h/a). In the case of DuoBlock units, the 480 MW steam turbine allows application of ultra-supercritical cycle parameters. Two boilers instead of one will allow for lower minimum continuous rating at about 10 to 20% power output level. In this case, a unit will be operated in a second market segment, i.e., with a capacity factor exceeding 4000 h/a. The flexibility of the unit (with a low minimum continuous rating and good ramping ability) will be an advantage compared to a single fossil-fired boiler serving one steam turbine arrangement.

Considering the scale of the problem in the Polish generation balance (40%) and the anticipated decommissioning time (middle of next decade), it must be concluded that unanswered questions concerning 200 MW units may undermine Polish power balance. It should also be noted that the project development time starting from conceptual design phase and ending with commissioning takes 10 years for large coal-fired projects (5 years for project development and 5 years for construction). Hence, a responsible approach to energy security in Poland requires action now. Consequently, a DuoBlock solution would enable Poland to limit its CO_2 emissions level, make units more competitive, and provide a potentially attractive model for other 200 MW unit owners (for example in Turkey).

5 Technical concept of the DuoBlock

The following ideas are cornerstones of the DuoBlock design concept:

- Take advantage of the existing balance of plant systems (e.g., cooling water, coal handling, ash handling, FGD, start-up fuel installation, compressed air and water treatment systems, etc.). The decision related to those components to keep or to reconstruct is site specific. The reason behind it is obvious, i.e., limitation of investment costs.
- Increase unit output to a level at which state-of-the-art cycle parameters can be used, thereby pushing unit efficiency to the highest commercially available level. Keep sizing at a level where more economical steam turbine-generator solutions are available (high- and intermediate-pressure casing solution and air-cooled generator).

- Take advantage of the steam turbine building.
- Use two boilers to feed one turbine, allowing a lower unit minimum rating and faster startup times with two boilers (taking advantage of the steam available from first boiler while the second boiler starts up). Two boilers instead of one also enables faster power ramping because of the lesser wall thickness of critical boiler pressure components.

5.1 General

The following sections present technical details and proposed solutions for the main systems of the DuoBlock.

5.1.1 Design parameters

The parameters outlined below were selected as they are considered optimum for investment:

gross power: 480 MWe,
live steam parameters: 600 °C, 26 MPa,
live steam flow: 680 t/h, 190 kg/s,
reheated (RH) steam parameters: 600 °C, 6 MPa,
technical minimum load: $\sim$ 10%,
net plant efficiency: $>$ 45%.

Due to the limited full-load operation time (the aforementioned 4000 h/a market segment), it is not necessary to focus on achieving an exceedingly high rate of efficiency. Rather, these efforts should be put to reaching maximum flexibility at limited expense. The temperatures of both the live and reheated steam are kept at around the 600 °C level, while gross power is proposed to be 480 MWe. Net efficiency according to the best avaiable technology conclusions will exceed 45%, but the specific value for particular projects will be strongly dependent on the local coal, main cooling conditions and environmental protection installations.

Two boilers shall feed the turbine with steam in the range $\sim$ 20–100% of nominal flow. It's possible to have just one boiler in operation, which decreases power output by half. However, both boilers operation would maintain the highest control capability.

5.1.2 Flexibility

Power generation has typically consisted of units operated under steady-state conditions with low load change rates. The currently ongoing world-wide expansion of electricity production from renewable energy sources requires a wholly different operating regime for fossil fuel power plants, which are now called on to generate the residual load for the grid. According to order of merit, gas-fired power plants are the first type of power plants that have to be shut down once renewables are brought on line. Following that logic, the initial approach has been to accommodate high load change rates by bringing on line and taking off line those combined-cycle power plants that were first to adapt to achieving fast startup and shutdown times. With the increasing volume of renewable energy available, today's coal-fired power plants are facing the same requirements as gas-fired units. The know-how gained from the water-steam cycle of combined-cycle power plants is now enabling engineers to adapt steam power plants to meet these challenging requirements. The gray line in Fig. 7. shows the operation line as it was in the past. The black line shows today's requirements. The arrows indicate the necessary improvements.

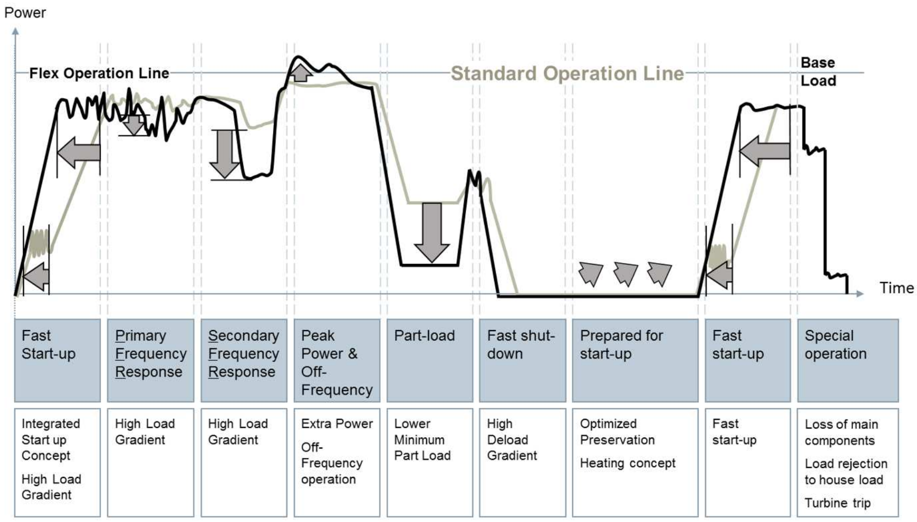

Figure 7: Power plant operation in the past and today.

To implement the functions for enhancing plant flexibility in accordance with the new operating requirements, various sets of technical measures have been developed that can be grouped as described below.

Fast startup and shutdown In traditional steam power plants and markets, the boiler and steam turbine are started in the following basic sequence:

- Ignite the boiler.
- Increase coal-fired boiler load to the minimum turbine load.
- Stabilize pressure and temperature.
- Start the steam turbine until the bypass is closed.
- Ramp the boiler to full load with the steam turbine valve wide open.

There might be many additional steps in between, like opening of gate valves which are not mentioned.

Modern plants must attempt to heat-up the boiler and all systems as well as the steam turbine as much in parallel as possible. This will ensure for maximum load ramp rate. For this purpose, boiler operation and steam turbine operation must be decoupled with regard to temperature. For example, for a coldstart the allowed steam temperature for the steam turbine might be in a range that the boiler has to stop at a certain load until the steam turbine is warmed-up. This load hold can be avoided by using desuperheaters which will limit the temperatures. The capacity of the boiler's internal desuperheaters are normally limited because of the near-saturation conditions. Therefore, an optimum can be reached by using external desuperheaters in the main steam and reheated steam headers. They will be able to reduce the temperatures by 100 K or even up to 150 K. External desuperheaters are meanwhile standard in combined cycle power plants (CCPPs).

Startup times for coldstart as well as for warmstarts will be reduced significantly without decreasing component service life. For hotstarts it would be beneficial to keep the steam turbine under vacuum to allow the steam turbine to be started without waiting for steam purity. Furthermore, it is beneficial to start even at a certain temperature mismatch. This way of starting is also well-known from CCPPs as COSTART. This is a sort of real parallel start of boiler and steam turbine without any hold. In general, for all types of startup the steam turbine will not limit startup time, but rather directly follow the load increase of the boiler.

The market situation today requires frequent startup and shutdown of plants. The task is therefore to get the unit on the grid in the shortest possible time without the thermal stresses impacting thick-walled boiler components violating permissible limits. Other requirements that must be met at the same time are reduced startup fuel consumption, ensuring repeatable startup and automatic differentiation between cold, warm and hot starts with bumpless transfer to coordinated power operation.

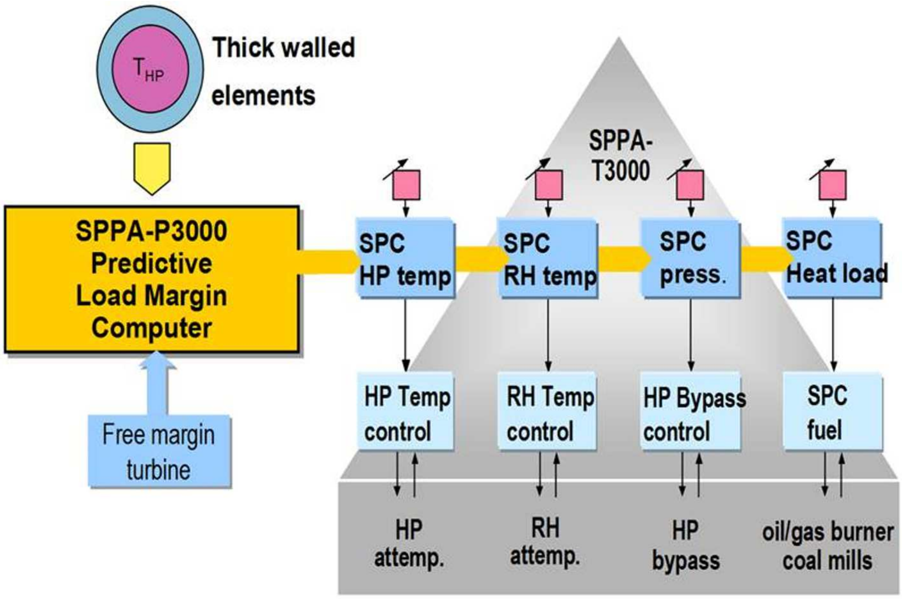

Figure 8: Siemens Power Plant Automation (SPPA) predictive load margin computer.

The predictive load margin computer calculates current thermal boiler stresses and forecasts future values for thick-walled parts from measured variables (steam temperature, pressure and mass flows). These data are used to control in Set Points Controllers (SPCs) the firing rate and the steam temperature such that material stresses do not exceed permitted limits. The process is much quicker and more reliable than pure gradient limitation as used in traditional startup circuits.

Warm standby operation Siemens has developed an electrical heating system for keeping the steam turbine warm and ready for startup while it is on the turning gear. This system heats all relevant steam turbine components to maintain the rotor shaft temperature at warm startup conditions. Compared to startup from ambient conditions, this system enables the steam turbine to be run up to full load more than 60 min faster. In addition, the number of equivalent operating hours used per startup is significantly reduced.

Part-load efficiency/load ramps A power plant unit needs to be operated at the most profitable operating point under all operating conditions, from partial load to full-load operation. This is the task of the unit master control structure.

The model-based unit master coordinated control concept is designed for low-stress operation of the power plant. Scheduled setpoint changes by the operator or load dispatcher are performed according to a model based on the natural transmission behavior (S-shaped) of the steam generator, and do not restrict primary frequency control capability. This is achieved by coordinating the steam generator and turbine. This minimizes the amount of actuation required for load changes (overfiring) and the consequential expenditure of steam generator service lifetime.

The unit coordinated control is a coordinated pressure/load control system with a model-based feedforward control. This permits very fast, stable and targeted load changes including frequency support mode. The heat release rate in the steam generator is always kept at an equilibrium both statically and dynamically. This ensures the least possible amount of stress on the plant.

The use of an integrated prediction feature ensures that overfiring of the coal mills is extremely smooth in the case of frequency-related load changes. With scheduled load changes, the load transients can be adapted in accordance with the natural S behavior of the steam generator.

The main control variables, unit output and boiler steam pressure must be controlled using the fast-acting steam turbine control valve and the slow-acting power plant boiler. A simplified unit model comprises the dynamic boiler response and steam storage.

The model-based unit master control is also the coordinator for all subordinated additional flexibility measures like condensate throttling measures or deactivation of high pressure (HP) preheaters. Tradeoff between best cycle efficiency with full sliding pressure operation and maximum steam velocities in boiler, main and reheat steam piping shall be elaborated on a project-specific basis.

One method for increasing the final feedwater temperature is the addition of what is termed a top feedwater heater, which is used only at part

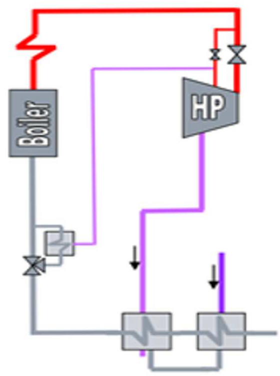

Figure 9: Top feed water heater arrangement.

load. Such a unit requires an additional extraction upstream in the HP blade path. Ideally, the steam is extracted from that point in the blading at which the additional main steam valve is connected (Fig. 9). This obviates the need for any additional nozzles on the HP turbine, and the stage valve admission point can simultaneously serve as an extraction point. Top heating steam flow is selected such that the final feedwater temperature remains constant over wide load ranges. The maximum heat rate benefit with the use of a top feedwater heater is thus approximately 0.6 percentage points at a part load of 50%.

Frequency response Figure 10 shows an overview of several options that are mainly concerned with facilitating frequency response. One common measure for frequency response is to eliminate throttling of the main steam valves (Fig. 10, item 1). While it has always been possible to do this, it bore the disadvantage of an increased heat rate during normal operation. Siemens offers the possibility of using an additional main steam valve (Fig. 10, item 2). This feature provides the advantage of optimum efficiency during normal operation with a possibility for instantaneously increasing the swallowing capacity of the steam turbine, along with the respective increase in load. The next measure is condensate throttling (Fig. 10, item 3) that enables the plant to produce at least 4% additional output by reducing the condensate flow through the low pressure (LP) preheaters and steam extraction through the respective extraction points. The surplus steam that remains within the steam turbine generates the additional power. Certain

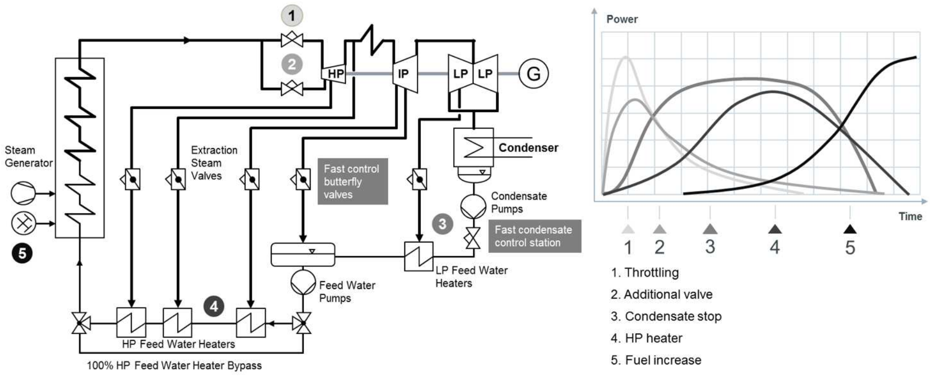

Figure 10: Measures in water-steam cycle for facilitating frequency response

features can be added to the condensate throttling system to increase response time up to 2 s. A similar approach can be used at the high pressure (HP) preheaters to increase output (Fig. 10, item 4). The response should be chosen carefully so as not to thermally stress the boiler and preheater hardware too much.

Other measures such as boiler spray and use of a bypass system with bypass spray can also be implemented to complete the set of measures chosen for project-specific needs.

Loss of main components and load rejection to house load To automatically reduce the unit load on loss of major components such as a feedwater pump or forced-draft fan, and to effect transition to a new safe operating mode by:

- Assignment of dedicated runback levels and ramps for all the major equipment units.
- Consideration of fuel-related restrictions on the load.
- Load reduction with the necessary gradient and coincident changeover of the turbine to stable inlet pressure control mode.

5.2 Steam turbine-generator package – compact, efficient and flexible

5.2.1 SST-5000 steam turbine

Siemens' proven SST-5000-Series steam turbine for USC parameters is a steam turbine consisting of at least two turbine sections: One combined high pressure/intermediater pressure (HP/IP) section (HI turbine) and either one or two LP sections, depending on cooling water temperatures. This is the best product for the lower load range of around 200 MW to 500 MW (Fig. 11). The chosen cycle parameters of 26 MPa/600°C/600°C provide a good tradeoff between product cost and product performance. Since the SST-5000 is the steam turbine module most often deployed in combined-cycle power plants, it is also Siemens' most flexible turbine. The experience gained from these power plants is excellent, especially in terms of fast load ramps.

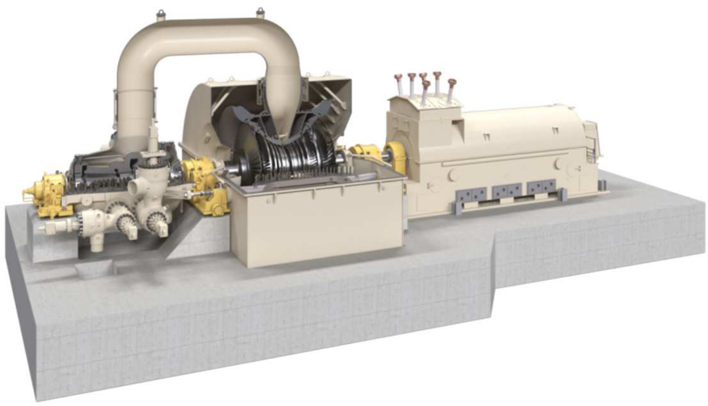

Figure 11: Steam turbine module SST-Pac 5000.

The HI turbine provides several advantages, not only in terms of maintenance but also with regard to integration into the overall power plant. Due to the fact that the main steam and reheat valves are flanged to the lower part of the HI outer casing, only the crossover pipe to the LP turbine has to be disconnected before the upper half of the turbine casing can be removed. In addition, the overall length of the turbine train is reduced to a minimum, which means the turbine foundation, too, and ultimately the entire turbine building can be as compact as possible. This is very important for incorporating a new steam turbine generator set into an available turbine building, as in the case of a DuoBlock. The reduced number of bearings also leads to lower foundation costs. The ultra-supercritical HI module is likewise suitable for inspection intervals of 50 000 h for medium inspections and 100 000 h for major inspections. This means that first opening of the turbine casing is not necessary until after around 12 years of operation.

5.2.2 Generator for the 300 MW to 500 MW class – the SGen-2000P Series

Global increase in utilization of renewable energy has a significant impact on the operating regimes in fossil fuel power plants. Today, turbine-generator shaft train components are exposed to extremely volatile operating modes with a high number of start/stop cycles, numerous steep load ramps, and frequency and voltage fluctuations. As a consequence, thermomechanical stresses and accelerated aging of the shaft train components, including generators, must be considered in the design to avoid unexpected cost and extensive outage periods.

Siemens' answer to the increased market requirements is the new air-pressurized generator SGen-2000P featuring innovative combination of verified technologies: air and water cooling. Air-cooled generators have an excellent track record in terms of robustness, reliability and low operational cost, while water-cooled generators provide the highest output capability and efficiency in the industry. Building on the success of these air-cooled and water-cooled units, the new product line is set to replace the indirectly hydrogen-cooled SGen-2000H Series up to approximately 550 MVA, and will become a standard product in future gas turbine and steam turbine packages. Replacing hydrogen cooling with pressurized air significantly reduces plant complexity and eliminates explosion safety concerns, along with further benefits such as reduced first-time installation and commissioning scopes, lower maintenance costs, and the capability of unstaffed operation for synchronous condenser applications.

Implementation of innovative design features and load-dependent air pressure control enable SGen-2000P generators to achieve efficiency levels comparable to indirect hydrogen-cooled generators. Figure 12 provides an overview of how the auxiliary systems have been simplified.

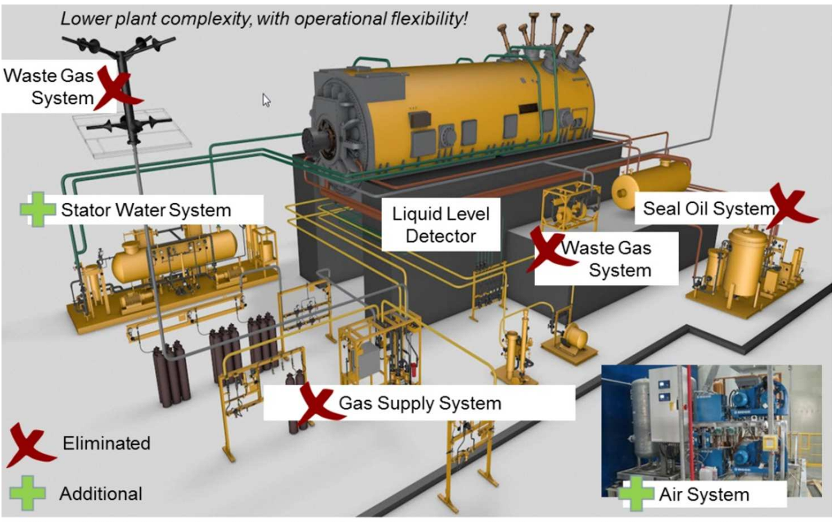

Figure 12: SGen-2000P's reduced scope of auxiliary systems compared to H_2-cooled generators.

5.3 DuoBlock boiler island

The boiler island for the DuoBlock design concept will not be characterized by any serious changes in comparison to conventional power unit configurations. Each boiler must be equipped with an independent technological line of feed and firing systems (coal feeders and mills) and flue gas selective catalytic reduction (SCR), Ljungstrom rotary air heater (LUVO) and electrostatic precipitator (ESP). Wet FGD should be used, which might possibly be configured in a common system serving both boilers.

It must be considered that individual project solutions may vary depending on the site arrangement of existing buildings and systems. What is more, some of them (like SCR and absorbers, rarely ESPs) may be used and modernized. In the feasibility study it is very important as the more existing components (installations and machinery) are used, the more cost-efficient DuoBlocks become.

5.3.1 Dedicated ultra-supercritical boiler

Boiler house layout Presented below is a boiler house at 0.00 m elevation, which is usually a shared structure in most Polish 200 MWe units.

The boiler house is designed and constructed as a conventional structure with 9 m x 12 m spacing. The boiler structure is supported on six pillars isolated from the boiler house structure. On the left side there are four coal mills on separate foundations, and in the middle a wet deslagger. Separate foundations were also used for primary and secondary air fans.

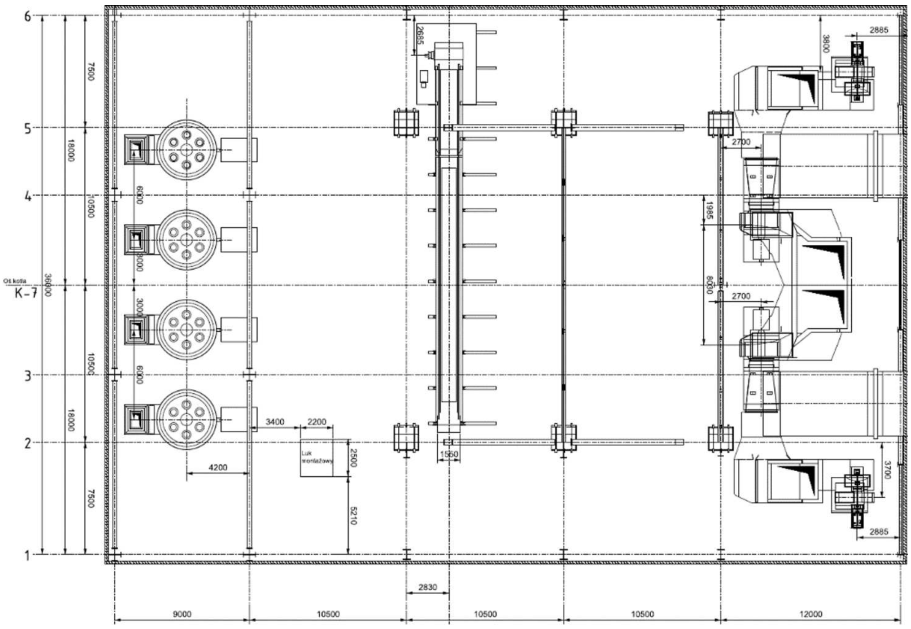

Figure 13: Typical boiler house 0.00-m elevation layout in Polish 200-MWe units.

BP-680 boiler design BP-680 boiler was designed by Rafako for an R&D project financed by the Polish National Research and Development Center in a program dedicated to working out solutions for the existing Polish fleet of 200-MWe power plant units commissioned in the 1970s.

It is assumed that the boilers serving the DuoBlock must be installed in the existing building, including in particular the foundations. This assumption leads to the following conclusions:

- To use the existing structure, a newly designed boiler combustion chamber must keep nearly the exact same dimensions of the old OP-650 unit;
- To ensure the integrity and safety of the foundations, tower-type boil-

ers cannot be used, and the existing shape of the two-pass boiler must be retained.

The resultant boilers shall have combustion chamber diameters of 15620 mm x 9020 mm, be two-pass type, and slightly taller than the OP-650. It fulfills the conditions of fitting within the existing structure.

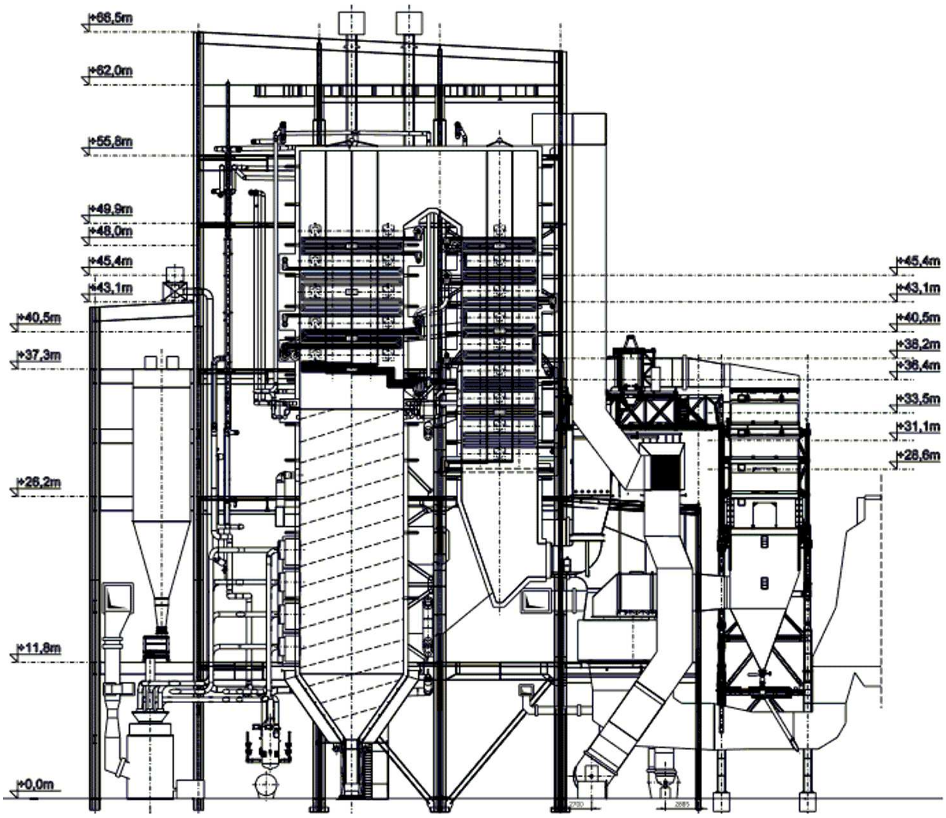

Figure 14: BP-680 boiler design concept (cross-section).

One of few changes introduced will be switching the primary air fan to the cold air duct; placing the fan behind the LUVO (on the hot side) was eliminated from engineering applications many years ago.

5.3.2 Example solution for the Kozienice project

One example of a Polish power station where the DuoBlock could be built is Kozienice Power Plant, where currently eight 200 MWe units are in operation. The plant has been adjusted to meet the present AELs – a SCR reactor for each boiler and a common wet FGD plant for four boilers were built. These installations would have to be modernized and a new ESP built in order to ensure compliance with the new BAT AELs.

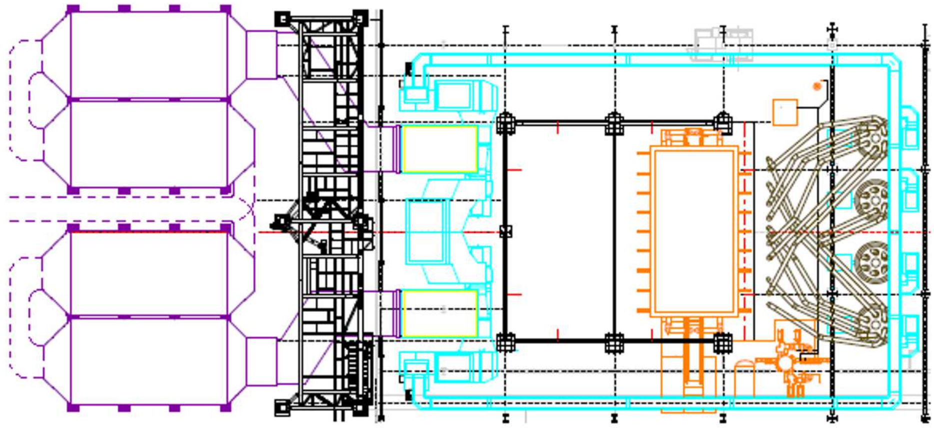

Figure 15: DuoBlock's boiler island for Kozienice.

The SCR system was already designed to be prepared for additional layers of catalyst, so the changes must focus on the choice of catalyst to ensure both NOx reduction and Hg oxidation. With limited space, it was proposed to build a complete new two-pass ESP (6 zones altogether). This avoids the high operating costs of bag filter technology and does not impact the existing layout – as the ESP fits between the existing SCR and foundation of a draught fan. As far as desulfurization is concerned, it's possible as well to modernize the absorber. The proposed investments are presented in Tab. 3.

Final selection of the way to reduce emissions must be preceded by thorough analysis, and detailed information about the existing installation must be provided.

6 Economic analysis of the DuoBlock design concept

The estimated investment cost for a DuoBlock unit has been identified at 2.3 billion PLN (roughly equivalent to EUR 550 million), which is at least EUR 200 million less than the price tag for a 500 MW-class greenfield unit.

Table 3: Ways to modernize existing absorber in the wet FGD installation.

Method	Result	Required investments
formic acid additive	increase efficiency of absorption	• complete installation of formic acid dosage
sieve tray	dynamic local flue gas – suspension mixing	• fan with higher compression • possible need of structural reinforcement
additional spray level	increase of suspension – flue gas reaction surface	• increase in absorber height • complete new pipeline with supports, valves and the circulation pomp • structural reinforcement of the absorber and pipelines

Investment costs for DuoBlock depend on the technical conditions of the existing balance of plant equipment, which must be thoroughly considered as site-specific parameters. In terms of income, the electricity market-related income has been taken into account in these calculations.

A forecast has been prepared of the capacity factors and energy price developments based on the Polish electricity market model. The electricity market model for the entire country was developed by EPK. It runs on the Plexos market simulation tool. The results are presented on the graphs in Figs. 16 and 17.

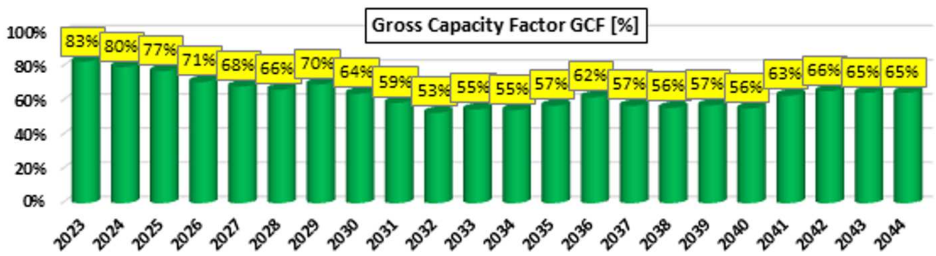

Figure 16: Capacity factors for DuoBlock units under Polish market conditions.

The net present value ratio (NPVR) achieved is 0.61, while the internal rate of return (IRR) is 9.37%. Both of these figures are acceptable from the perspective of the economy of contemporary power investments.

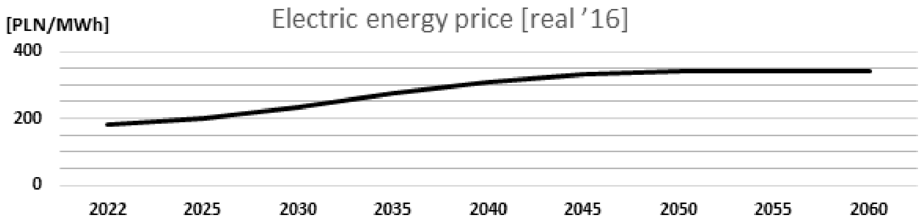

Figure 17: Electric power price forecast.

7 Conclusions and strengths of the DuoBlock idea

In a number of countries where the energy market is a cornerstone of power generation business, power plant assets are under continuous economic pressure. The consequential choice is to optimize both operation and maintenance. Yet, high investment costs for new units and relatively slow technological progress (the incremental efficiency growth of new technology over years) create a situation in which the total energy costs of new units are no lower than those of existing plants. This creates hardly any incentive for investment.

Considering the nature of demand curves, particular attention has to be given to the market segment where generating assets operate at a capacity utilization factor of approximately 4000 h/a. This particular regime requires tradeoff between efficiency and flexibility. On the other hand side, long investment cycles and aging among older generating assets are putting the energy security of a number of countries at risk. Poland is one good example. The design concept of the DuoBlock answers these challenges.

From a macroeconomic standpoint, it is a perfect fit for Poland's national demand. At lower investment costs and shorter construction times, the solution is competitive with any other solution in its market segment (GCF 4000 h/a). The optimized design enables use of state-of-the-art cycle parameters while keeping CAPEX low in comparison to 1000 MW coal-fired greenfield plants, especially for the power island.

From the plant operators' technical perspective, the design concept fits into existing power plant arrangement plans, allowing for staged rehabilitation of older units. The concept as thus presented grants a second life to aging power plants.

What transmission system operators require from plant operators is fast response to demand changes. The concept of a 2-on-1 configuration allows unprecedented flexibility. Normally, one limit to minimum continuous rating of the unit is boiler flame stability. A low minimum continuous rating resulting from a single-boiler operating mode in a DuoBlock arrangement is of course two times lower than in a standard one-on-one concept. With a large steam source available from the first boiler in the startup process of the second boiler, it is possible to shorten startup times and cut the costs of startup below what are considered industry standards. This makes the operational difference in terms of changeover between single- and dual-boiler operation unnoticeable for the transmission system dispatcher.

Another perspective arises from environmental concerns. The fuel for the described unit is coal, which does not sound particularly 'green'. However, the design concept has been tailored specifically for DuoBlock cooperation with large numbers of wind power and PV power sources. Those latter 'volatile' sources must be backed up by predictable, reliable yet flexible power generation. Thus, from the point of view of environmentally concerned persons, application of the DuoBlock will enable renewables to assume an even larger share of the power generation system.

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