BRIEFING PAPER

Understanding flexibility of thermal power plants

www.iesr.or.id

IMPRINT

Understanding flexibility of thermal power plants :
Flexible coal power generation in the power system with higher renewable energy penetration

Author :
Agus Praditya Tampubolon

Reviewers :
Fabby Tumiwa, IESR
Pamela Simamora, IESR
Philipp Godron, Agora Energiewende

Please cite this report as :
IESR (2020). Understanding flexibility of thermal power plants: Flexible coal power generation as a key to incorporate larger shares of renewable energy. Jakarta: Institute for Essential Services Reform (IESR).

Publication :
March 2020

Disclaimer :
This briefing paper is written and summarized using materials from IESR's workshop on power system flexibility which held on 14 November 2018.

FOREWORD

Energy transitions are happening around the world, and it takes place at a fast pace. Renewables become more competitive than fossil fuel power plants. This situation brings fundamental changes in how power systems are operated, primarily due to the higher penetration of variable renewable energies (VREs), such as wind and solar. The conventional power system has been relying on continuously running thermal power plants, which served as a baseload. However, as we are moving toward renewables and distributed generation systems from VRE, we will sooner or later be experiencing a paradigm shift in the power system from baseload to flexibility.

Flexibility is needed to provide the necessary short and mid-term balancing due to the variability of wind and solar generation. This flexibility can be incorporated with some measures. Flexible hydro generation, battery storage technologies, and flexible thermal power plants are among the options to keep the system steady and reliable.

This technical paper addresses the flexibility options to integrate more variable renewables. More specifically, we elaborate and discuss measures to make the existing thermal power plants more flexible. We showcased examples from successful thermal power plants' retrofitting, actions to be undertaken, and possible options to overcome barriers in each of these measures.

These options and measures might play a role as an introductory reference for Directorate General (DG) of Electricity of the Ministry of Energy and Mineral Resources (MEMR) and PLN to start exploring and deepening their understanding of this subject. From there, they can set a plan and pathway in upgrading the national power system to prepare for the ongoing power system transformation in the foreseeable future. We also list some policy options and their enabling condition to incorporate this flexibility in existing power system operation.

Through this paper, IESR intends to inspire and inform policymakers and stakeholders in the power sector to start taking into account the flexibility options in the planning and decision-making process, as well as build a body of knowledge in Indonesia on this matter.

IESR would like to thank our partners, Agora Energiewende and International Energy Agency (IEA), for their cooperation and support for the training in Power System Flexibility, which organized by IESR and DG Electricity of MEMR and PLN in 2018. This briefing paper has reflected the topic and materials presented in that training.

March 2020

Fabby Tumiwa
Executive Director

TABLE OF CONTENT

IMPRINT 2
FOREWORD 3
BACKGROUND 6

1. How renewables change power system operation 7

2. Flexibility options applied today: examples from Germany 8

3. Flexible options for the power system 10
3.1. Flexibility options 11
3.2. Handling challenges during different phases of VRE integration 12
3.3. International Experiences 14
3.3.1. Germany 14
3.3.2. India 14
3.3.3 China 14

4. Flexible coal power plant as a key to incorporate larger shares of renewables 15
4.1. FFIntroduction to the thermal power plant 15
4.2. Current technical parameters regarding the flexibility of thermal power plants 15
4.3. Retrofit measures to increase coal power plants' flexibility 17
4.3.1. Options for decreasing minimum load 17
4.3.1.1. Indirect Firing 18
4.3.1.2. Switching from two-mills to single-mill operation 18
4.3.1.3.Upgrade of the control system in combination with plant engineering update 18
4.3.1.4. Auxiliary firing with dried lignite ignition burner 18
4.3.1.5. Thermal energy storage for feed water preheating 18
4.3.2. Options for reducing start-up time 19
4.3.2.1. Optimized control systems 19
4.3.2.2. Thin-walled components/special turbine design 19
4.3.3. Options for increasing ramp rate 19
4.3.3.1. Repowering 20

TABLE OF CONTENT

4.3.3.2.Upgrading control systems and plant engineering 20
4.3.3.3. Reducing the wall thickness of the critical component 20
4.3.3.4. Auxiliary firing with dried lignite ignition burner in booster operation 20
4.3.4. Potential of the retrofits 20
4.4. The economic impacts of more flexible generation 21
4.5. The impact of the flexible coal-fired power plant on CO2 emissions 21
4.6. The importance to adapt the power market conditions 22

5. Policy options to enhance flexibility 22

REFERENCES 25

APPENDIX I – Comparison of power plants with most commonly used technologies vs. power plants with state-of-the-art technologies for each generation type 26

APPENDIX II – Illustrative subdivision of a coal-fired power plant 29

BACKGROUND

Electricity demand vary throughout the day. Changing power plant output and thus ramping the generation is something operators must perform and have learned over time to manage. However, when renewables, especially variable renewable energy (VRE) comes in, operators need to adapt again. Furthermore, a more a flexible power system is needed to respond to the change in demand and supply. Without a flexible power system, the cheap and clean energy from wind and solar might be curtailed to balance the system, hence wasting the full potential of the installed renewable energy. In some cases, it could happen that the power system could not handle the fast variation of supply-and-demand and therefore causes the system's breakdown. Not only that it will create significant losses, both to the utility and communities/government, but it will also disrupt many sectors that rely on electricity.

Rapidly falling cost of renewables, in particular solar and wind, local value creation, local environmental concern, and meeting climate mitigation target are boosting global renewable energy capacity and Indonesia is without exception. Throughout 2019, 385 MW renewables have been added in Indonesia, giving a total of 10,169 MW. Hydropower still dominates with 5.4 GW, followed by geothermal and bioenergy at 2.13 GW and 1.9 GW respectively. Meanwhile, on-grid solar and wind are still on the MW-scale, with total installation at 62 MW and 148.5 MW successively (IESR, 2019a). These numbers are still far below 1 percent of the Indonesia's solar and wind total potential[1], which means there is still room for a vast capacity incremental.

To reach the 23% target of renewable in the primary energy mix by 2025, PLN, in their business plan (Rencana Umum Penyediaan Tenaga Listrik/ RUPTL) 2019-2028, is targeting 3.2 GW new solar PV and around 1.4 new wind[2] generation. However, one of IESR's study reported, that ambitious target is viable. A total of 35 GW solar PV and 19 GW wind by 2027 is possible to reliably meet growing electricity demand in Java-Bali and Sumatra, with lower price as compared to PLN's plan if the cost of capital and technology is brought down following international prices (IESR, 2019b). Ultimately, it means, that shares of VRE in Indonesia's power system will steadily increase. As variability is a concern to operators and policy makers and is seen as obstacle to renewables development; to overcome it, the discussion about power system flexibility should get more attention.

Designing a flexible power system requires time and investment. Decisions must be made, whether to focus first on the supply side (flexible generation), on the transmission side, on creating flexible demand-side, or on utilizing flexible system operations. Each decision comes at a cost, thus understanding what type of flexibility might be needed and how much is essential. Finding the optimal solution will require consideration not only for a short-term operation but also for long-term planning. For Indonesia now is the right time to carefully plan a flexible power system to balance variable renewable generation, just because Indonesia is on the process of building many new power plants to satisfy its growing energy demand.

[1] Total potential for solar and wind is taken from Statistik EBTKE 2016 (Renewables Statistic) by MEMR.
[2] including hybrid power plant (combination of solar PV and wind)

1. How renewables change power system operation

Power systems used to be operated with many large baseload power plants (mainly nuclear, coal and hydro power plants) and only a few peakers. Figure 1 below shows how nuclear and lignite were used in Germany's power system as baseloads, hard coal and gas as mid merit plants, and mainly hydro and others were providing peak generation.

However solar PV and wind energy are getting competitive in some part of the world and are likely to become even more competitive. Based on data from Agora Energiewende, Germany's total gross power production in 2018 is estimated to be around 649 TWh (Agora Energiewende, 2019). Out of this total, 229 TWh or around 35.2 percent of it comes from renewables with the share as follow: 14.5% from onshore wind, 3% from offshore wind, 7.1% from solar PV, 8% from biomass, and 2.6% from hydropower. In August 2015, renewables covered more than 80 percent of Germany's consumption during few hours as can be seen from Figure 2 below. High shares above 65% can actually be observed frequently in the German power system now.

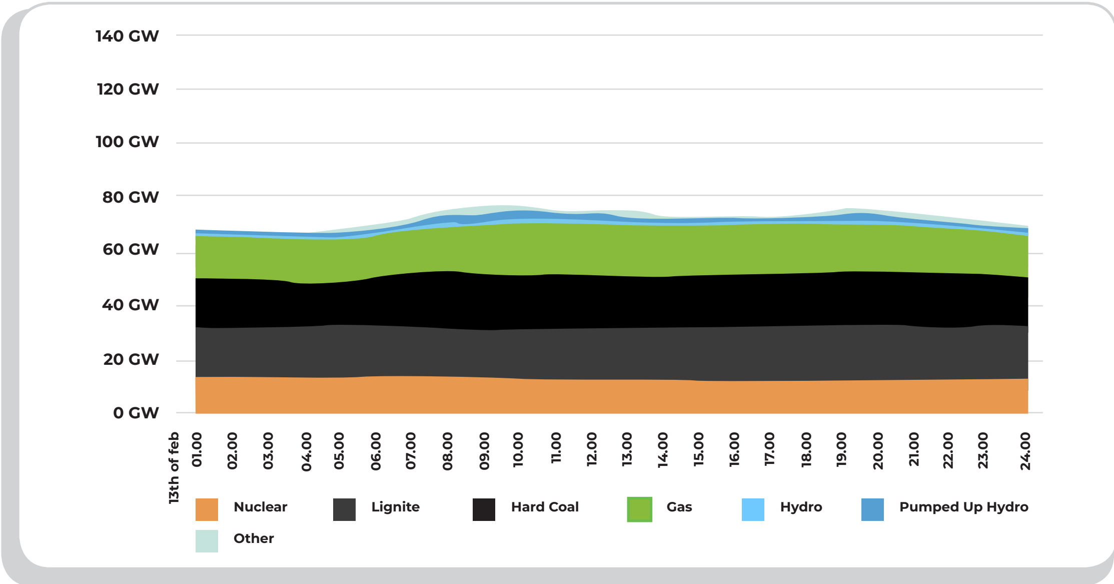


Figure 1 Snapshot of Germany's power system operated with many large baseload power plants
Source: Agorameter in Godron, 2018a (redrawn)

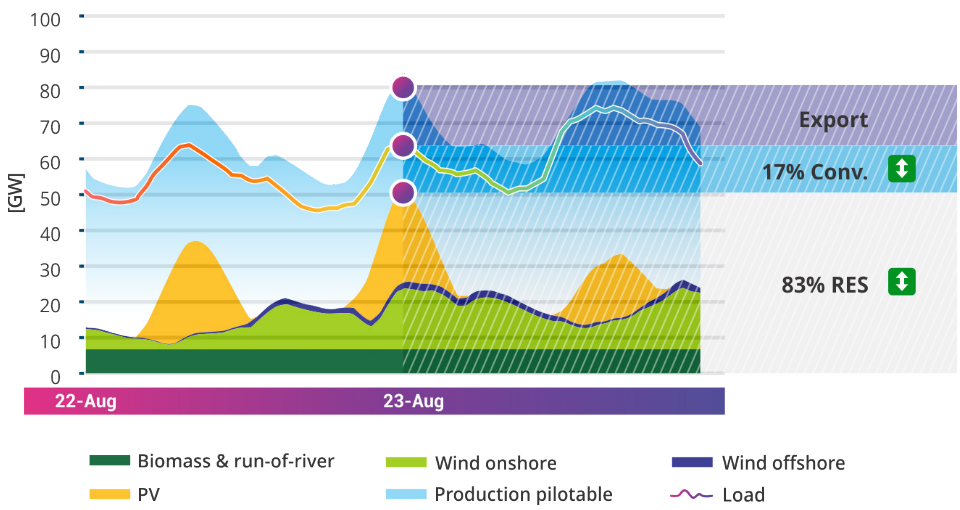


Figure 2 Power generation in Germany 22-24 August 2015
source: Agorameter in Godron, 2018a (redrawn)

Wind and solar PV have specific characteristics: high capital cost, low variable cost, and high variability. Because of these characteristics, high penetration of renewables will bring out new challenges. These challenges will change the operation and investment structure of the power system, bring out steeper ramp rates, and lead to times with excess power or times with lack of generated power.

Many renewable power plants (in Germany > 90 percent) are connected directly to the distribution grid. This design encourages for modern and flexible electricity distribution grid with higher reliability and better durability, especially since wind and solar generation are very fluctuating and are dependent on the weather. Furthermore, wind and solar energy also shift the residual demand towards more mid-merit and peak load, without reducing the maximal residual demand.

Conclusively renewables, especially variable renewable energy (VRE), will upsurge and change the narrative of the existing power system, from the investment, planning, until operation. Making the power dispatch more flexible will be critical to face these evolving power systems. Key flexibility options that are available namely:

- Flexible fossil and bioenergy power plants, including Combined Heat and Power (CHP);
- Grids and transmissions capacities' upgrade to accommodate exports/imports of electricity;
- Administration of Demand Side Management;
- Incorporation of storage technologies (batteries, power-to-gas); and
- Integration of the power, heat, and transport sectors (power-to-heat, electric cars).

2. Flexibility options applied today: examples from Germany

Renewables have become the most important source of energy to generate electricity in Germany, followed by lignite and hard coal. Despite renewables' proportion in power generation today, Germany's electricity system still is highly reliable.

This reliability can be seen for example from a stable electricity supply despite solar eclipse on March 20, 2015, where electricity production generated by solar PV ramped down 12 GW within 65 minutes and ramped up again approximately 19 GW within 75 or despite strong wind in October 2017 while nuclear, coal, and natural-gas CHP plants were also still in operation. In both of these examples, electricity prices and volumes traded on the Intraday market reacted to the price signals, which incentivize generators and consumers to adjust their generation and consumption to provide flexibility. Figure 3 shows the situation when there was high wind power generation, which led to negative electricity prices. This negative price then led to a decrease in net power generation of the conventional energy sources, which then balance the system.

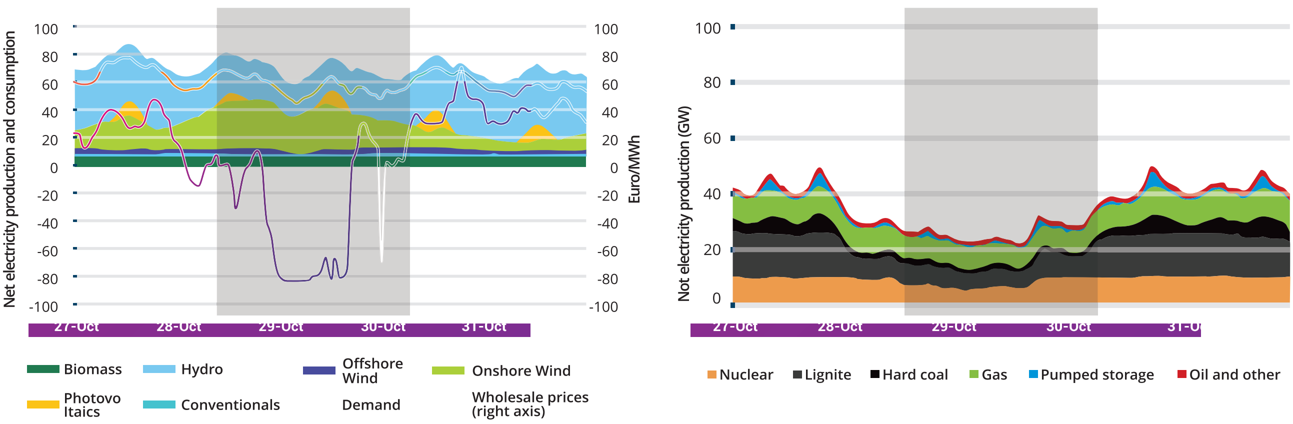


Figure 3 Net power generation and consumption by energy source and wholesale market prices (27-31 October 2017)
source: Agora Energiewende in Godron, 2018b (redrawn)

Electricity market in Germany

Germany has liberalized electricity market. As a commodity, electricity is traded in wholesale electricity market and retail electricity market. Selling price for the electricity is based on the marginal costs of producing it. Given the fact that martial costs consist of fuel costs, costs for CO2 emission certificates, and variable operating costs, electricity from renewables will always be the cheapest and placed first in the Merit Order (a method to rank available sources of energy based on ascending order of price together with the generated electicity capacity).

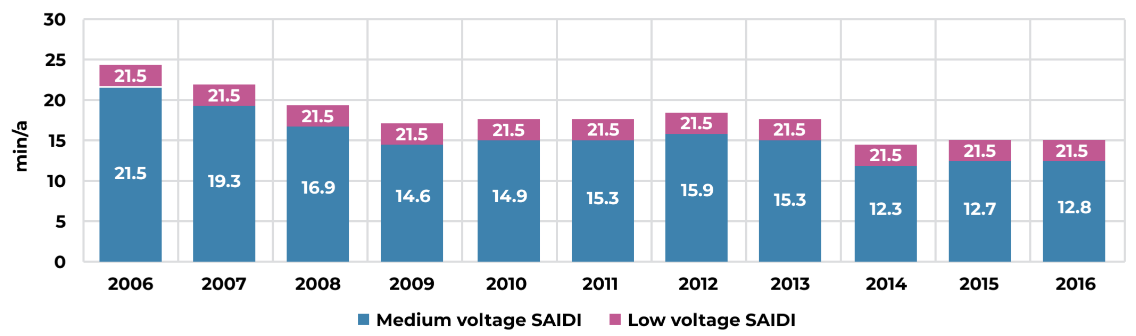


Figure 4 SAIDI (System Average Interruption Duration Index) 2010-2016: shows high system reliability despite increases share of renewables
source: Agora Energiewende in Godron, 2018b (redrawn)

Variable renewable energy capacity has multiplied by three-fold in Germany since 2008, while the balancing costs have decreased by 50 percent over the same period. This decrease was joint contribution of Transmission System Operator (TSO) cooperation, more competitive balancing power market, improvement of forecasts, and more liquid spot market. About forecasting methodologies, they have significantly improved in Germany which results in minor deviations between day-ahead forecast and real feed-in that need to be covered by the system operator.

Key priorities in Germany for managing the flexibility challenge

More grids to transport wind energy to the south of Germany and the promotion of regional markets as a new framework for decentralization

- Reinforcing the grid infrastructure is crucial (wind power will be installed mainly near the coast in the north of Germany, but key consumptions centers are in the south)
- Decentralization is a new and lasting structural characteristic of the Energiewende

Enhance the cooperation between regions/countries and deepen power market integration

- The flexibility requirements of interconnected power systems decrease, implying reduced residual load gradients & balancing requirements; and fewer renewables curtailment
- Cross border system integration (grid interconnection, cooperation in system operations and market design) is key for minimizing flexibility challenges.

The future market for battery systems can be small or large, depending on regulatory framework and development of EV market

ICT as an enabler for more flexibility: market actors (producers, direct marketers, suppliers, consumers) can trade their products within shorter timeframes

- ICT technically enables communication and control of decentralized units and flexibility options. However, incentives for flexibility are still crucial to reap benefits.

3. Flexible options for the power system

Flexibility has always been important to stabilize the supply and demand of a power system even before significant amount of VRE being connected to the grid, for example to balance the system when there is a failure. As more intermittent solar and wind come onto the grid, the need for a more flexible power system also increases. To better prepare the power system, utility and system operator must also understand at what phase their system right now. The International Energy Agency (IEA) has classified the integration of variable renewable energy (VRE) into six different phases, differentiated by the impacts on power system as a result of increase shares of VRE capacity.

Table 1 Different phases of VRE integration

Phase	Description	Country Examples
1	VRE capacity is not relevant at the all-system level. No noticeable impact on the system	Most countries, e.g., Indonesia, Thailand, Mexico
2	VRE generation becomes noticeable to the system operator but has a moderate impact	Brazil, China, India, Sweden, Texas
3	Flexibility becomes relevant with more significant swings in the supply/demand balance	Italy, Germany, Portugal, Spain, UK
4	Stability becomes relevant. VRE capacity covers nearly 100% of demand at certain times	Ireland, South Australia, Denmark
5	Growing amounts of VRE surplus; electrification of other sectors become relevant	
6	Seasonal surplus or deficit of VRE supply; seasonal storage & synthetic fuels	

source: IEA 2018 in Peerapat, 2018

These phases are a conceptualization, intended to identify the central experiences and challenges related to VRE integration, which are context specific. The phase in which each system sits depends on not only the share of VRE generation share, but also some other factors, such as the size of the system, the transmission infrastructure, existing operational practices, and existing levels of flexibility.

VRE deployment beyond Phase Four is possible. In Phase Five there might be a structural surplus of VRE generation. If left unchecked, these surpluses would result in large-scale curtailment of VRE output, and thus a cap on further expansion. At this point, further VRE deployment is likely to require the use of smart electrification of heating and transport.

Phase Six may be characterized by structural energy deficit periods resulting from seasonal imbalances between VRE supply and electricity demand. Bridging occasional multi-day/week shortfalls of supply is likely to stretch beyond the capabilities of demand-side response or electricity storage, which are stronger sources of flexibility over shorter periods.

3.1. Flexibility options

Increasing VRE in the power system is driving the power system transformation. This transformation can either be targeting the VRE itself or be targeting the overall system as shown by Figure 5.

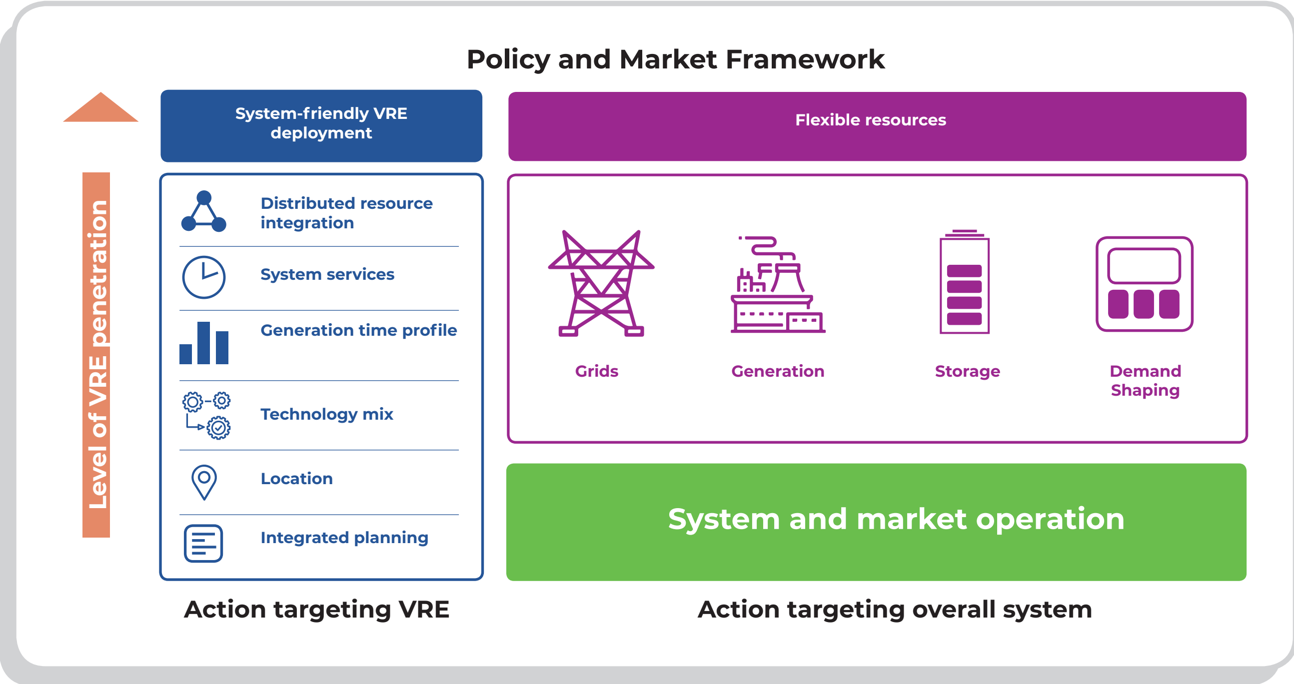


Figure 5 Power system transformation's actions
source: IEA 2018 in Peerapat, 2018 (redrawn)

Grid infrastructure incorporates all assets that connect generation to demand: transmission lines (for both AC and DC), distribution lines, protection devices, transformers, and include distribution network components. Larger and meshed networks, as well as grid's digitalization, will also help to integrate VRE generation. Aggregating distant VRE plants and flexible resources smooths overall VRE output and allows cost-effective utilization of flexibility options.

Dispatchable generation is currently the dominant source of system flexibility in all power systems, accommodating the variability of demand and VRE output. Dispatchable generators provide flexibility by reducing power output or shutting down completely when VRE output is plentiful or when demand is low. Similarly, they ramp up or start up rapidly to cover periods of low VRE availability or rapid increases in demand. They also provide a range of short-term and ultra-short-term flexibility services throughout the day. Retrofits and retirement/replacement of power plants may be required to improve fleet flexibility.

Electricity storage describes all technologies that can absorb electrical energy and return it as electrical energy at a later stage. Arbitrage opportunities have driven storage deployment in the last 40 years, in particular, pumped storage hydro (PSH). Electricity storage technologies can provide multiple services ranging from fast frequency response to bulk energy storage, which cover timescales from ultra-short- to long-term and which help to accommodate new challenges related to VRE variability. Recently, battery storage technologies have seen rapid cost declines, and although not suitable for seasonal storage, could play a greater flexibility role in the short-term timescale in future power systems.

Demand-side resources have the potential to cost-effectively balance supply and demand, offer back-up power during system contingencies, facilitate the integration of VRE, and provide a range of other system services. A range of technologies is suitable for demand response purposes. Their common property is the ability to shift or adjust power consumption for a certain amount of

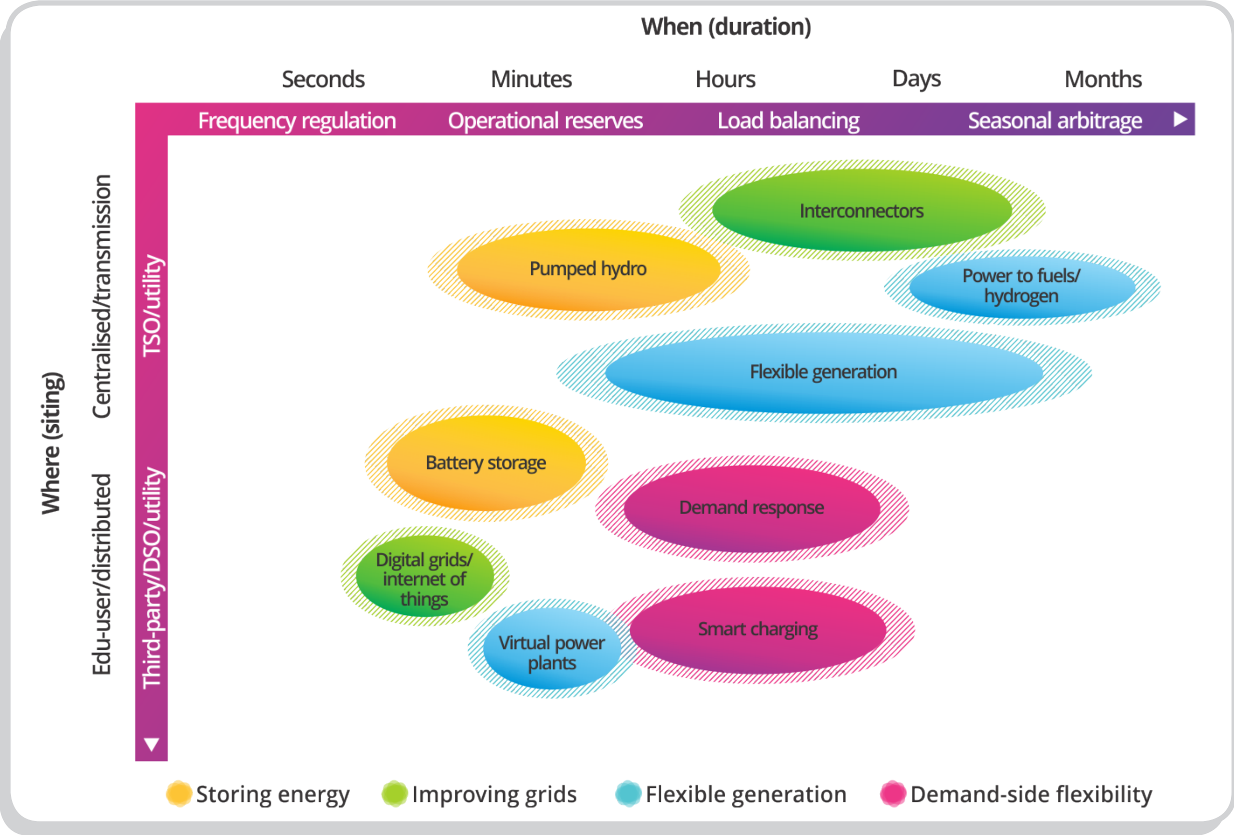


Figure 6 Growing need and range of flexibility options at all scales
source: World Energy Outlook 2018 in Peerapat, 2018 (redrawn)

time, or interrupt electricity consumption in exceptional circumstances at short notice. These resources are typically more useful for very short-term and short-term flexibility. Another form of the demand-side resource is the implicit use of price signals to change consumers' behavior and load profile.

Expansion of electrification, distributed generation, and variable renewables will broaden the need and range of flexibility options. On the supply side, pumped hydro provides the bulk of storage capacity. As VRE shares grow, the need for flexibility in power systems also increases. On the demand side, digitalization opens the possibility of making demand more flexible. Steep reductions in battery storage costs unlock new flexibility options, while smart grids have the potential to become the backbone of the modern and reliable electric system.

3.2. Handling challenges during different phases of VRE integration

Solar PV and wind are now growing in many countries in the world. However, the variability of wind and solar power needs to be managed well. Otherwise, it may lead to curtailment or even threaten energy security.

Challenges in integrating VRE are varied based on its phase:

a. Phase-1. Many countries are in this phase. It means that there is no problem yet.
b. Phase-2. This phase brings the first integration challenges. However existing power plants and grids can still handle this if we update the way they are operated.
c. Phase-3. In this phase, new investments in more flexibility will be needed.
d. Phase-4. This phase is very technical and only very few countries have reached this yet.

Figure 7 and Figure 8 show priorities in mitigating challenges for VRE integration in both phase-1 and 2. Basically, the main idea is to make the power system fit for handling variability and uncertainty by making it more flexible. As flexibility needs increase, the play increasing demands on power plants, grids, demand-side flexibility, and storage, with implications for regulatory and market design.

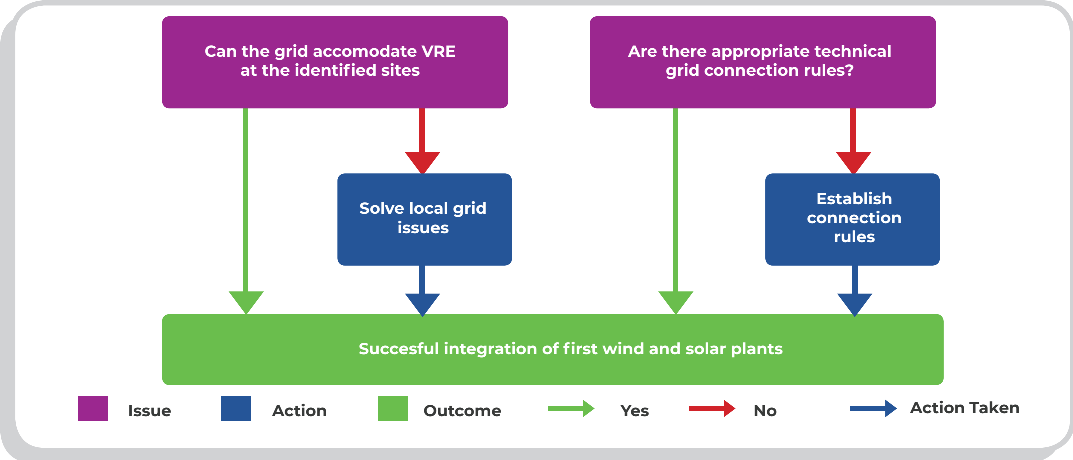


Figure 7 Priorities for VRE integration in Phase-1
source: IEA 2018 in Peerapat, 2018 (redrawn)

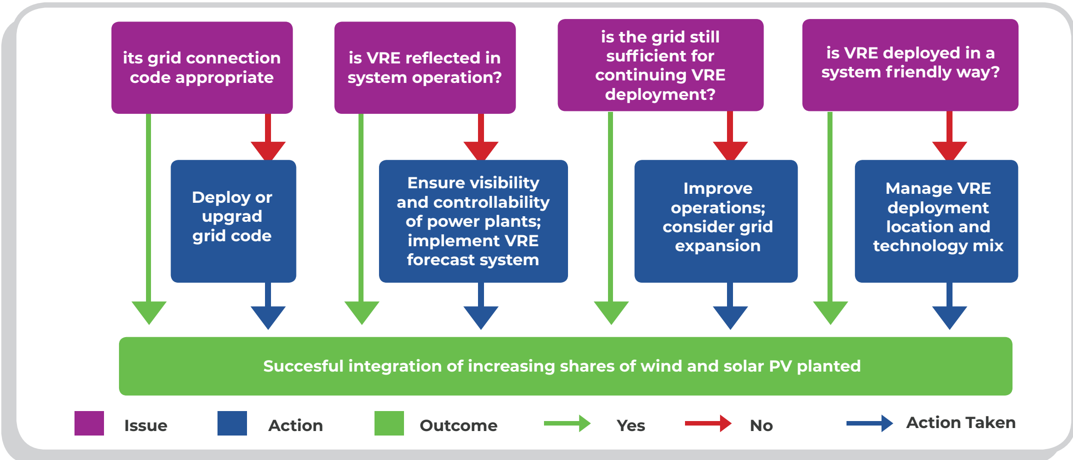


Figure 8 Priorities for VRE integration in Phase-2
source: IEA 2018 in Peerapat, 2018 (redrawn)

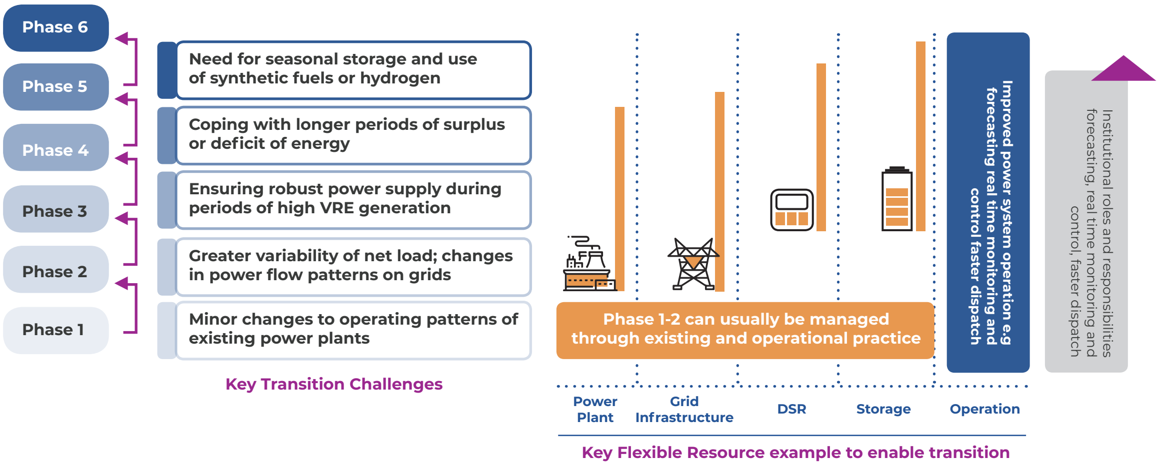


Figure 9 Key transition challenges and flexible resources to enable the transition
source: IEA 2018 in Peerapat, 2018 (redrawn)

3.3. International Experiences

Germany, India, and China have significant amount of installed solar PV and wind capacity. Due to solar and wind variability characteristic, these countries will need a flexible power system. Below are some countries that have retrofitted their thermal power plants.

3.3.1. Germany

Germany has modernized the technology of its old coal-fired power plant. For example, coal-fired power plant Neurath. This is a 630 MW lignite power plant built in 1975. After retrofit, below are some of its improvements:

- Ramp rate tripled from 5 to 15 MW/min;
- Minimum load reduced by 40% from 440 to 270 MW;
- Start-up time reduced from 4 hours 15 minutes to 3 hours 15 minutes; and
- Optimization of all subordinated controllers, e.g., feedwater, fuel, etc.

3.3.2. India

India has modernized and increased typical ramp rate and peak requirement of its coal-fired power plant into 250 MW/min and 500 MW/min respectively. Additionally, hourly variations in a thermal generation have significantly been increased due to increased net demand from 2-4 GW in 2008 to 6-8 GW in 2017.

3.3.3 China

China plans to retrofit around 200 GW of its conventional power plant by 2020 (or around 20% of the total capacity in China). Other than that, lowering the minimum stable operation load is the priority shortly

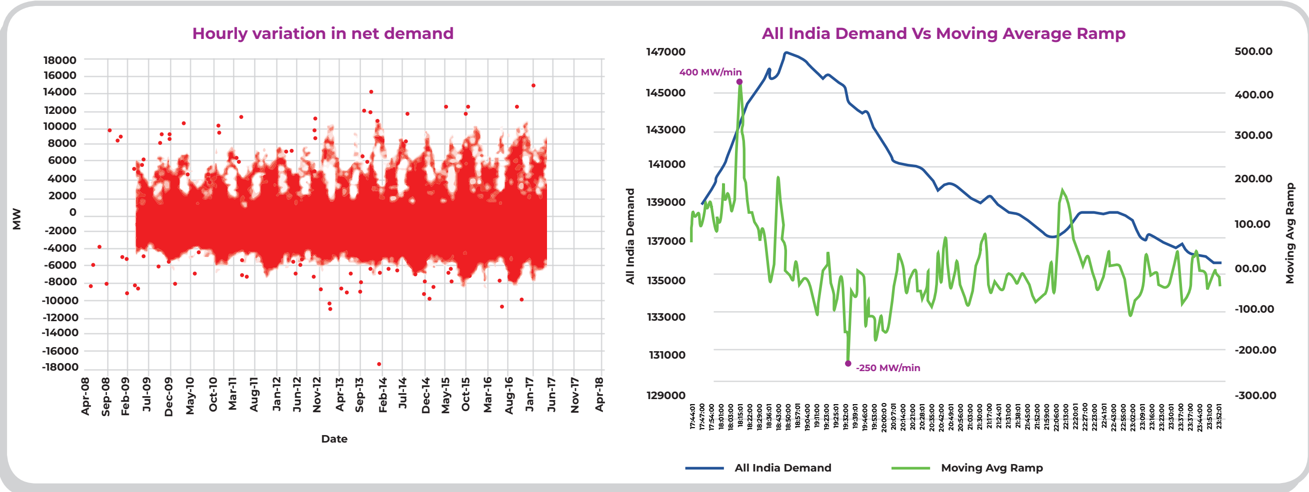


Figure 10 Flexibility requirements in India's power system
source: IEA 2018 in Peerapat, 2018 (redrawn)

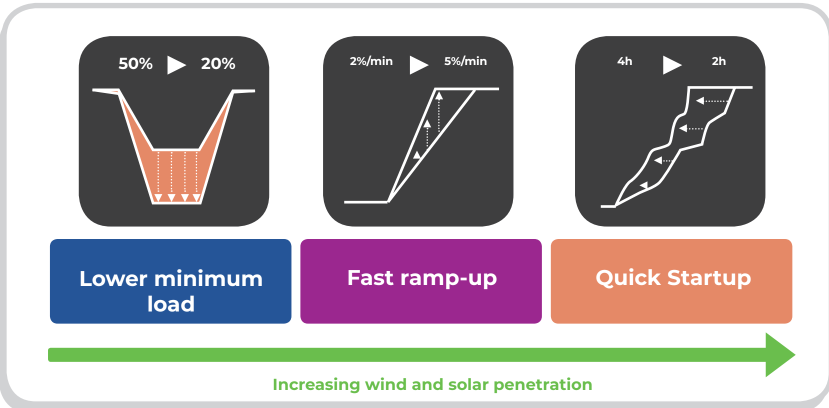


Figure 11 A roadmap for power system flexibility enhancement in China
source: IEA 2018 in Peerapat, 2018 (redrawn)

4. Flexible coal power plant as a key to incorporate larger shares of renewables

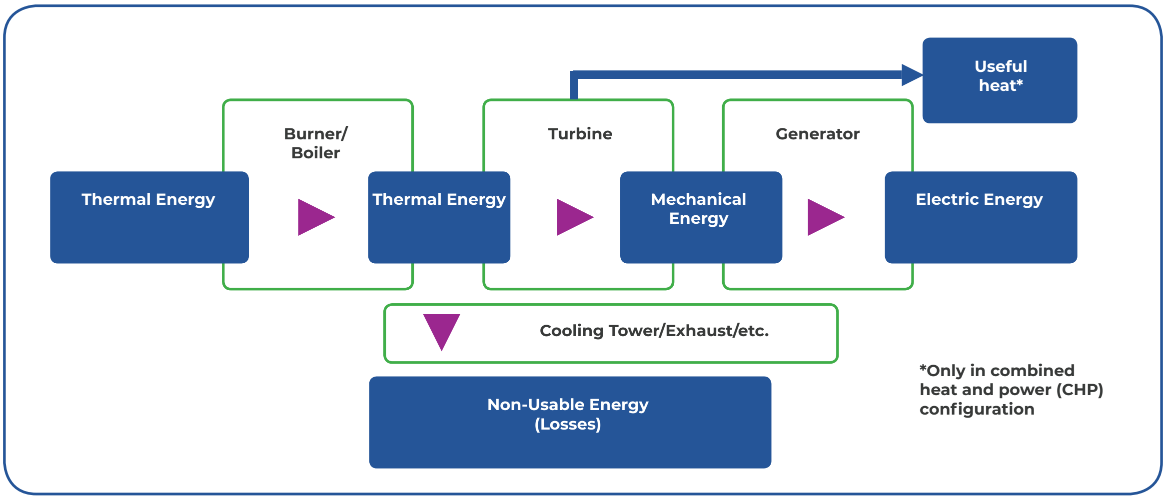


Figure 12 Energy conversion process for thermal power plant
source: Fichtner (2017) in Peter, 2018 (redrawn)

4.1. Introduction to the thermalpower plant

The thermal power plant is characterized by an energy conversion process, where thermal energy (e.g., released through coal or gas combustion) is converted into electric energy. Based on the fuel type, thermal generation can be divided into several categories, and two of them are coal-fired and gas-fired power plant.

4.2. Current technical parameters regarding the flexibility of thermal power plants

Flexibility of a power plant is determined mainly by three parameters: the ability of that power plant to adjust the time required to attain stable operation when starting (start-up time), its overall bandwidth of operation (minimal load), and the net power fed to the grid (ramp rate).

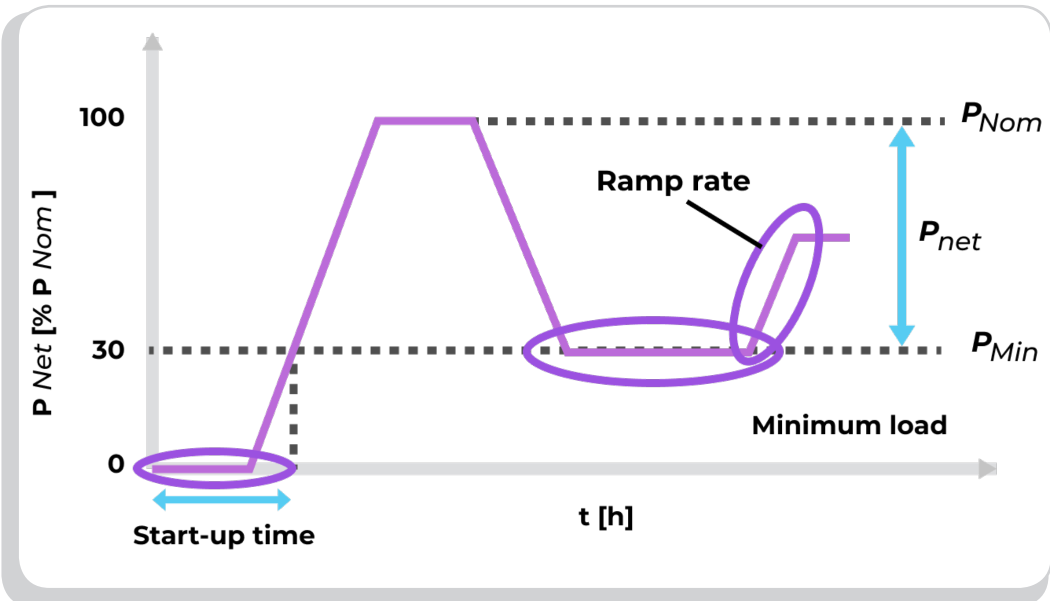


Figure 13 Representation of key flexibility parameters of a power plant
source: Fichtner (2016) in Peter, 2018 (redrawn)

Adjusting the key flexibility parameters of a thermal power will improve the way this power plant can be operated. However, these improvements are also subject to some restraints. Below is the summary of the advantages, disadvantages, and limitations of the critical parameters of operational flexibility.

State-of-the-art design improves the flexibility characteristics of fossil-fueled power plants significantly. In the minimum load for example, while many coal fired power plants in China cannot reduce their load below 60% of their name plate capacity, the most advanced power plants in Europe are able to reduce minimum load to below 20% of name plate capacity, as can be seen in Figure 14. Respectively, in the ramp rates, many coal-fired power plants in South Africa cannot achieve 1% of the nominal capacity in one minute, while the state of the art power plant can achieve until 6% of the nominal capacity within the same minute (see Figure 15).

Table 2 Qualitative representation of key flexibility parameters of a power plant

Key Parameters	Advantage	Disadvantage	Limitations
Start-up time	The shorter the start-up time, the quicker a power plant can reach the minimum load	Faster start-up times put greater thermal stress on the component	The thermal gradient for components
Minimal Load	The lower the minimal load, the larger the range of generation output	At minimum load, the power plant operating at low efficiency	At low load, it is difficult to ensure a stable combustion
Ramp rate	A higher ramp rate allows a power plant operator to adjust net output more rapidly	Rapid change in firing temperature results in thermal stress	Allowable thermal stress and unsymmetrical deformations, storage behavior of the steam generator, quality of fuel used, the time lag between coal milling and turbine response.

source: Fichtner (2016) in Peter, 2018

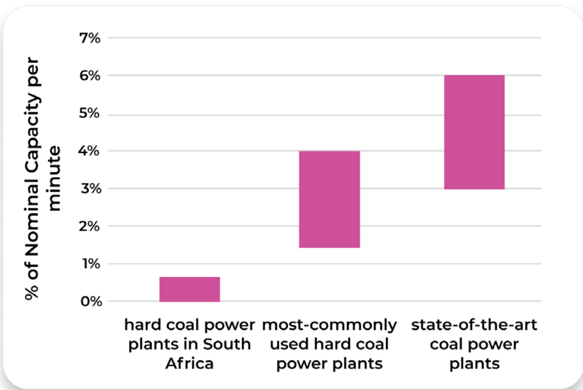


Figure 14 Minimum load of different hard-coal-fired power plants (as a percentage of nominal capacity)
source: DEA, NREL, Fichtner in Peter, 2018 (redrawn)

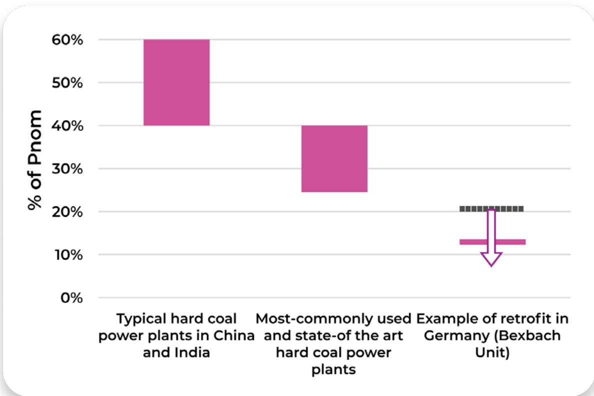


Figure 15 Ramp rates of hard-coal-fired power plants in South Africa compared to most-commonly used and state-of-the-art designs
source: Prognos, Fichtner in Peter, 2018 (redrawn)

4.3. Retrofit measures to increase coal power plants' flexibility

The flexibility of a thermal power plant is determined by the combination of a variety of operational hardware elements, which can be improved through retrofitting. A detailed overview is provided in Table 3.

4.3.1. Options for decreasing minimum load

Minimum load describes the lowest possible net power a power plant can deliver under stable operating conditions. A lower minimum load provides a more extensive range of generation capacity. This extensive range helps plant operators maintain operation when power demand is low and avoid expensive start-up and shutdown procedures. From a system standpoint, reducing the minimum load of conventional power plants allows a greater share of renewables by avoiding potential curtailment.

There are several significant limitations to reduce the minimum load of a power plant:

a. Fire instability at specific load (35-50% for lignite, 25-40% for hard coal) for state of the art plants;
b. Minimum flue gas temperature for DeNOx operation; and
c. State of steam (pressure and temperature) in the water-steam circuit.

Table 3 Retrofit measures for reducing minimum load, start-up time, and ramp rate

No	Retrofit measures for reducing:	Minimum load	Start-up time	Ramp rate	Limitations
1	Indirect Firing	√		√	Fire stability
2	Switching from two mills to single mill operation	√			Water-steam circuit
3	Control system and plant engineering upgrade	√		√	Fire stability/thermal stress
4	Auxiliary firing with dried lignite ignition burner	√		√	Fire stability and boiler design
5	Thermal energy storage for feed water pre-heating	√			N/A
6	"Repowering"		√	√	N/A
7	Usage of the optimized control system		√		Thermal stress
8	Thin-walled components/unique turbine design		√		Mechanical and thermal stresses
9	"New" turbine start		√		Turbine design
10	Reduction of critical components' wall thickness			√	Mechanical and thermal stresses

source: Fichtner (2017) in Peter, 2018

Despite these limitations, there are several possible options to decrease this minimum load:

4.3.1.1. Indirect Firing

Implementing indirect firing in combination with a staged vortex burner retrofit, led to a decrease in minimum stable firing rate from 25-30% down to 10%. This leads to a similar reduction in minimum load. Another advantage of reaching such a low, stable fire is that the need for ignition fuels, such as oil or gas, was reduced by 95%.

4.3.1.2. Switching from two-mills to single mill operation

Operating with only one instead of two mills in combination with a single burner stage can reduce minimum load by achieving a lower steady firing rate.

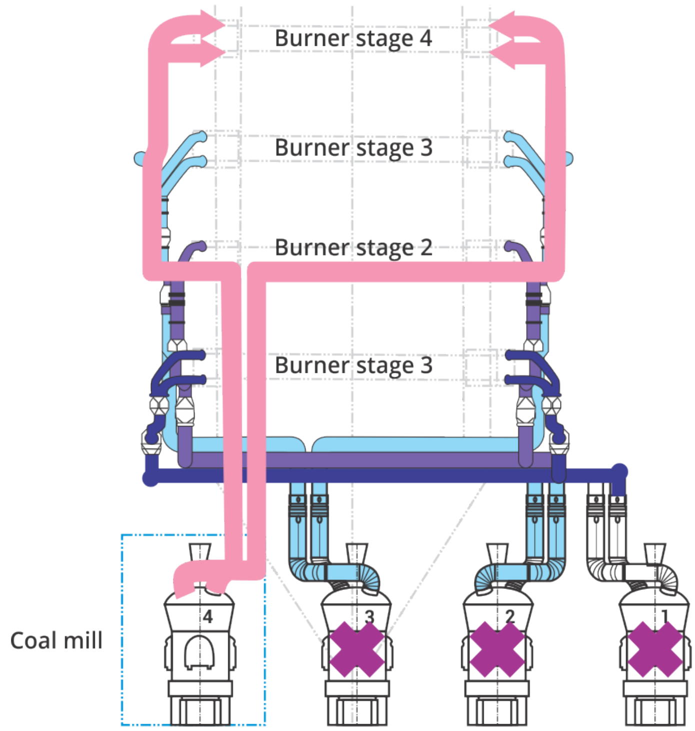


Figure 16 Coal mill and burner arrangement of a boiler in tangential firing configuration with four burner stages (single-mill operation)
source: Fichtner (2017) based on Heinzel, et al. (2012) in Peter, 2018 (redrawn)

4.3.1.3. Upgrade of the control system in combination with plant engineering update

This upgrade describes a retrofit option where the control system is upgraded (e.g., from analog to digital), while also performing the upgrade on required plant engineering. An improved control system leads to faster, more precise and more reliable monitoring and control of processes, which can reduce the minimum load.

4.3.1.4. Auxiliary firing with dried lignite ignition burner

Auxiliary firing describes the process of stabilizing the fire in the boiler by combusting auxiliary fuels, such as heavy oil or gas, in addition to the PC-fired main burners. This process allows for an overall lower stable firing rate in the boiler and thereby reduce the minimum load.

4.3.1.5. Thermal energy storage for feed water preheating

Thermal energy storage can be used to store heat and release it at a later point in time. In a typical configuration, the feed water is pre-heated via a heat exchanger with extracted steam from the steam turbine. Releasing or absorbing heat to or from the feed water, therefore, has a direct influence on net power as it influences the amount of steam extracted from the turbine. Charging a thermal energy storage system during times of low load (e.g., at night) intentionally lowers the net power as more steam needs to be extracted from the steam turbine. This leads to a reduction of minimum load.

4.3.2. Options for reducing start-up time

Start-up time defines the period from starting plant operation until reaching minimum load. Decreasing start-up time will enable a more rapid response to power demand. Start-up procedures are complex and expensive since they usually require additional fuel, such as oil or gas, during the ignition period.

There are several significant limitations to reduce the start-up time of a power plant:

a. Allowable thermal stress in thick-walled components; and
b. Minimum required state in the boiler before a stable pulverized coal fire can be achieved.

Despite these limitations, there are several possible options to decrease this minimum start-up time:

4.3.2.1. Optimized control systems

Several parameters of a real boiler are analyzed and optimized using a predictive controller for shortening start-up times (e.g., fuel costs and thermal stress on thick-walled components).

4.3.2.2. Thin-walled components/special turbine design

Some challenges that will be faced:

a. The quicker a start-up, the faster the temperature of thick-walled components rises;
b. The allowed thermal stress on components limits the temperature change rate that can be run by power plant; and
c. To realize quicker start-ups, the wall-thickness of thick-walled components needs to be reduced.

Tacking these challenges, several available solutions are:

a. Utilization of high-value material (e.g., ferritic-martensitic steel P92 that can cope with thermal stress in a better way; and
b. Particular component design (e.g., SST5-6000 steam turbine).

Steam with very high pressure and temperature is the only requirement to achieve the highest possible efficiency. However, to withstand this, components need to be designed rather thick-walled, which in turn make the components less flexible in regard to load and temperature changes. Choosing between thin-or thick-walled components means a consideration if a power plant operator wants the power plant to be more flexible (using rather thin-walled components) or to have the highest efficiency possible (using rather thick-walled components).

4.3.3. Options for increasing ramp rate

The ramp rate is defined as the change in net power per time. Increasing ramp rate will allow dynamics adjustments to net power, which is especially important in power systems with rising shares of renewables.

There are several significant limitations to increase the ramp rate of a power plant:

a. Allowable thermal stress in thick-walled components, such as headers;
b. Quality of fuel used for combustion; and
c. The time lag between coal milling and turbine response.

Despite these limitations, there are several possible options to increase this ramp rate:

4.3.3.1. Repowering

Repowering is a retrofit measure, in which a gas turbine is implemented into a coal-fired power plant upstream of the water-steam circuit. With repowering, a second heat source can be used to pre-heat the feed water. It is, therefore, possible to achieve a more significant change in heat input per time, which translates into a faster ramp rate.

4.3.3.2. Upgrading control systems and plant engineering

Upgrading the control system in combination with plant engineering upgrades improves precision, reliability, and speed of control.

4.3.3.3. Reducing the wall thickness of the critical component

Reducing the wall thickness of components, such as headers or separators increases the allowable temperature change rate. This increase in temperature change rate allows for faster ramping.

4.3.3.4. Auxiliary firing with dried lignite ignition burner in booster operation

By operating the ignition burner as a booster, which is as an auxiliary burner operated under normal power plant load, the firing rate in the boiler is increased. It is an option to rapidly increase the firing rate without changing the load point of the coal mills and main burners.

4.3.4. Potential of the retrofits

Retrofits to increase flexibility were employed to numerous coal-fired power plants in recent years and were carried out by plant owners not because they were forced to, but rather because it allowed them to run their power plants at more hours during the year. These retrofits significantly improved the flexibility of the coal-fired power plants in balancing the fluctuation of renewables with regard to minimum load, start-up time and ramp rate. The retrofits often had a positive impact on plant efficiency and thereby lowered specific CO2 emissions. However, these retrofits will only happen when there are incentives to do so.

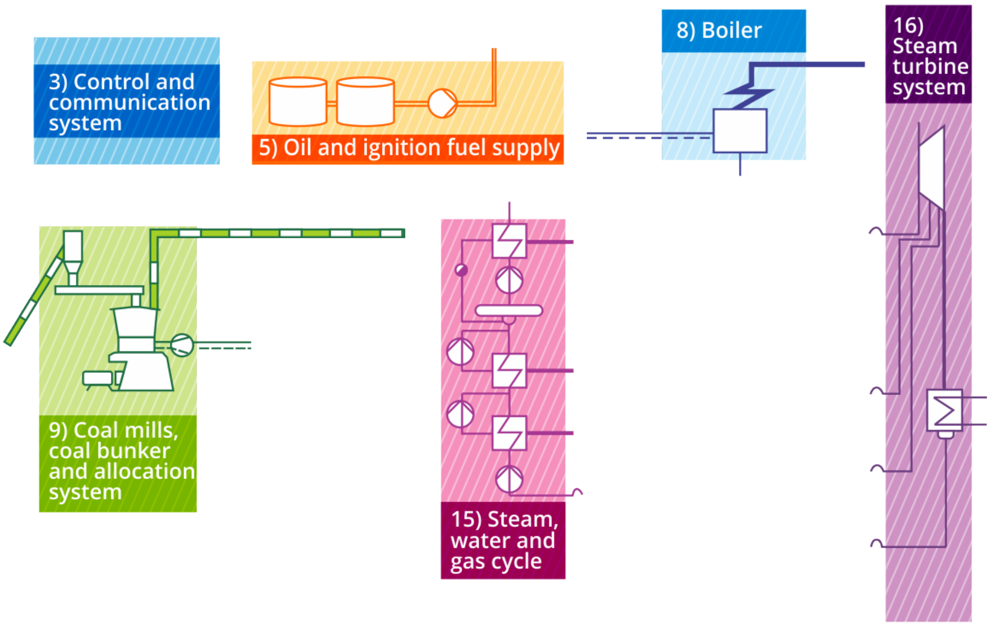


Figure 17 Major subsystem in a coal-fired power plant for retrofits to improve flexibility
source: Fichtner (2017) based on Heinzel, et al. (2012) in Peter, 2018 (redrawn)

4.4. The economic impacts of more flexible generation

Power system with significant shares of renewable generation requires more flexibility to cope with the fluctuating generation. Enhancing the flexibility parameters of coal power plants can improve their economic situation significantly within a proper market environment. In the market with a mixed portfolio of coal power plants and other lower-emission technologies, such as natural gas, flexible coal retrofit improve the competing position of the coal plants, compared to the other technologies. This also means that the goal to limit the CO2 emissions in the power sector must also be addressed explicitly with effective CO2 policy.

Below is an illustration of the profit margin from a coal-fired power plant in a short-term market with high shares of renewables under a different level of flexibility and must-run conditions.

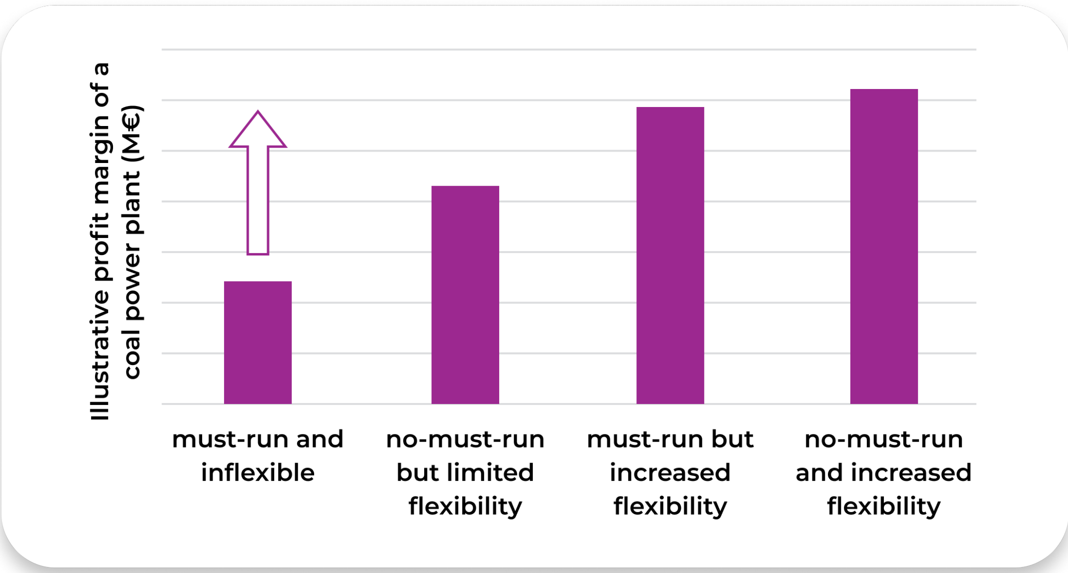


Figure 18 Illustration of the coal-fired power plant's profit margin with high shares of renewables under different flexibility and must-run conditions
source: Agora Energiewende (2017) in Peter, 2018 (redrawn)

4.5. The impact of the flexible coal-fired power plant on CO2 emissions

In a system with a high share of VRE, the flexible operation of coal power plants generally reduces its overall CO2 emissions, since the coal power plants produce in general less electricity over the year, avoiding wasteful curtailment of renewables. However, the flexible operation of coal power plants can hurt CO2 emissions at very low load operation points (lower efficiency at low load) and if lower minimum load prevents the power plant to shut-down during the period of non-profitable operation. That is why, to measure the global effect comprehensively, it is crucial to assess the CO2 emissions of the power plant under specific dispatch conditions and over the entire operation cycle of the power plant. Embracing this comprehensive view shows that in many cases, the gained flexibility of the power plants outweighs the CO2 emission drawbacks at low operating points.

4.6. The importance to adapt the power market conditions

Economics of flexible coal (retrofit) is significantly influenced by the availability of remuneration options for flexibility. A market design which hampers the investment in flexibility is constraining the realization of retrofit in coal power plants, as well as alternative flexibility options. Shorter electricity markets (e.g., intraday) and products, as well as the adjustment of the balancing power arrangements, are among the necessary measures. In doing so, renewables can be integrated more easily and in an economically efficient way into the power systems, limiting in particular wasteful renewable energy curtailment.

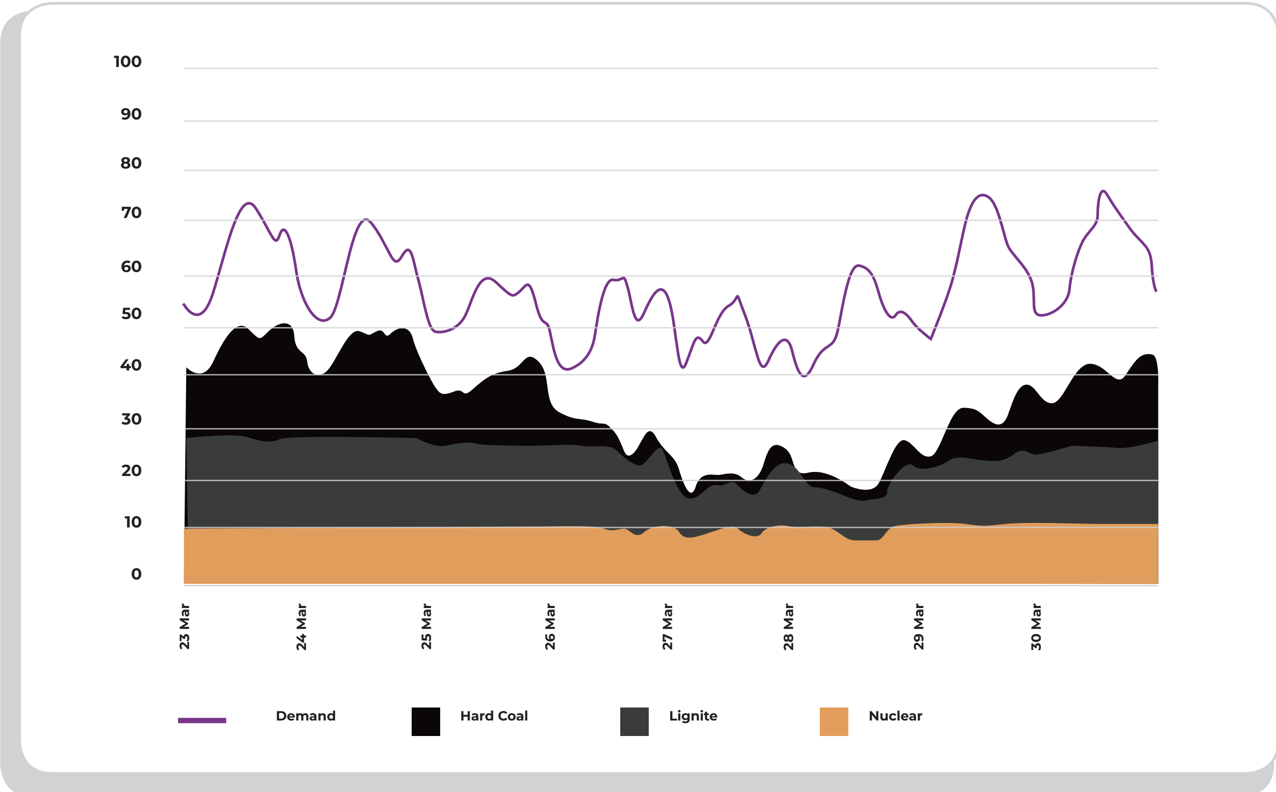


Figure 20 Power generation from nuclear, hard coal and lignite power plants and demand in Germany, 23 to 30 March 2016
source: Agora Energiewende (2016) in Peter, 2018 (redrawn)

5. Policy options to enhance flexibility

Power system transformation is underway in many countries, although the speed and scope of change vary significantly. Changes to power systems are path dependent and are influenced by the prevailing market structure and regulatory mechanisms. Technical, economic, and institutional policy layers mutually influence each other and have to be addressed consistently to enhance power system flexibility. Policies aimed at unlocking flexibility should aim beyond the technical level, taking into account markets and institutions.

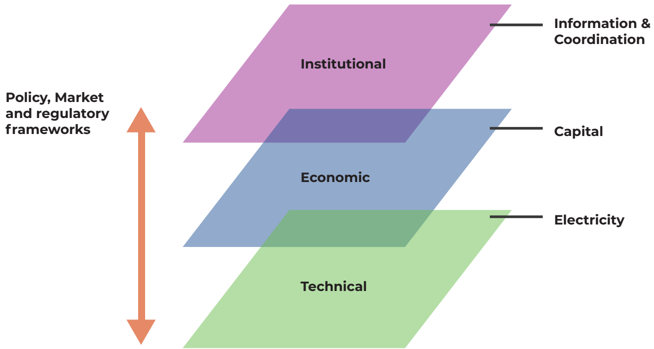


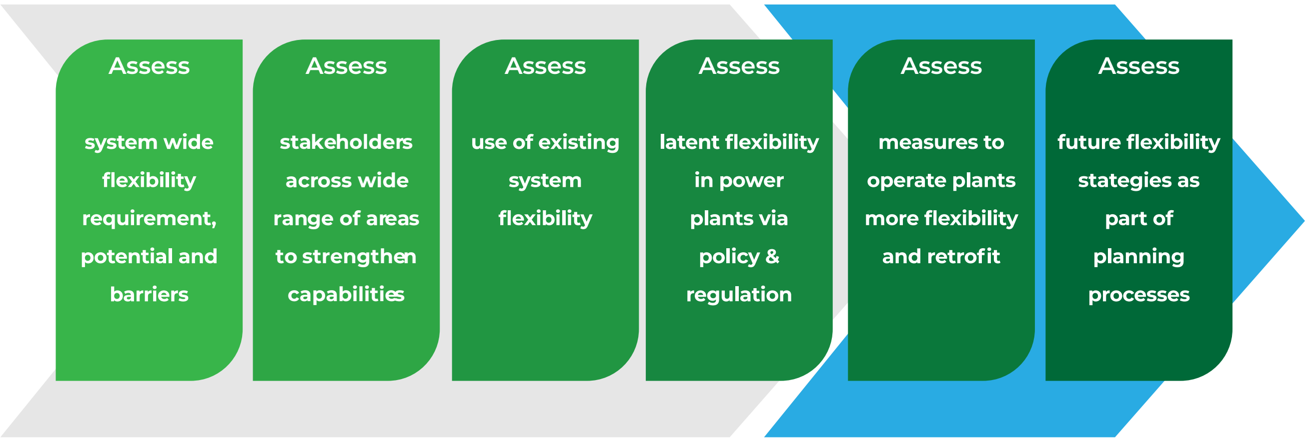
Figure 21 Policies, markets and regulatory frameworks link technical, economic, and institutional aspects
source: IEA 2018 in Peerapat, 2018 (redrawn)

The table below shows policy options to enhance flexibility

Sources of system-wide inflexibility	Policy options to enhance flexibility
Inflexible generation fleet	-Mobilize flexibility in existing power plants -Facilitate investment in flexible plants -Enhance long-term planning processes
Limited access to flexible resources in neighboring power systems	Co-ordination among neighboring balancing areas through institutional co-operation and additional interconnection
Frequent transmission network congestion – when transmission lines operate at or near their rated capacity	Increase available grid capacity. Investments in HV lines, distribution networks, protection schemes, and other components.
Limited storage capacity and lack of demand that can be shifted	-Enable demand shifting and create rules that encourage DSR participation. -Introduce instruments that reflect the system value of electricity storage.

source: IEA 2018 in Peerapat, 2018

Following a set of best practice policy guidelines allows successful roll-out of power plant flexibility. These guidelines can be divided into near-term actions and long-term planning as follow:

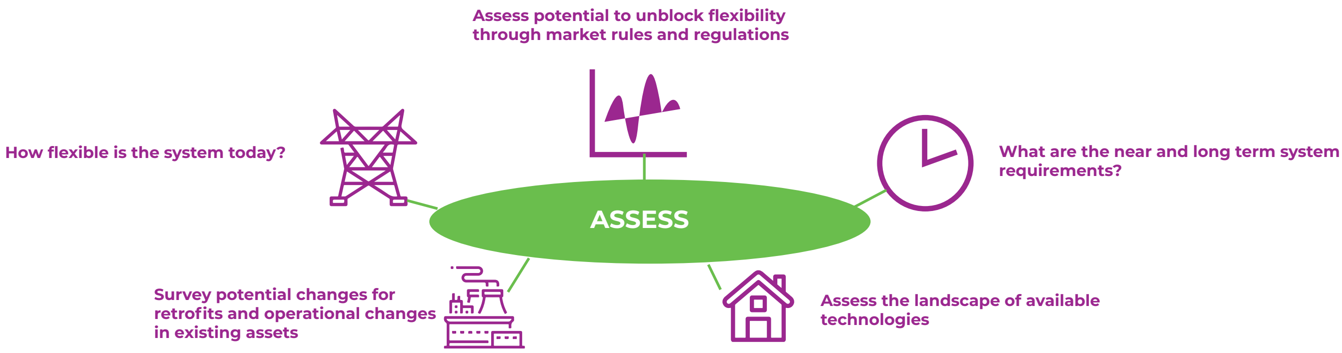


source: IEA 2018 in Peerapat, 2018 (redrawn)

a. Consideration 1 – Assess
Building up a flexibility inventory can allow policymakers to see what options are available today and how to plan for future flexibility requirements.

b. Consideration 2 – Engage
Knowledge sharing across all levels of the power system, including stakeholders beyond the typical scope of the power sector can improve the development of technical and economic strategies for increased flexibility. Moreover, sharing experiences internationally is crucial in avoiding duplicating efforts. Finally, domestic and international stakeholder engagement can help build momentum for embedding flexibility in modern power systems.

c. Consideration 3 – Enhance
Enhancing system-wide flexibility relates to encouraging system operators to engage in faster power system operation, which allows for greater flexibility in operations and reduces the need for balancing. It also means transition towards centralized VRE forecasting system. Geographically communication and coordination between balancing areas must be increased to allow system operators to make use of a wider pool of resources. What is also essential is to incentivize technologies that make the demand more flexible and adopt advanced strategies to increase available grid



source: IEA 2018 in Peerapat, 2018 (redrawn)

capacity.

d. Consideration 4 – Unlock

There are several ways to unlock flexibility from existing assets:

- Technical approaches, such as reducing minimum stable load can help reduce curtailment of VRE output; and
- Market approaches, such as ensuring contract flexibility can both increase power system flexibility and result in increased savings from power system operation when compared with technical approaches.

Contract flexibility leads to lower costs due to the ability to fully optimize the choice of fuel for generation.

e. Consideration 5 – Incentivize

Introducing fair remuneration that accounts for the system value of flexibility is important. It can ensure that the developers of new plants use resilient materials that can cope with the increased stress from the flexible operation, which in turn also help reduce maintenance costs throughout the plant's operation. For the existing assets, it is important to allow cost recovery on plant retrofits. However, it is necessary to understand the difference in the regulated and liberalized market.

In regulated markets	In liberalized markets
·Allow cost recovery for retrofit investments ·Provide incentives that allow for resilient, high-flexibility components in new power plants	·Improve wholesale market design ·Implement market instruments for all relevant system services ·Implement additional mechanisms that appropriately value capacity, flexibility, and other relevant resource attributes

source: IEA 2018 in Peerapat, 2018

f. Consideration 6 – Roadmap

Including flexibility assessments in system adequacy assessments will become increasingly important as systems integrate increasing shares of VRE. These assessments can provide a picture of available inertia, and the cost and parameters of the existing and planned reserves necessary to meet critical hours. Modern state-of-the-art decision tools include production cost models. The most modern tools are commercially available and provide a clear picture of system and plant performance under several scenarios.

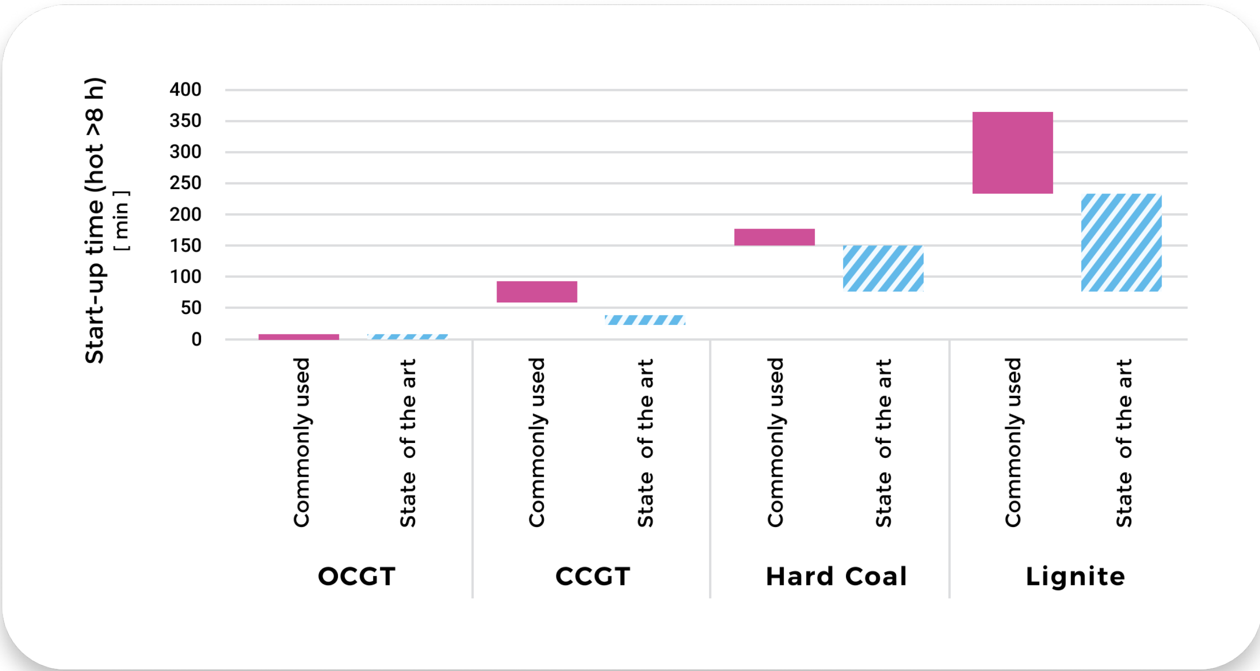
REFERENCES

- Agora Energiewende. (2019). The Energy Transition in the Power Sector: State of Affairs in 2018
- Godron, Philipp. (2018a). How Renewables change power system operation. Agora Energiewende.
- Godron, Philipp. (2018b). Flexibility options applied today: Examples from Germany. Agora Energiewende.
- IESR (2019a). Indonesia Clean Energy Outlook: Tracking Progress and Review of Clean Energy Development in Indonesia. Jakarta: Institute for Essential Services Reform (IESR).
- IESR (2019b). A Roadmap for Indonesia's Power Sector: How Renewable Energy Can Power Java-Bali and Sumatra. Institute for Essential Services Reform (IESR), Jakarta.
- Vithayasrichareon, Peerapat. (2018). Grid integration of variable renewables: Flexible options for the power system. IEA.
- Peter, Frank. (2018). Flexibility of thermal power plants. Agora Energiewende.
  Vithayasrichareon, Peerapat. (2018). Flexibility challenges for Indonesia's energy transition. IEA.

APPENDIX I – Comparison of power plants with most commonly used technologies vs. power plants with state-of-the-art technologies for each generation type

COMPARISON ON HOT START-UP TIME (INTERRUPTED < 8h)

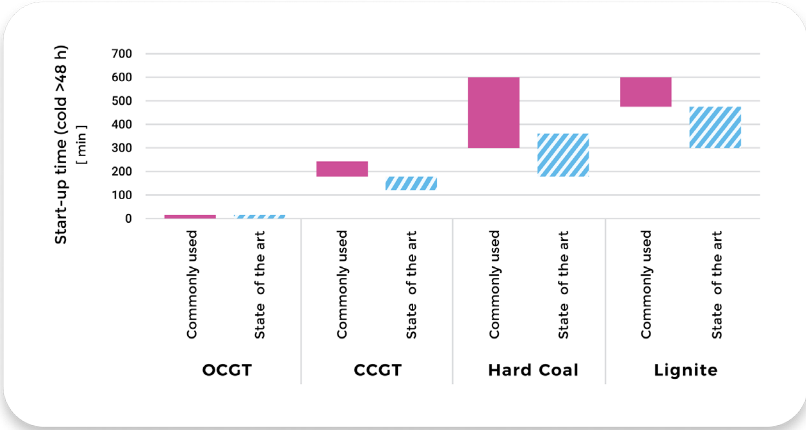
This figure illustrates the difference between power plants with most commonly used and state-of-the-art technologies with regard to hot start-up time. OCGT has the shortest hot start-up in both categories, followed by CCGT, hard coal-fired, and lignite-fired power plants. The range of hot start-up time for OCGT decreases only slightly but decreases significantly for lignite-fired power plant.



source: Agora Energiewende (2018) (redrawn)

COMPARISON ON COLD START-UP TIME (INTERRUPTED > 48h)

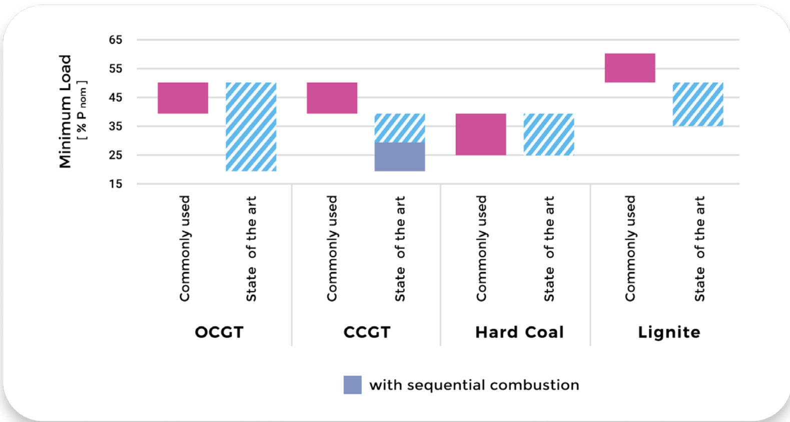
This figure illustrates the difference between power plants with most commonly used and state-of-the-art technologies with regard to cold start-up time. OCGT provides the shortest cold start-up in both categories, followed by CCGT, hard coal-fired, and lignite-fired power plants. The range of cold start-up time for OCGT decreases only slightly, but decreases significantly for hard coal-fired power plant.



source: Agora Energiewende (2018) (redrawn)

COMPARISON ON MINIMUM LOAD

This figure illustrates how most of the state-of-the-art power plant can achieve significant improvement compared to the commonly used coal-fired power plants. Technological improvement significantly reduced the minimum load in OCGT and CCGT state-of-the-art power plant.

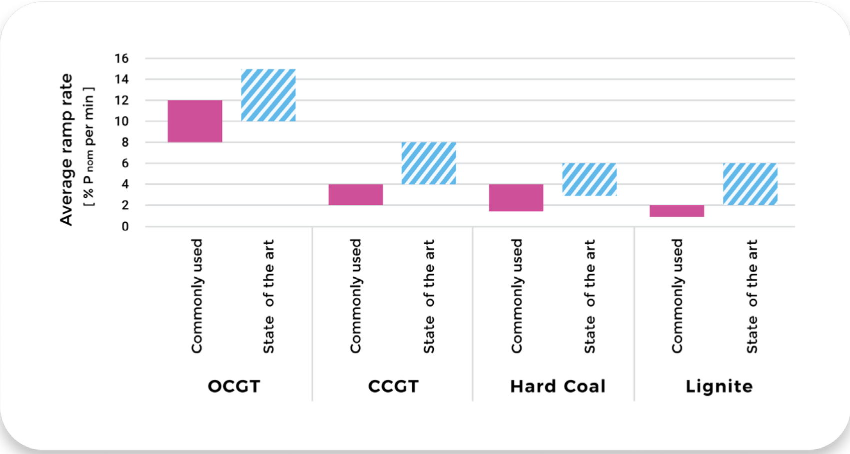


source: Agora Energiewende (2018) (redrawn)

COMPARISON ON RAMP RATE

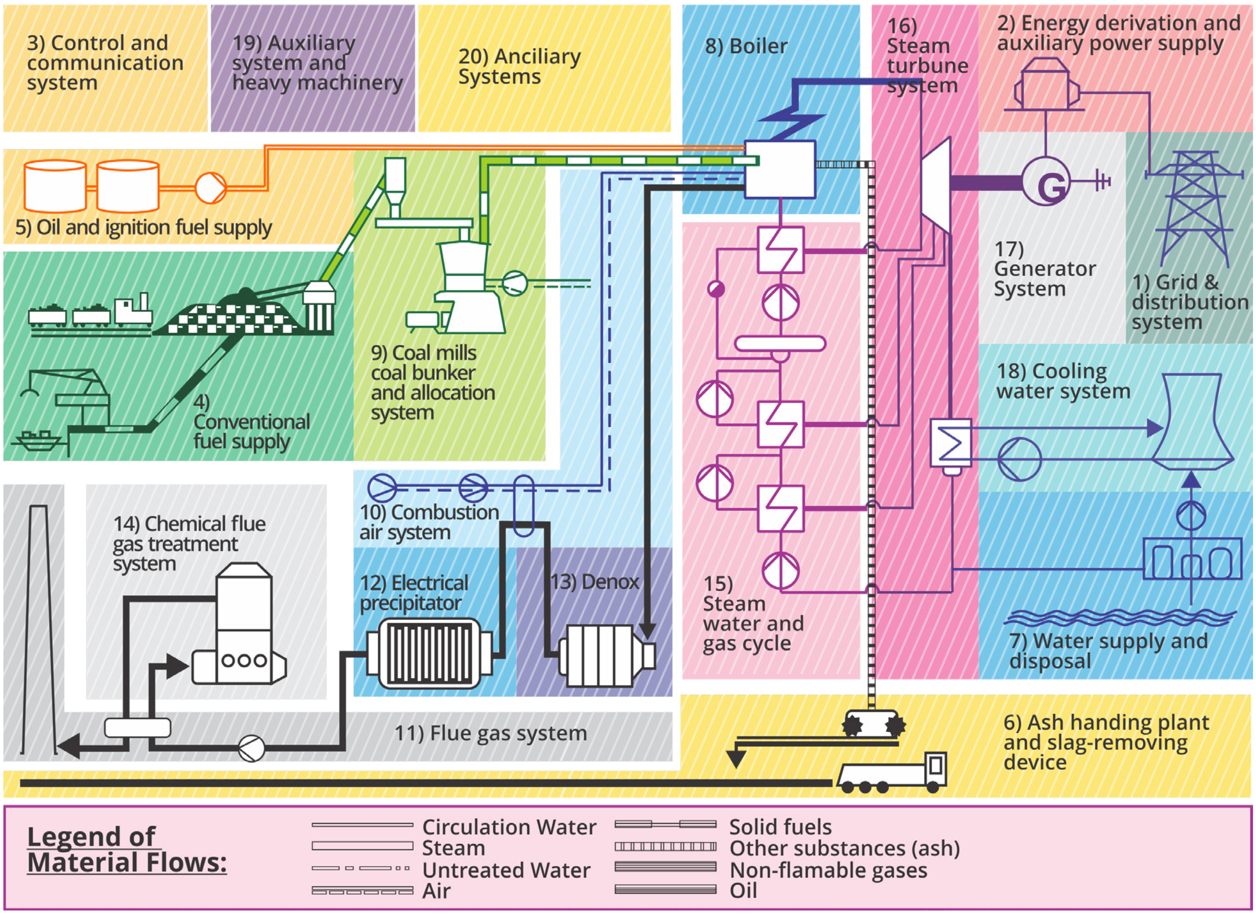
This figure illustrates how most of the state-of-the-art power plant can achieve significant improvement compared to the commonly used coal-fired power plants.

Technological improvement significantly increased the ramp rate in almost all of the state-of-the-art power plant.



source: Agora Energiewende (2018) (redrawn)

APPENDIX II – Illustrative subdivision of a coal-fired power plant



source: Klumpp (2009) (redrawn)

IESR
Institute for
Essential Services
Reform

Jalan Tebet Barat Dalam VIII No. 20
Jakarta Selatan 12810 | Indonesia
T: +62 21 2232 3069 | F: +62 21 8317 073

iesr.id iesr.id www.iesr.or.id IESR iesr