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Dr. Andreas Feldmüller, Expanded Scope Solutions

From base to cycling operation - innovative concepts for thermal power plants

From base to cycling operation – Innovative concepts for thermal power plants

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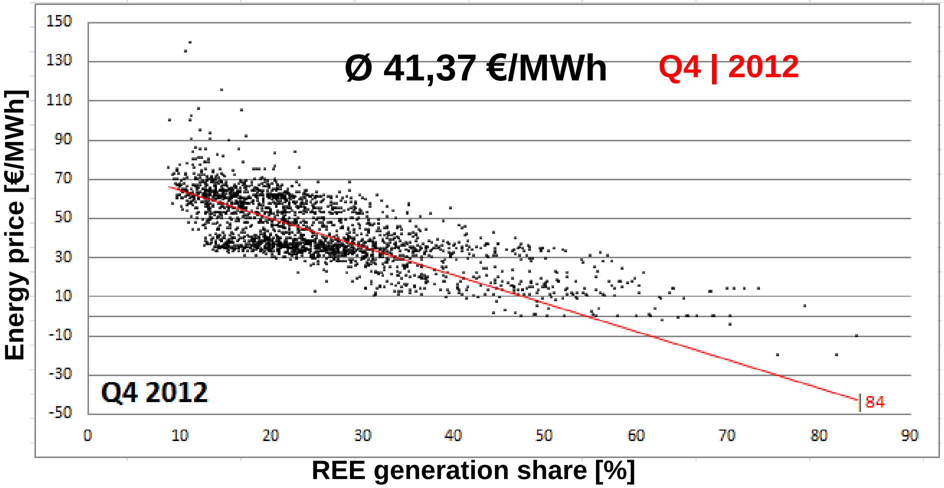
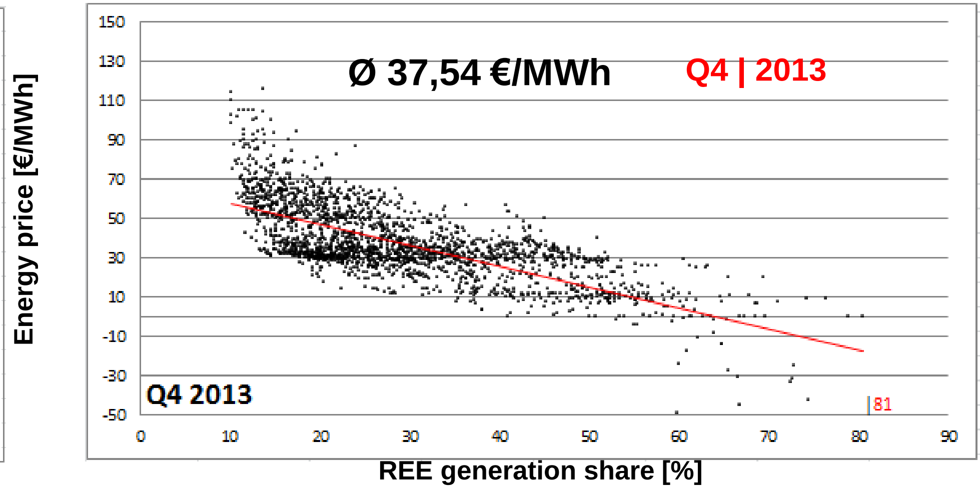
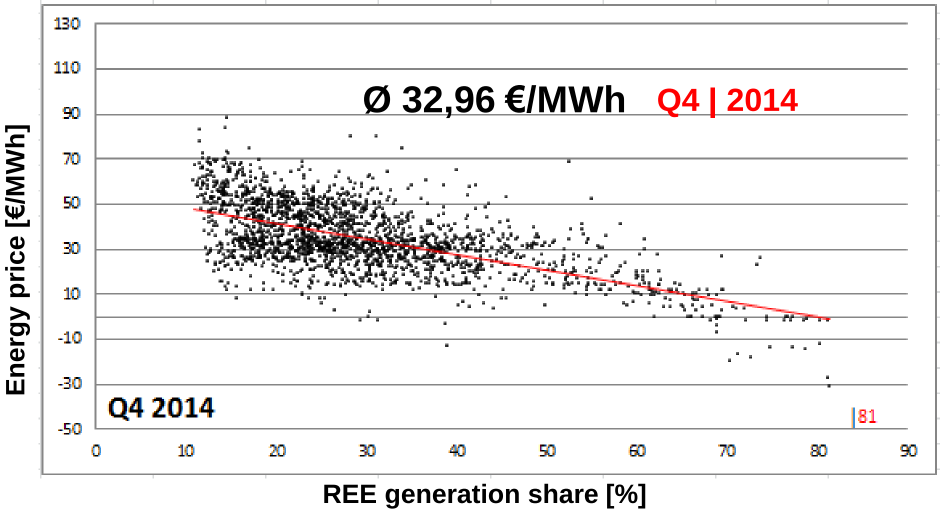
- The need for operational flexibility – Flex-Power Services™
- Fast load transients
- Low minimum load
- Advanced control concepts
- Digital transformation of service

Decline of wholesale power prices in Germany



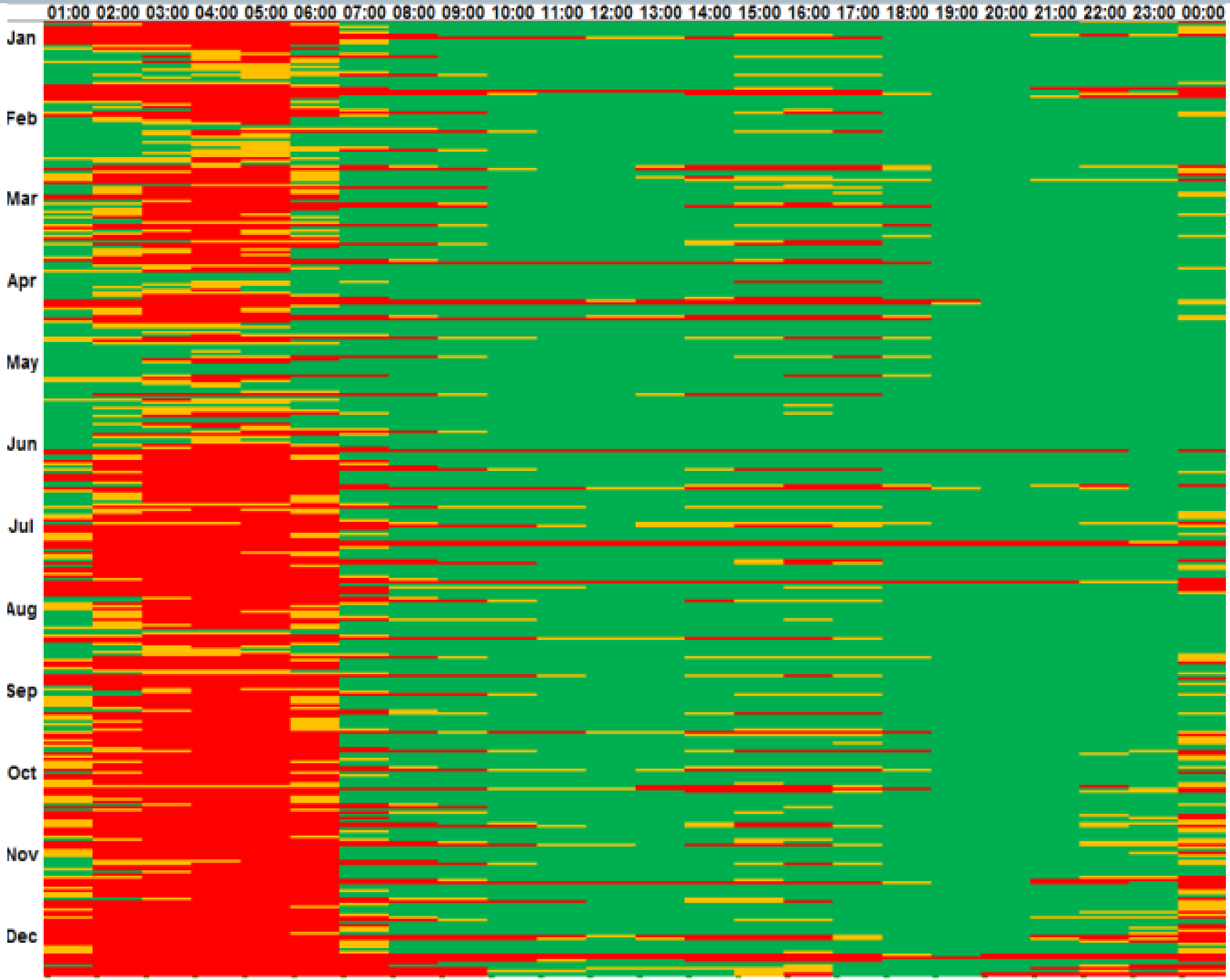




Av.price/ Max. share REE	2011	2012	2013	2014	
Q 1	51,85 €/MWh 58%	43,38 €/MWh 74%	42,26 €/MWh 77%	31,13 €/MWh 73%	↓
Q 2	53,60 €/MWh 62%	40,39 €/MWh 74%	32,59 €/MWh 85%	31,61 €/MWh 84%	↓
Q 3	49,16 €/MWh 56%	43,51 €/MWh 72%	38,75 €/MWh 75%	31,43 €/MWh 83%	↓
Q 4	49,93 €/MWh 61%	41,37 €/MWh 84%	37,54 €/MWh 81%	32,96 €/MWh 81%	↓

Source: Illustration of 3. Quarter of the shown year on basis of ENTSO-E and EEX Data

Clean spark spread spectrum 2011 Germany



- **6.054 hours (69,1 %) with a positive spread** for a typical F-class Combined Cycle Power Plant (CCPP)
- Hard coal plants and CCPP are „neighbors" in the German merit order
- Slide gives indication for hard coal plants well

Source: own illustration based on EEX data

PowerGen Europe Presentation 2015, Feldmüller, Röhr, Zimmerer

Decline of clean spark spreads in Germany F class CCPP

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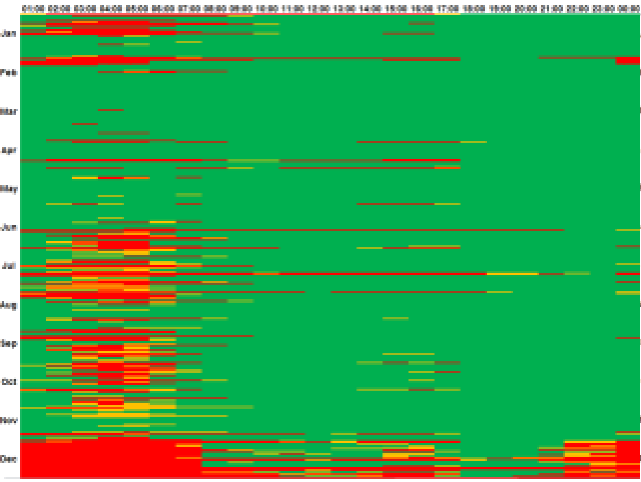
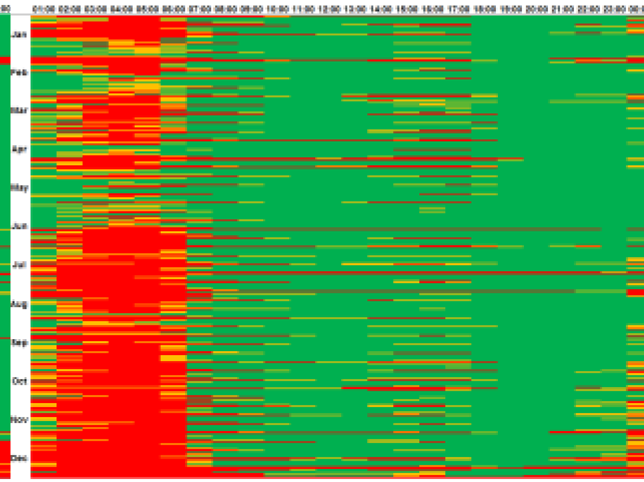
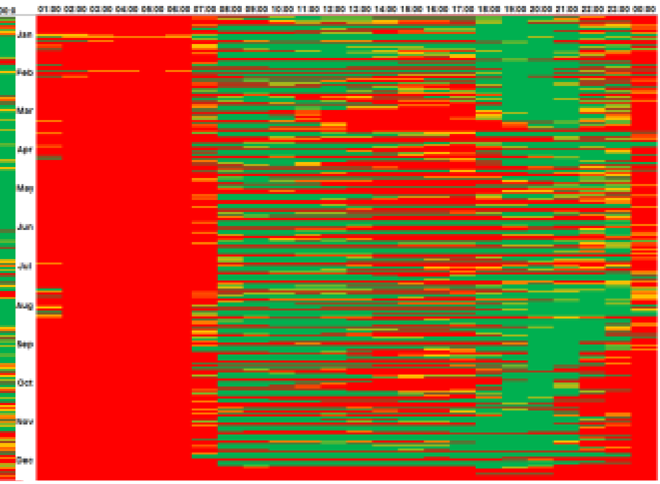
2010



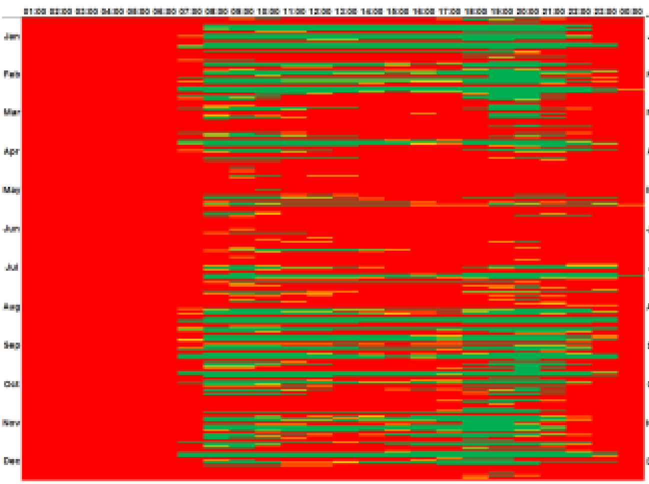
2011



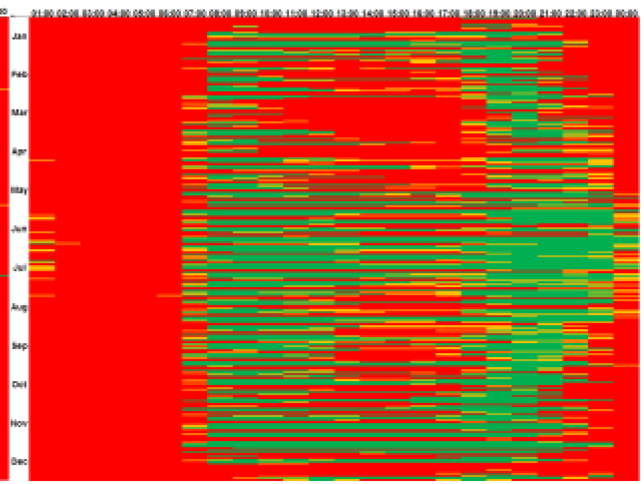
2012



2013



2014



Year	Share of positive hours	Positive hours
2010	84,9 %	7.437 h
2011	69,1 %	6.053 h
2012	36,3 %	3.180 h
2013	19,7%	1.726 h
2014	28,9 %	2.540 h

Source: own illustration based on EEX data - PowerGen Europe Presentation 2015, Feldmüller, Röhr, Zimmerer

Example of the load regime change at a glance
F class CCPP in Germany

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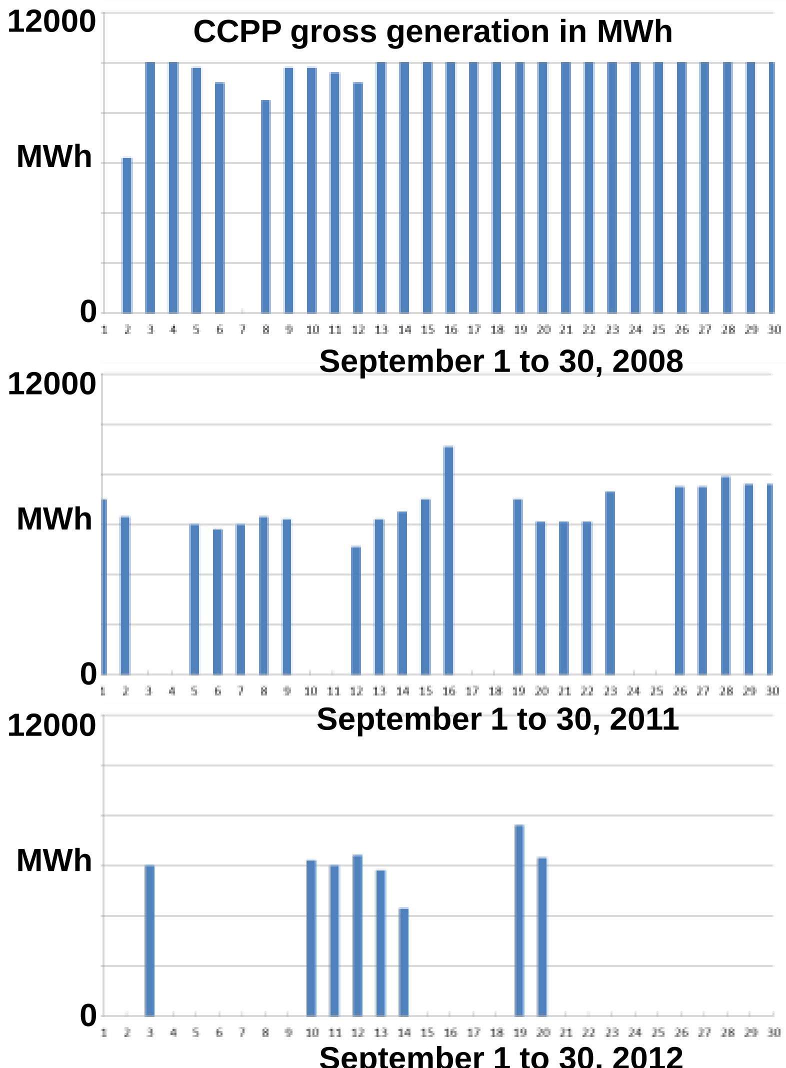
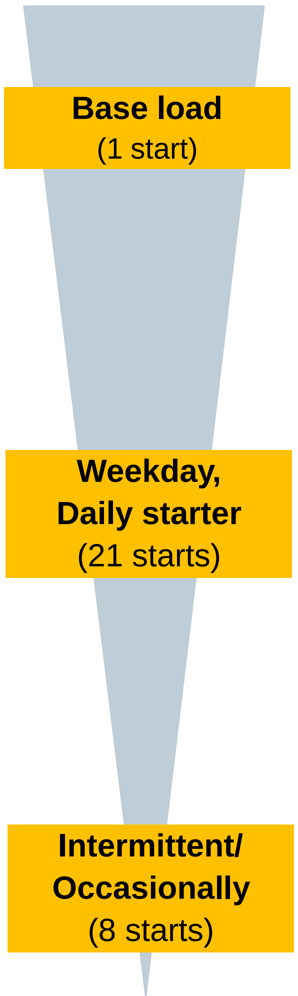


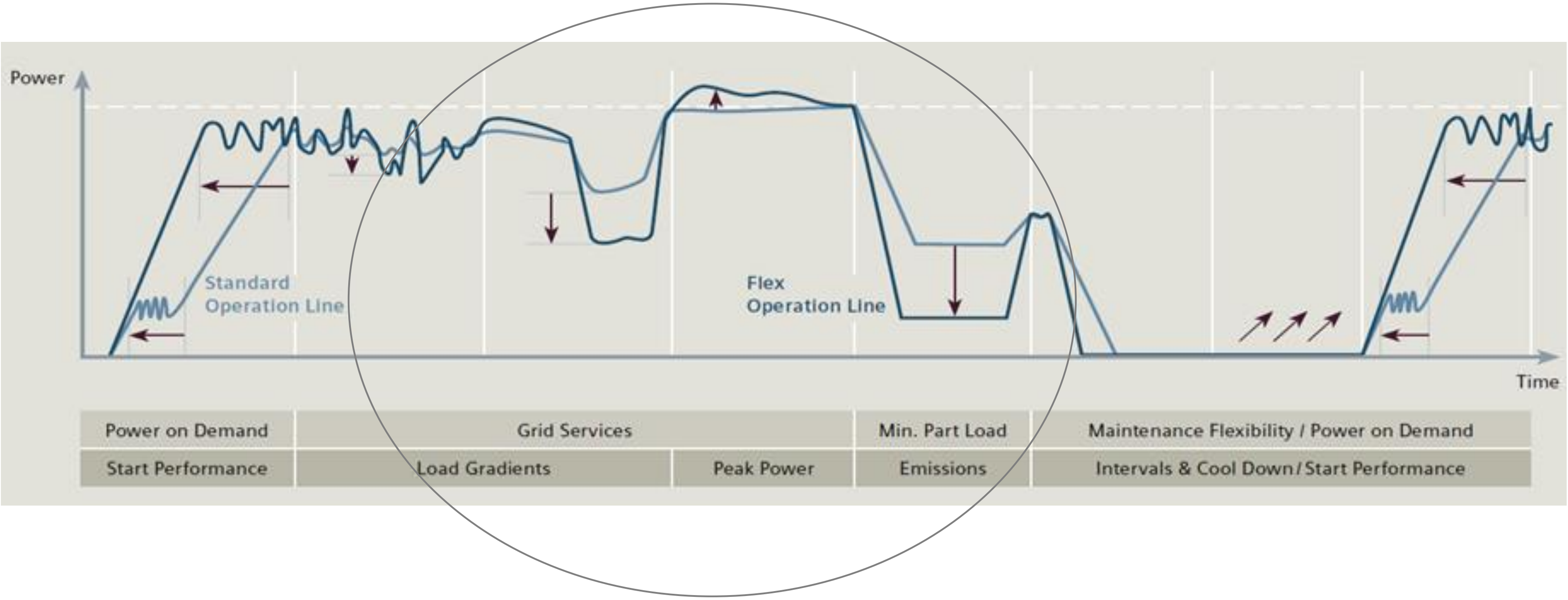


Changing situation

- Increase of starts
- Less operating hours
- More part load hours and load transients
- Change from hot starts to cold starts
- Shift to unpredictable and new load regimes

Source: Site data from a German CCPP - PowerGen Europe Presentation 2015, Feldmüller, Röhr, Zimmerer

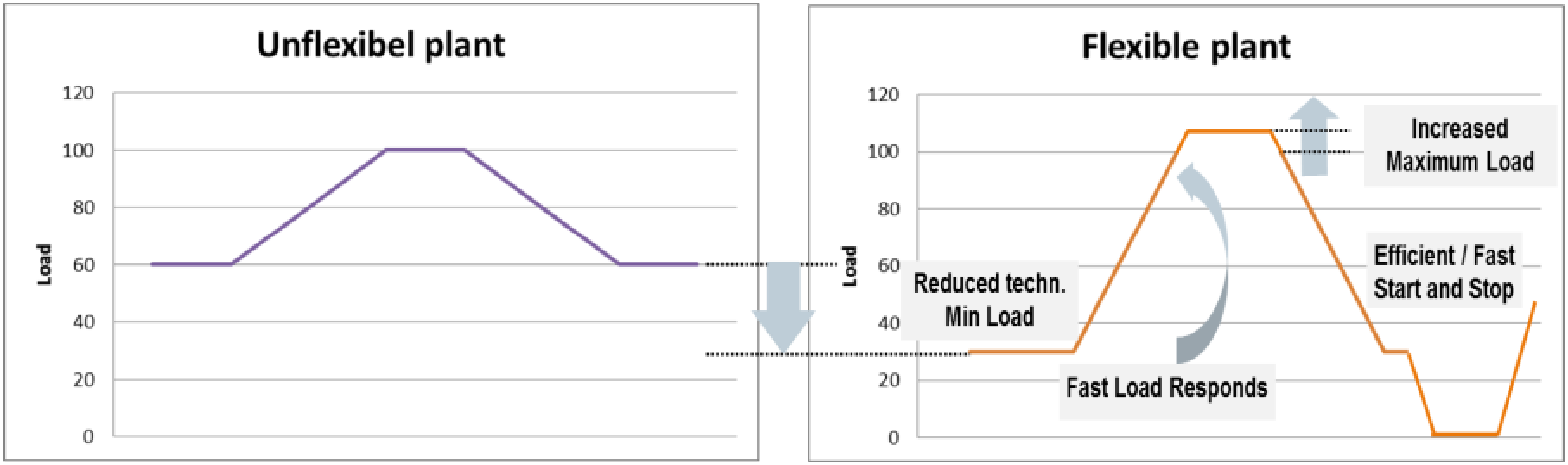
Aspects of Flex-Power Services™



Flex-Power Services™

- Activity of Siemens Power Generation Services
- Targets all aspects of plant operation

Flexibility for thermal power plants



Flexibility is characterized:

- *Highest ramping up operation with maximum load gradient*
- *Lowest stable minimum load operation*
- *Fast start-up and stop operation with less fuel consumption*

***Beyond**:*

- *Maximum plant efficiency and lowest emission values over the whole load range*

From base to cycling operation – Innovative concepts for thermal power plants

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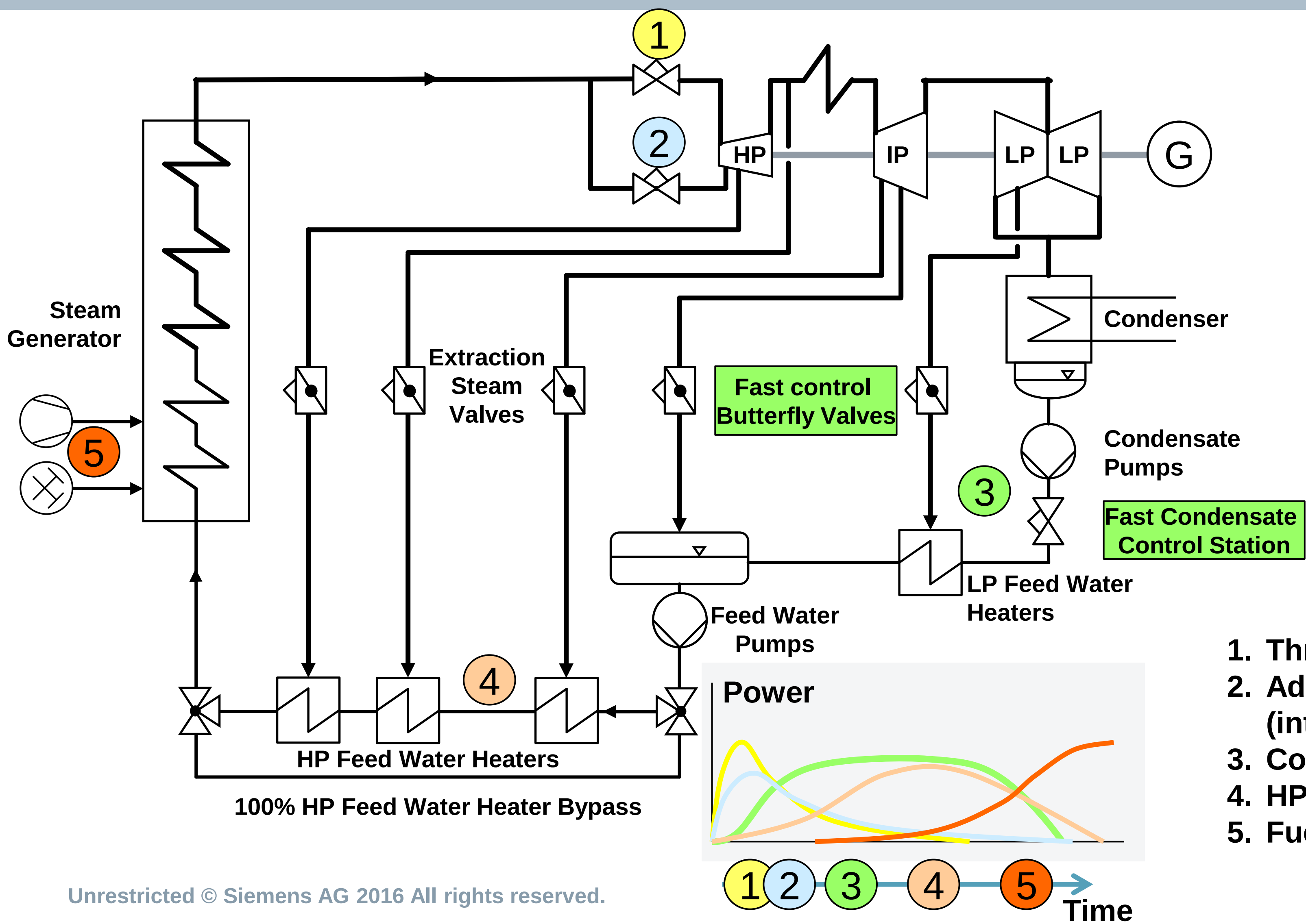
Fast load ramps of steam power plants – frequency support with the water steam cycle



1. Throttling
2. Additional Valve (interstage valve)
3. Condensate Stop
4. HP Heater
5. Fuel Increase

Overall optimization of steam power plant to improve plant frequency support

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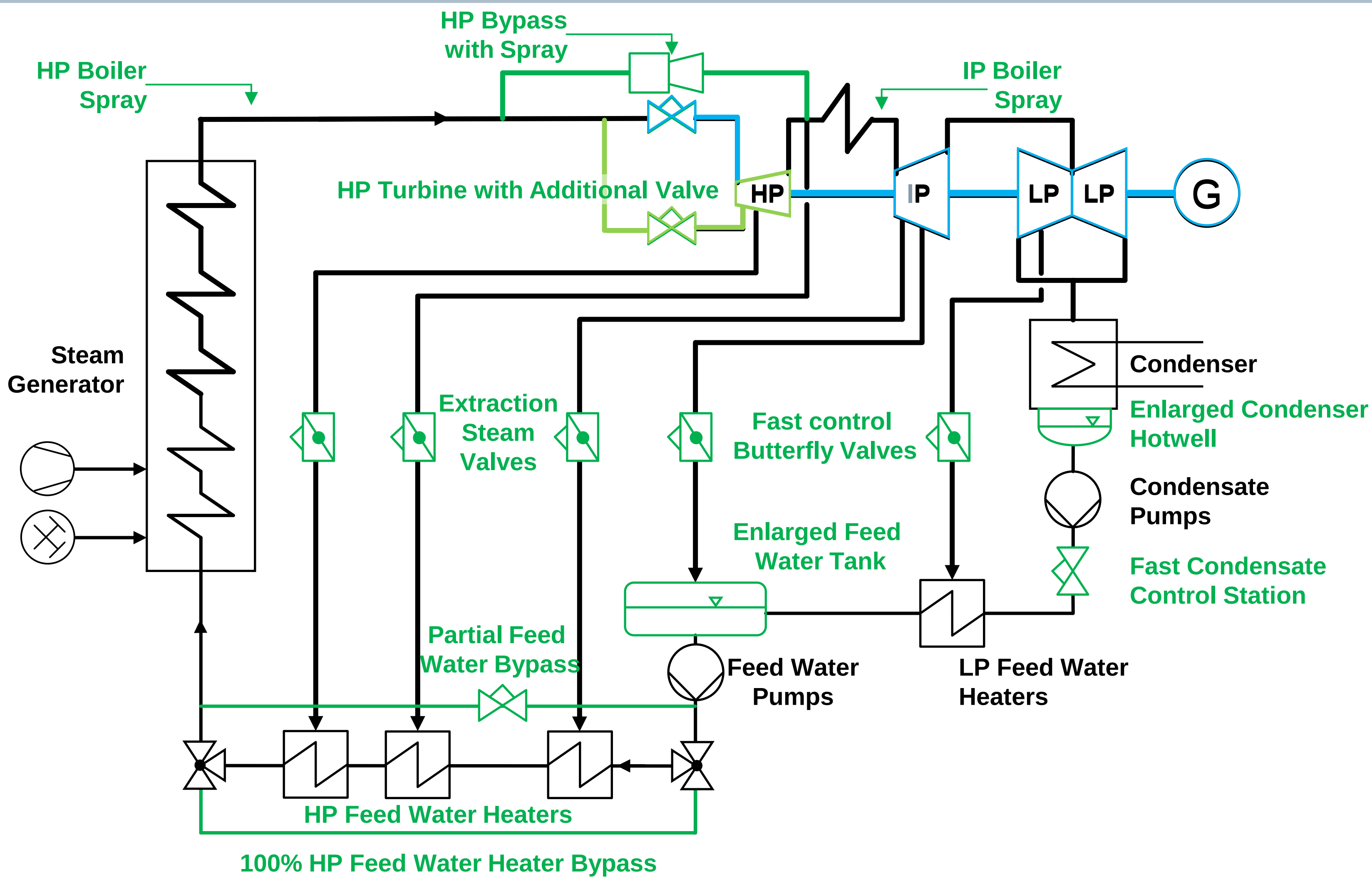
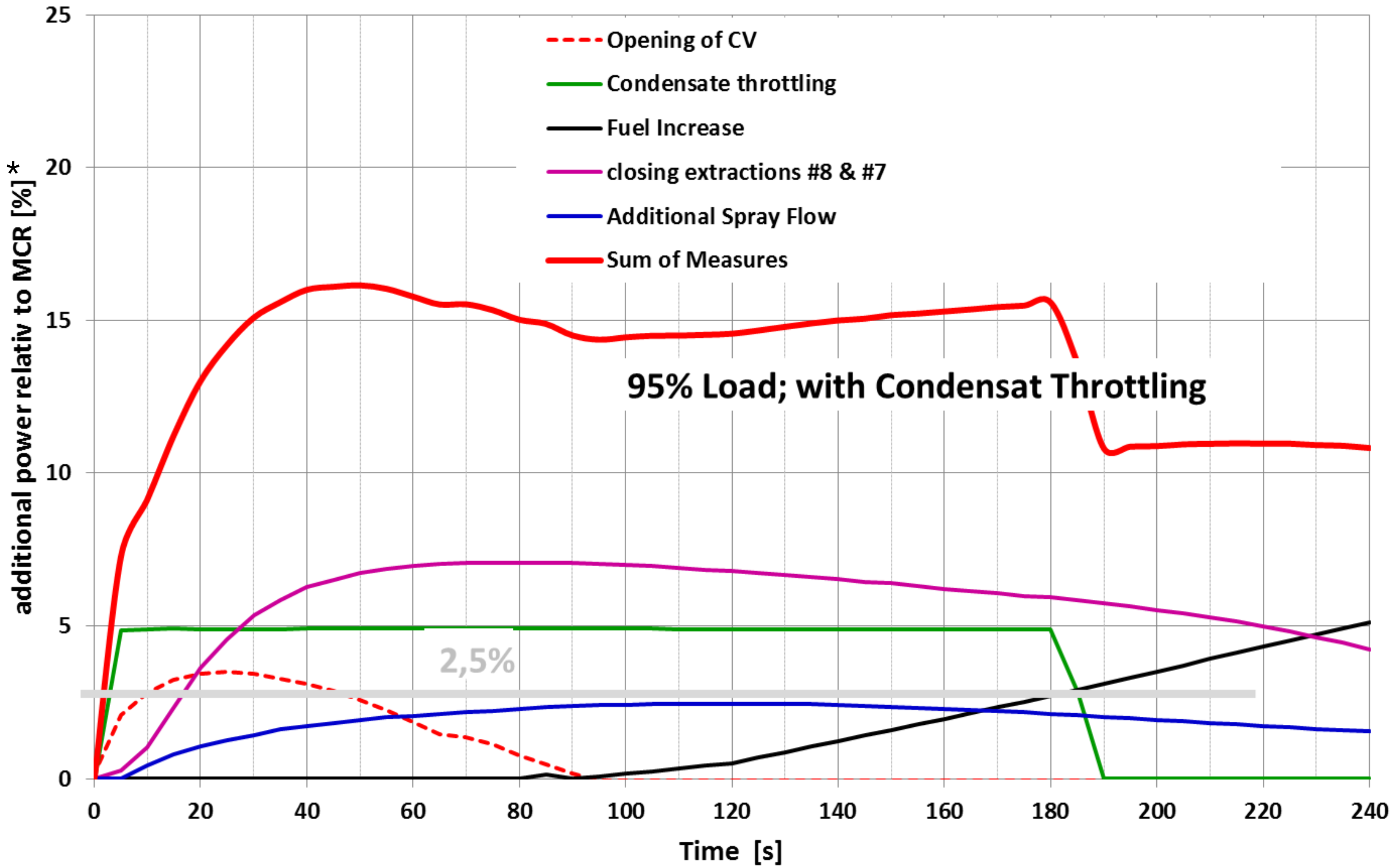
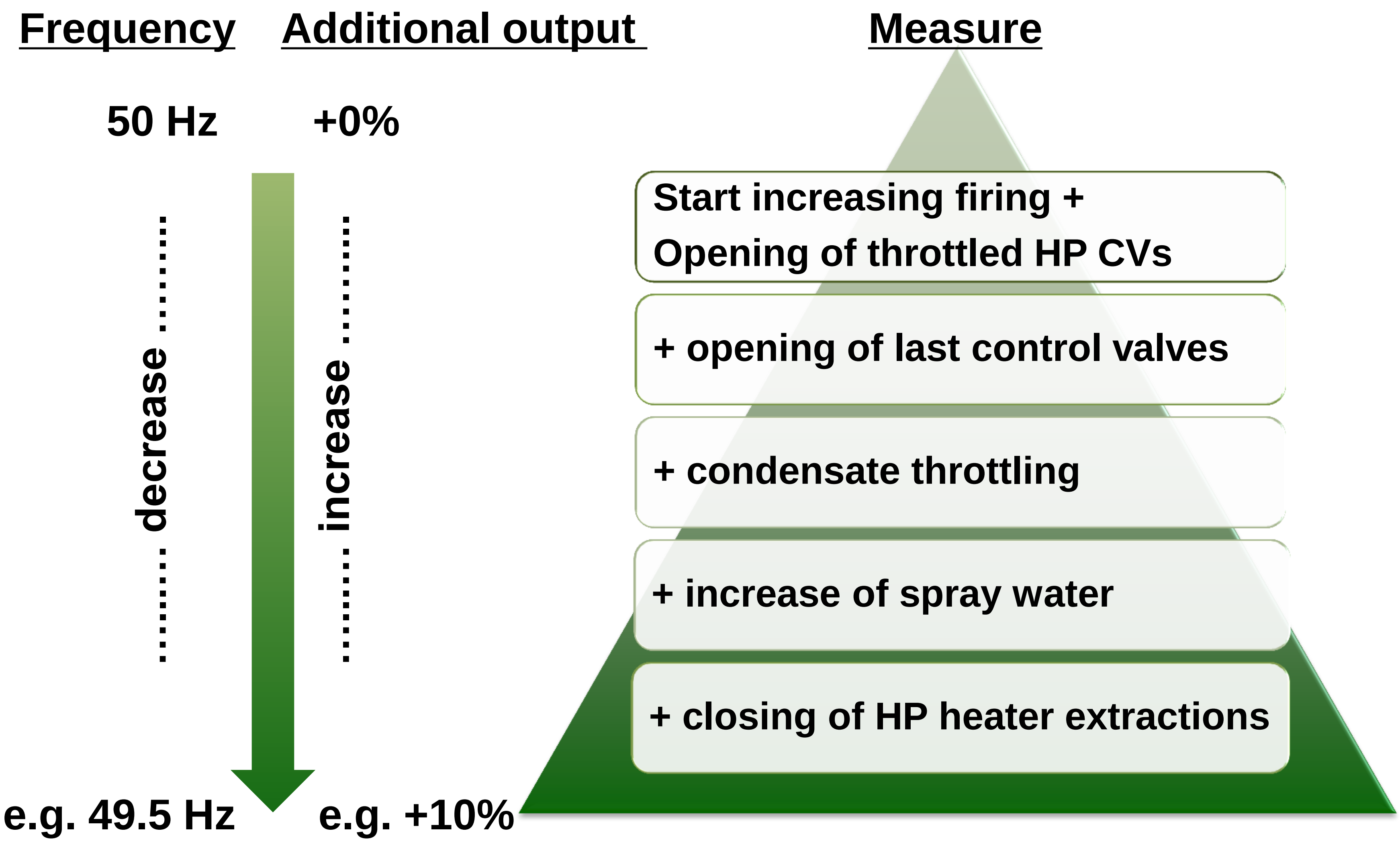


Simulation with all measures – typical example



* Typical values only – plant specific engineering required

Concept for staggering of measures



Higher profitability through intelligent solutions
SPPA-P3000 process optimization for steam power plants

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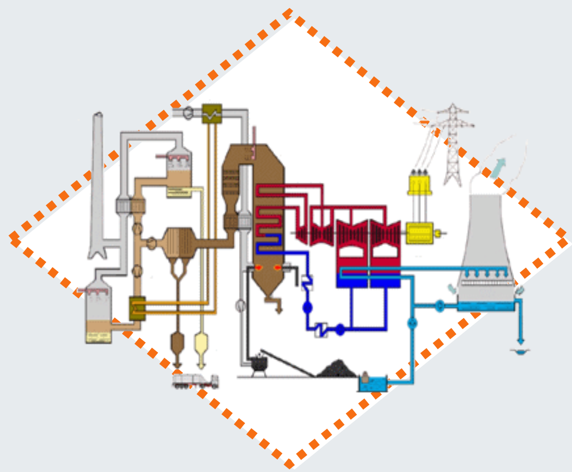
Runback Plus
Life Time Plus

High availability

Low Loss Start
Combustion Optimizer
Sootblower Optimizer

High efficiency

Temperature Optimizer
Low Throttling
Best Point



Fast Start
Fast Ramp
Frequency Control

High flexibility

Dispatch Control
Minimum Load Reduction
Maximum Load Plus

Low emissions

NO_x Reduction
CO_2 Reduction
LoI Reduction

SPPA-P3000 process optimization
Example: RWE Neurath Unit D

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- 630 MW, tangential, lignite-fired, from 1975
- Boiler design for base load
- Fuel changed massively compared to design

	starting situation	contract	proven (trial run)	further possible potential	
Load gradient	5 MW/min	12 MW/min	15 MW/min ✓	20 MW/min	x 3.0
Minimum load (gross)	440 MW	290 MW	270 MW (w/o bypass operation) ✓	250 MW	40%
Primary frequency control (PFC)	18 MW by with throttling losses	18 MW by without losses	45 MW ✓	50 MW	x 2.5
Secondary frequency control (SFC)	n.a.	66 (75) MW	100 MW ✓	110-115 MW	New
Simultaneous PFC and SFC	n.a.	18 MW 66 (75) MW	18 MW 75 MW ✓	still under investigation	New
"Hot" commissioning	-	10 days	D: 9 days E: 32 hours ✓	-	
Optimsation phase	-	-	D: 8 months E:1-2 months	-	

RWE Neurath Unit D built 1975 for Base Load
has become “One of the most Flexible Lignite Power Plants”

Source: PowerGen Europe Presentation 2013

Results at RWE Neurath Unit D:
Load gradient tripled, Minimum load reduced by 40%

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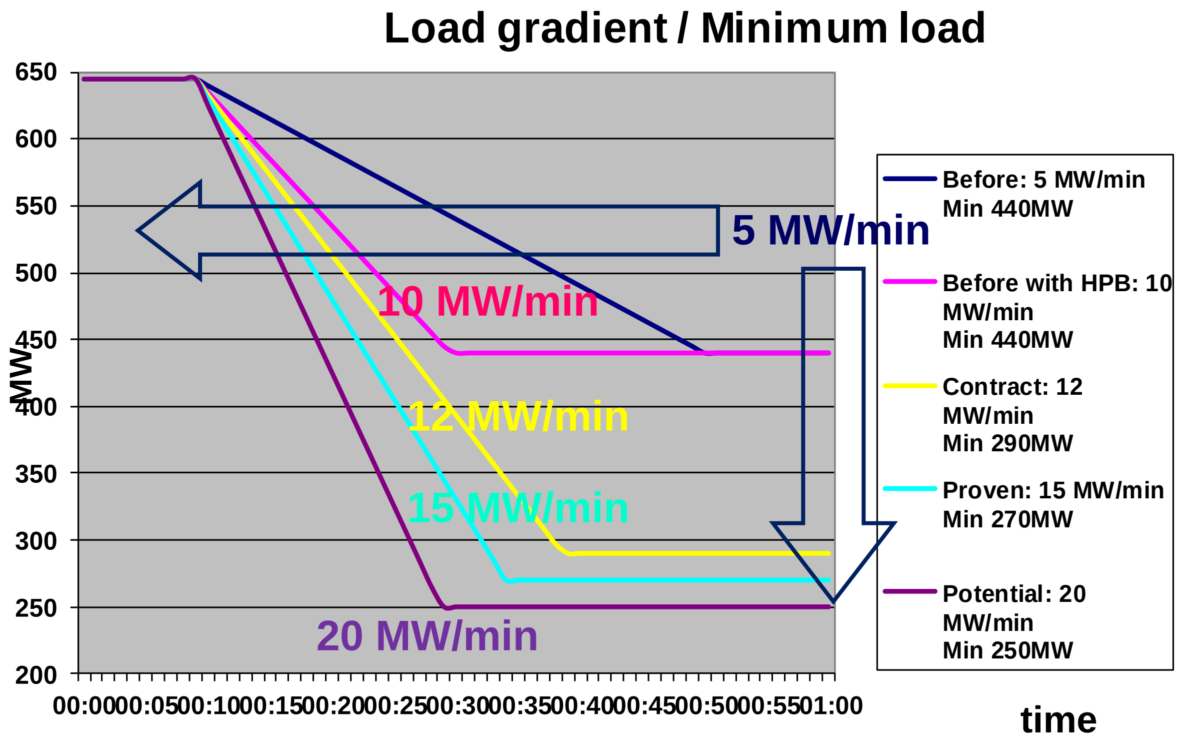

- Installation of a new robust state-space unit control
- Fully automatic mill shut-on and shut-off
- Optimisation of all subordinated controllers, e.g. air, feedwater, fuel

Source: PowerGen Europe Presentation 2013

From base to cycling operation – Innovative concepts for thermal power plants

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SPPA-P3000 Minimum Load Reduction
Reduced minimum load level

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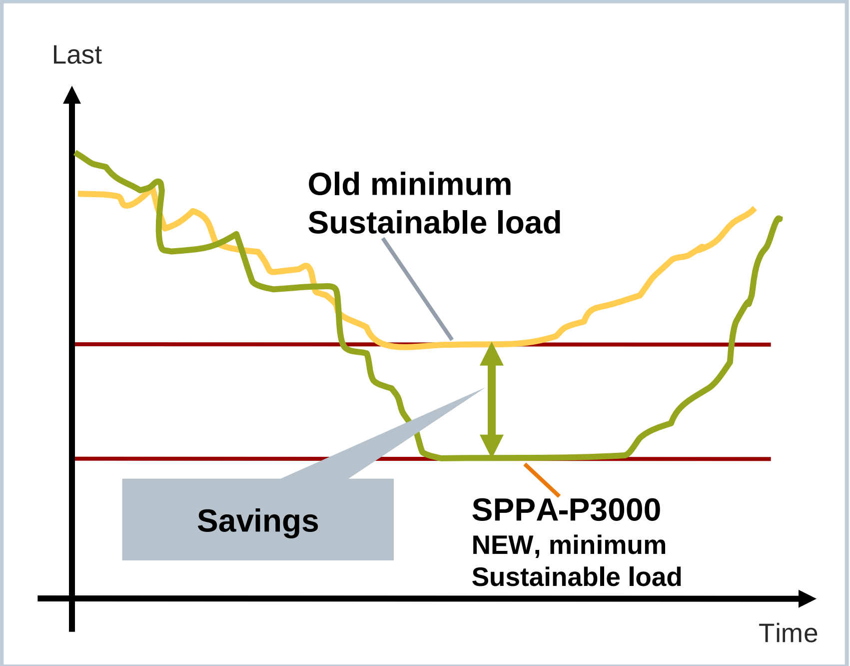
Task

To upgrade the plant so that the specified minimum load level can be reduced and to make the plant capable of fast and low-stress load increases on demand in accordance with market requirements.

Solution

- Adaptation, optimization and setting of lower-level controls for new minimum load level
- Installation of additional field valves and sensors if necessary



The Minimum Load Reduction solution results in savings for minimum load operation through optimization of lower-level controls

Benefit

- Reduced financial losses during off-peak periods
- Faster response to increased load demands as unit does not need to be shut down
- Avoidance of unnecessary startups and shutdowns

Flex-Power Services™
Siemens steam turbine EOH counter innovations

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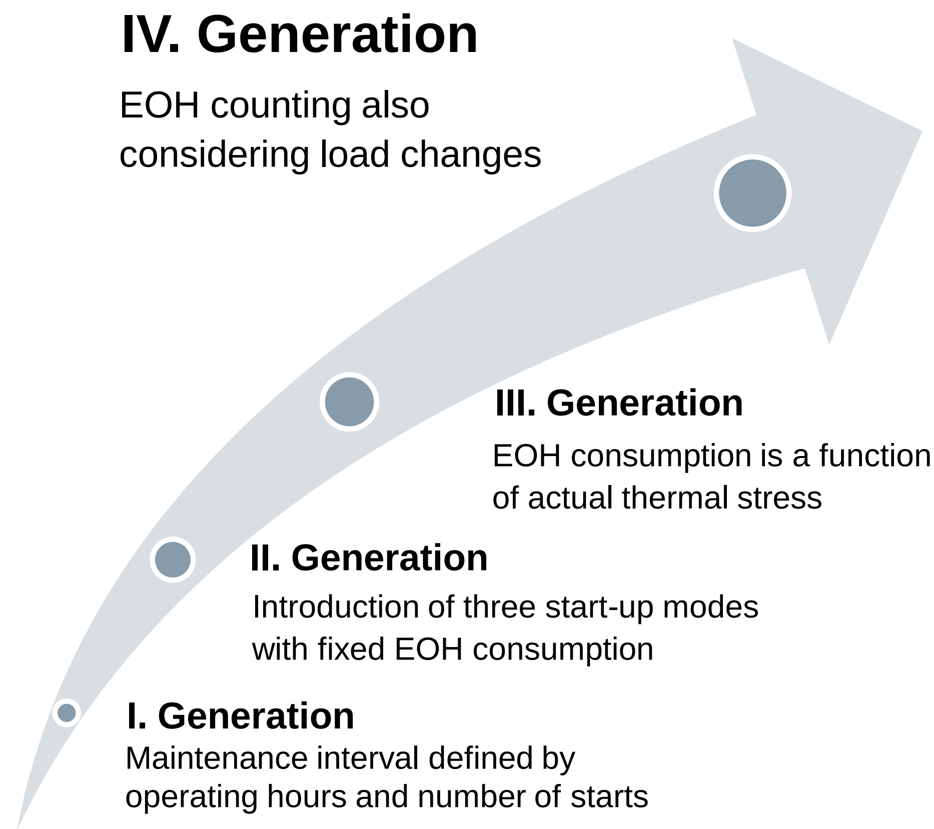
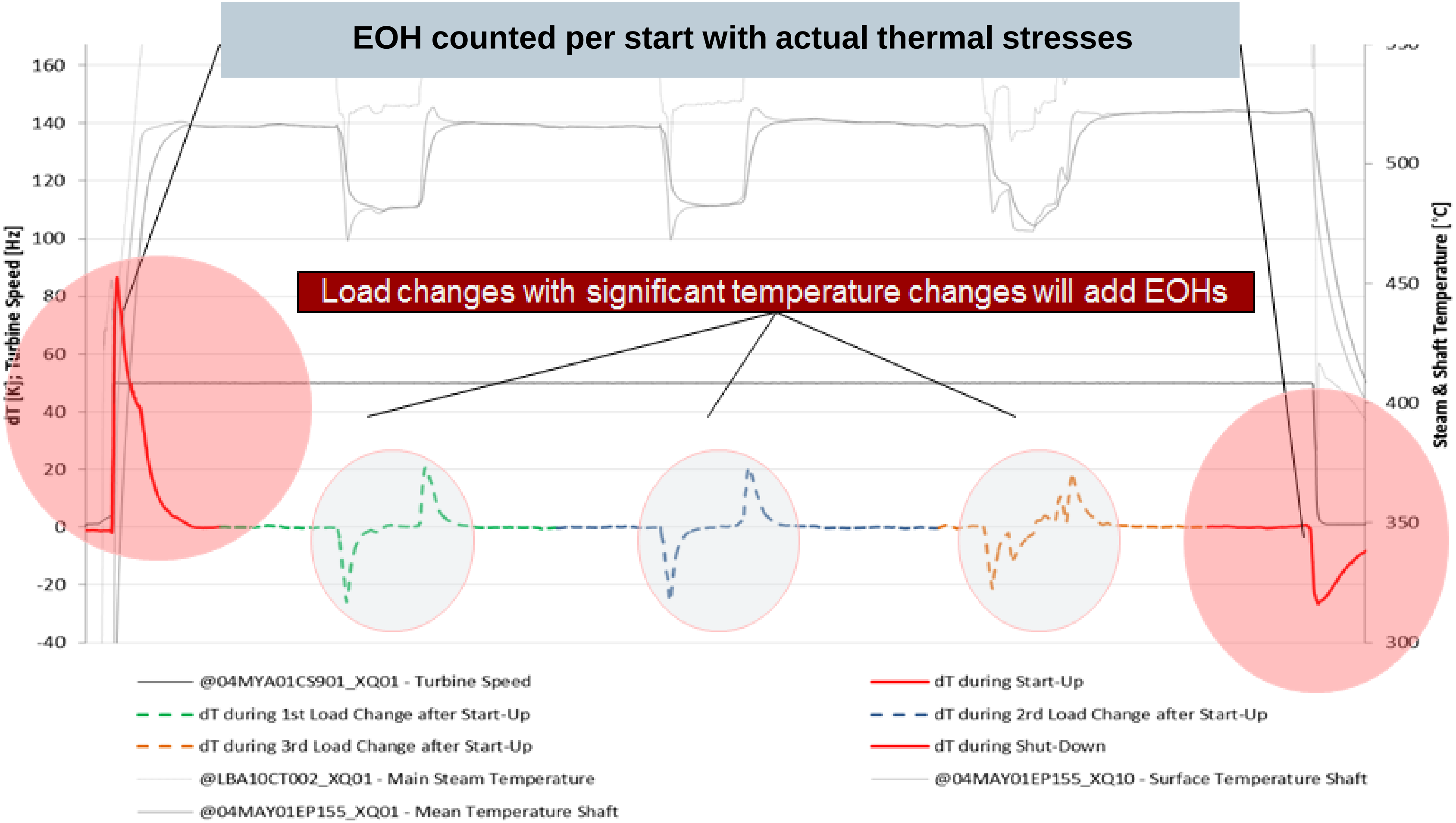
Task
- Part load may lead to steam temperature changes, especially hot reheat temperature
- Thermal stresses during operation are not considered in standard counting of equivalent operating hours (EOH counter)
- Maintenance needs may not be recognized

Solution
- Evaluation of operational history
- Implementation of a state of the art EOH counter considering load changes

Benefit
- More accurate EOH counting
- Improved outage planning
- Enhanced operational flexibility



Steam turbine EOH counter
Consideration of thermal stresses during operation



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Higher profitability through intelligent solutions
SPPA-P3000 process optimization for steam power plants

Runback Plus
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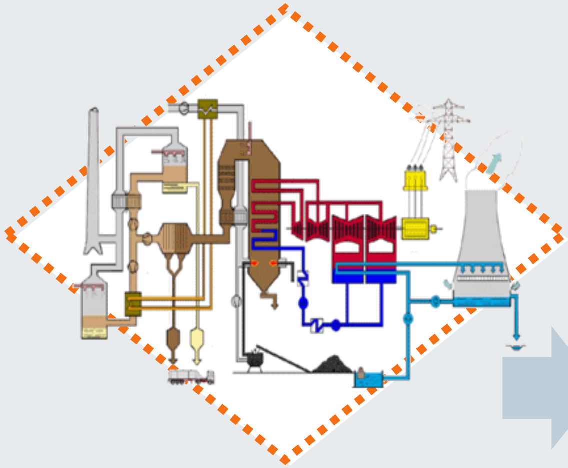
Best Point



Fast Start
Fast Ramp
Frequency Control

High flexibility

Dispatch Control
Minimum Load Reduction
Maximum Load Plus

Low emissions

NO_x Reduction
CO_2 Reduction
LoI Reduction

Combustion optimization / NOx reduction – Improved combustion through laser-based optimization

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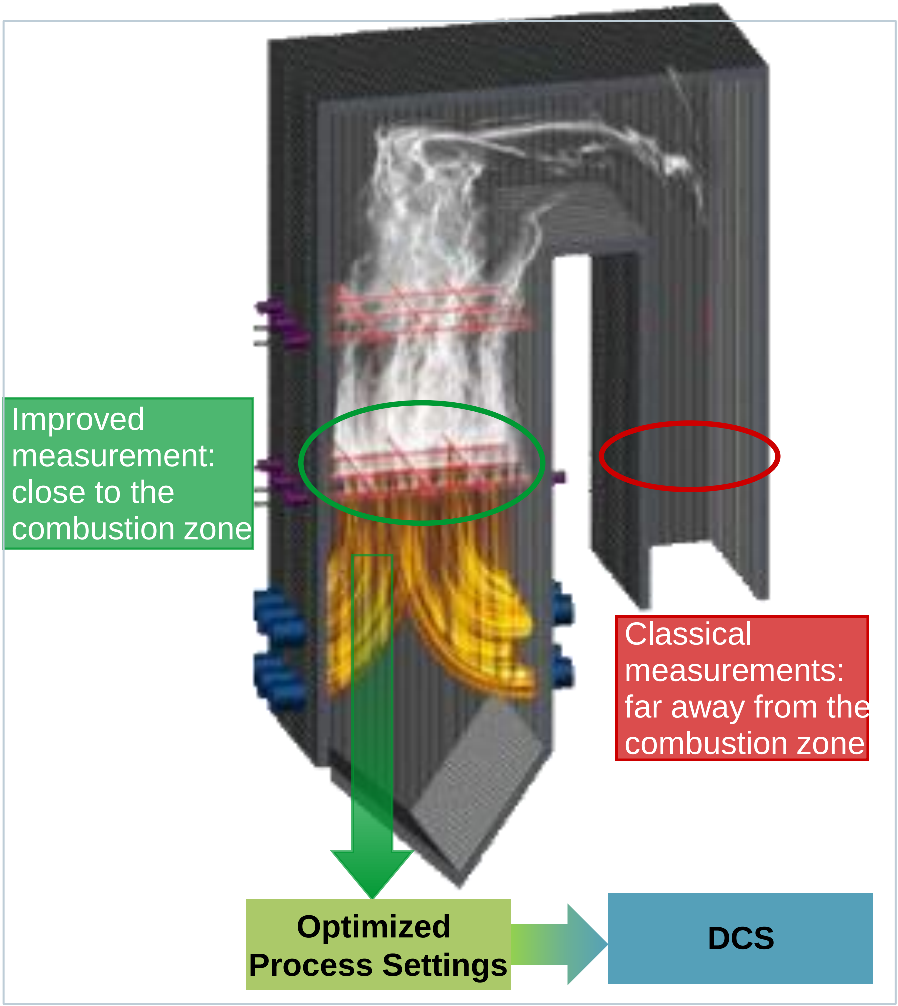
Task

- Optimize combustion/reduce NO_x emissions in order to fulfill tightened emission regulations and to save ammonia usage in SNCR or SCR as secondary measure.

Solution

- **Laser-based measurement** of temperature and concentration averages for H_2O, O_2, CO close to the combustion zone
- Calculation and evaluation of temperature and concentration distributions based on **computer-aided tomography** (CAT)
- **Adapted control strategy, e.g.:**
  - Automatic O_2 setpoint control
  - Vertical air staging strategy
  - CO balancing strategies for homogenization of the combustion



Results in EdF UK plants West Burton & Cottam: …beyond NOx reduction

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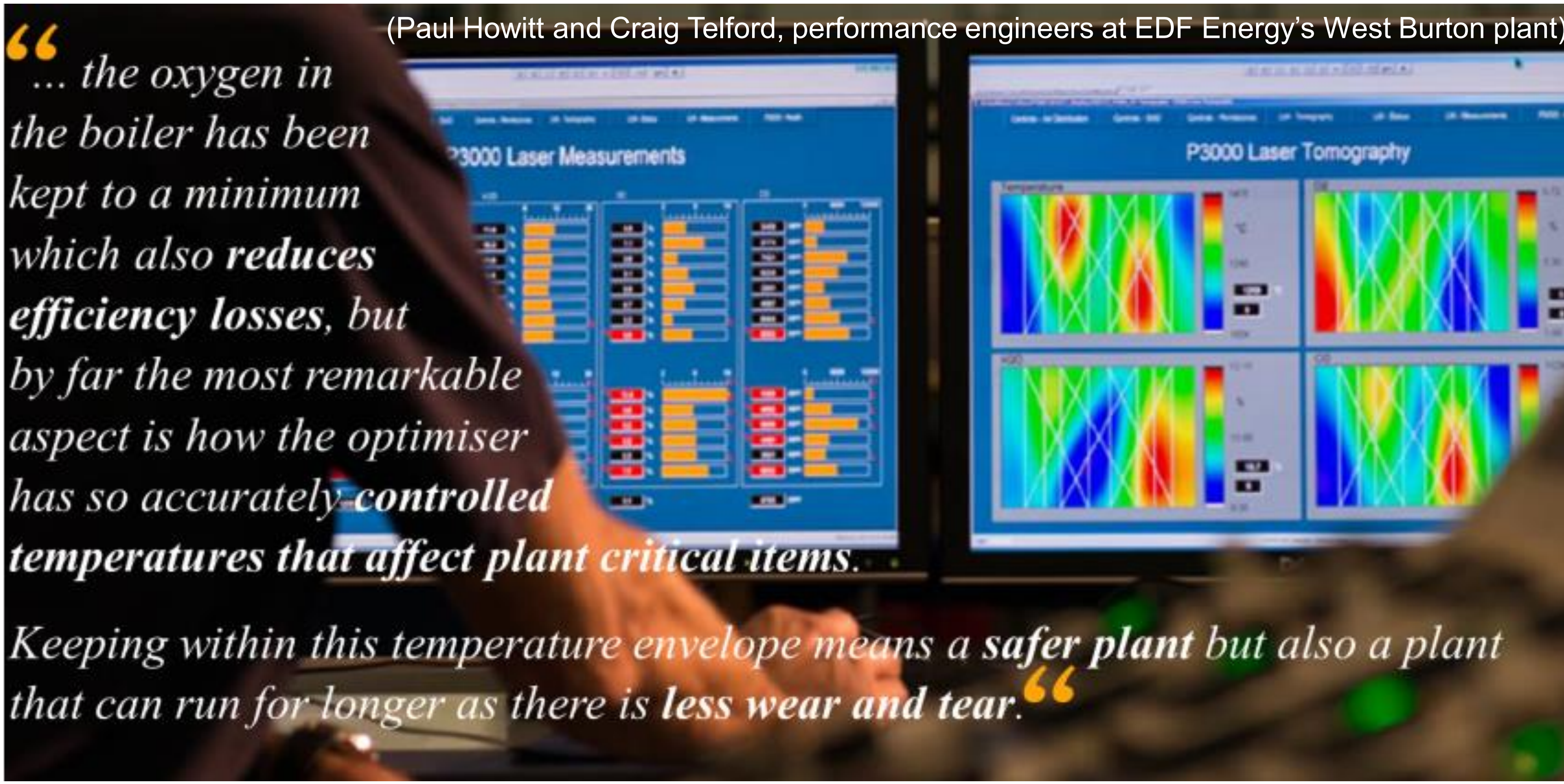

Flexibility of Coal Fired Plants
Selected references

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Frequency & Dispatch Control

Altbach, Germany
420 MW, hard coal, built 1985:
5% in 30 s up to 100% load (with turbine & condensate throttling + partial HP preheater deactivation

Neurath D&E, Germany
630 MW, lignite, built 1975:
Increase from 18 to 45 MW in 30 s (with turbine & condensate throttling)

Wilhelmshaven , Germany
820 MW, hard coal, built 1976
Increase from 60 to 90 MW in 5 min (w/o throttling)

Reliable and efficient start-ups

Franken I, Germany
383MW, gas, built 1973:
20% reduction of start-up costs

Reduced minimum load

Steag Voerde, Germany
700 MW, hard coal, built 1985:
Minimum sustainable load w/o oil support and bypass reduced from 280 (40%) to 140 MW (20 %)

Emissions & Efficiency Improvement

EDF Cottam, UK
4x500 MW, coal, built 1965-70:
NOx emission levels reduced by 22% and efficiency increased in parallel by ~0.35%

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- Fast load transients
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The Digital Transformation of Service

Classical time and material maintenance → **Performance- and outcome-based contracting** → **Network platforms**

Improving efficiency of classical services

Objective
Prevent unplanned downtime

Objective
Increase availability and reliability

Objective
Improve customer ROI through flexible service in any market condition

Reactive maintenance → **Preventive maintenance** → **Condition-based maintenance** → **Predictive maintenance** → **Prescriptive maintenance**

Advanced modeling and predictive analytics enable valuable solutions for the customer

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Collected inputs	Data assets	Business applications

Design
Simulation
Configuration

Engineering models

Repair records
Service records
Sensors

Plant data

OEM and third-party sources

Digital Fleet

Digital Twin

Global fleet data

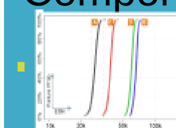
Domain models

External data

Advanced diagnostics

- Reduce trips
- Minimize unplanned downtime
- Recover quickly

Component life models



- Predict future failures
- Optimize inventory
- Plan service events

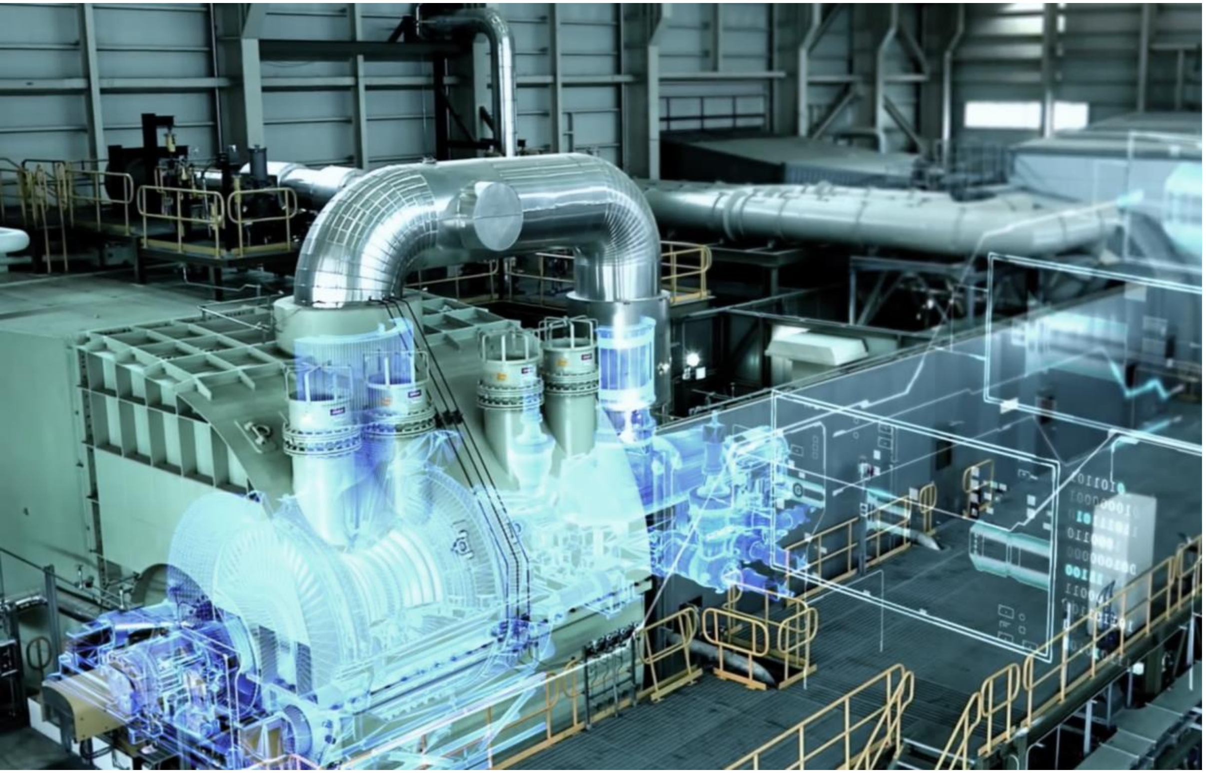
Dispatch optimization

- Run more often
- Provide ancillary services
- Maximize plant return

Performance optimization

- Maximize load gradient
- Increase efficiency
- Reduce emissions

The digital value chain provides the bases for Digital Services – e.g. flexible maintenance program for turbines



Flexible maintenance program based on customer demands

Service individualized to customers' needs creates asset availability and increases operating efficiency

Customer requirements · **Engineering** · **Supply chain** · **Manufacturing** · **Service**

From base to cycling operation –
Innovative concepts for thermal power plants

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Summary

- Thermal power plants need operational flexibility to be the partner of renewable energy generators

- Siemens Flex-Power Services^{TM} offer a wide portfolio of products and solutions to improve plant flexibility
  - Fast load transients
  - Low minimum load
  - Advanced control concepts

- The digital transformation of service will enable services individualized to customers' needs

Thank you for your attention!

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Backup

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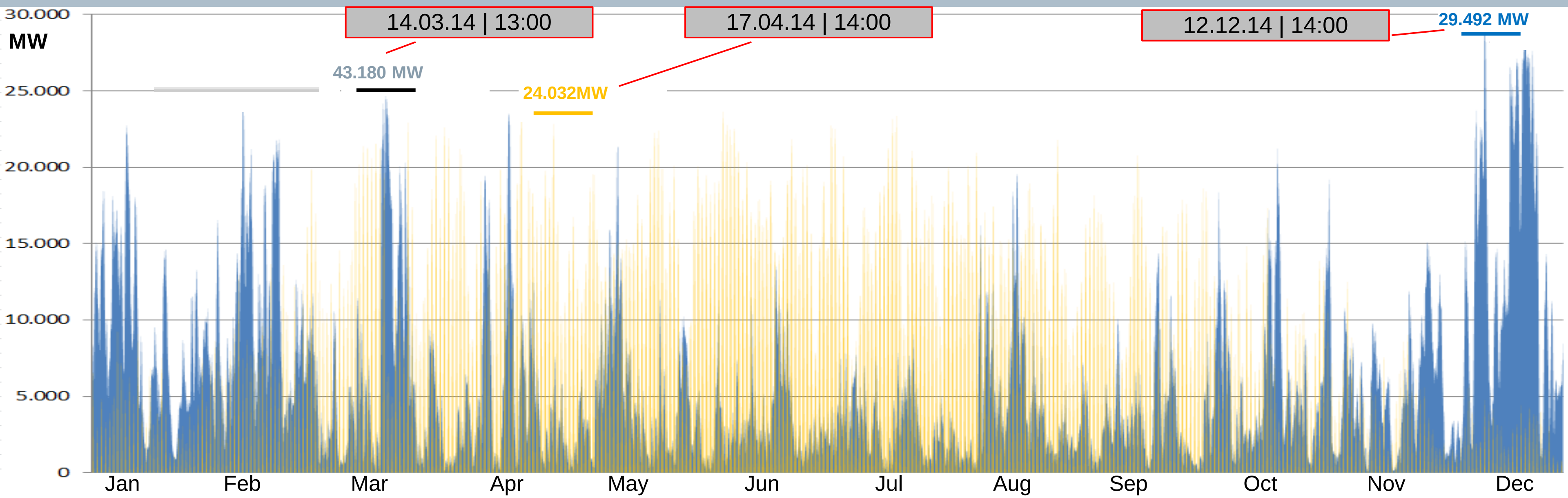
German generation of wind and PV power 2014



Source: own illustration based on TSO data

Installed generation capacity in Germany (2014)
approx. 175 GW

approx. 100 GW conventional generation

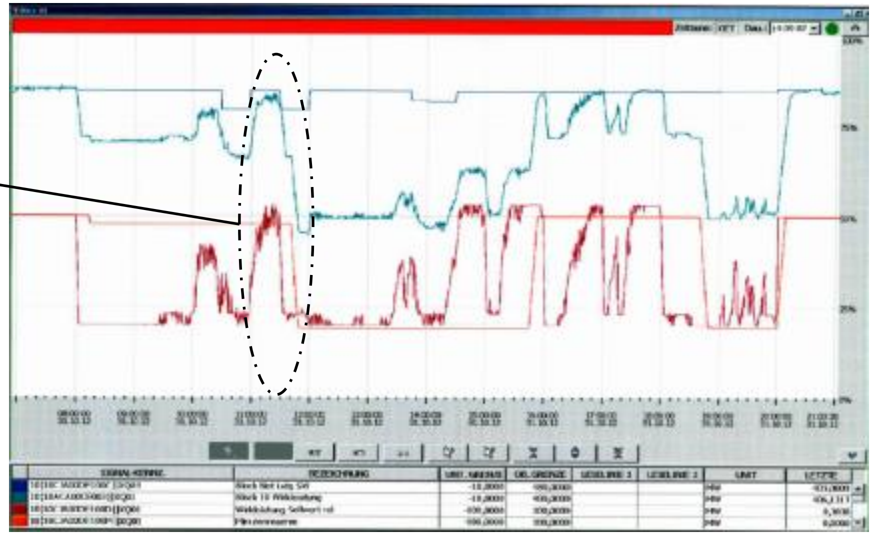
Daily need (min/max)
29,5 GW / 70,5 GW

Yearly generation (2014)
456 TWh

In MW	2011	2012	2013	2014
Wind max.	**22.876** [04.02.11 |20:00]	**24.021** [03.01.12 |17:00]	**26.040** [05.12.13 |14:00]	**29.492** [07.02.14 |17:00]
Wind min.	**92** [06.07.11 |10:00]	**134** [24.10.12 |16:00]	**137** [16.02.13 |14:00]	**38** [12.03.14 |12:00]
PV max.	**13.177** [09.05.11 |14:00]	**22.152** [25.05.12 |14:00]	**23.975** [21.07.13 |14:00]	**24.032** [17.04.14 |14:00]
Wind und PV max.	**27.768** [04.08.11 |14:00]	**31.565** [14.09.12 |14:00]	**35.741** [18.04.13 |14:00]	**43.180** [14.03.14 |13:00]
Wind inst./gen.	**29GW / 49TWh**	**31GW / 50TWh**	**34GW / 50TWh**	**34GW / 51,4TWh**
PV inst./gen.	**25GW / 19TWh**	**32GW / 26TWh**	**36GW / 26TWh**	**37GW / 35,2TWh**

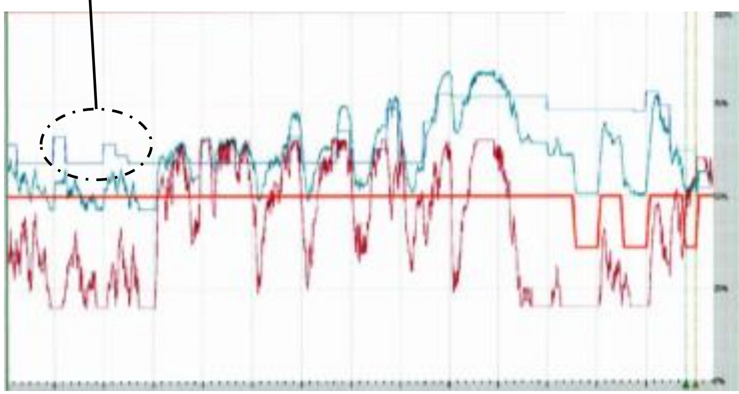
Example of the operational load changes F class CCPP in Germany

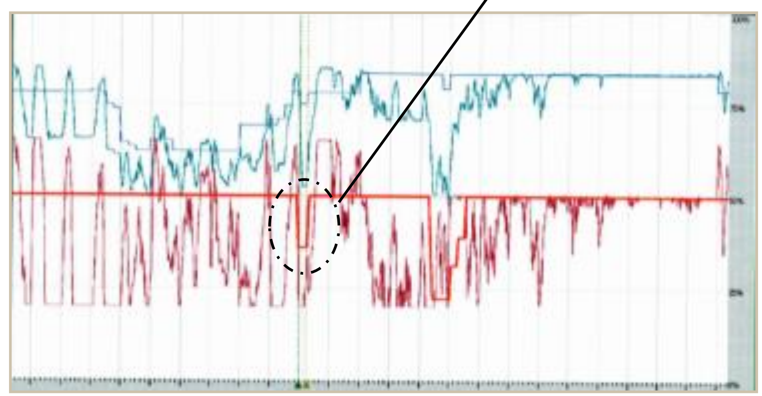
Delivery of maximum tertiary and secondary frequency response (- 171 MW)



Delivery of tertiary frequency Response (minute reserve) for 15 minutes (- 50 MW)

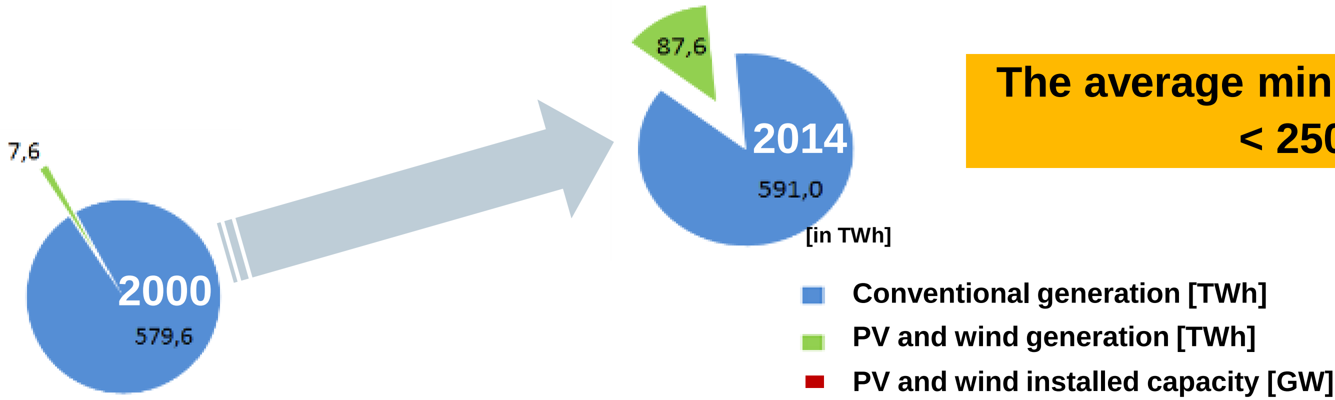
Changed load schedule for 15 minutes (e. g. + 30 MW)



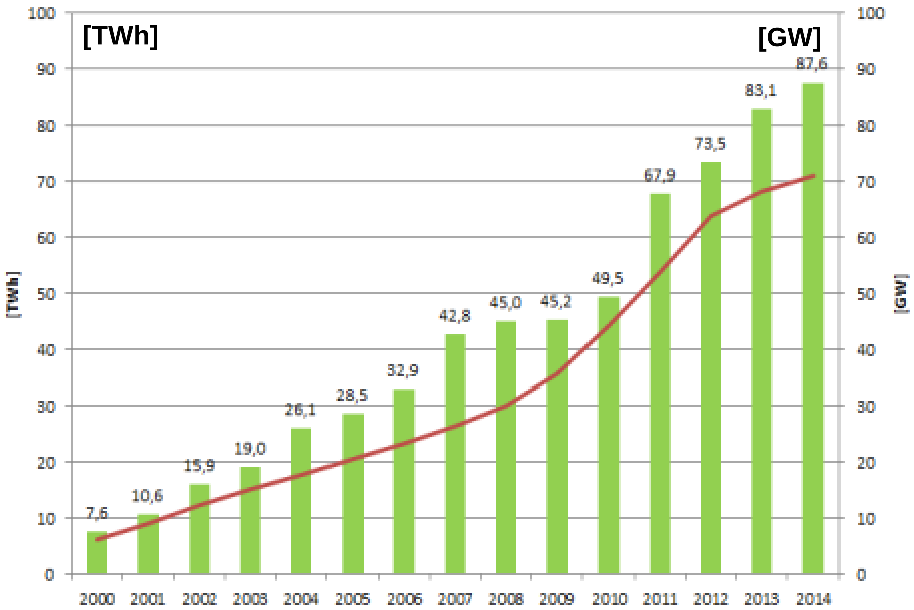


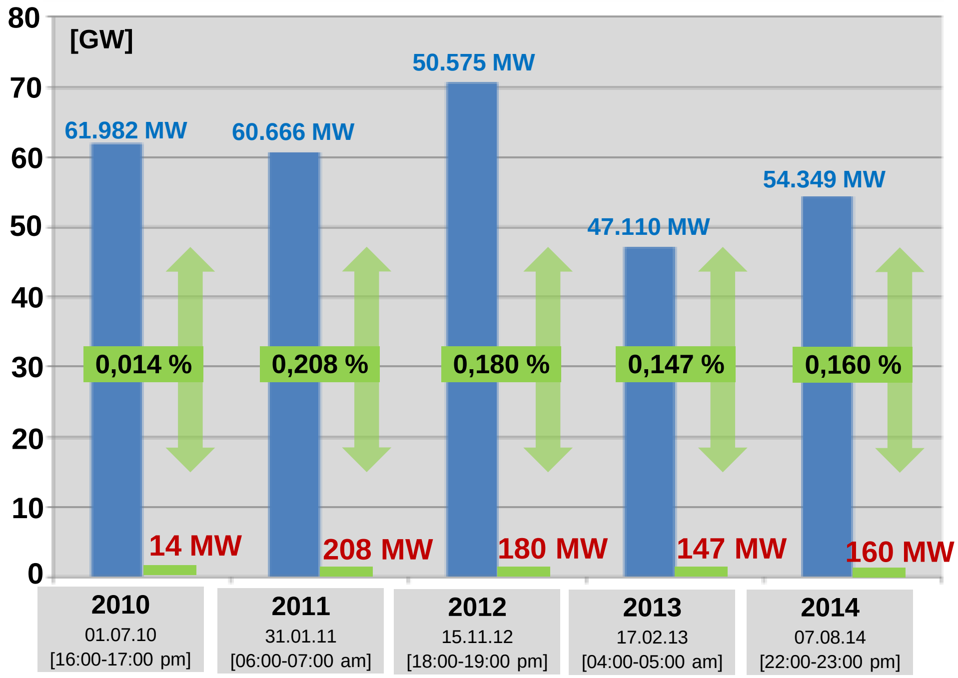
Source: Site data from a German CCPP

Volatile wind and PV power in Germany



The average minimal wind and PV feed-in: < 250 MW (0,14 %)





Source: own illustrations based on TSO data