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Flexibility of thermal power generation for RES supply in Germany until 2020

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SUMMARY

Directive COM (2008) 19 gives individual targets in emission reduction and renewable energy share to the member states of the European Union [1]. Germany has to reduce its green house gas emissions by 14% until the year 2020 related to the reference year 2005 and the share of renewable in the final energy demand should reach 18%. In the sector of electrical energy – which is the main topic of this paper – the portion of renewable electricity has to be increased from 12.4% in 2005 to 40% until 2020 [2]. Because of the short period of time, this forms a big challenge in development of adequate renewable generation and storage capacities, extension of the transmission and distribution grid and flexible operation of the energy system with a high portion of fluctuating generation especially from wind and photovoltaic (PV).

To maintain the high standard of security of supply, a Task Force of VDE investigated over a period of two years the needs for balancing of the German energy system under the aspect of high penetration of RES. For the analysis of the consequences for the residual power generation a sophisticated simulation model of regions of the German energy system has been elaborated, comprising the development of RES, demand, storage and line capacities until 2020. Under the assumption that the peak load of 80 GW will not change due to measures for more efficiency, the installed power of RES will probably show the following development: wind approximately 60 GW, photovoltaic (PV) 60 GW, running hydro 5 GW (constant) and biomass 7 GW. In total the installed power of RES will achieve 130 GW. Considering the coincidence of RES generation it will touch the peak load and to a small extend overshoot. As no overshoot of the peak load will occur over a longer period of time, flexible power generation with the ability of total maximal gradients of 15 GW/h will be able to balance the German energy system. As the power stations will in future have only a capacity factor below 20% it will be difficult to find an economic operation scheme within the existing electricity market model.

KEYWORDS

Power Generation – Flexibility - Renewable Energy – Balancing - Energy Turnaround

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1. The National Renewable Energy Action Plan in Europe

The member states of the EU had to provide in 2010 a National Renewable Energy Action Plan (NREAP), showing how the individual national targets can be reached until 2020 [4]. Fig. 1 shows the individual targets of a selection of EU countries, showing, that Austria starts at a high level of renewable electricity of about 60% and has to reach 71.4% until 2020. Germany and Spain have the highest increasing rates, e.g. Germany start from 12.6% and wants to reach a portion of 40% RES in electricity.

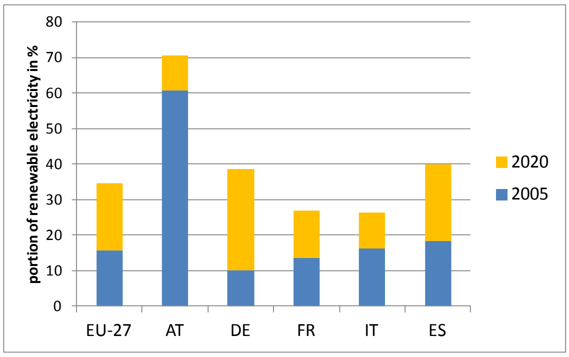

fig. 1 portion of renewable electricity until 2020

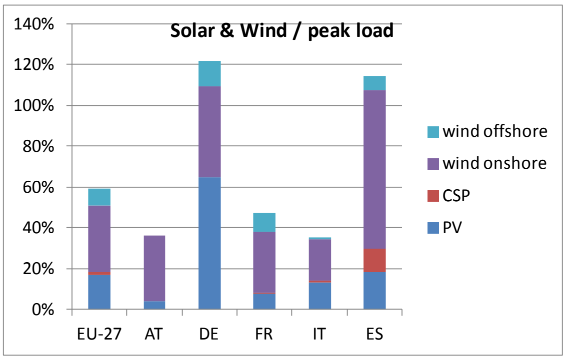

fig. 2 portion of solar and wind on the peak load

In Germany and Spain the generating power of wind and PV will form the main sources and exceed the peak load. In reality the statistical coincidence has low probability. In the mean Europe has the target to reach until 2020 about 34.5% of RES on electricity, starting from 15.8% in 2005. The main strategy of Europeans energy turnaround is to replace fossil energy by renewable electricity from hydro power, wind, PV, concentrated solar power (CSP), biomass and geothermal sources.

The high fluctuating power content forms in future big challenges for the system operation in direction of providing flexible balancing energy with high gradients, to develop storage capacities, which short term and long term capabilities and to adapt the end-use characteristics by demand side management in accordance to renewable generation characteristics.

2. Scenarios of renewable generation in Germany until 2020

For an accelerated implementation of the renewable targets in Germany different scenarios have been developed in 2009 [2] and 2012 [3], covering a period until the year 2050. In both long term scenarios there is the need to install high power of RES because of low capacity factors, which are with PV 11.5%, onshore wind 23%, offshore wind 40%. Furthermore the high installations of power at low capacity factors necessitates short and long term storage capacities and an extension of the existing grid. The extension of the transmission grid especially for the wind energy and the distribution grid for PV forms because of high investments and long ranging approval procedure as well as by the low acceptance of the population the most significant obstacle for a rapid realization.

In the year 2009 an expert group formed a task force of VDE to investigate the challenges on thermal power stations and to elaborate suggestions for the future operation of these stations [4]. The study has been limited to the year 2020, as in this shorter period the prognosis is better and a simulation model of the dynamic operation of the energy system including power stations and grid will be near to reality. In this study a VDE scenario of RES was developed (Table 1). Main difference in the scenarios is the development of demand. In the lead scenarios 2009 and 2012 a reduction of demand by efficiency improvement is assumed. The VDE scenario presumes also efficiency improvement. But as the European energy strategy is towards replacement of fossil energy by renewable electricity new electrical end-use by heat pumps and electrical mobility will in the best case keep the electrical demand as it is.

German Electricity	**Lead scenario 2009** [2]		**Lead scenario 2012** [3]		**VDE scenario** [4]	
Demand develop-ment until 2020	- 1 %/a		- 0,9 %/a		0 %/a	
Portion of RES	34,5 %		41,4 %		40,3 %	
Demand 2020	560 TWh/a		564 TWh/a		603 TWh/a	
RES 2020	**GW**	**TWh/a**	**GW**	**TWh/a**	**GW**	**TWh/a**
hydro power	5,1	24,5	4,7	22,2	5,0	21,0
wind	41,9	96,3	49,0	114,8	58,0	127,0
onshore	*32,9*	*66,1*	*39,0*	*81,8*	*42,0*	*73,4*
offshore	*9,0*	*30,2*	*10,0*	*33,0*	*16,0*	*53,6*
photovoltaic	23,2	20,0	53,5	45,1	60,0	48,0
biomass	7,85	50,6	8,96	49,6	7,0	47,0
RES total	**78,8**	**193,3**	**116,8**	**233,5**	**130,0**	**243,0**

Table 1 Scenarios of renewable electricity development in Germany until 2020 [2], [3], [4]

If no annual reduction of the electricity demand is assumed, much higher power of RES has to be installed. This is more critical for the electrical infrastructure operation and is thus used as the only scenario for the further investigations.

3. Simulation Model and Results

To evaluate the influence on the thermal power stations a sophisticated simulation model of the German energy system has been developed, including the state of the grid, of the generating and storage scheme and the demand. It has been included that the nuclear power stations will be shut down until 2022 and in 2020 only two of them will still be in operation. Further a limited extension of the grid and of the hydro storage capacities is assumed. Germany has been clustered into six areas. From existing time table of wind and PV the renewable generation was simulated and balanced with demand, existing storage capacities and energy transport capacities between regions. Also an energy exchange model with a merit order scheme was included.
Fig. 3 shows the operation of power stations in Germany in the year 2009 and fig. 4 in 2020.

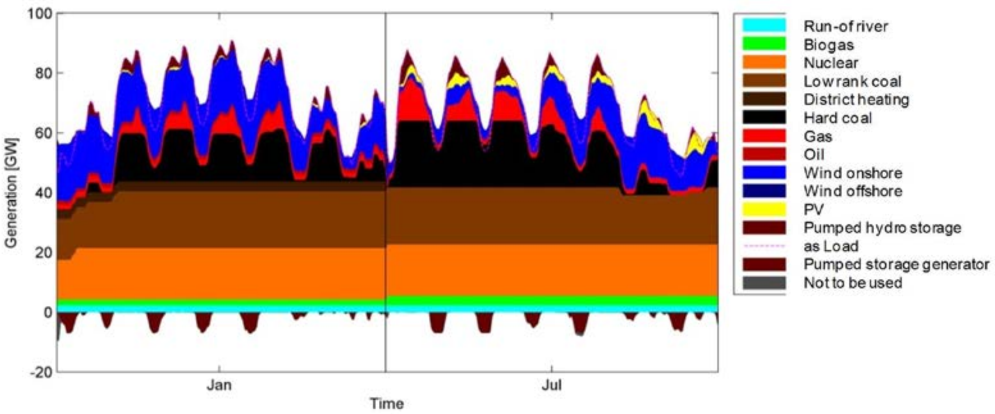

Fig. 3 Scheduling of power stations in Germany in 2009 [4]

On the left side is the operation in winter with high generation of wind and on the right side in summer with PV generation. Nuclear and low rank coal stations for the base load and small part is formed by hydro and nuclear stations. Hard coal fire steam power plants (SPP) and combined cycle gas turbine plants (CCGT) represent the balancing plants. Below the horizontal axis the not usable renewable energy because of limitations in grid or storage capacities and or as a result of high renewable generation at low demand is depicted, showing that this is only some percent.

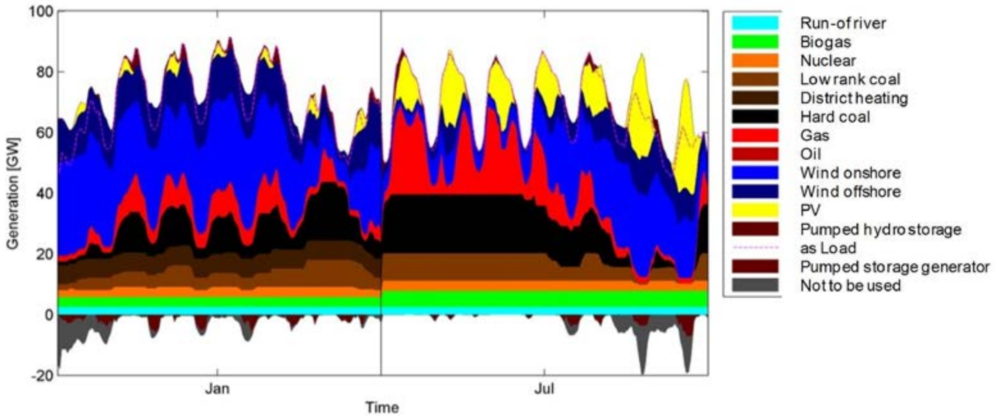

Fig. 4 Scheduling of thermal power stations in Germany in 2020 [4]

Until 2020 the operation scheme of thermal power stations will dramatically change as base load has to be replaced by flexible operation. Only run-of-river, biogas and the remaining two nuclear power stations will form a small base load, whereas all other thermal plants need to be operated for system control. The content of flexible power stations has to be increased and the base load is substituted by RES especially from wind and PV.
Considering energy balancing, in winter (left) there are periods, where wind energy can meet the demand. Even under surplus generation with RES some fossil power stations in the south of Germany cannot be switched off, as the electricity transport from north to south is not sufficient with the grid capacities of today. During summer (right) PV generation shows some peaks with surplus generation which cannot be used because of slow reaction of thermal power stations, which cannot be switched off for some hours because of technological and economical reasons. The surplus energy can be used for pumping but the available pumped storage capacities are significant lower than the available renewable power. Thus the in feeding power of wind and PV has to be partly reduced and is shown as "not to be used" below the horizontal axis of fig. 4.
The operation scheme of thermal power stations will be in direction of more flexibility, meaning, that they will be more frequently switched on and off. Compared with today the frequency will double. Further the following operational requirements are in future valid:

- Ability to perform high power gradients
- Ability to be operated at low minimal generation (e.g. 15 – 20% instead of 40%)
- Showing high efficiency under partial load, not only at nominal load
- Higher number of start up and shut down operations
- Ability of scheduling under unsecure day ahead power prognosis

The simulations show, that up to 40 to 50% of all thermal power stations have to be switched on and shut down within a day compared with a value of about 25 to 35% of today.
The portion of base load generation will go down from about 40 to 50% today to about 25% in 2020.

The thermal power stations are still needed in future, as wind and PV show periods with no generation. But they will undergo a change in their operation from mainly a energy supplier with high capacity factor to predominant a supplier of ancillary services with low capacity factors. Their duty of the future will be to reduce their load when renewable electricity is fed in and to balance their fluctuating generation scheme to enable security of supply. This means frequency control, balancing of active and reactive power, black start ability and providing short circuit power.

VDE Scenario 2020	Installed RES	1h-Gradient	3h-Gradient
Onshore Wind	42 GW	4 GW/h	2,5 GW/h
Offshore Wind	16 GW	3 GW/h	2 GW/h
Photovoltaic	60 GW	12 GW/h	8 GW/h
maximum gradient (system planning)	**118 GW**	**15 GW/h**	**10 GW/h**

Table 2 Generating gradients of wind and PV and system gradient in Germany in 2020 [4]

For the planning of system operation a maximum gradient of 15 GW/h should be possible with the thermal power stations in Germany [table 2]. This gradient is lower than the sum of the individual gradients or wind and PV, representing the probability of overlapping of these sources, which has been derived by analysis of weather data from wind and sun.
In principle most thermal power station can participate in flexible system control but in future those with ability to high gradients will be more economic. For a gradient of 15 GW/h there must be about 25 GW with controllability of 1%/min of thermal power capacity available (fig. 5). In case of flexible power stations with an ability of 3/min the power can be reduced to only 8 GW. This reduces the number of power stations in hot standby and is an advantage seen from energy economy and emissions.

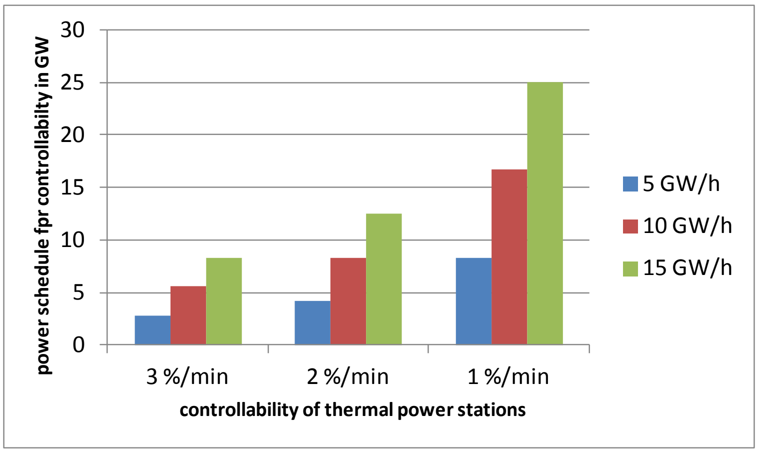

Fig. 5 Gradient dependent schedule of thermal power staions

4. Development of storage capacities in EU until 2020

Electricity is today predominantly stored with help of pumped storage hydro power plants. In future additionally also decentralized small scale pumped storage plants as well as batteries in buildings and mobile batteries in electrical vehicles form a possibility to store electricity and to feed back into the grid. Seen from the time horizon of 2020 it seems to be unsecure batteries and electrical vehicles with significant capacities are available and if regulatory and technological preconditions for these storage capacities in the grid are fulfilled. In this study

therefore until 2020 it is assumed, that only pumped storage hydro power stations are available. This represents the more critical situation with limited storage capacities.
Pumped storage power plants represent nearly ideal storage technologies: they have no emission and waste problems, have high efficiency of 80% in charge discharge cycle and show compared to electrochemical batteries nearly no self discharge phenomena. Table 3 shows the power im pump and turbine operation and the storage capacity of Germany, Austria and Swiss.

Country	Pump	Turbine	Storage capacity	Storage time constant
	MW	MW	GWh	hours
Germany	7.200	8.200	48	5,85
Austria	5.100	4.800	142,5	29,7
Swiss	2.300	1.840	369	200

Table 3 Pump and turbine power and storage characteristic [4]

The storage time constant results from the storage capacity divided by the turbine power. It is a coarse value, as the volume of the lower basins are not taken into consideration and water can be lost if the lower basin has a smaller volume than the upper one. It can be seen, that only short term storage capacities are available. Short term pumped storage capacities are vital necessary in connection with the rapid development of PV as they enable to store energy during the day for the peak demand in the evening.
The development of pumped storage capacities until 2020 in EU-27 and Germany according to NREAP [5] is shown in fig. 6 and 7.

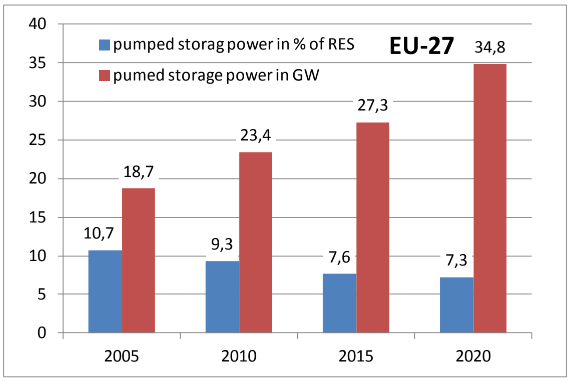

Fig. 6 Pumped sotrage development in EU-27

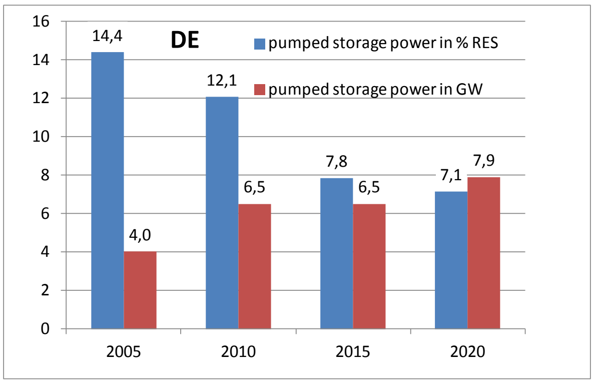

Fig. 7 Pumped storage development in Germany

In EU-27 the pumped storage capacities (power in GW) will be neary doubled. If this power is relatet to the total installe power of renewable energy sources it will shrink from 10.7% to only 7.2%, showing that the renewable energy power is growing much faster than the development of new pumped storage capacities can follow. In Germany, because of the need for rapid development of RES according to NREAP these effects are more pronounced.

5. Future technological and economical developments

As a consequence of the lack of storage capacities until 2020, the balancing energy necessary with the development of RES must in future be provided by thermal power stations. Besides of technological development of new or modification of existing thermal power stations the economical problems of operation will become in future more severe, if the existing market models are not adapted. Today the thermal power stations are mostly operated for base load with a capacity factor of 70 to 90% and for middle load 40 to 60%. In future base load will be replaced by flexible middle load and the capacity factors will shrink to values of 15 to 25%. This will result in a higher portion of CAPEX and approximately double the generating cost. Fig. 8 compares the generating cost in 2020 of thermal power stations, pumped storage power plants and future storage technologies for capacity factors of 23% (2000 full load hours per year).

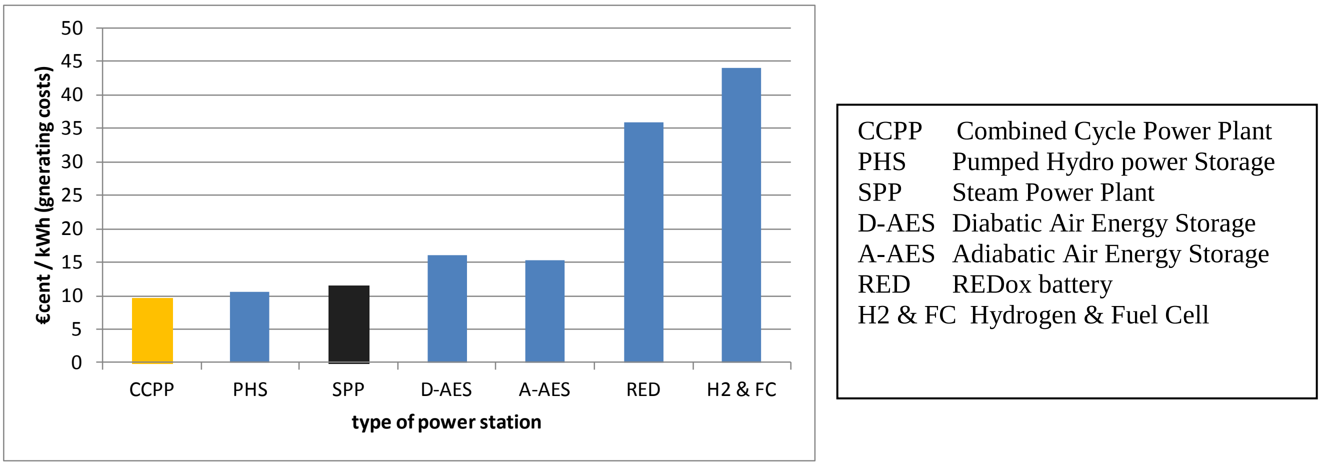

Fig. 8 Specific generation costs of storage technologies and thermal power plants

The generating costs of thermal power plants (CCPP, SPP) are comparable to pumped storage hydro plants (PHS, 200h pumping and 2000 h turbine operation). Compared to other storage technologies the pumped storage plants are most competitive.
If in future line capacities and pumped storages cannot be developed in adequate capacity in time, thermal power stations can compensate these missing capacities, especially if they are placed in regions with these preconditions. To enable the energy turnaround until 2020 there are some new market models for a flexible market for balancing energy and fair cost models for thermal generation at low capacity factors necessary.
Today the tendency can be seen in the energy market, that temporarily surplus generation of RES results in a collapse of market prices and the difference between peak and base prise is reduced in a manner, that balancing energy from storage capacities or flexible thermal power stations cannot delivered in due manner.

6. Long term scenarios of renewable development and system operation

AS could be seen until 2020 in Germany the in feeding power of RES will just touch the peak load value but will not exceed it significantly. Thus by flexible thermal power stations a balancing of the energy system will be possible.
Beyond 2020 the renewable power sources can exceed the peak load significantly. The following measure could be used for balancing of the system:

- Development of pumped storage capacities
- Integration of mobile or stationary batteries into the grid
- Transforming surplus energy into hydrogen (power to gas)
- Development of fuel cell technology (power to gas and gas to power)
- Development of long term storage capacities (hydrogen to methane and storing in natural gas deposits)

The last three points seem to be promising, as they enable a to cut down the temporarily overloading of the grid and provide large long term storage capacities of methane at limited costs. Furthermore with help of the systhetic methane, the thermal combined cycle power stations can also in future be uses for energy balancing and combined heat and power. As methane can be generated from renewable hydrogen and atmospheric CO_2, the thermal power stations can be considered as renewable generation in closed loop carbon cycle.

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