

GRID CODE REQUIREMENTS FOR GENERATING UNITS TO ENSURE A SECURE SYSTEM OPERATION

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Abstract: Wind and solar energy as renewable energy sources play a more and more important role in the energy supply in Germany. But the increase in production of renewable energy sources generates new problems in the German energy system concerning energy transportation and a secure system operation. The fluctuation of the wind power and photovoltaic (PV) production in addition to the fluctuations of the consumption are resulting in a significantly high demand on fast power reserve from the thermal power plants. Due to this expected tendency 50Hertz has upgraded the requirements for thermal power plants with application for grid connection in its own grid code. According to § 19 EnWG 50Hertz is obliged to determine minimum requirements for the grid connection of all types of generating units. In this context all existing power plants and all power plants with application for grid connection will be treated equally in a transparent manner in respect to their system behaviour. In addition to the urgently needed network expansion and the improved system compatibility of the new wind turbine generators also an enhanced transient behaviour of the thermal power plants is indispensable in future. For those purposes the upgraded grid code of 50Hertz describes the essential technical minimum requirements for a secure system operation.

Keywords: Grid Code, Network Expansion, Renewable Energies, Thermal Power Plants, Fast Valving, PSS.

1. GENERAL REQUIRMENTS FOR A SECURE GRID OPERATION

The 50Hertz Transmission GmbH (50Hertz) is responsible for the operation, maintenance, planning and expansion of the 380/220-kV transmission grid throughout the German Federal States of Berlin, Brandenburg, Hamburg, Mecklenburg-Western Pomerania, Saxony, Saxony-Anhalt and Thuringia. The transmission grid runs a length of approx. 9,700 km.

Currently the share of wind turbine generators feeding into the control area of 50Hertz has risen to over 11 GW. An increase to a magnitude up to 25 GW inclusive of offshore wind turbine generators until 2020 is expected. These figures were also taken into account in the "National Action Plan for Renewable Energies" (NAP-EE). For the year 2020 an installed capacity of 46 GW in Germany is quite realistic. The "Energy Economy Law" (EnWG) as well as the "Renewable Energy Law" (EEG) belongs to the valid legal provisions in the energy sector in Germany. Both laws regulate the prioritizing of the power from renewable energy sources into the public transmission and distribution grid. Under certain prerequisites system states can occur especially in the transmission grid which can endanger the secure grid operation. For the protection of the system security 50Hertz is entitled and obliged to take measures in accordance with § 13 EnWG. In the first applicable step these measures are grid-related and market-related according to § 13 Sect. 1 EnWG. Grid-related measures can be distinguished into the following main instruments:

- Grid topology measures (e.g. corrective switching) and
- Taking advantage of operationally permissible ranges for voltage and current.

Market-related measures have a wider area of application and they can be divided mainly into

- Service of control reserve power,
- Preventive congestion management,
- Contractual connection or disconnection of loads,
- Mobilization of additional reserves by the TSO,
- Countertrading and redispatch of power plants.

In the second applicable step if an endangering or disturbance cannot be solved by means of these measures, the already accepted schedules of the power stations have to be curtailed in accordance with § 13 Sect. 2 EnWG. On the instructions of the Transmission Control Center of 50Hertz the infeed of all generating units has to be adapted to the current situation in the control area. This also applies to all privileged infeed from renewable energy sources and combined heat and power plants in the transmission and distribution grid. Figure 1 shows the yearly number of days with an application of measures according to § 13 Sect. 1 EnWG beginning in the year 2006. The tendency is that in the upcoming years the transmission grid of 50Hertz will be extremely burdened. All grid-related and market-related measures have to take into account the technically necessary characteristics of the control area. For a secure system operation the following requirements have to be fulfilled:

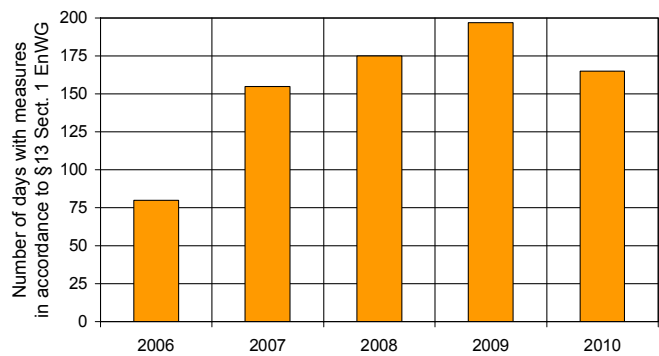


Fig. 1: Number of days with measures according to § 13 Sect. 1 EnWG

- The control capability of the power stations must be guaranteed in positive and in negative direction according to the appearing power gradients in the grid. The fluctuation of the wind and solar energy has today a large impact on the appearing power gradients in the grid.
- The rules such as average control speed and response time regarding the frequency stability (primary control) and reserves of the active power regulation (secondary and tertiary control) in the Continental European grid of ENTSO-E must be fulfilled.
- The (n-1)-criterion in the grid shall be fulfilled. The online assessment of the fulfilment of the (n-1)-criterion considers only stationary aspects. Stability issues will be calculated in future.
- The reactive power provision of the generating units has to ensure that the voltage band in the network will be in the permitted range. The requirement of the reactive power capability of synchronous connected power plants at the Point of Grid Connection is depicted in Figure 7.
- Any kind of grid failures which are cleared in fault clearing times (FCT) ≤ 150 ms shall not lead to a trip of generating units.
- A sufficient short circuit power of the grid is indispensable for the operational reliability of the functioning of the grid protection and has to be available at any time. The provision of short circuit current is an inherent property of all synchronous connected generating units. The level of short circuit current will decrease in future due to the displacement of thermal power plants. The short circuit current contribution of all renewable energy sources is limited to values up to ca. 1.5 p.u. (depends on the converter technology). In future rotating phase shifters could fill the gap of short circuit current and system inertia.
- Generating units with primary renewable energy sources like wind and solar and future offshore windfarms have to comply with the existing rules and grid codes.

Presently an installed capacity of 12,857 MW of thermal power plants is connected to the grid of 50Hertz. In addition, qualified connection applications of 10,719 MW of thermal power plants have to be submitted which fulfil the requirements of the “Legal Ordinance for the Grid Connection of Power Plants” (KraftNAV). In Figure 2 the location within the grid of 50Hertz and the type of the power plant is shown. This planned, massive addition of thermal power plants and the thereupon concentrated thermal power station capacity in the 50Hertz grid requires the necessary grid expansion as

well as the enhanced requirements for the thermal power plants. These technical requirements are further increased by the integration of the renewable energy sources into the grid which is mandatory by the EEG law.

	D81	D82	D83	D84
Existing thermal power plants	1,153	2,464	2,740	6,500
	3 units	6 units	4 units	11 units
Thermal power plants with application for grid access	5,849	1,640	660	2,570
	11 units	2 units	1 unit	5 units

Table 1: Capacity of power plants in [MW] related to Fig. 2

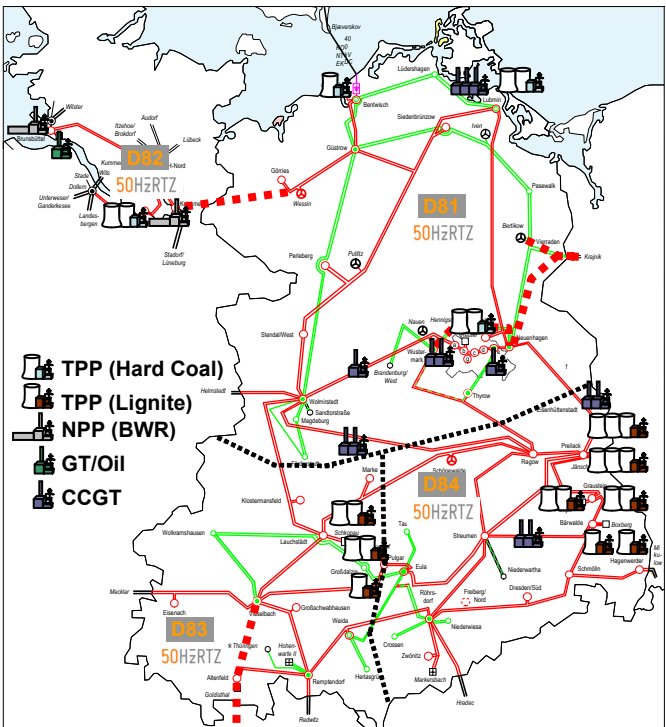


Fig. 2: Existing thermal power plants and power plants with application for grid connection (State 31/03/2011)

2. ACTIVE POWER OUTPUT OF THERMAL POWER PLANTS

Figure 3 shows the typical impacts from a stormy weather situation on the power plants and the grid. Vattenfall Europe operates a huge number of the existing thermal power plants in the 50Hertz control area. Due to the increasing prioritizing wind power infeed and the simultaneous load decrease at this weekend in January 2010 50Hertz was entitled and obliged to apply market related measures at a maximum of 2,520 MW (in particular countertrading and redispatch) in order to ensure a secure network operation. Due to that fact all Vattenfall power plants (mainly lignite fired) had to operate in minimum load conditions over a long time period.

The rotating power of the thermal power plants in the control area of 50Hertz has to be sufficiently planned so that the secondary control is able to regulate the maximum change of the power demand within a ¼ hour according the amount and the gradient of the possible change of active power. Due to today’s load and infeed conditions in the control area of

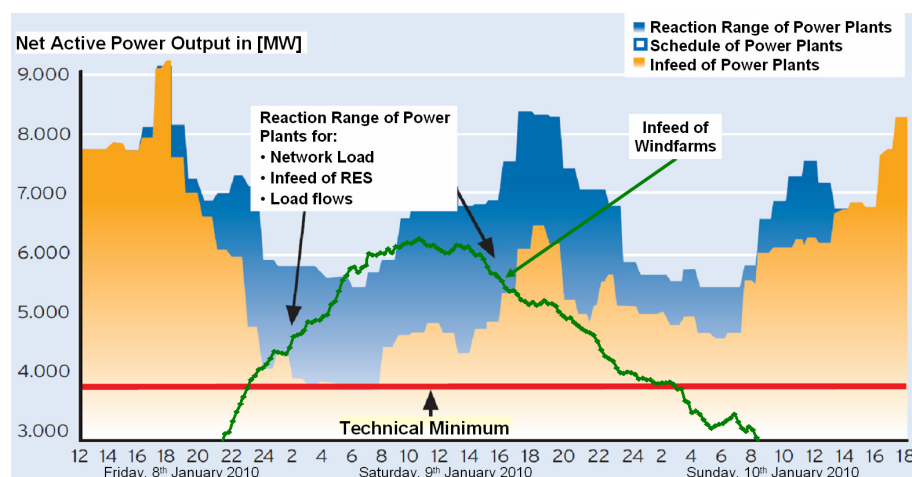


Fig. 3: Schedule and Operation of Power Plant Operator Vattenfall Europe during low "Daisy"

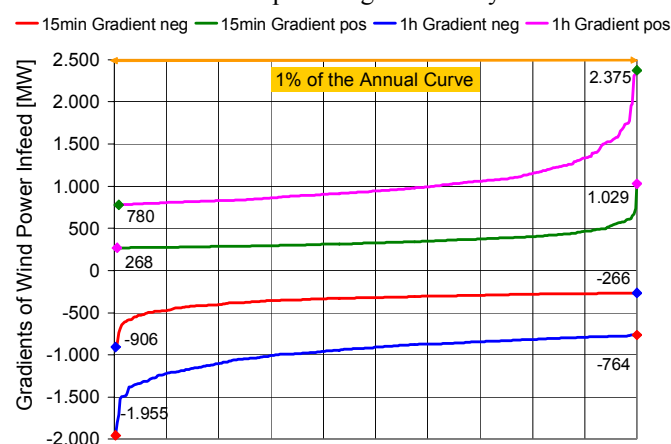


Fig. 4: Annual curve for 2010 of the Wind power Gradients 50Hertz the gradients for changes of active power are required up to $\pm 1,000$ MW per $\frac{1}{4}$ hour. Figure 4 shows the maximum positive and negative gradients from windfarms in the control area of 50Hertz in the year 2010. This figure shows only 1 % of the annual curve both in positive and negative direction. In the remaining 98 % of the year wind power gradients less then ± 270 MW per $\frac{1}{4}$ hour occur. Because of the forecasted rise of the infeed from wind turbine generators up to the year 2020 the gradient for changes of active power also increases up to $\pm 2,000$ MW per $\frac{1}{4}$ hour. Figure 5 shows the calculated gradients of wind power and consumption in the control area of 50Hertz within the next ten years. The gradients were calculated on the basis of the wind power data from the years 2008-2010.

Due to the expected load decrease in the control area of 50Hertz as a result of the population decline the forecasted gradient of load demand would also decrease. In further investigations it is assumed that the gradient of load demand in the $\frac{1}{4}$ hour range will be constant. The gradient for changes of active power which results from the increasing installation of PV-plants must be taken into account in future, too. The NAP-EE specifies an installed capacity of 52 GW for Germany in 2020. First projections assume that the maximum gradients for changes of active power from PV-plants can be up to $\pm 17 - 18 \% P_N$ per hour. For the future, the average gradients for changes of active power of $2 \% P_N/\text{min}$ from older thermal power plants will not be sufficient to fulfil the

enhanced requirements for the need of fast acting power reserve. The rise of the control speed and the lowering of the technical minimum power of the thermal power plants is the only suitable way to fulfil the requirements for both secondary and tertiary control in the future. According to first estimates the average control speed of the thermal power station park feeding into the 50Hertz grid should increase to at least $3 - 4 \% P_N/\text{min}$ up to the year 2020. Figure 6 shows the relation between the need for fast acting power reserve calculated from the wind and load gradients depicted in Figure 5, the rotating thermal power plant capacity at the grid (must-run-units) and the resulting control speed of the thermal power station park.

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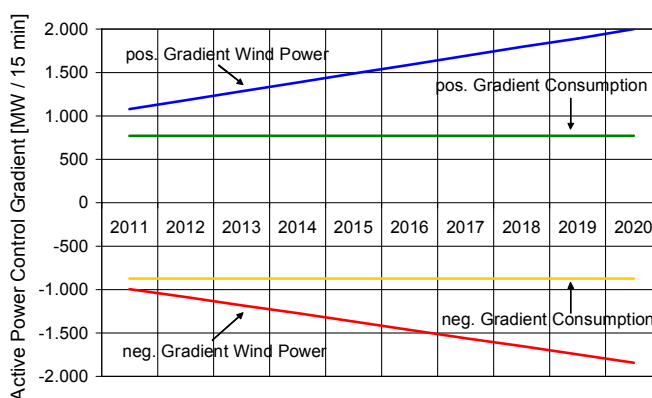


Fig. 5: Expected Future Wind Power and Load Gradients

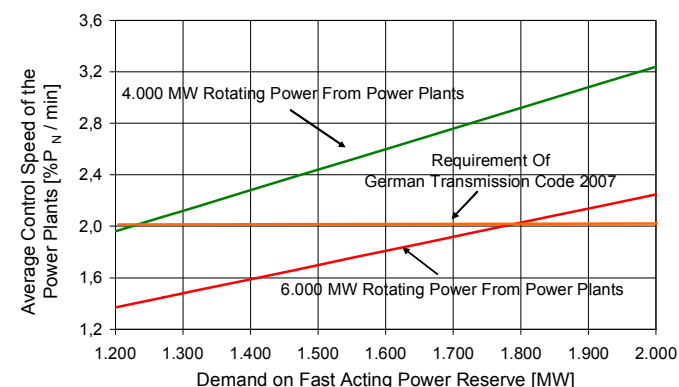


Fig. 6: Needed average control speed of the thermal power plants in the 50Hertz grid

The grid code of 50Hertz is based on the German "Transmission Code 2007" and the ENTSO-E "Operation Handbook". Mainly caused by the described foreseeable tendency 50Hertz has upgraded the requirements for thermal power plants in its own grid code. The new grid code was released after an informal consultation process with the operators of existing power plants and operators of power plants with application for grid connection as well as manufacturers for power plants. Depending on the used primary source of energy 50Hertz requires the values shown in Table 2 regarding the technical minimum power, the control range and the average speed for changes of active power for the different types of

new generating units. The required parameters of the thermal power plants are in line with the recommended values of “state of the art” power plants described in /Tomschi et al./. In addition to that, CCGT’s from ALSTOM (types KA 24, KA 26) are designed with a sequential combustion. The innovative combustion technology and the Low Load Operating Concept enables both CCGT’s to operate in a stable park position of 20 % P_N . The overall benefit is that the active power reserve remains online; the normal CCGT active power gradient is available, as well as the CCGT contributes to the system inertia and the short circuit power in the grid. The emissions regarding NOx still meet the regulation.

Power Plant Type	Technical Minimum Power	Control Range	Average Speed For Changes Of Active Power
	[% P_N]	[% P_N]	[% P_N /min]
TPP (Lignite)	50	50-100	3
TPP (Hard Coal)	30	30-100	4
CCGT	20	20-100	5
GT/Oil	20	20-100	10
NPP (BWR)	60	60-100	4
PSPP (Turbine Mode)	25	25-100	100
RES	0	0-100	-

Table 2: Grid Code parameters for new Power Plants

3. REACTIVE POWER PROVISION OF POWER PLANTS

The U-Q/ P_N -profile is representing the reactive power capability of a Generating Unit at the grid connection point in context of varying voltage at the high-voltage terminals of the step-up transformer to the voltage level of the Grid Connection Point. Different network topologies and characteristics (ratio of infeed and consumption, degree of network meshing) need different ranges of reactive power. The provision of reactive power at a certain point in the 50Hertz grid strongly depends on the local needs. Highly meshed and/or heavily loaded parts of the grid need more lagging reactive power, whereas remote parts of the grid with modest power flows and low consumption need more leading reactive power in order to keep the network voltage within the permitted range.

Figure 7 shows the compliance of the 50Hertz requirement

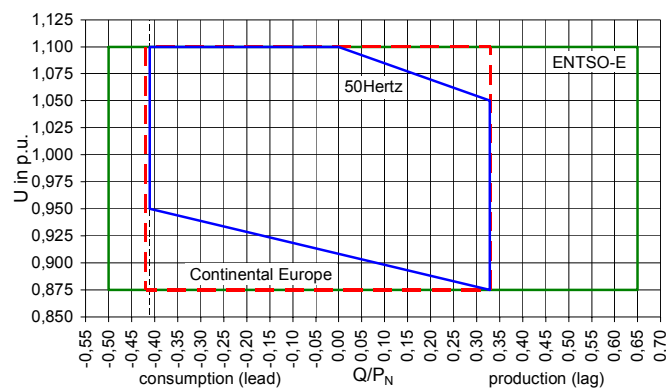


Fig. 7: Reactive Power Capability of Generating Units in the 50Hertz control area

for reactive power capability with the future ENTSO-E Network Code. The size of the Q/ P_N -Range (green envelope) in the U-Q/ P_N -profile is determined by the maximum leading reactive power and by the maximum lagging reactive power which appeared in today’s different Network Codes of European TSO’s. The dimension of the red envelope is defined for the Synchronous Area of Continental Europe. 50Hertz is allowed to define his particular shape (blue parallelogram) inside the red envelope of its Synchronous Area.

4. MEASURES TO ENHANCE THE GRID STABILITY

In addition to the improvement of the protection system (to ensure a fault clearing time ≤ 150 ms) the most sustainable stability measure is the network expansion and reinforcement in the transmission grid. The network expansion causes the reduction of the grid impedance and the growth of the short circuit power at the point of connection which leads evidently to an increase of the stability limit.

3.1 Fast Valving in Thermal Power Plants

In addition to the network expansion and the improved system compatibility of the modern wind turbine generators (Fault Ride Through Capability, participation in the U-Q-control, short circuit current injection, reduction of active power due to over-frequency) an enhanced transient behaviour of the thermal power plants is essential in future. A stable power plant operation is given if in smooth operation and after the appearance of a disturbance in the grid no transition into asynchronous operation of generators will occur.

In case of a three-pole fault in the Hamburg area (Region D82, see Figure 2) with a high concentrated capacity of thermal units generators oscillate and therewith active power oscillations could overlap. The generators together in the Hamburg area are a coherent group of power plants and could loose the synchronism against the transmission grid. In case of a failure a huge amount of energy would be injected into the grid and take out of the grid due to the acceleration and braking of the coherent group of generators. This leads to a reduction of the transient stability limit in the grid at high loaded transmission lines and very low voltages. In other regions (D81, see Figure 2) within the 50Hertz grid the short circuit power from the transmission grid is very low compared with the rotating active power from the power plants with application for grid connection. The factor between both values amounts only to two till three. The German “Transmission Code 2007” requests a transient stable operation after fault clearing at a ratio of six. Due to this fact the grid would have a shortage of braking energy to keep the acceleration of the coherent power plant group within the acceptable range. Additionally, the protection of the network can not react as fast as desired; the stability limit is there very low as well.

Hence 50Hertz demands in the proceeding for grid connection with the applicants, to assemble Fast Valving, where an improved transient behaviour of the power plants is necessary. The very fast reduction of the mechanical energy supplied to the generator is a method to allow the generator to remain in synchronous operation after fault clearing of a short circuit nearby the power plant. This is done rapidly by direct action on the turbine valves to keep the acceleration of the

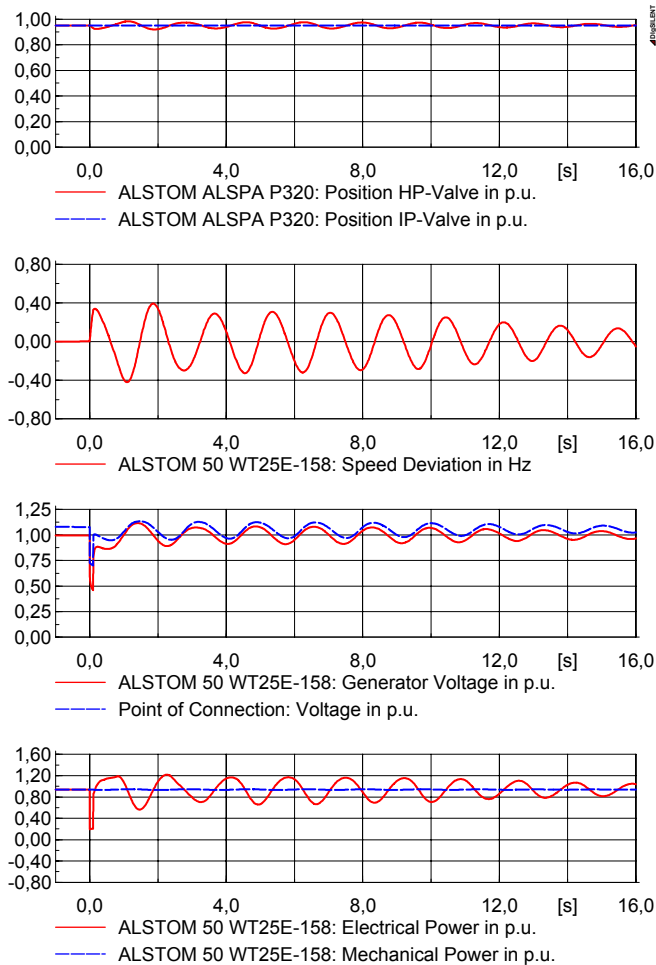


Fig. 8: Power Plant without Fast Valving and FCT = 100ms generator in the permitted range. The preferable criterion for activation of Fast Valving is the active power gradient. However, if the rate of change of active power cannot be measured the positive sequence current and positive sequence voltage can be used instead of this. The logic can operate based on the following conditions:

- The positive sequence voltage was high and then drops below a settable threshold (under voltage start).
- The positive sequence current was low and then rises above a settable threshold (over current start).
- The active power drops below a settable threshold (under power start).

All of the above conditions must be fulfilled simultaneously. An output signal is given around 30-40 ms after the fault inception. In the used model in the simulation the combined criterion for under voltage / under power are assumed as all other criteria are considered implicitly fulfilled. Figure 8 shows the response of a power plant without Fast Valving on a three-pole short circuit nearby the power plant. Despite a very fast fault clearing time of 100 ms, which can not be guaranteed always, the power plant is operating at the stability limit with poor damping. In contrast, the effect of Fast Valving as a measure for the enhancement of stability is clearly depicted in Figure 9. Shown is the reaction of a planned power plant with Fast Valving installed on the high pressure turbine and the intermediate pressure turbine on a three-pole short circuit which will be cleared in 150 ms.

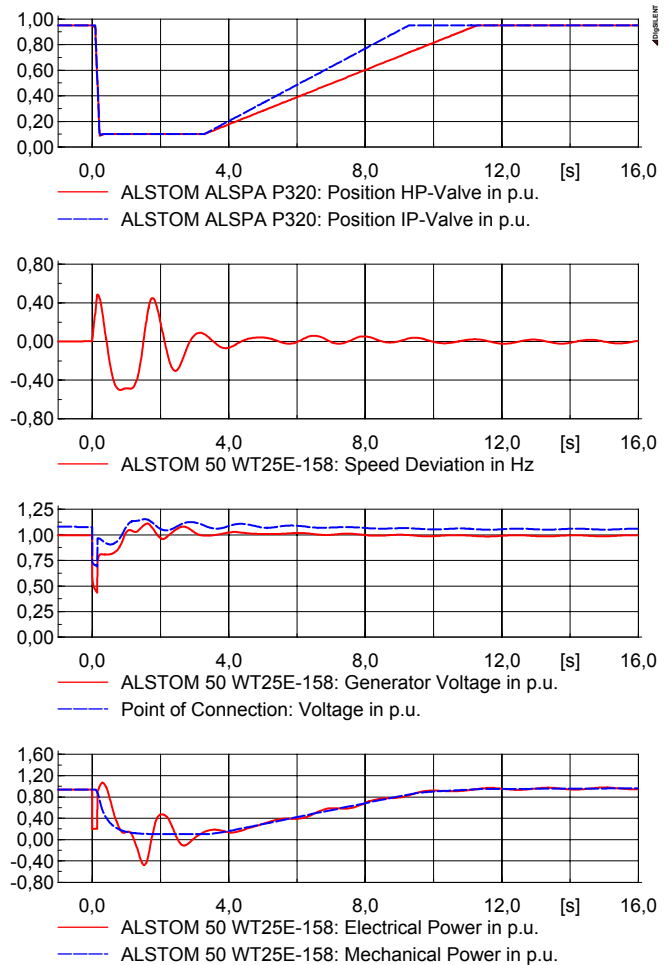


Fig. 9: Power Plant with Fast Valving and FCT = 150 ms

The Fast Valving requirement in the 50Hertz Grid Code is also in compliance with the future ENTSO-E Code. Furthermore the need and effect of Fast Valving is described in /Erlach et al., Rosendahl et al., EWIS/.

3.2 Power System Stabiliser in Thermal Power Plants

With deviations from steady state conditions between production and consumption, which are caused e.g. by switching operations in the transmission grid, short circuits or outages of generating units, the rotor angles of the generators will change. During this transient phase the automatic voltage regulators (AVR) of the generators in combination with the turbines and their regulations cause the network to absorb continuously oscillating energy. Only natural damping elements like the damping windings of the generators and asynchronous machines are not able to absorb this oscillating energy from the grid. Because of this the oscillation of the rotor angles would lead to an undamped or amplified effect.

To prevent this and to avoid tripping on faults, additional synthetic damping elements like power system stabilisers (PSS) are needed. PSS are used in selected power plants within the grid to increase the small signal stability. The damping effect of the PSS is based on the making of a component of the excitation current which leads to the change of the rotor angle. Thereby the lagging component of the AVR will be compensated. PSS can have different functionalities and configurations. A combined signal is formed from the

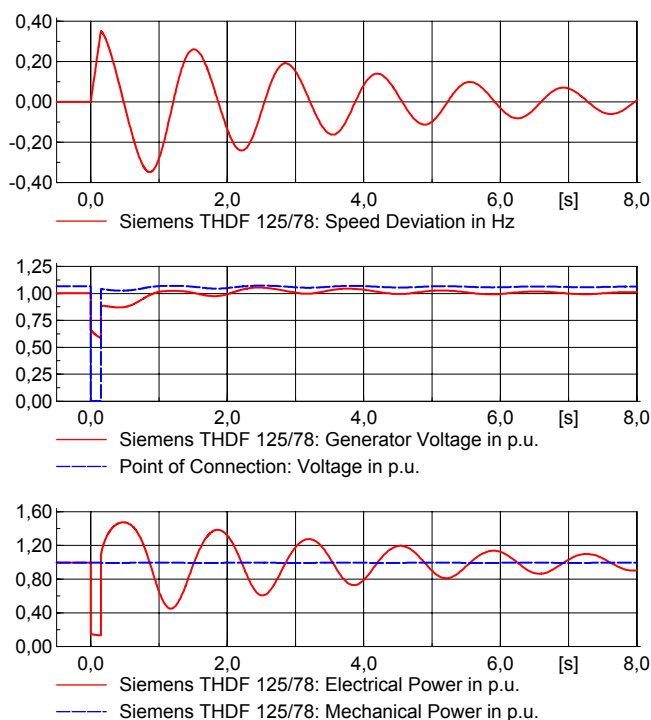


Fig. 10: Power Plant without PSS

generator speed and the active power of the generator and is connected to the input of the AVR. The desired damping effect of the power oscillations of the generator and of the grid is realised by filter circuits in the PSS. Figure 11 shows, in contrast to Figure 10 the positive damping effect of the PSS from a large power plant as a result of a conceivable three-pole short circuit nearby the power plant. The power plant oscillates with an eigenfrequency of 0.75 Hz against the grid. 50Hertz requires from the applicants of thermal power plants the following characteristics of the PSS:

The eigenfrequency (local mode) of the generator-turbine-set of approx. 0.7 – 1.5 Hz shall be damped sufficiently. Because the 50Hertz grid is located at the northern edge of the Continental European grid, an effective damping of the north-south power mode from 0.5 – 0.6 Hz is feasible and desired. Furthermore the PSS shall not react to non-oscillatory admissible power changes in smooth system operation due to a sudden load reduction of 40 % of maximum power of the unit from 1 p.u. to 0.6 p.u. within three seconds. This would lead to fluctuations of the voltage at the grid connection point. Additionally the PSS shall be disabled during transition to houseload operation in order to avoid transient voltage changes of the houseload of the power plant.

5. CONCLUSION

In accordance with § 19 EnWG 50Hertz is obliged to determine minimum requirements for the grid connection for all types of generating units. In this context all existing power plants and all power plants with application for grid connection will be treated equally in a transparent manner in respect to their system behaviour. New power plants shall be planned in accordance with the current state of the art. However, existing power plants shall fulfil the enhanced technical requirements in the scope of appropriate economic feasibility. The thermal power plants in the control area of 50Hertz have

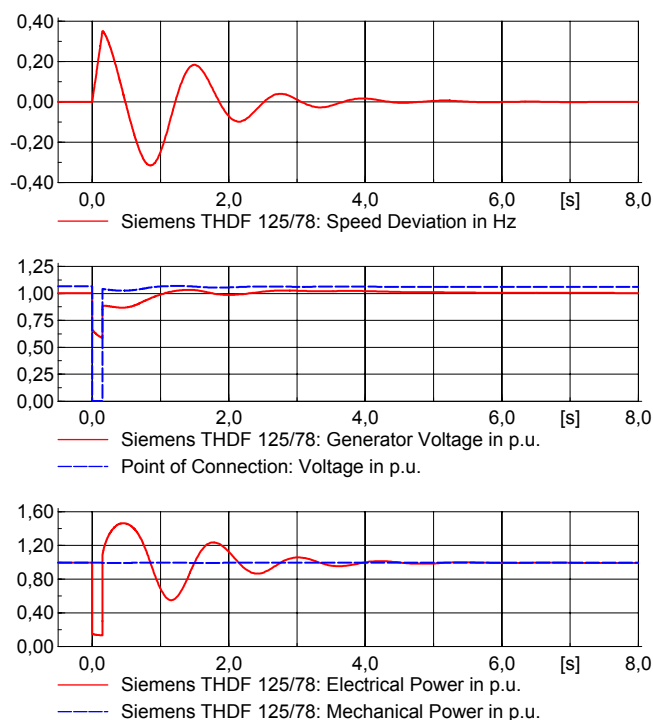


Fig. 11: Power Plant with PSS

to be able to provide the requirements for a secure grid operation. For this purpose the upgraded grid code of 50Hertz describes the essential technical minimum requirements.

In the framework of the third legislative package for the internal market for electricity the EU Commission has assigned the association of the European Transmission System Operators for Electricity (ENTSO-E) to make a proposal for a harmonised European-wide, legally binding Network Code. This Network Code determines the minimum technical requirements for all types of generating units with synchronous and asynchronous connection to the grid as well as offshore generators. The Network Code will be in line with the Framework Guidelines drafted by the association of European Energy Regulators (ACER). In this process 50Hertz is actively involved in the elaboration and consultation of the Network Code of ENTSO-E.

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