Consequences on Grid Operation by Decentralized Renewable Power Generators and their Consideration in the German Low Voltage and Medium Voltage Directive and Technical Guidelines

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To:
Agência de Cooperação Técnica Alemã – GIZ
Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

March 2012

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REPÚBLICA FEDERATIVA DO BRASIL
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Brazilian-German Energy Program

ANEEL

Study about International Standards for the connection of Small Distributed Generators to the power grid

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Developed for: Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

Program: Energy Program, GIZ Brazil

Program No.: 2007.2189.4-001.00

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March 2012

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1 Introduction and Summary

The scope of this document is to describe the latest developments in Germany with respect to renewable power generation and its connection to the different voltage levels. Due to the enormous increase of such installations and the fact that renewable power generation units so far have been considered more or less as “negative loads” but without consideration of their capabilities to act in the same way as conventional power plants certain problems arose. Those problems – or more positively spoken: challenges – are described in section 2 of this document.

In section 3 of the document a very short introduction to the two relevant guidelines for connection of generation units to the low and medium voltage grid is given and for those parts that are relevant for the topic of this document are highlighted.

In section 4 of the document the latest changes to these guidelines are described in detail. All the changes are related to the new situation of increasing fractions of decentralized and renewable power generation and to overcome possible problems in grid operation.

The document ends with an overview about the latest changes for the operation of renewable power generation units currently discussed in the federal parliament that in case they are put into force means a dramatic cut in policy for the advancement of renewable power generation. There, only the consequences relevant to plant operation are considered.

1.1 Summary of most important changes

Generation units between a nominal power of 3.68 kVA up to 13.8 kVA

- Reactive power provision with $\cos\varphi = 0.95_{ind}$ to $\cos\varphi = 0.95_{cap}$
- Maximum unbalanced load of 4.6 kVA (also relevant for other power categories)
- Active power provision remotely controllable by grid operator (according to renewable energy sources act 2012), or
- Alternatively, inverter capacity is installed only to 70% of the respective DC capacity of a PV generator

Generation units between a nominal power of 13.8 kVA up to 30 kVA

- Reactive power provision with $\cos\varphi = 0.90_{ind}$ to $\cos\varphi = 0.90_{cap}$
- Application of three-phase inverters is comprehensible, or
- Alternatively symmetrical operation of several single phase inverters
- Active power provision remotely controllable by grid operator (according to renewable energy sources act 2012), or
- Alternatively, inverter capacity is installed only to 70% of the respective DC capacity of a PV generator

Generation units between a nominal power of 30 kVA up to 100 kVA

- Reactive power provision with $\cos\varphi = 0.90_{ind}$ to $\cos\varphi = 0.90_{cap}$
- Application of three-phase inverters is comprehensible, or
- Alternatively symmetrical operation of several single phase inverters

- External (from inverter) placed grid protection unit, but not anymore accessible by the grid operator personnel (compare giz-study of 2011[1])
- Active power provision remotely controllable by grid operator (according to renewable energy sources act 2012)

Generation units with a nominal power above 100 kVA

- Reactive power provision with $\cos\varphi = 0.90_{ind}$ to $\cos\varphi = 0.90_{cap}$
- Application of three-phase inverters is comprehensible, or
- Alternatively symmetrical operation of several single phase inverters
- External (from inverter) placed grid protection unit, but not anymore accessible by the grid operator personnel (compare giz-study of 2011)
- Active power provision remotely controllable by grid operator
- Provision of actual power feed-in information on demand of the grid operator

[1] I. Stadler: Study about International Standards for the connection of Small Distributed Generators to the power grid

2 Impact of decentralized renewable power generation on grid operation

2.1 Impacts in low voltage distribution grids

Increasing installation capacities of renewable power generators on the lowest voltage level could have several consequences on either the capability of further increasing installations or on the operability of the grids. For low voltage grids these are the simultaneity of power production, grid asset limitations, voltage deviations and frequency deviations. The latter one is discussed in section 2.3 as this is of a global dimension and not specifically dedicated to low voltage grids but the problem source of course could be found in the low voltage grid.

2.1.1 Simultaneity

Grid assets have been planned according to the maximum load that has to be expected. With only one household connected the assets have to be dimensioned according to the maximum load of the household. The more households (or other loads) connected the less the probability is that all have their peak consumption at the same time. This theory results in the simultaneity factor according to which grid assets are dimensioned (illustration 2.1.1.a).

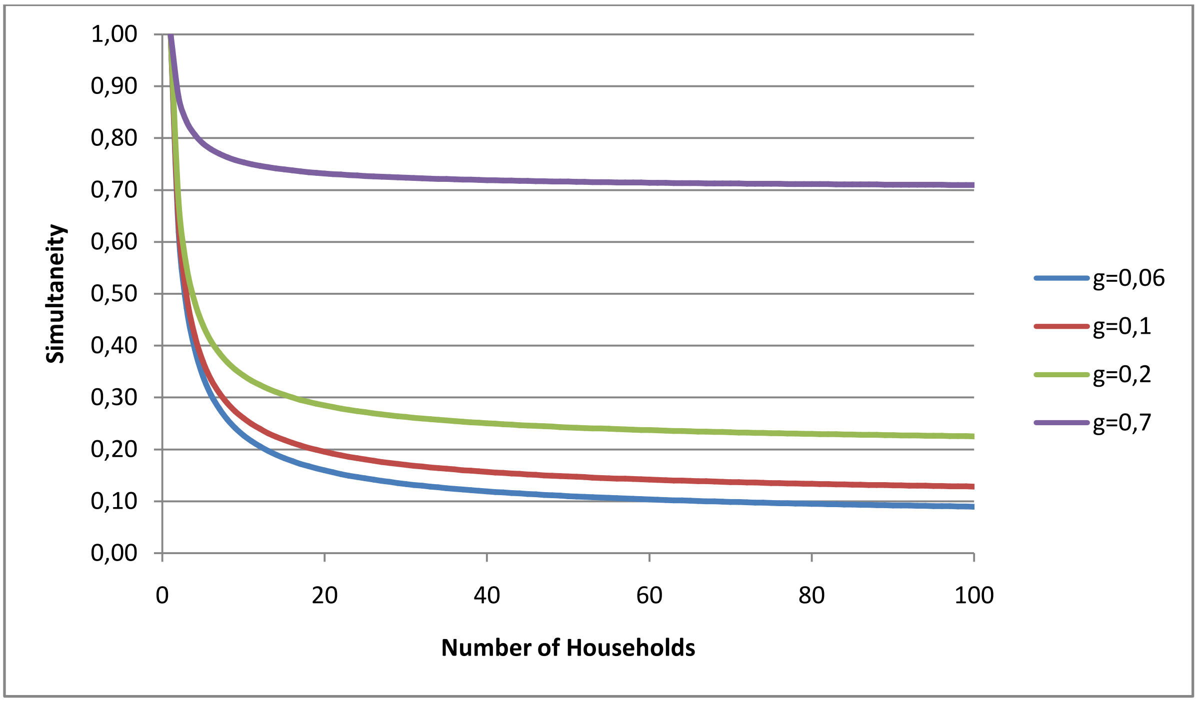


Illustration 2.1.1.a: Simultaneity and peak electrical load depending on number of households considered as function of simultaneity factor "g" for an infinite number of households (g=0,06: high electrification degree including hot water generation; g=0,1: partly electrified with electrical cooking; g=0,2: weak electrification; g=0,7: household with electrical heating), derived from [Kaufmann 1995]

That means that in a neighborhood with typical households including electrical cooking transformers and lines are not dimensioned to every households peak load but only for about 20 % of it.

With users who are independent from each other this procedure leads to an economic grid design because a sufficient large group of people never behave in the same way (and therefore never consume peak electricity at the same time).

That is completely different with photovoltaic systems. Within a geographically limited local district weather conditions are almost equal for all systems at any time (with small deviations when clouds are passing through). That results in a simultaneity factor of almost “1” for PV generators.

As a consequence a single house connection is designed for more than 15 kW and by logics also could feed electricity back to the grid in the same amount. But when all houses of a district feed electricity to the grid at the same time the maximum capacity is reduced to 20 %.

As a consequence large installation capacities could lead to high asset loadings, see section 2.1.2.

2.1.2 Cable and transformer loading

The maximum loading of assets is defined according to their design boundary conditions. A violation of defined loading limits either decreases the life time of the asset or even could destroy it. Relevant parameters are current and voltage.

Increased voltages result in an increased stress to insulation by electrical fields, losses and partly discharges. As insulation of low voltage assets are designed for a limit of 1000 V this criterion does not play a role when discussing decentralized power generation.

Electric currents cause losses in all assets and as a consequence they heat up. When the thermal load is too high aging is accelerated and life times decrease considerably (in case of short circuit currents to only few seconds). Allowed current loadings with boundary conditions like ambient temperatures are given in the asset’s norms.

> Consideration in directives: Limitations due to asset loadings are not taken into consideration in any low voltage directive.
>
> The renewable energy sources act deals with this topic. According to §9 grid operators are obliged to optimize, to strenghten or to expand their grids in order to absorb the power generated by renewable power generators. This is only the case when the necessary actions are economically reasonable.
>
> §11of the renewable energy sources act deals with feed-in management. This is explained in section 4.1.3, 4.1.4.

2.1.3 Voltage deviations

For a safe operation of the grid and operation of appliances connected to the grid requirements on the voltage levels have been defined. A definition of grid voltages and voltage limits is defined in DIN-IEC 60038 and VDE 0175. A more detailed description contains the European norm DIN-EN 50160. The voltage has to be kept within a limit of $\pm 10\%$ of the rated voltage.

In order to guarantee those norms different bodies have established further guidelines. Relevant to this publication is especially the maximum allowed voltage deviation through decentralized generation capacities. In Germany this is the VDEW guideline for parallel operation of electricity generation units in the low voltage grid. Although the voltage band allowed in low voltage grids is $\pm 10\%$ the guideline limits the contribution of decentralized generation with the criterion of $\Delta U \leq 3\%$.

Medium and low voltage grids have a fixed coupling. The last possibility (in non-smart grids) to influence the voltage is at the feeding transformer of the medium voltage grid. Those transformers can change their transmission ratio during operation. Within the medium and also the low voltage grid the voltage at any point results from the load distribution in the grid (Illustration 2.1.3.a).

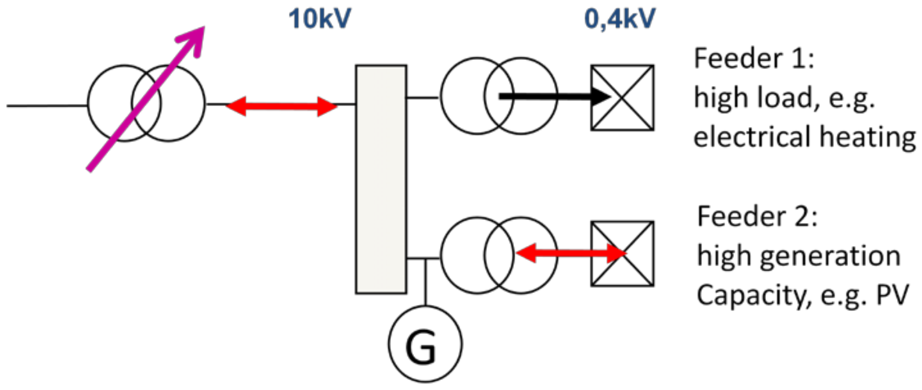


Illustration 2.1.3.a: Exemplary grid to explain voltage deviation limits with feeder 1 as a highly loaded string and feeder 2 as a highly feeding string.

The worst case in terms of voltage spreads is shown in the illustrations below and leads to the $\Delta U \leq 3\%$ criterion. Grid feeder 1 is in a high load condition. The grid is dimensioned in a way that in this case the last connection to a house is kept within the $\pm 10\%$ limit with a safety reserve of 1 %. As a result the voltage at the 20 kV level is increased to its maximum of 104 %. The voltage drop is then:

- 5 % voltage drop in the low voltage grid
- 3 % in the distribution system transformer
- 5 % in the medium voltage grid
- 1 % safety reserve.

It is further assumed that at the same time in grid feeder 2 there is no load and the maximum possible feed-in from decentralized power generators. This would lead to a voltage increase instead of a voltage decrease (see Illustration 2.1.3.b). At the last house connection of this string the $\pm 10\%$ criterion also has to be kept. It is not possible to lower the voltage at 20 kV level because of grid string 2. Therefore, the remaining voltage drops are distributed accordingly:

- 3 % voltage drop in low voltage grid including transformer
- 2 % voltage drop in medium voltage grid
- 1 % reserve.

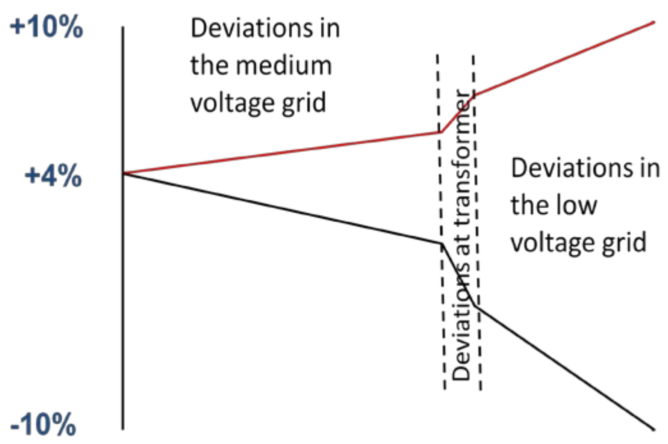


Illustration 2.1.3.b: Voltage distribution in the exemplary grid according to Illustration 2.1.3.a

Consideration in directives: To delay limits of renewable power installation capacities in low voltage grids reactive power management has been introduced also the low voltage grids. This is described in section 4.1.2, directive E VDE-AR-N 4105.

2.2 Impacts in medium voltage distribution grids

In medium voltage grids wind turbines are the dominating renewable power generation technology. But also an increasing number of large photovoltaic power generators (and also biomass) are connected to the medium voltage grid level.

The impacts of renewable generation capacity in the medium voltage grid are similar to those described for the low voltage grid and therefore only specific circumstances related to medium voltage grids are mentioned here.

Typical installation sites for wind parks and photovoltaic power stations are in more rural and more sparsely populated areas. That means that those generation capacities are installed in areas where the medium voltage grid capacity is less developed or less strong than in populated areas (cities, industrial areas, neighborhoods). And as a consequence bottlenecks in grid assets are a potential limitation for further renewable power capacity. The way this is dealt with is exactly the same like in low voltage grids:

> Consideration in directives: Limitations due to asset loadings are not taken into consideration in any medium voltage directive.
>
> The renewable energy sources act deals with this topic. According to §9 grid operators are obliged to optimize, to strenghten or to expand their grids in order to absorb the power generated by renewable power generators. This is only the case when the necessary actions are economically reasonable.
>
> §11of the renewable energy sources act deals with feed-in management. This is explained in section 4.2.3, and 4.2.5.

As a consequence of high renewable power installation rates and weak grid assets at installation sites also voltage deviations have to be dealt with. Both, wind turbines and photovoltaic power stations have actively to contribute to voltage (reactive power) control.

After the decision of the federal government to back out of nuclear power and the immediate shut-down of eight nuclear power stations the role of reactive power management by wind parks has even increased. The assurance of voltage stability in the German grid became more demanding as five of the shut-down nuclear power stations are located in southern Germany and the bulk wind capacity is more located in the northern part.

So, voltage regulation by renewable power capacities is required in both, low and medium voltage grids. But whereas in low voltage grids the implementation of voltage control has been established with the aim to increase renewable power installations in the medium voltage grid reactive power management is done in order to guarantee power quality and voltage stability.

> Consideration in directives: In 2009 the so-called “Ordinance on System Services by Wind Energy Plants (SDLWindV)” was set into force, see section 4.
>
> Further, in the Guidelines about generation units connected to the medeium voltage grid this aspect is dealt with, see section 4.2.6.

2.3 Frequency stability impacts by renewable generation capacities in low and medium voltage distribution grids

The enormous success in renewable power installations in the low and medium voltage grid has caused a new danger of grid instability. This danger has become generally known as the so-called "50.2 Hz problem".

The philosophy for grid management so far has been that decentralized power generation facilities should behave as passive as possible. As a consequence, whenever the system frequency would exceed 50.2 Hz the complete installed decentralized power would have been disconnected immediately (within 200 ms) from the grid, see illustration 2.3.a.

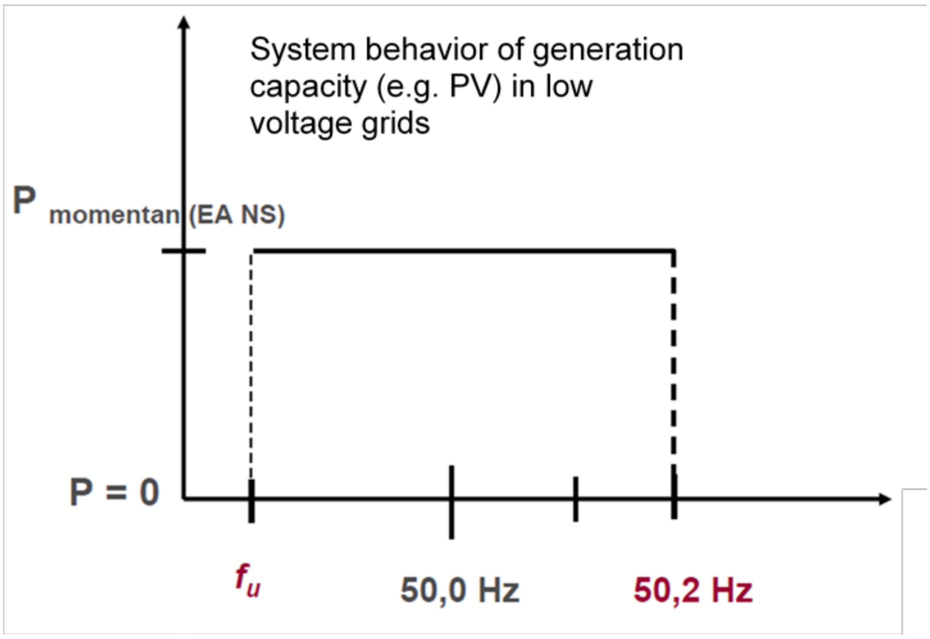


Illustration 2.3.a: Former frequency control pattern of generation capacity in low voltage grids

With only few installations in the low voltage grid this has been an appropriate way to operate grids. But with the enormous success of e.g. photovoltaics in distribution grids this way of operation became a danger of grid stability of the complete European interconnected grid. Illustration 2.3.b shows the installed photovoltaic capacity only in Germany which has been at the end of 2011 almost 25 GW_p. This is equivalent to an installed power almost equal twice the capacity of Itaipú [14 GW] – but distributed in the low and medium voltage grid.

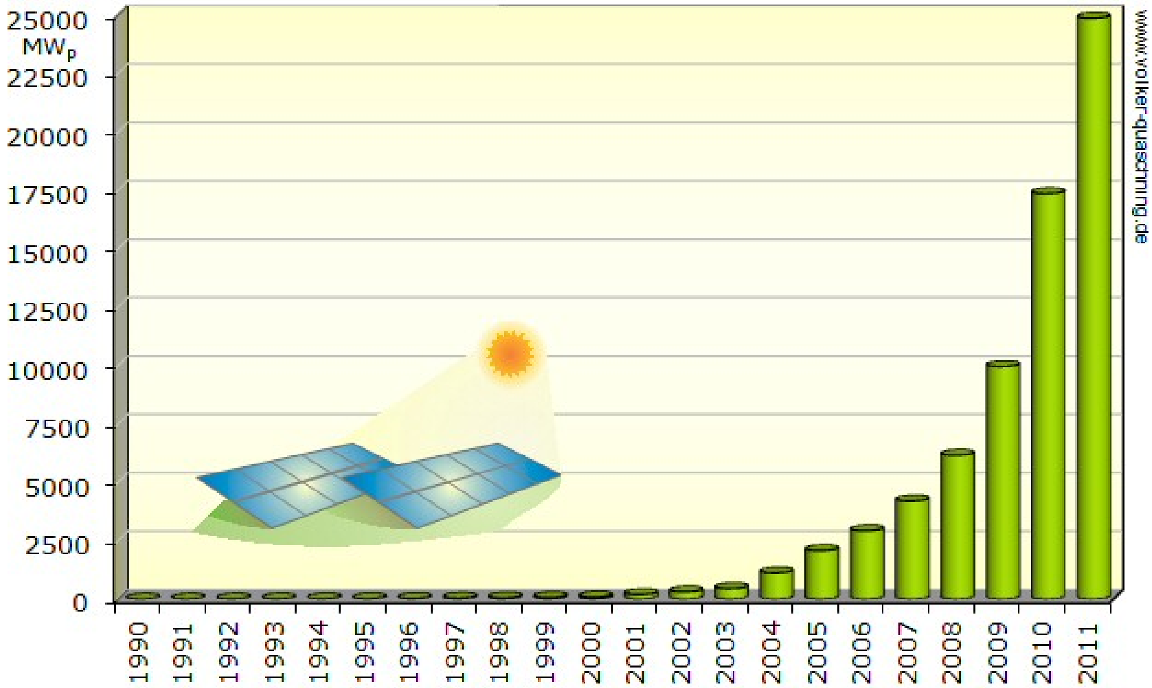


Illustration 2.3.b: Installed photovoltaic generation capacity in Germany [Source: V. Quaschning]

In comparison to that total European primary control capacity is only 3 GW. In case of a slight over frequency (50.2 Hz) enormous capacities could disconnect themselves from the grid – by far more than primary control capacity is available. As a consequence grid frequency drops rapidly, originally caused by a too high frequency. The European grid control strategy directly would counteract with its five stage plan to disconnect parts of the load (see illustration 2.3.c). The consequence finally would be European wide blackout.

The five stage plan for the control of large-scale failures with a drop in frequency is described in Table 2.3.a.

In Stage 1, the distribution grid operators directly connected and the operators of generating facilities directly connected to the transmission system shall be alerted by the transmission system operator as soon as possible, if the evolution of the disturbance allows doing so, in order to enable them to respond quickly and appropriately to the situation. To this end, the measures agreed in advance between the parties concerned are to be launched.

Stage 1:	49.8 Hz	Alerting of personnel and scheduling of the power station capacity not yet activated, according to the TSO's directions, shedding of pumps.
Stage 2:	49.0 Hz	Instantaneous load shedding of 10 - 15 % of the system load.
Stage 3:	48.7 Hz	Instantaneous load shedding of a further 10 - 15 % of the system load.
Stage 4:	48.4 Hz	Instantaneous load shedding of a further 15 - 20 % of the system load.
Stage 5:	47.5 Hz	Disconnection of all generating facilities from the network.

Table 2.3.a: 5-Stage Plan for the control of large-scale failures with a drop in frequency

Stages 2, 3 and 4 ensure that selected load shedding does not reach Stage 5, and that disconnection of the generating units from the network is thereby avoided. The frequency relays needed for that purpose are installed, parameterized and operated by the directly connected distribution grid operators after previous agreement with the transmission grid operator. Distribution grid operators not directly connected to the transmission system shall install, parameterize and operate requisite frequency relays in consultation with their upstream distribution grid operators.

Stage 5 has the function of ensuring auxiliary supplies and operation of the generating units for rapid commitment for the purpose of restoration of supply and avoidance of damage to the power station facilities.

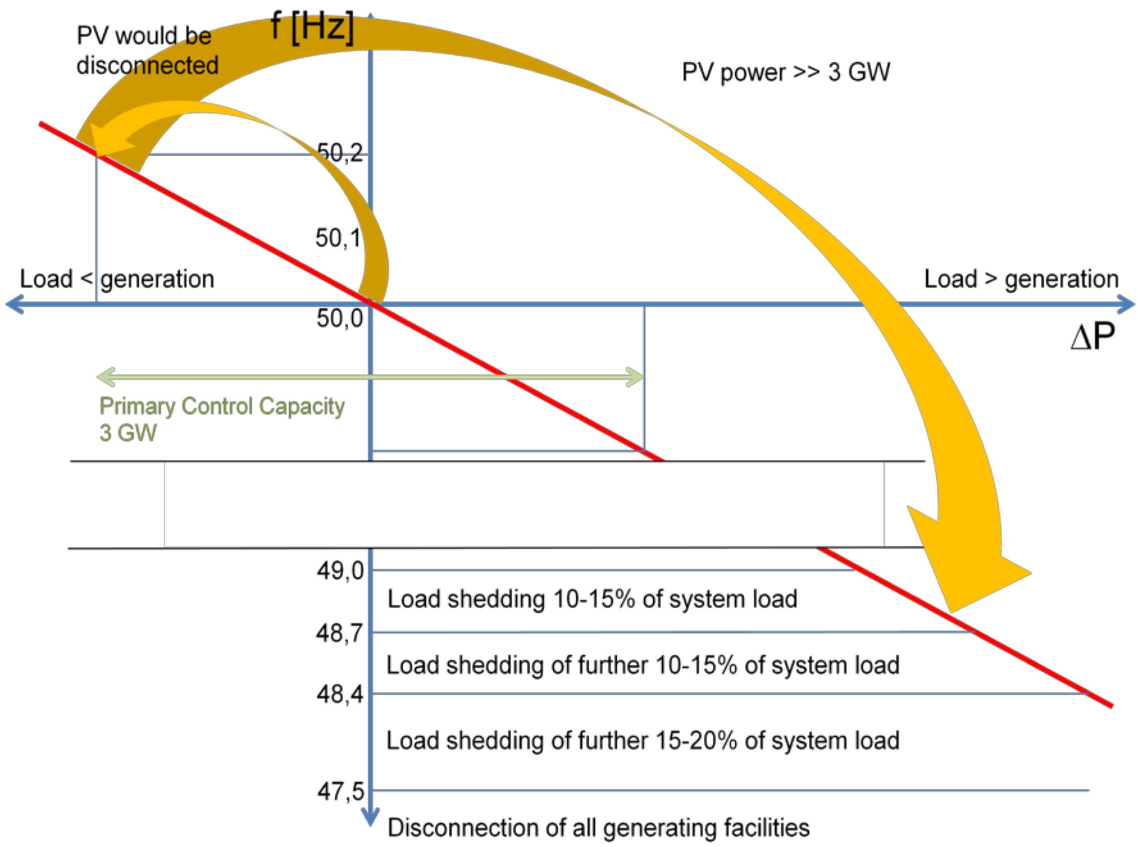


Illustration 2.3.c: Illustration of the so-called 50.2 Hz problem

> <u>Consideration in directives</u>: The 50.2 Hz problem is dealt with in directive E VDE-AR-N 4105 and described in section 4.1.1, and 4.2.4.

2.4 Non-technical aspects

> <u>Consideration in directives</u>: Apart from technical impacts, discussion on subsidies and electricity prizes, also have an impact on new developments in laws and guidelines. Those latest developments will be described in section 5.

3 Content of Directives for low and medium voltage grids

The two main directives that deal with the topics relevant of this study are the guideline about generation units connected to the low voltage grid and the guideline about generation units connected to the medium voltage grid. In the following the purpose of these guidelines, their contents and references to topics important for this study are given.

3.1 Guideline about generation units connected to the low voltage grid

The guideline about generation units connected to the low voltage grid, more specific the VDE-AR-N4105 guideline, describes everything that is required to know and to consider when connecting a generation unit to the respective voltage level. As a planning device it is relevant for both grid operator and plant operator. Further, information is given that is also relevant during operation of the plant itself.

The guideline recently has been completely new designed and its content is now similar to the one of the guideline for medium and high voltage grid. As it is already the case in higher voltage levels generation units now also need to support static voltage control in the low voltage grid. All considerations that are necessary for a safe and reliable grid operation are dealt with in a way that they are in accordance with the energy industry act and the in DIN EN 50160 mentioned limits for power quality.

In the appendix of the guideline calculation examples are presented that determine whether a generation plant can be connected to the low voltage grid or not. In case the result is that it cannot be connected to the low voltage grid normally the consequence is that it has to be connected to the medium voltage grid. Therefore, the guidelines for the medium voltage grid are valid, see section 3.2.

The guideline’s content in brief:

- It clarifies its purpose and gives relation to further norms and guidelines
- Describes the registration process for generation units
- Describes the commissioning process
- Clarification of point of grid connection
- Grid quality aspects as voltage deviations, harmonics, transients, flickers, non-symmetric voltages, ripple control aspects, etc.
- **Connectivity requirements**
  → described in section 4.1
- **Behavior of generation units connected to the grid**
  → described in detail in section 4.1
- Grid protection aspects (has been described in detail in giz-study of 2011)
- Electricity counter aspects
- Description of procedures to provide proofs of the different aspects

3.2 Guideline about generation units connected to the medium voltage grid

The guideline about generation units connected to the medium voltage grid describes everything that is required to know and to consider when connecting a generation unit to the respective voltage level. As a planning device it is relevant for both grid operator and plant operator. Further, information is given that is also relevant during operation of the plant itself.

Within the new version special consideration was given to the connection of generation units that are addressed by the renewable energy sources act (renewable energy sources). This resulted in a new structure of the document.

Equivalent to renewable power generation units connected to the high and highest voltage grid from now on also units connected to the medium voltage grid must participate in grid support activities. In case of a grid fault they are not allowed to be disconnected from the grid and also during normal grid operation mode they require to feed reactive currents to the grid. This has a consequence on generation plant design

All considerations that are necessary for a safe and reliable grid operation are dealt with in a way that they are in accordance with the energy industry act and that the in DIN EN 50160 mentioned limits for power quality are kept even with increasing fractions of renewable power generation.

The guideline's content in brief:

- It clarifies its purpose and gives relation to further norms and guidelines
- Describes the registration process for generation units
- Describes the commissioning process
- Clarification of point of grid connection
- Grid quality aspects as voltage deviations, harmonics, transients, flickers, non-symmetric voltages, ripple control aspects, etc.
- **Connectivity requirements**
  → described in section 4.2
- **Behavior of generation units connected to the grid**
  → described in detail in section 4.2
- **Dynamic grid support**
  → described in detail in section 4.2
- Primary and secondary technologies
- Grid protection aspects
- Electricity counter aspects
- Operability aspects
- Description of procedures to provide proofs of the different aspects

4 Latest Changes within directives to react on increased renewable power generation

4.1 Directives with relation to low voltage grids

At August 1st in 2011 the working group "Netztechnik/netzbetrieb (FNN)" of VDE has published the directive VDE-AR-N 4105 with the name "Generation facilities in low voltage grids". Here, one finds mechanisms for frequency control, bottleneck management and voltage stability control mechanisms.

With the new version of the renewable energy sources act that came into force at January 1st in 2012 especially bottleneck management is addressed in §6. Expressions made here, partly are identical to VDE-AR-N 4105 and partly supplement them.

4.1.1 VDE-AR-N 4105 with respect to frequency control

According to the old VDEW guideline 0126-1-1 power generation facilities in the low voltage grid had to immediately switch-off in case the grid frequency has exceeded 50.2 Hz (see illustration 2.3.a) which could lead to consequences explained in illustration 2.3.c.

According to the new directive generation units in the low voltage grid are not any more allowed to disconnect immediately when the 50.2 Hz limit is reached. From now on generation units have linearly to decrease active power feed-in according to the curve displayed in illustration 4.1.1.a. Only in case the frequency exceeds 51.5 Hz generation units in the low voltage grid switch-off completely.

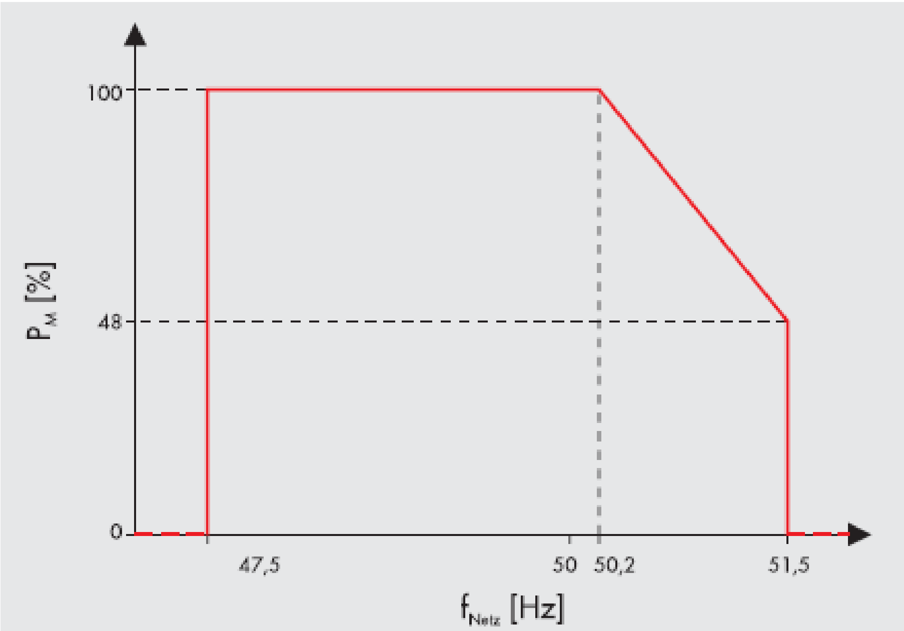


Illustration 4.1.1.a: Frequency control of generation units in the low voltage grid according to VDE-AR-N 4105 [Source: SMA]

After generation units have been disconnected or had to reduce active power feed-in due to over frequency the feed-in power is not allowed to be increased before the grid frequency has decreased to values less or equal to 50.05 Hz.

4.1.2 VDE-AR-N 4105 with respect to voltage control

According to the new directive power generation units need to participate at static voltage control. With static voltage control is meant that with slow changes of the grid voltage those facilities have to contribute to voltage stability in order to keep it in its limits. Participation in dynamic voltage control (fault ride through) is not foreseen for generation units in low voltage grids.

Generation units need to be able to be operated within certain intervals of shift factors ($\cos(\varphi)$) when the grid voltage is within its tolerance band of $\pm 10\%$ and in case their active power generation is above 20% of their rated power.

For generation units with an apparent power of $\sum S_{\max} \leq 3.68kVA$ at point of grid connection:

- Within $\cos(\varphi) = 0.95_{underexcited}$ to $\cos(\varphi) = 0.95_{overexcited}$, but without any specification from the grid operator

For generation units with an apparent power of $3.68kVA \leq \sum S_{\max} \leq 13.8kVA$ at point of grid connection:

- Within $\cos(\varphi) = 0.95_{underexcited}$ to $\cos(\varphi) = 0.95_{overexcited}$, according to a characteristic curve provided by the grid operator (since 1st January 2012)

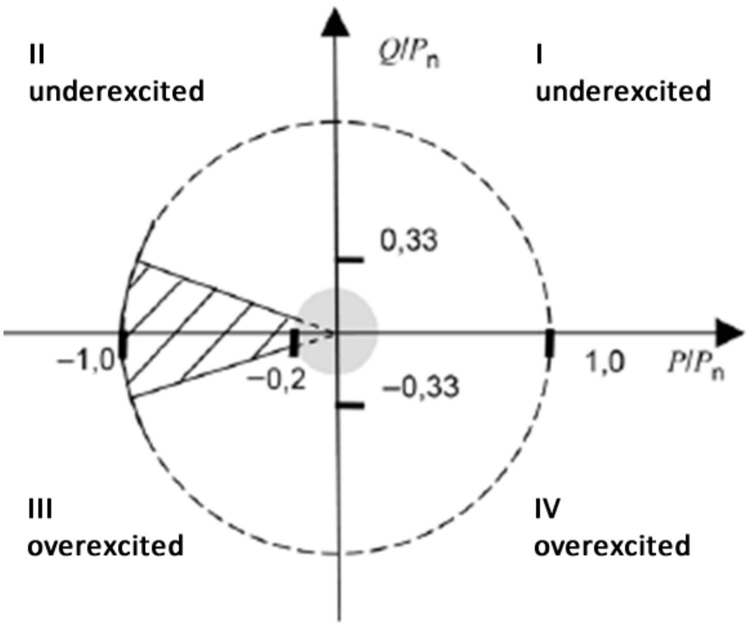


Illustration 4.1.2.a: Area in which generation units have to be able to be operated in the power range of $3.68kVA \leq \sum S_{\max} \leq 13.8kVA$ *[Source: VDE]*

For generation units with an apparent power of $\sum S_{\max} > 13.8kVA$ at point of grid connection:

- Within $\cos(\varphi) = 0.90_{underexcited}$ to $\cos(\varphi) = 0.90_{overexcited}$, according to a characteristic curve provided by the grid operator (since 1st July 2011)

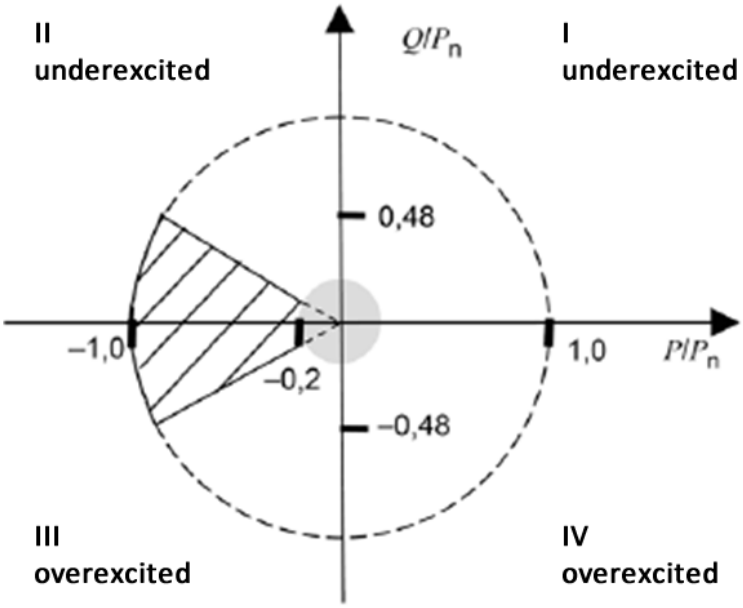


Illustration 4.1.2.b: Area in which generation units have to be able to be operated in the power range of $\sum S_{\max} > 13.8kVA$ *[Source: VDE]*

The grid operator provides the generation unit operator with the characteristic curve together with the allowance to connect the generation unit to the mains. Set point values need to be reached within a time frame of 10 seconds.

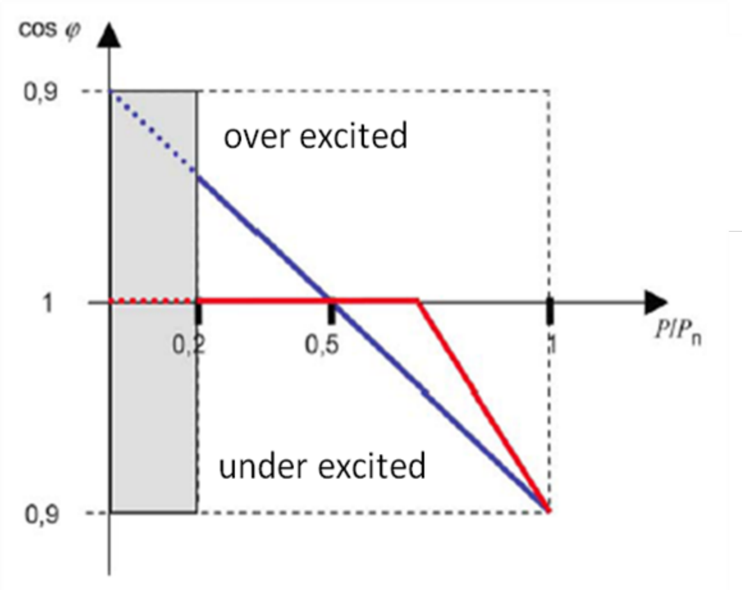


Illustration 4.1.2.c: Examples of $\cos\varphi(P)$ *-curves with two (blue line) and three (red line) supporting points. The curve needs to be matched with* $P \geq 0.2P_N$ *[Source: VDE]*

As a result of reactive power management application significantly more decentralized power generation can be installed within low voltage grids. Illustration 4.1.2.d shows the result of different exemplary calculations.

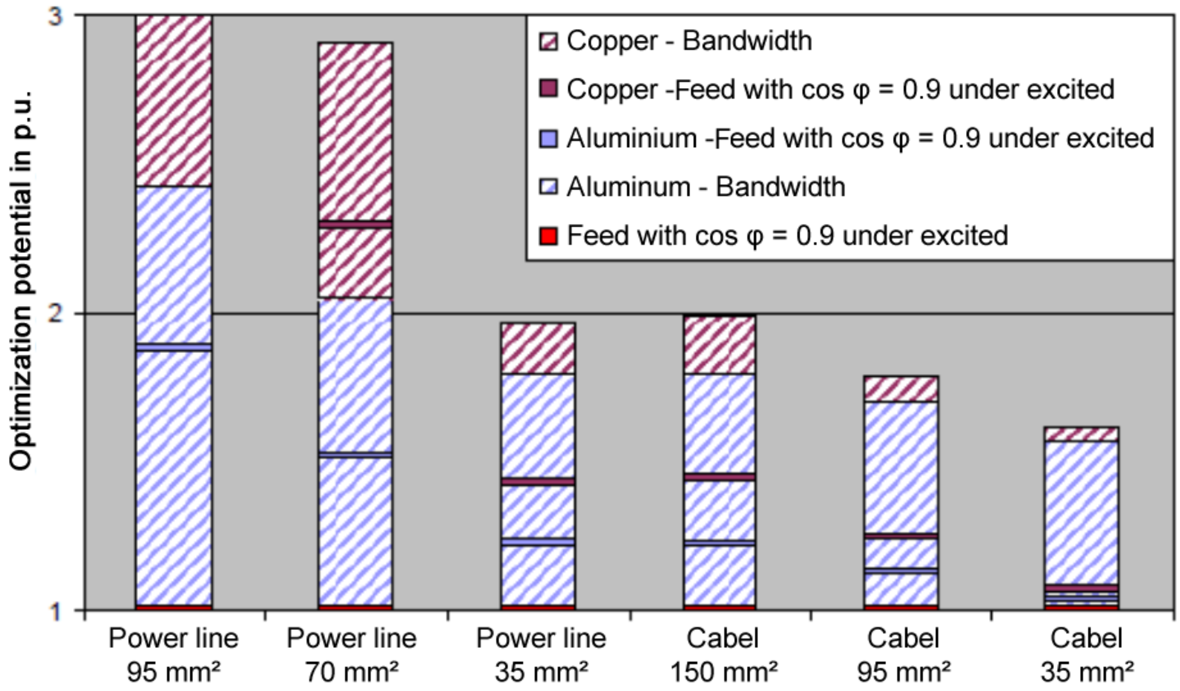


Illustration 4.1.2.d: Optimization potential by reactive power feed-in with exemplary overhead lines and cables in relation to an operation with $\cos(\varphi)=1$*. With overhead lines the optimization potential is higher due to a lower R/X-relation what is equivalent to a better suitability of voltage control through reactive power feed-in. [Source: VDE]*

Normally, with low active power feed-in $\cos(\varphi)=1$ is applied. When active power feed-in tends towards its nominal power $\cos(\varphi)=0.95$ or $\cos(\varphi)=0.90$, respectively, is approximated. Illustration 4.1.2.e shows the factory settings from the world largest inverter manufacturer SMA.

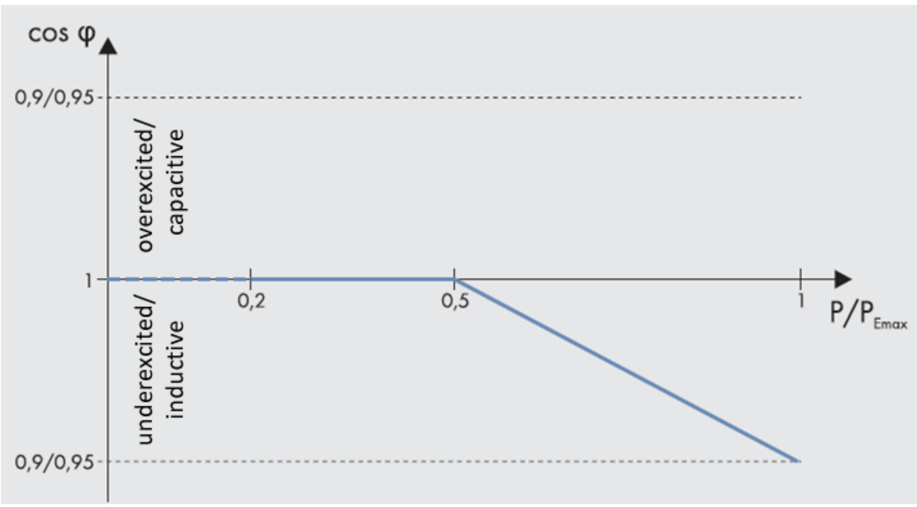


Illustration 4.1.2.e: Factory setting of reactive power control curve from SMA [Source: SMA]

As a consequence of reactive power management by decentralized power generators inverter apparent power needs to be increased even nominal active power remains the same. Illustration 4.1.2.f explains the geometric addition of active and reactive power and the need for higher apparent power.

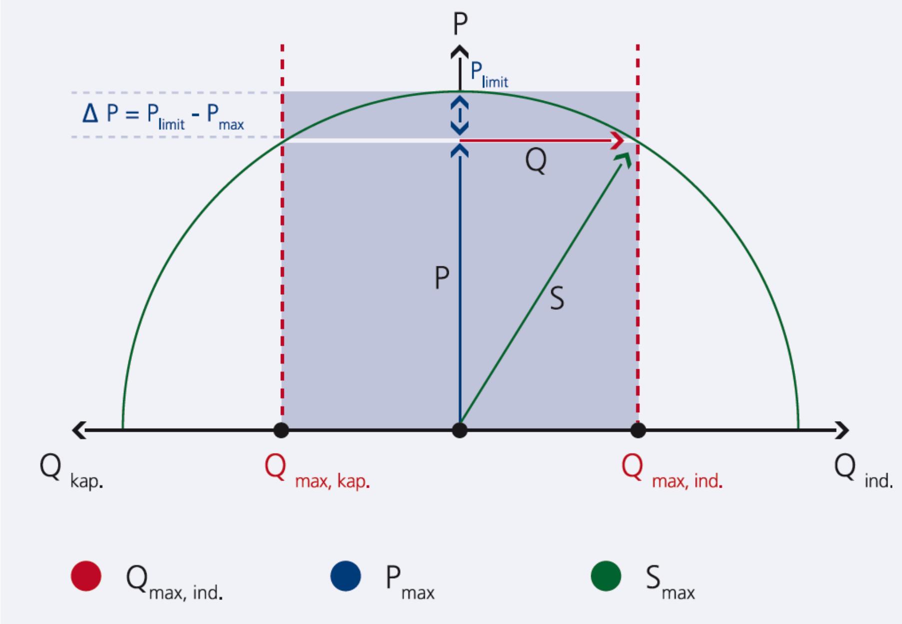


Illustration 4.1.2.f: Decreasing active power limit with reactive power provision [Source: Kaco]

The additional requirement for apparent power is as follows:

- for inverters with a nominal power between $3.68kVA \leq \sum S_{\max} \leq 13.8kVA$:

$$S_{new} = S_{old} \cdot \frac{1}{\cos\varphi} = S_{old} \cdot \frac{1}{0.95} = 1.053 \cdot S_{old}$$, and

- for inverters with a nominal power between $\sum S_{\max} > 13.8kVA$:

$$S_{new} = S_{old} \cdot \frac{1}{\cos\varphi} = S_{old} \cdot \frac{1}{0.90} = 1.11 \cdot S_{old}$$

This also means a slightly higher investment cost for decentralized power generators. But compared to an increase of power line capacity these costs are of a minor dimension.

On the other hand whenever renewable power generation units operate less than with nominal power there are plenty resources for reactive power available, see illustration 4.1.2.g.

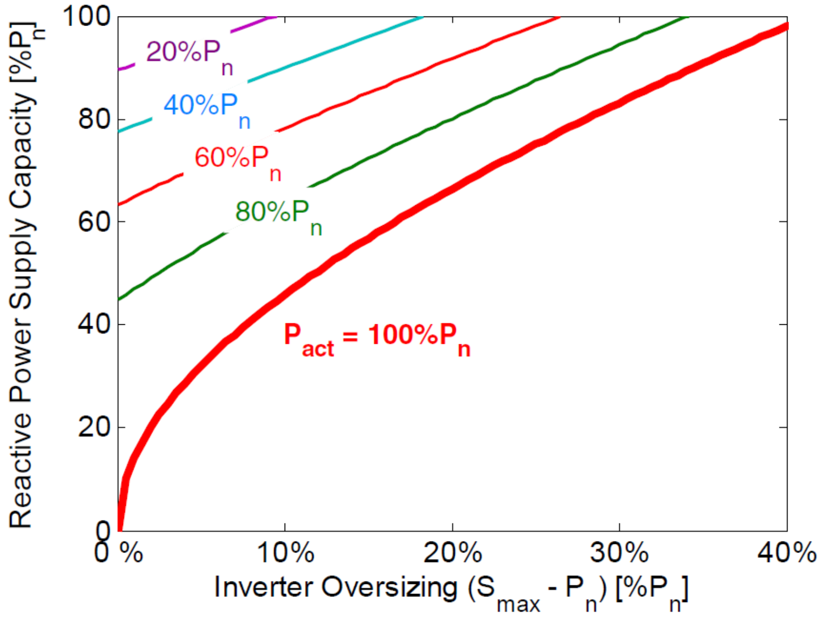


Illustration 4.1.2.g: Reactive power supply capacity as a percentage of the rated power P_n depending on the converter's over sizing $(S_{max} - P_n)$ also as a percentage of the rated power with the actual active power P_{act} as a parameter. [Source: Braun]

4.1.3 VDE-AR-N 4105 with respect to asset loading and bottleneck problems

Generation units need to be able to be operated with reduced power feed-in. Grid operators are allowed to decrease power feed-in or even to switch generation units off when one of the following circumstances appear:

- danger of secure grid operation
- bottlenecks / overload of grid infrastructure
- danger of islanding
- danger of static or dynamic grid stability
- dangerous frequency increase
- maintenance work or construction activities

The possibility to reduce power injection for the first time has been foreseen within the renewable power sources act of the year 2009. Here, only generation units with a nominal power exceeding 100 kW have been tackled by this rule.

Practical implementation has been done via ripple control signals with four contacts. Each contact was representing a power level – 100%, 60%, 30%, and 0% of the nominal power.

For the resulting minor power generation the renewable energy sources act foresees a financial compensation.

For new installations since 1st January 2012 this rule is now valid for all generation units, even those with a nominal power of less than 100 kW. For generation units with a nominal power of less than 30 kW it is possible to equip a photovoltaic power generator with an inverter that only supplies 70% of the photovoltaic DC generator.

4.1.4 Renewable energy sources act with respect to asset loading and bottleneck problems

Notwithstanding their obligation in accordance with grid capacity expansion, grid system operators shall be entitled, by way of exception, to take technical control over installations connected to their grid system for the generation of electricity from renewable energy sources, combined heat and power generation or mine gas, if

- the grid capacity in the respective grid system area would otherwise be overloaded on account of that electricity,

- they have ensured that the largest possible quantity of electricity from renewable energy sources and from combined heat and power generation is being purchased, and

- they have called up the data on the current feed-in situation in the relevant region of the grid system. Taking technical control over installations in accordance with the first sentence above shall only be permitted for a transitional period until measures referred to in grid capacity expansion are concluded.

Grid system operators shall, upon the request of those installation operators whose installations were affected by measures referred to under feed in management, provide verification, within four weeks, for the need for the measure.

To do so generation system operators shall provide installations with a technical or operational facility that allows active power feed-in management. The rules are different for different nominal power classes.

Generation units with a DC power of less than 30 kW:

- power is controllable remotely by the grid operator
- for this power class alternatively the generation unit operator can equip a photovoltaic power generator with an inverter that only supplies 70% of the photovoltaic DC generator.

Generation units with a DC power between 30 kW and 100 kW:

- power is controllable remotely by the grid operator
  - o valid since 1st January 2012
  - o for generation units installed between January 2009 and December 2011 this becomes valid with 1st January 2014

Generation units with a DC power exceeding 100 kW:

- power is controllable remotely by the grid operator
- to call up the current electricity feed-in at any given point in time to which the grid system operator may have access
  - o valid since 1st January 2012
  - o for all other units installed earlier this becomes valid with 1st July 2012

4.2 Directives with relation to medium voltage grids

Whereas the renewable energy sources act gives specifications for generation units with a nominal power exceeding 100 kW the guidelines about generation units connected to the medium voltage grid do not make any relation to nominal powers. Here, all generation units that are connected to the medium voltage grid are targeted independent from their nominal power.

Demands are very similar to those for the low voltage grids specified in VDE-AR-N 4105.

Generation units connected to the medium voltage grid must contribute to both, static and dynamic voltage control. Further, it is dealt with frequency control and bottleneck problems.

4.2.1 Guidelines about generation units connected to the medium voltage grid with respect to static voltage control

The medium voltage guideline summarizes the essential aspects which have to be taken into consideration for the connection of generating plants to the network operator's medium voltage network. The guideline considers the security and reliability of network operation in accordance with the provisions of the EnWG in the light of a growing share of dispersed generating plants (using e.g. renewable energies). The requirements of the EEG have been adequately taken into consideration and the aspects of voltage quality determined in EN 50160 are included.

Concerning reactive power of generating units connected to the medium voltage grid the medium voltage grid guideline has specified in chapter 2.5.4 the following requirements:

With active power output, it must be possible to operate the generating plant in any operating point with at least a reactive power output corresponding to a power factor at the network connection point of $\cos\varphi$ = 0.95 (under excited) to 0.95 (over excited). In the consumer reference arrow system, that means operation in quadrant II (under excited) or III (over excited). Values deviating from the above must be agreed upon by contract.

With active power output, either a fixed target value for reactive power provision or a target value variably adjustable by remote control (or other control technologies) will be specified by the network operator. The setting value is either

a) a fixed power factor $\cos\varphi$ or
b) a power factor characteristic $\cos\varphi$ (P) (see illustration 4.2.1.a) or
c) a fixed reactive power in MVar or
d) a reactive power/voltage characteristic Q(U).

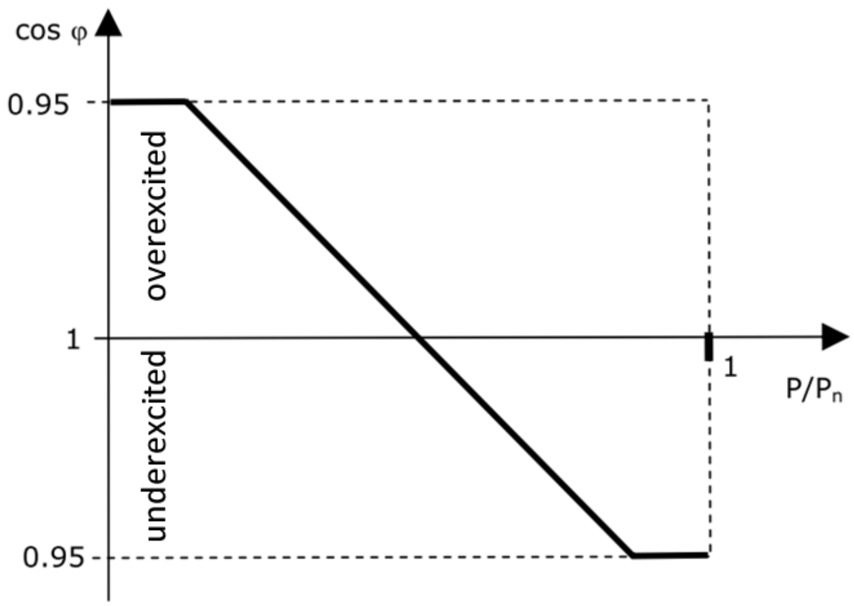


Illustration 4.2.1.a: Example of a cos φ (P) – characteristic

The reactive power of the generating plant must be adjustable. It must be possible to pass through the agreed reactive power range within a few minutes and as often as required. If a characteristic is specified by the network operator, any reactive power value resulting from the characteristic must automatically adapt as follows:

- within 10 seconds for the cos φ (P) - characteristic and
- adjustable between 10 seconds and 1 minute for the Q(U)-characteristic (specified by the network operator).

To avoid voltage jumps in the event of fluctuations in active power feed-in, it is advisable to choose a characteristic with continuous profile and limited gradient. Both the chosen approach and the target values shall be determined individually for every generating facility by the network operator. The specification can be based on

- the agreement of a value or, where applicable, of a schedule or
- online presetting of target values.

In the case of online presetting of target values, the new specifications for the working point of reactive power exchange shall be implemented at the network connection point after one minute, at the latest.

The behavior of the generation units connected to the medium voltage grid shall be verified by tests on the generating units or by means of a validated computation model of the generating plant.

Static voltage control is understood as control under normal operating conditions with slow voltage deviations and in order to keep the system voltage within accepted limits.

4.2.2 Guidelines about generation units connected to the medium voltage grid with respect to dynamic voltage control

With dynamic voltage control, voltage support activities are understood in order to avoid that large generation capacities are disconnected from the grid in case of voltage dips in the medium or high voltage grid.

Even renewable power generation units connected to the medium voltage grid need to be able to:

- remain connected at the grid in case of grid faults
- support grid voltage during a grid fault by feeding currents to the grid
- after clearing of the grid fault not to absorb more reactive power than before the fault

Those requirements are valid for all kind of short circuits: phase-to-earth, phase-to-phase, double line to ground fault, and three-phase short circuits.

Like in the transmission code 2007 (see appendix A) for transmission grids it is distinguished between type-1 and type-2 generation units. Type-1 generation units are connected via synchronous generators whereas type-2 generation units are all others, and among them those that are connected via inverters.

Illustration 4.2.2.a demonstrates the requirements for wind turbines with directly coupled synchronous generators. With voltage dips above the red line wind turbines are not allowed to disconnect themselves from the grid.

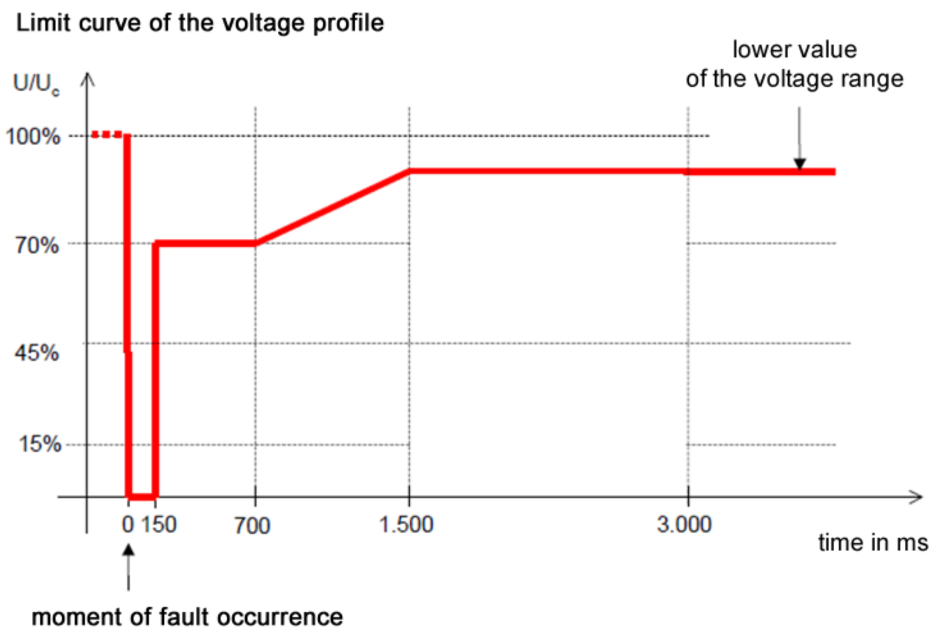


Illustration 4.2.2.a: Requirements for wind turbines connected to the grid via a synchronous generator

Illustration 4.2.2.b shows the requirements for all other grid connection possibilities. Below the blue line no requirements have to be fulfilled. Voltage dips above line 1 must not lead to instabilities or to a disconnection of the generation facility from the grid. Between line 1 and line 2 short disconnections are allowed with resynchronization after two seconds.

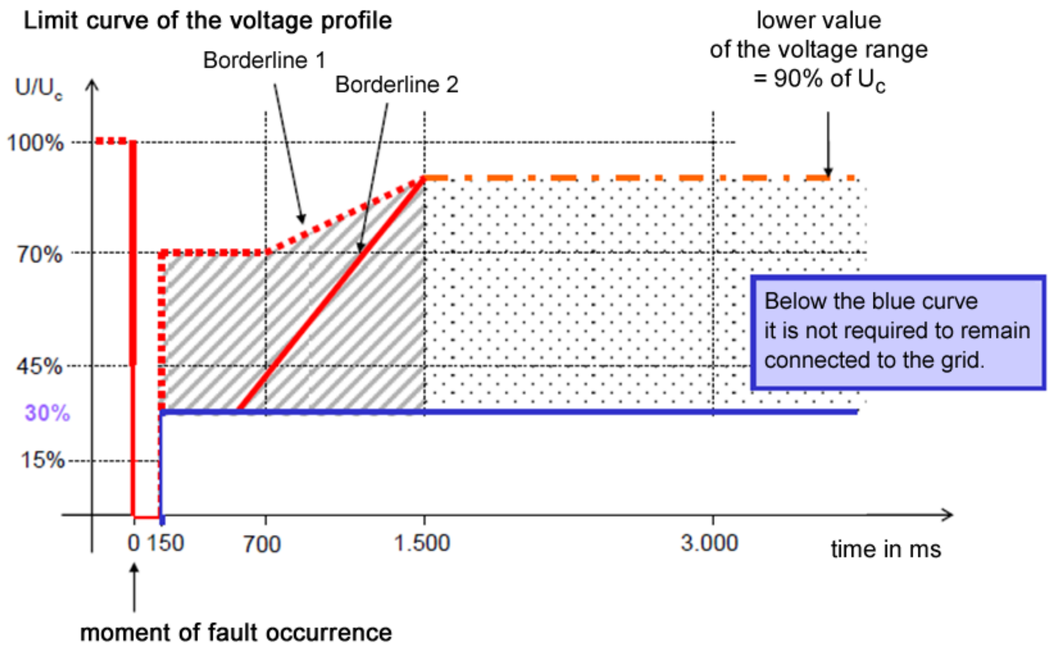


Illustration 4.2.2.b: Requirements for wind turbines connected to the grid not via a synchronous generator

4.2.3 Guidelines about generation units connected to the medium voltage grid with respect to asset loading and bottleneck problems

Generation units need to be able to be operated with reduced power feed-in. Grid operators are allowed to decrease power feed-in or even to switch generation units off when one of the following circumstances appear:

- danger of secure grid operation
- bottlenecks / overload of grid infrastructure
- danger of islanding
- danger of static or dynamic grid stability
- dangerous frequency increase
- maintenance work
- in the frame of feed-in management

Generation units need to be able to reduce active power injection in steps of 10% of their nominal power. Practical implementation has been done via ripple control signals with four contacts. Each contact was representing a power level – 100%, 60%, 30%, and 0% of the nominal power. Grid operator only provides the signal. Generation unit operators are responsible for power reduction.

The requested power reduction must be followed immediately, at latest within one minute. A reduction down to 10% of the nominal active power is required without that the generation unit will disconnect itself from the grid. Only with less than 10% of the nominal power the generation unit can be completely disconnected.

4.2.4 Guidelines about generation units connected to the medium voltage grid with respect to frequency control

All generation units connected to the medium voltage grid need to reduce active power feed-in in case the grid frequency exceeds 50.2 Hz with a gradient of 40% of the momentary available power per Hertz. When the grid frequency reaches 51.5 Hz the generation unit needs to be disconnected.

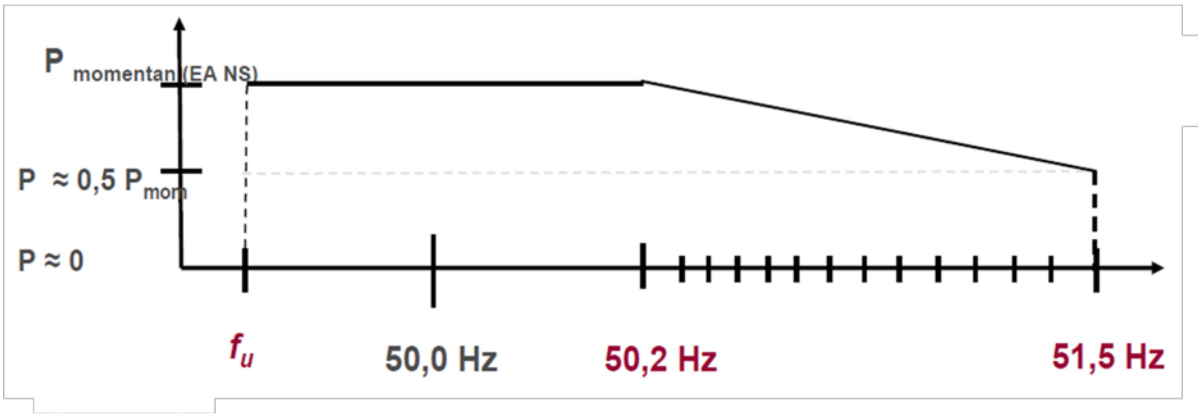


Illustration 4.2.3.a: Frequency control characteristic of generation units connected to the medium voltage grid

Only after the frequency has decreased to 50.05 Hz or less the active power feed-in is allowed to be increased again. Insensitivity margin must be less than 10 mHz.

To help grid operators to restore the grid after a black-out generation units with a nominal power above 1 MW need to be reconnected with a ramp function. An increase of feed-in power is limited to 10% of the nominal capacity per minute.

4.2.5 Renewable energy sources act with respect to asset loading and bottleneck problems

As the renewable energy sources act does not differ between the different voltage levels but according to rated power of generating units at this place it is referred to section 4.1.4.

4.2.6 Ordinance on System Services by Wind Energy Plants SDLWindV (Systemdienstleistungsverordnung)

In May 2009 the German government released the „ Ordinance on System Services by Wind Energy Plants" (Verordnung zu Systemdienstleistungen durch Windenergieanlagen).

The aim of the act is to guarantee security and stability also with very high wind loads in the grid, to bring technology in this area ahead and to lay the foundation for further increases in wind turbine installation.

The content of this act is more or less that wind turbines have to fulfill the same requirements for the management of reactive power than conventional power stations have to do.

The ordinance is dedicated towards the high and medium voltage grid. It more or less gives wind turbines the same duties than conventional power stations. Therefore the ordinance relates a lot to the transmission code for high voltages which is not part of this study. But for a better understanding some details are given in Appendix A.

For the medium voltage grid these are the regulations according to "Guidelines about generation units connected to the medium voltage grid" which have been dealt with in sections 4.2.1 to 3.2.3.

5 Critical analysis of latest changes to the directives and laws

The latest changes made in the respective guidelines for connection of generation units to the low and medium voltage grid – and also within the renewable energy sources act – represent a clear answer to the new situation that is caused by the increasing power generation capacities in the low and medium voltage level.

It has no longer been possible to ignore the renewable power generation or just look at them as negative loads. The more renewable power generation units replace conventional ones the more renewable power stations have to overtake the grid managing tasks from them.

Therefore, (almost) all previsions made in the guidelines and laws are reasonable.

The author of this study considers one of the pillars of the renewable energy sources act to be not anymore adequate for an electricity supply system that is converted towards a decentralized and renewable power based one. This is that the act allows everybody to install capacities wherever he/she is interested in to invest in renewable power capacity – and has the right to feed all of the electricity generated to the grid, or, when this is not possible to receive financial compensation.

Historically, this is one of the main success factors of the renewable energy sources act in Germany. It has been the pre-requisite for this enormous fast growth of installations. But from the point on when renewable power generators become a significant part in the electricity supply mix and they also need to take over grid management tasks, energy planning becomes of bigger importance. Neglecting energy planning activities directly implies the guidelines and renewable energy sources act's content:

1. Active power provision remotely controllable by grid operator, or even worse
2. To limit AC power output to 70% of the theoretical maximum

The first means a significant investment for small and decentralized generators. The second just wastes an amount of electricity generation without variable costs. The reason why this became part of the acts and guidelines is that more and more grids cannot absorb anymore the rated power of all decentralized installed generators. But that is only the case because especially in rural (and therefore weak grid) areas people and farmers install high power capacities.

Within cities grids have more or less no limits but here photovoltaic installations hardly can be found[2]. But because of the right to feed all electricity to the grid all installations suffer from this new regulation: Even those that have no grid capacity limitations.

It is discussed how much energy is wasted by that. Some claim that only 2% is lost (Federal Ministry for Environment), others claim 5% (German Association for Solar Energy), and others even more. Every percent of less power generation is a percent of higher electricity generation cost.

With the presence of energy planning still enormous capacities could be integrated into the German low and medium voltage grids and without any limitations.

5.1 Currently discussed changes to the renewable energy sources act

At 23rd February 2012 the secretaries for Environment (Norbert Röttgen) and Economics (Philip Rösler) presented a new draft of a revised renewable energy sources act. Parliament discussions about it are at the moment ongoing.

[2] I. Stadler, R. Bahndari, D. Madeiro: Implementation of small grid connected decentralized power generators using renewable energies

The main changes for photovoltaic generators are:

1. Feed-in tariffs should be reduced dramatically, they should be:
    - 19.5 €ct/kWh for installations up to 10 kW_p; (this would be significantly less than electricity end users pay for electricity; less than net metering)
    - 16.5 €ct/kWh for installations up to 1 MW_p, and
    - 13.5 €ct/kWh for installations up to 10 MW_p
2. Starting from May 1st every month feed-in tariffs will be lowered by 0,15 €ct/kWh.
3. With the euphemism “market integration” is meant that for installations up to 10 kW_p only 85 % of the electricity generated is paid for. For larger installations the fraction paid for is 90 %. The rest should be consumed by the plant owner itself or should be sold on which market ever.
4. Changes in the act should become possible without parliament decisions.

All changes are significant but for system operation, especially for the future electricity supply system design and its management number 3.) is of importance and should be discussed here.

In the existing renewable energy source act there is a rule that sets special feed-in tariffs for installation owners who consume at least a part of the electricity produced by themselves. With the new suggestion of just paying less this rule more or less becomes valid for everybody.

The intention of the rule cannot be criticized. When using a part of the electricity generated directly at the place of generation the grid will be unburdened and more installations theoretically could be placed at the grid.

But with respect of the overall electricity supply system operation it is the completely wrong way! The energy balance of generation and consumption must be considered country wide and not “building wide”. Efforts of consuming electricity at the site of production can counteract the situation that this electricity is absolutely required for the energy balance elsewhere. And see section 5, first part, when installations are made with an adequate energy planning there are no grid restrictions.

APPENDIX A: Transmission Code aspects dedicated to renewable power generation

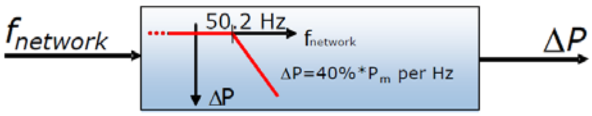
Renewable energy systems are capable to contribute to reactive power management and therefore they can contribute to voltage and system stability. In May 2009 the German government released the „Act for the provision of anxiliary services by wind turbines" (Verordnung zu Systemdienstleistungen durch Windenergieanlagen).

When feeding to the high voltage grid wind turbines have to fulfill the "TransmissionCode 2007". In the following sections the regulations with regard to the high voltage system are described in detail.

Active Power Output

Generating units using renewable energy sources must be controllable in terms of active power output according to the requirements of the TSOs with a view to counteracting a risk to or disturbance of the system balance. It must then be possible to reduce the power output under any operating condition and from any working point to a maximum power value (target value) defined by the network operator. This target value is given by the network operator at the grid connection node and corresponds to a percentage value related to the network connection capacity. The reduction of the power output to the signalized value must take place with at least 10 % of the network connection capacity per minute without disconnection of the plant from the network.

All renewables-based generating units must reduce, while in operation, at a frequency of more than 50.2 Hz the instantaneous active power with a gradient of 40 % of the generator's instantaneously available capacity per Hertz, and see illustration A.1.a.



$$\Delta P = 20\, P_m \frac{50.2\,Hz - f_{network}}{50\,Hz} \quad \text{at } 50.2\text{ Hz} < f_{network} < 51.5\text{ Hz}$$

P_m instantaneously available power

ΔP power reduction

$f_{network}$ network frequency

within the range of $47.5\text{ Hz} < f_{network} \leq 50.2\text{ Hz}$ no limitation

at $f_{network} \leq 47.5\text{ Hz}$ and $f_{network} \geq 51.5\text{ Hz}$ disconnection from the grid

Illustration A.1.a: Active power reduction of renewables-based generating units in the case of over-frequency

If the frequency returns to a value of f ≤ 50.05 Hz, the active power output may be increased again as long as the actual frequency does not exceed 50.2 Hz. This control is realized in a decentralized manner (at each individual generator).

Reactive Power Supply

After a few minutes, reactive power supply must equal the target value defined by the network operator. The working point for steady-state reactive power exchange shall be determined in accordance with the need of the grid. The determination shall relate to one of the following three possibilities:

- power factor (cos φ)
- reactive power value (Q in Mvar)
- voltage value (U in kV), where necessary with tolerance band

The determination can be made by means of:

- an agreement on a value or, where possible, on a schedule
- a characteristic dependent on the generating plant's working point
- online target-value specification.

For online target-value specification, the new specifications for the working point of the reactive power exchange shall be realized after one minute.

Behavior at Network Disturbances

Here, the transmission code distinguishes two types of renewable generating units. A type 1 generating unit exists if a synchronous generator is directly connected to the network. A type 2 generating unit exists where this condition is not fulfilled.

In the event of network faults outside the protection range of the generating facility, the latter must not be disconnected from the network. During the fault duration, a short circuit current shall be injected into the network. Depending on the plant technology used, such as asynchronous generators or frequency converters, the short-circuit current contribution shall be agreed with the network operator on a case-by-case basis.

If the voltage at the grid connection point decreases and remains at and below a value of 85 % of the reference voltage (380/220/110 kV, e.g. 110 kV x 0.85 = 93.5 kV) and if reactive power is simultaneously consumed at the grid connection point (under-excited operation) the generating facility must be disconnected from the network with a time delay of 0.5 s. The voltage value relates to the largest value of the three line-to-line network voltages. The disconnection must take place at the generator circuit breaker. This function performs the supervision of voltage support.

If the voltage at the low-voltage side of each individual generator transformer decreases and remains at and below a value of 80 % of the lower value of the voltage range (e.g. 690 V x 0.95 x 0.8 = 525 V) one fourth of the generators must disconnect from the network after 1.5 s, after 1.8 s, after 2.1 s and after 2.4 s, respectively. The voltage value relates to the largest value of the three line-to-line network voltages. A different time graduation can be agreed on a case-by-case basis.

If the voltage at the low-voltage side of each individual generator transformer rises and remains at and above a value of 120 % of the upper value of the voltage range (e.g. 690 V x 1.05 x 1.2 = 870 V) the generator concerned must disconnect from the network with a time delay of 100 ms. The voltage value relates to the lowest value of the three line-to-line network voltages.

The reset ratio of the measuring equipment for the under-voltage and over-voltage system automatics must be $\leq$ 1.02 or $\geq$ 0.98, respectively.

At frequencies of between 47.5 Hz and 51.5 Hz, automatic disconnection from the network due to the frequency deviation from 50 Hz is not admissible. If the frequency falls below 47.5 Hz, automatic disconnection from the network must take place without delay; if the frequency rises above 51.5 Hz, automatic disconnection may be carried out.

After disconnection of the generating facility from the network due to over-frequency, under-frequency, under-voltage, over-voltage or after termination of isolated operation, automatic synchronization of the different generators with the network is only permitted if the voltage at the grid connection point is higher than 105 kV in the 110 kV network, higher than 210 kV in the 220 kV network and higher than 370 kV in the 380 kV network. The voltage value is related to the lowest value of the three line-to-line network voltages. After this disconnection, the increase of the active power supplied to the network of the network operator concerned must not exceed a gradient of maximally 10 % of the network connection capacity per minute.

Three-phase short circuits or symmetrical voltage drops due to disturbances must not lead to instability or to a disconnection of the generating facility from the network above the borderline 1 in illustration A.1.b.

Within the shaded area and above the borderline 2 in illustration A.1.b, the following shall apply:

- All generating facilities shall pass through the fault without being disconnected from the network. If a generating facility, due to the grid connection concept (plant concept, including generators) is not capable of meeting the requirement, it is permissible to shift the borderline by agreement with the network operator concerned while the resynchronization time is simultaneously reduced and a minimum reactive current feed-in during the fault is guaranteed. Reactive current feed-in and resynchronization must be carried out in such a way that the generating facility appropriately meets the respective requirements of the network at the grid connection point.
- Should individual generators become instable when passing through the fault, or the generator protection be activated, a short-time disconnection of the generating facility from the network is permitted by agreement with the network operator concerned. From the beginning of a short-time disconnection, the resynchronization of the generating facility must take place after 2 seconds, at the latest. Active power feed-in must be increased with a gradient of at least 10 % of the nominal generator capacity per second to the original value.

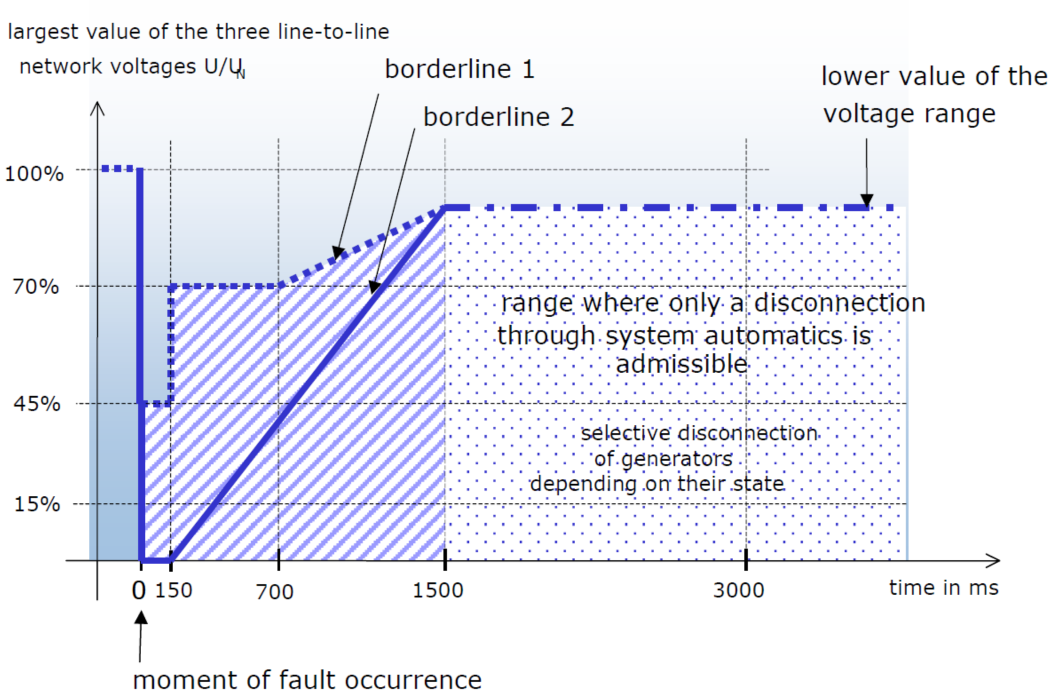


Illustration A.1.b: Limiting curves of voltage at the grid connection point for a generating facility using renewable energy sources of type 2 in the event of a network fault

Below the borderline 2 in illustration A.1.b, a short-time disconnection of the generating facility from the network is always permitted. In exceptional cases and in consultation with the network operator concerned, resynchronization times of more than 2 seconds and an active power increase after fault clearance of less than 10 % of the nominal capacity per second are also possible.

For all generating facilities which are not disconnected from the network during the fault, active power supply must be continued immediately after fault clearance and increased to the original value with a gradient of at least 20 % of the nominal capacity per second.

The generating facilities must support the network voltage during a voltage drop by means of additional reactive current. To this end, voltage control according to illustration A.1.c shall be activated in the event of a voltage drop of more than 10 % of the effective value of the generator voltage. This voltage control must ensure the supply of a reactive current at the low-voltage side of the generator transformer with a contribution of at least 2 % of the rated current per percent of the voltage drop. The facility must be capable of feeding the required reactive current within 20 ms into the network (control response time). If required, it must be possible to supply reactive current of at least 100 % of the rated current.

After return of the voltage to the dead band range, voltage control must be maintained at least over additional 500 ms according to the given characteristic.

In particular within the extra-high voltage grid, continuous voltage control without dead band may be required.

If the distances from the generators of the generating facility to the grid connection point are too long and thus lead to ineffectiveness of voltage control, the network operator shall require that the voltage drop be measured at the grid connection point and that the voltage be controlled there as a function of this measured value.

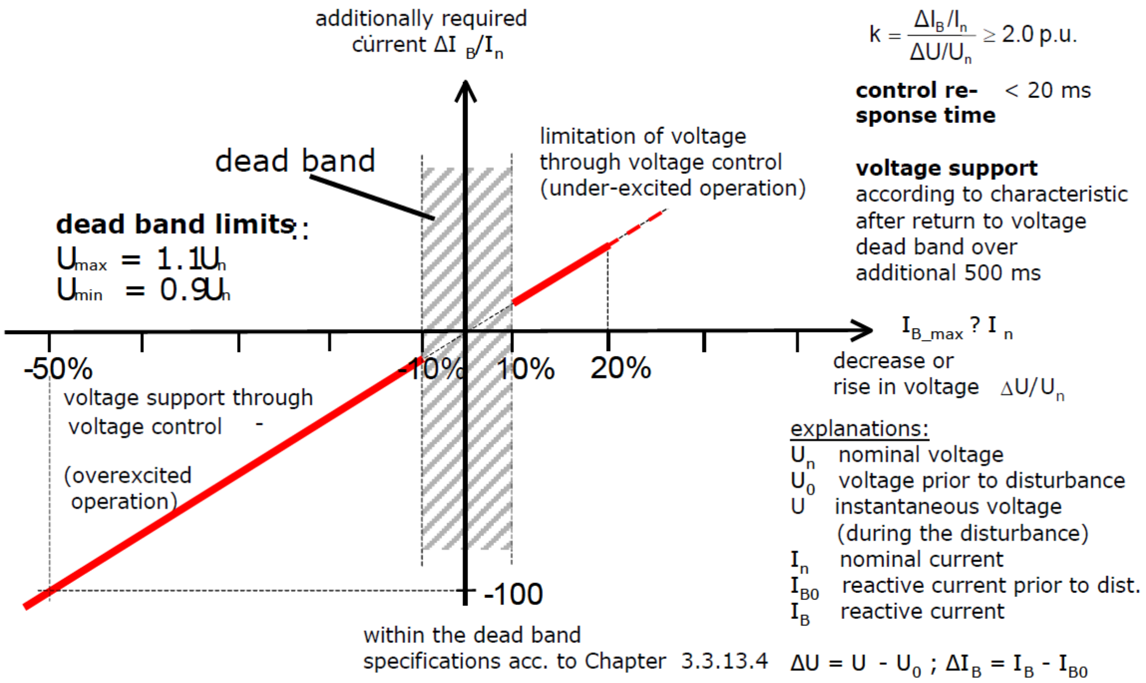


Illustration A.1.c Principle of voltage support in the event of network faults with renewables based generating facilities

Exceptional Rules for Renewables-based Generating Facilities

Generating units using renewable energy sources may be exempted from the requirement to be capable of operation under primary control.

In accordance with the capabilities of conventional generating units to interfere in the event of sudden power imbalances by means of network sectionalizing and islanding, and in order to contribute to network restoration, renewables-based generating facilities shall utilize control concepts which correspond to the latest state of the art.