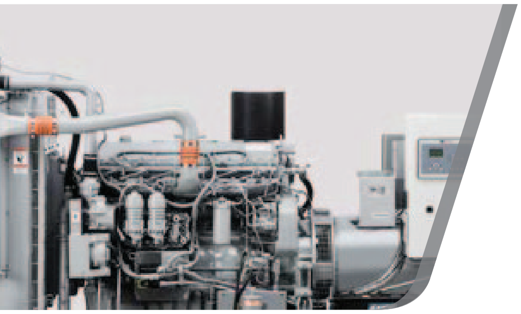
GRID CODE REQUIREMENTS FOR DIESEL AND GAS GENSETS
SOLUTIONS FOR COMPLIANCE WITH NEW GUIDELINES

The top priority in power production is keeping the grid stable. Power production plants feeding electricity into the grid must therefore follow clearly defined guidelines.



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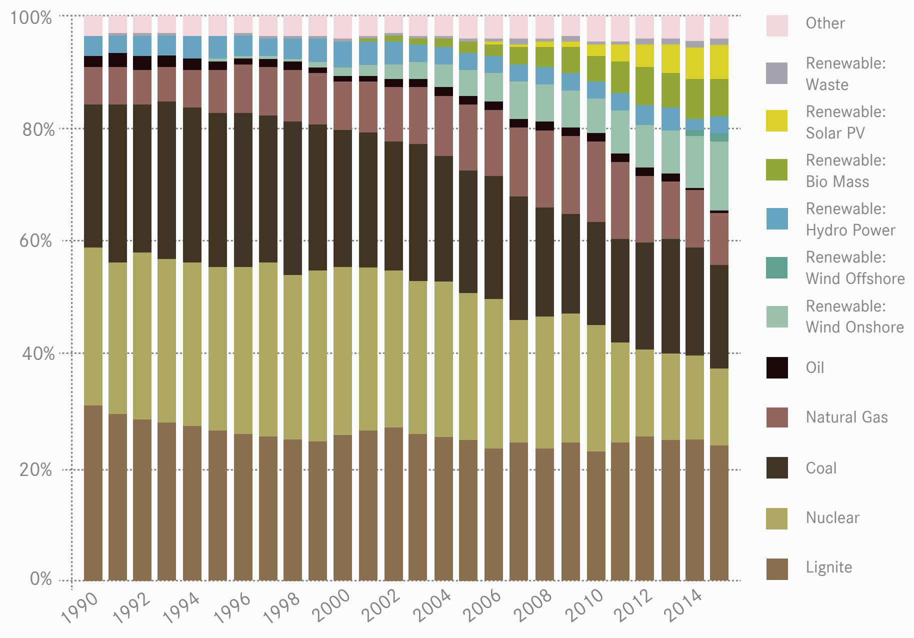
Renewable sources of energy with fluctuating output, such as wind and solar power, are becoming increasingly competitive compared with conventional energy producers. As a result, these sources will be supplying a greater share to the world's power grids. Against this backdrop, the challenge facing operators is to keep the grid stable and secure the supply of utility power. To deal with this, grid operators define standards in the form of so-called "Grid Codes" which all energy producers intending to supply the grid are obliged to follow. MTU Onsite Energy gas cogeneration systems and diesel gensets are playing a perceptibly more significant role in the global energy mix. They form a key component in driving the energy transition being highly efficient and, in marked contrast to renewable sources, available at any time to deliver controlled power precisely when it is needed most. What's more, they already meet existing requirements for generating plants, such as the German BDEW guideline for medium-voltage networks, to supply power grids in normal operation and in case of disruption.

The power sector has been undergoing one of the biggest transformations since its early days. The world is moving from high carbon-footprint energy production centered strongly on fossil fuels such as coal, lignite and oil towards renewables such as solar power, wind power and hydro power. However, this transformation features more than just the rapid increase in the use of renewables: some countries are seeing growth in distributed power production featuring smaller combustion engines to boost the overall efficiency of energy use.

Both changes may be observed strongly in Germany, not simply because investment in renewable energies is becoming a cheaper, more competitive proposition, but primarily because of the German Renewable Energies Act ("EEG") which, in the year 2000, began to promote the growth of renewable energy sources by offering subsidies for this kind of power generation.

CHANGE OF ENERGY PRODUCTION

Gross electrical energy production in Germany from 1990 - 2015[1]



Until 2000, the main renewable energy source was hydro power. By 1996, wind power was making itself felt, and has been increasing steadily since 2000. The balance of import and export of electrical energy was stable up to 2004. Since then, the amount of electrical energy exported by Germany has been growing and, in 2015, reached 50 TWh of a total production of 652 TWh.

Renewable energies constituted 30% of German electrical power generation in 2015. At 13.3%, the largest proportion of renewables is wind, followed by biomass (7.7%) and solar power (5.9%). Hydro power amounted to just 3%. In view of the current "EEG" Renewable Energies Act and the growth in renewables over the last two years, the share of wind power is set to rise strongly.

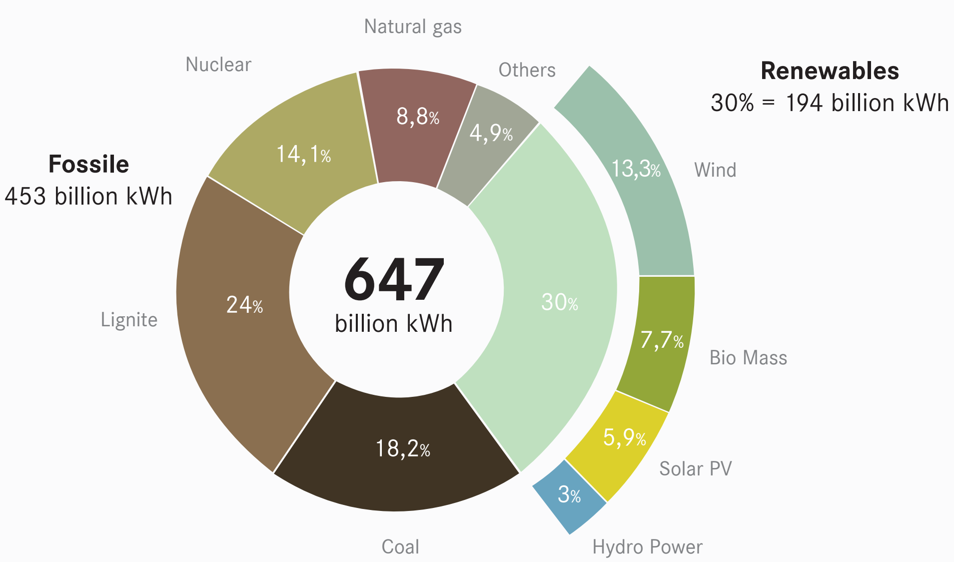
New wind power installations totalled 4.3 GW in 2014 and approx. 3.6 GW in 2015. The best years for solar power are now behind us. From 7-8 GW of additional power in 2010-2012, growth has been a mere 1.9 GW and 1.5 GW in the last two years.

The growth of the renewables is set to continue. Improved competitiveness due to cost reductions will be one reason, but another is political effort to achieve greener power generation. Germany is targeting 35% renewables by 2020. Given the 30% seen in 2015, this goal is capable of being reached even earlier than planned. The subsequent steps are at least 40% by 2030, 55% by 2040 and 80% by 2050. However, Germany is not alone on this journey. In March 2007, the Council of Ministers of the European Union decided to achieve a 20% share of renewables (20% of total energy consumption: power, heating and transportation) by 2020. European directive 2009/28/EC has distributed this European target down to national targets.

Seen historically, big conventional power plants have delivered all system services necessary to ensure the stability of the system at a very high level. In the past, when the share of renewables of grid and distributed power producers was quite low, the main rule specified for these power generators was that, in the event of any malfunction, they had to trip their systems within a very short time (e.g. VDEW, "Generators in the low voltage grid"). But tripping these renewables in response to a grid failure when most generation is being powered by renewables will produce a complete system blackout, as the UCTE network can only absorb a power drop of 3 GW. Therefore, it is necessary for renewable and distributed power producers to deliver system services to the grid in the same manner as the large conventional power plants. Since 2009, this requirement has been added to the German BDEW MV Directive (German medium voltage grid technical directive entitled "Generating Plants Connected to the Medium-Voltage Network", further abbreviated as BDEW Directive). Other countries also already have national directives to keep their grids stable, e.g. CEI 016 in Italy and G59 in the UK. To harmonize local requirements at European level, Network Code Requirements for Generators (NC RfG) has been introduced. NC RfG sets a frame of requirements for the implementation of national directives.

GERMANY'S ELECTRICITY GENERATION MIX 2015

Share of Germany's gross electric power generation - Renewables reach 30%[2]



Data: German Association of Energy and Water (as of December 21, 2015)

GRID CODES

The main purpose of grid codes is to specify the rules for delivery of system services by all power generators, including renewable and decentralized power generation units. The requirements of these grid codes can roughly be broken down into four groups:

- Power quality
  - Harmonics / Interharmonics / Flicker
  - Switching operations
- Static grid support
  - Frequency and active power control
  - Voltage and reactive power control
- Dynamic grid support
- Grid code compliance

POWER QUALITY

With the increase of numerous types of power electronics, it was necessary to specify boundaries to keep grid repercussions of renewable and distributed power within an accept-

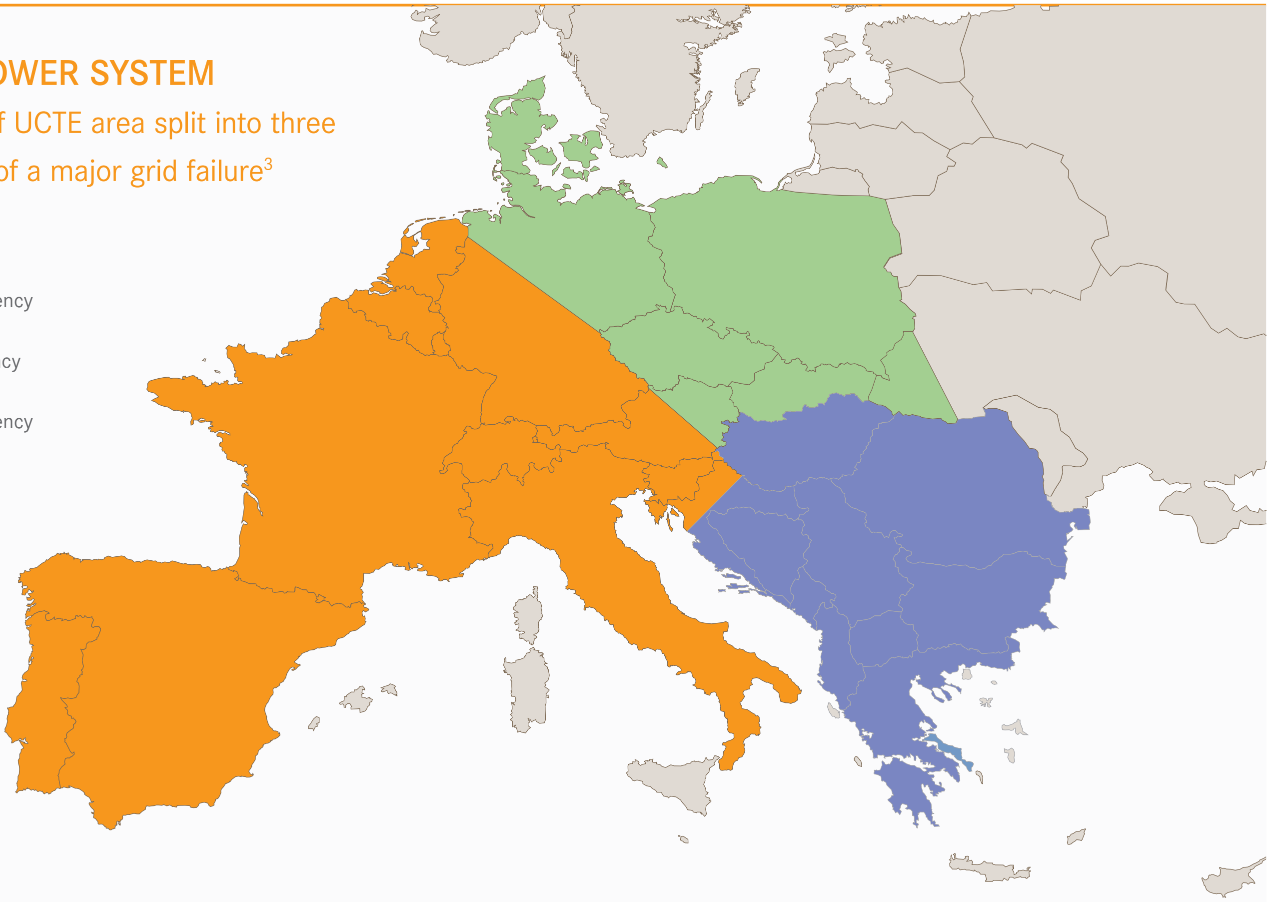
EUROPEAN POWER SYSTEM

Schematic map of UCTE area split into three areas as a result of a major grid failure[3]

Area 1 under-frequency

Area 2 over-frequency

Area 3 under-frequency



able range. Power quality is not a system service. This part of regulation originates mainly from the power electronics of converters of wind turbines and solar parks. The demands of the grid codes include regulations for harmonics, flickers and switching operations. These topics are not critical for gensets as these are typically equipped with a directly coupled synchronous generator. NC RfG does not specify power quality requirements. But these requirements are usually built into the national directives.

STATIC GRID SUPPOPRT

This part describes behavior during normal grid operation for purposes of stabilizing the grid. Key factors for normal grid operation are frequency and voltage stability. Another requirement is reactive power, which has a major impact on voltage stability. When feeding in reactive power, decentralized power generation units have the ability to adjust voltage at the point of common coupling.

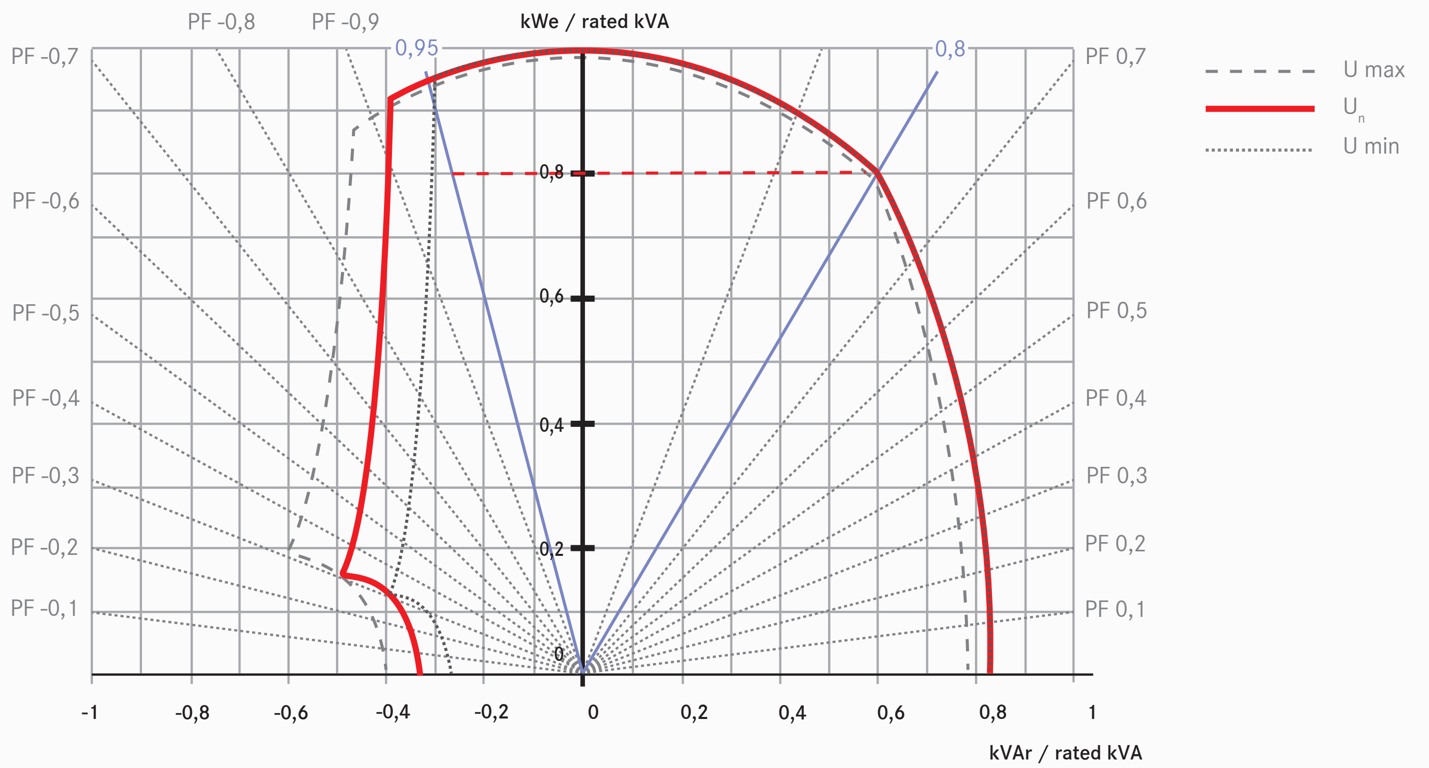
// FREQUENCY AND ACTIVE POWER

In the past, gensets have been allowed to disconnect from the grid in Germany and in many other countries where frequency deviated outside very tight limits (e.g. 49.00Hz and 51.00Hz). This is no problem during normal operation. The UCTE network frequency is adjusted by primary control in a region of +/- 200mHz. The critical issue is maintaining the network during a malfunction scenario. Such a situation occurred in November 2006 when the European power system was divided into three different frequency areas.

At this point, prior to the incident, there was huge production of wind energy in the north of Germany and a power flow of 10 GW from north to south. The split produced one area with too much power production and over-frequency, and two areas with less power production and under-frequency.
In the absence of adjusted frequency requirements for renewable and distributed power producers, a situation as described above would be even more dangerous today and would not be manageable. By virtue of the formerly fixed frequency thresholds, all renewable and distributed power producers in one area would disconnect at the same time. If a huge amount of power generation were to trip out all at once, a power outage in these areas would be the result.

To avoid such a sudden drop, grid code rules have been developed for the distributed power producers. Firstly, the frequency

P-Q DIAGRAM OF A SYNCHRONOUS GENERATOR



ranges have been widened, typically to a range of 47.5 Hz to 51.5 Hz. Secondly, special features have been designed to deal with over-frequency (LFSM-O) and under- frequency (LFSM-U).

General requirements in NC RfG demand different frequency ranges between 47.0 Hz and 51.5 Hz for different areas of Europe (Continental Europe, Nordic, Great Britain, Ireland and Northern Ireland and the Baltics).

Another requirement is the LFSM-O mode. Where a specific frequency threshold (between 50.2Hz and 50.5Hz) has been reached, the power producer has to reduce its actual active power under a droop function to avoid a further increase in frequency over and above the threshold. The droop setting must be adjustable between 2% and 12%. LFSM-U in NC RfG is only required for bigger power modules (type C and D). In this case, the power generating unit has to increase power if the frequency is below a threshold, and if it is technically feasible for the power generating unit to increase power.

// VOLTAGE AND REACTIVE POWER

With the rise of renewable and distributed power generation, the direction of the power flow has changed. Formerly, the power flow went from the transmission network to the distribution network and thence to the consumer. The systems' voltage gradient was specified, and conventional power plants were able to control voltage and reactive power. Nowadays, many conventional power plants are being closed down, and a substantial amount of production takes place within distribution and on the low voltage network. In this case, the voltage gradient will no longer be specified, and a distributed power plant can lift the voltage at its point of common coupling. If there are no rules for controlling the voltage or to feed in reactive power, it could result in unacceptable figures in some parts of the grid.

In the past, conventional power plants were also responsible for delivering reactive power. Nowadays, renewable and distributed power generation has to deliver the reactive power previously supplied by the large power plants which have since been shut down. Reactive power is a very powerful tool for adjusting voltage. If a synchronous machine is in under-excited mode, it decreases voltage at the point of common coupling. If a synchronous machine is over-excited, it is possible to increase voltage at the point of coupling. With the development of intelligent rules regarding voltage and reactive power control, it is also possible to avoid further investment in grids. With these rules, it is even possible to connect more distributed power to a connection point in existing networks without reactive power management. NC RfG does not define the reactive power capability for Type B synchronous power generation modules. In this case, the system operator has the right to specify the capability of a synchronous machine (NC RfG Article 17/1 b).

The BDEW Directive outlines four different methods for controlling reactive power:
1) A fixed active factor cosϕ or
2) An active factor cosϕ (P) or
3) A fixed reactive power in MVar or
4) A reactive power/voltage characteristic Q(U).

In the BDEW Directive, the demand for reactive power capability is currently specified as being in a range between 0.95 under-excited and 0.95 over-excited. However, system operators want to widen this span to between 0.90 under-excited and 0.90 over-excited. In particular, 0.90 under- excited at undervoltage is very challenging and usually implies oversizing of generators, resulting in higher installation costs and lower efficiency.

In the BDEW Directive, the normal voltage operating range for a genset is specified as being between 0.9 U_n and 1.10 U_n. In NC RfG, there is no specification for the voltage operating range of Type B units.

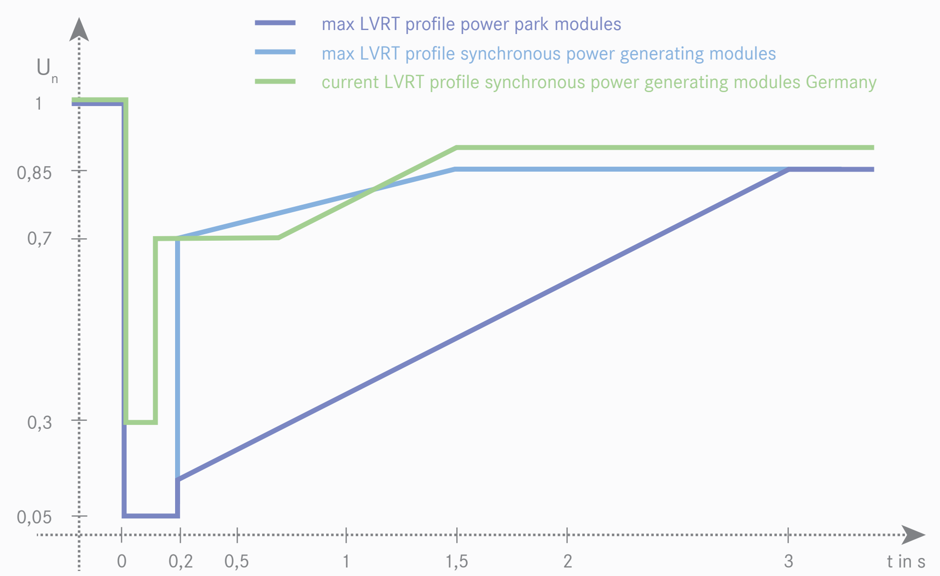
DYNAMIC GRID SUPPORT

The requirement for dynamic grid support is the ability to withstand sudden voltage dips. The gensets must ride through grid failures in a controlled manner and support the network with reactive current to maintain voltage. The dynamic grid support for a voltage dip is called "Low-Voltage Ride-Through" (LVRT).

In most cases, the reasons for such voltage dips are the fault rectification events on the transmission grid. In the case of a short-circuit on the transmission grid, the affected area of the grid will be isolated within a few hundred milliseconds. As long as the short-circuit is connected to the grid, voltage within the transmission and distribution grid drops (falls). In the past, all renewable and distributed power generators tripped and disconnected from the grid when such an incident occurred. With today's energy mix, such action is no longer acceptable because of the reduction in the number of conventional power plants. During a malfunction, the power plants have to feed in reactive power and deliver short-circuit current. Without this short-circuit current, rapid isolation of the malfunction is not feasible; reactive power is needed to trigger the protection systems. Another reason for the necessity of reactive power during malfunctions is to maintain grid voltage in order to avoid disconnection of further power plants. In Germany, the goal is to protect the transmission system and, as a result, the European grid. A potential partial breakdown of the distribution system cannot be entirely prevented.

Dynamic grid support is very challenging for gensets with synchronous generators. In case of a small voltage dip (e.g. down to 70% U_n), the full mechanical power of the engine could be transferred to the grid. The result of the voltage drop is an equivalent increase in current. However, during a major voltage dip, the electrical power can no longer be transmitted to the grid. If voltage drops to 30% U_n, the electrical power will also drop to approx. 30%. During the first moment of failure, the engine will deliver the same torque as before the incident. The reaction time of the engine depends on the gas volume between the throttle valve and the

LVRT CURVES[4,5]



cylinder inlet, and on the responsiveness of the engine controller. Depending on engine size, time spans greater than 100ms are realistic. If the torque is constant and the active power decreases, engine speed will rise. The moment the voltage is recovering, the generator is underexcited, the load angle rises and can reach the transient stability limit for the synchronous machine. In this case, the outcome would be a pole slip which could result in mechanical damage to the synchronous machine.

The situation is more critical, the weaker the electrical connection, the faster the speed increases, the deeper the duration and the longer the malfunction. The most critical situation is a voltage dip down to 0% U_n. In such a scenario, no coupling to the network is left and the speed would increase very quickly.

A common presentation for an LVRT requirement is the visualization of the lower required limit of a voltage-against-time profile of the voltage at the connection point.

NC RfG defines this requirement as non-exhaustive. Each member state may determine its own shape regarding this limit profile in order to complete the requirements. The current German regulation for gensets with synchronous machines is less strict than the NC RfG's basic framework.

For converter technologies, it is easier to ride through sudden voltage dips because they are not directly coupled to the grid and there is no risk of a pole slip. For that reason, in many countries the LVRT curves for converters are deeper and wider than those for synchronous machines. The big advantage of synchronous machines over converters is the deleveraging of a huge amount of reactive current during malfunction. Converters are not able to deliver that much short-circuit current. By contrast with other directives, NC RfG takes this into account. There are different limit curves for both technologies which is also the case with the BDEW Directive. With NC RfG, the separation in FRT requirements between synchronous power generating modules and power park modules will also become standard in other national European regulations.

GRID CODE COMPLIANCE OF MTU SOLUTIONS

Where a grid code is in force, proof of compliance is required by the grid operator. This procedure differs from country to country. Possible requirements of the procedure are: manufacturer declarations, plant owner declarations, manufacturer unit test, plant test, models for static and/or dynamic behavior and studies of static and/or dynamic behavior. It is also possible that only parts of compliance or full compliance must be proven via certificates issued by an authorized certifier.

The proof of compliance to NC RfG requires an operational notification by the power generating facility owner to the relevant grid operator. For Type B and C generating modules, a power generating module document (PGMD) has been issued which includes the proof of compliance. The format of the PGMD and the information to be given therein shall be specified by the relevant system operator. The system operator is allowed to request the following information in the PGMD:

- Evidence of an agreement regarding the protection and control settings
- Itemized proof of compliance
- Detailed technical data
- Equipment certificates issued by an authorized certifier
- Compliance test reports demonstrating steady-state and dynamic performance
- Studies demonstrating steady-state and dynamic performance
- Simulation models (Type C only)

In Germany, under the BDEW Directive, a multi-step approach has been established during recent years. In the first step, the manufacturer of power generating modules has to undergo a certification process. For this reason, a power generating module is measured by an independent measurement institute under Technical Rule 3 from FGW. Based on these measurements, and on a simulation model provided by the manufacturer, an independent certification company verifies that the power generating module complies with the requirements of the BDEW Directive. If this is the case, a unit certificate based on certification rule Technical Rule 8 from FGW12 will be issued.

For every power plant, a second certificate – the plant certificate - is required during the planning stage. On the basis of the unit certificate of the chosen power generation modules and on the data of the additional scope like transformers, medium voltage cables and additional protection devices, a certification company assesses whether the plant is meeting the requirements as a whole. After construction and commissioning, a declaration of conformity has to be provided to the relevant system operator, confirming that the power plant will be operated as defined by the plant certificate. It is quite interesting how the topic of compliance is handled under NC RfG across Europe, especially because of the wide range of Type B power generating modules from 1 to 50 MW. What is economically feasible for a 50 MW power generating module might not be feasible for a 1 MW power generating module.

With certified gas CHP units 0.1 to 2.5 MW and diesel gensets from 0.6 to 3.2 MW as per the BDEW Directive, MTU Onsite Energy has demonstrated that the company is able to supply products that comply with the new requirements. MTU, as one of the leading manufacturers, played an active part in the process of developing the German grid code. With this knowledge, MTU will also be able to assist customers in other European countries in fulfilling the requirements of their national grid codes based on NC RfG.

FUTURE AND OUTLOOK

Renewable, albeit fluctuating energy sources such as wind and solar are becoming more and more competitive when compared to conventional power producers. This is set to result in such energy sources penetrating grids more strongly, worldwide. As a result, all grids that are penetrated by a higher share of renewable energies will have to continue developing and will have to apply regulations to keep the system stable and ensure security of supply at a high level. These new regulations can already be found in several countries. The need for action has also been recognized by the European Union. The European regulation known as NC RfG (Network Code Requirements for Generators) was published in the Official Journal of the European Communities on April 27, 2016. This regulation specifies not only rules for renewable energies, but also for other kinds of power generation such as combined heat and power (CHP) and diesel genset applications using reciprocating engines.

Unfortunately, the European regulation NC RfG only specifies principles for new regulations. However, it is necessary for all unexhausted issues to be specified in detail at national level. This will result in national regulations which will differ from country to country. Therefore, manufacturers of gensets using reciprocating engines will have to keep careful track of these national processes as they progress, in order to be able to adapt their products to the changing requirements. Of special interest will be the specified way of demonstrating compliance with national regulations. In Germany, there is a quite complex – but established – certification process: firstly, the genset is measured by an independent measurement company and then, based on these measurements, an independent certification company verifies compliance. If similar procedures end up being established in other European countries, the effort of providing compliant products to different national regulations will increase.

For the further development of solutions based on reciprocating engines, grid code compliance will be as important a development target as increasing efficiency and meeting emission requirements.
But it is definitely worth the effort! Gensets using reciprocating engines are a key success factor in moving our power infrastructure system towards being a system with lower CO2 emissions but continuing to offer high-reliability power supplies. The solutions offer inertia to the grid, provide short-circuits, are flexible and controllable, boost efficiency in the use of heat and power and also harmonize with upcoming new technologies like power-to-heat and power- to-gas.

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