Nidec Power

TECHNICAL NOTE

TN10

DESIGN CALCULATIONS FOR SIZING A COMPATIBLE ALTERNATOR GRID CODE

The challenges associated with energy transition, especially the development of decentralised production systems, have caused a major upheaval in the energy distribution sector. Against a background of volatile conditions for the offer associated with renewable energies (wind, solar), the grid code rules that define the conditions a producer must adhere to in order to connect to the national grid have changed.

A new step has been taken with the adoption of (EU) regulation 2016/631 by the European Commission. Applicable from April 2019, this regulation has been transcribed into law by each member country in order that it can be adapted and supplemented to meet the specific requirements of each country.

NIDEC POWER'S POSITION

As a supplier of alternators and automatic regulation systems, Nidec Power is able to provide its customers with the expertise they need to succeed with their projects.
Nidec Power's expertise extends to more than its products. Integration and certification of the generation installation are the responsibility of the owner, the genset builder or similar.

Nidec Power is responsible for complying with the characteristics in the technical data sheet as per the tolerances corresponding to the applicable standards.

THE MAIN REQUIREMENTS IN THE GRID CODES

Under European regulations, the applicable requirements are split into 4 types. These types depend on the installation power rating and the voltage at the connection point.

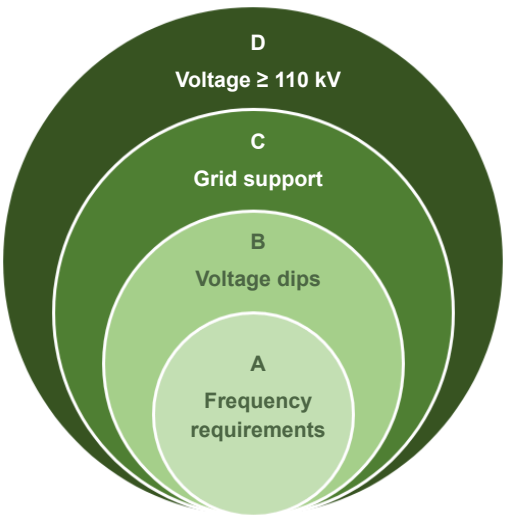
The European code RfG (Requirements for Generators) proposes these categories for continental Europe:

Type A	≥ 800 W
Type B	≥ 1 MW
Type C	≥ 50 MW
Type D	≥ 75 MW or Voltage ≥ 110 kV

These thresholds vary from one country to another, in the sense that they may be more restrictive. The codes are also likely to change over time, even if the European code has not been updated.

The requirements are similar to Russian dolls in the sense that, apart from a few exceptions, they are applied cumulatively.

To make this document easier to read, we will focus on the requirements that are directly relevant to Nidec Power's business.

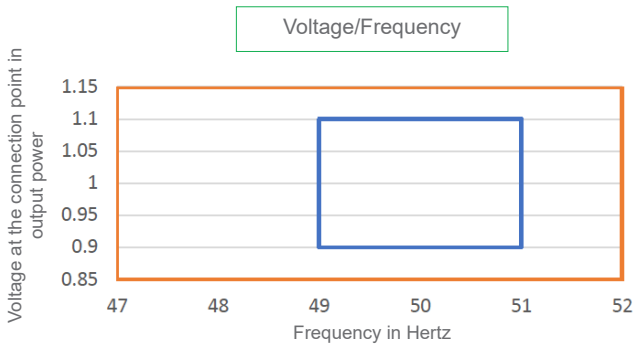


REQUIREMENTS IN STATIC STATE

Withstand to frequency and voltage variations:

From type A for frequency.

In standard continuous operation, the frequency can vary by ±2% and voltage by ±10%, but, depending on the country, the installation may need to stay connected with greater variations: +4%/-6% frequency and ±15% voltage as in the UK and Ireland (ENA Engineering Recommendation G99).

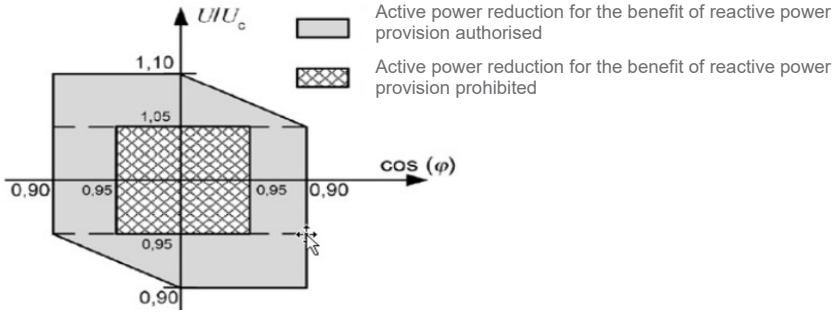


Reactive power absorption/Short-circuit ratio (Scr):

On the grid, the voltage is the image of the balance between consumption and production of reactive power (kVAr), the frequency is itself the image of the balance between consumption and production of active power (kW).

For our synchronous machines, the most dangerous thing, in terms of stability, is to absorb reactive power. This involves under-excited power factor operation (“leading” according to active sign convention), in other words on the left-hand part of the PQ diagram illustrated in our datasheets.

Despite the assertion that too much reactive power on the grid causes high voltage, some codes insist that it is possible to operate with leading power factor in undervoltage mode.



Reference: Summary of VDE 4110 slide 9

This requirement can take the form of an imposed Scr, tan(ϕ), an amount of power in kVAr or even a clearly-expressed leading power factor.

Rate of change of frequency:

This is known as the RoCoF, and concerns the capacity of an installation to follow the frequency variation of the grid. This capacity therefore essentially depends on the total inertia of the transmission. Alternators can therefore make a significant contribution to this capacity.

Our customers’ specifications may therefore insist on a low inertia limit to ensure the alternator’s capacity to change its speed of rotation to that of the RoCoF.

For information, the RoCoF can change considerably depending on the applied Grid code and be as high as 2.5 Hz/s according to CENELEC TS 50549 -1/-2.

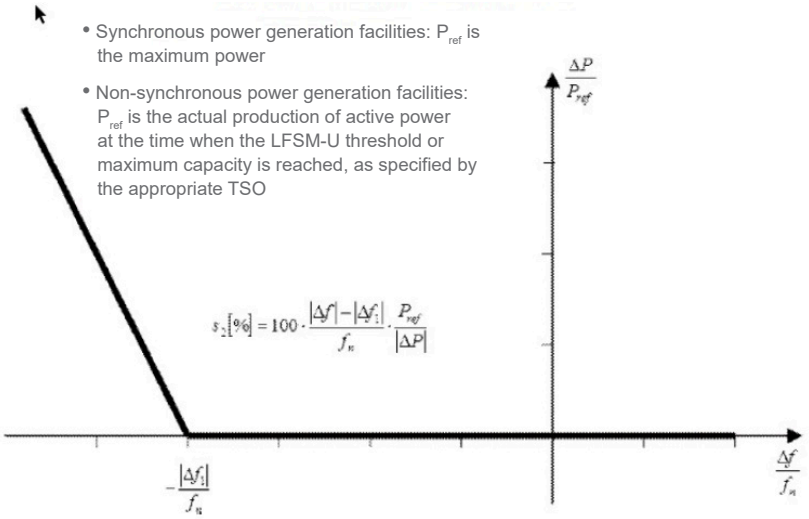
Active power support for the grid:

From type C upwards.

With the frequency on the grid being the image of the balance between production and consumption of active power, the RfG code requires the grid to be supported if there is underfrequency. In other words, producers are asked to increase the active power if there is underfrequency in order to increase the production part of the balance.

In the RfG code this operating mode corresponds to LFSM-U mode (Limited Frequency Sensitive Mode - Underfrequency).

Active power response capacity to frequency variations in power generation facilities in LFSM-U mode



• REQUIREMENTS IN DYNAMIC STATE (LVRT AND OVRT)

From type B upwards.

Concept of a connection point:

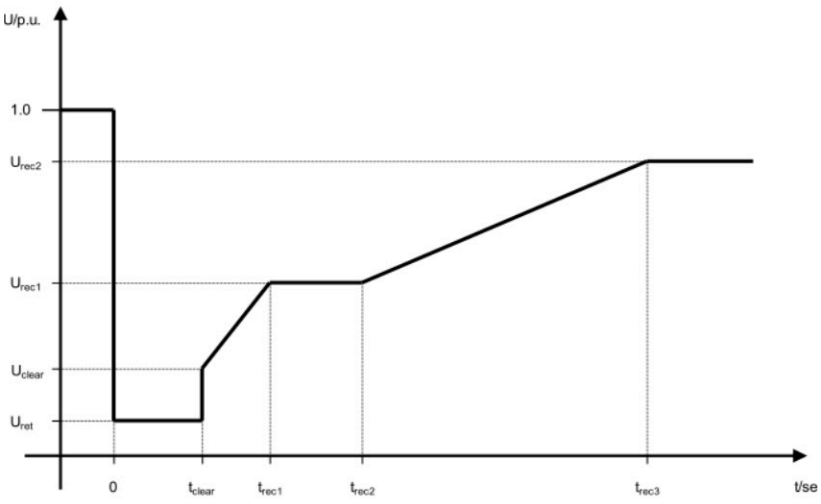
According to the connection convention governing operation of the power generation facility, the connection point is more or less close to our alternator. This connection point can even be located downstream of a transformer which can itself contain a tap changer. This is used to adjust the transformation ratio between the primary and the secondary.

The voltage dips and overvoltages below are defined at the connection point. So these can be taken into account during sizing, the topology of the final installation and the connection convention need to be known, and it is up to the facility owner (power plant operator) to ensure overall stability.

Voltage dips:

The theoretical voltage dip is defined as below in the European regulations, in the knowledge that the minimum residual magnetism can go as low as 0% on the highest-power installations (Type D in the RfG) and that this type of profile can apply in three-phase, but also on a two-phase or even single-phase fault.

Illustration of an LVRT





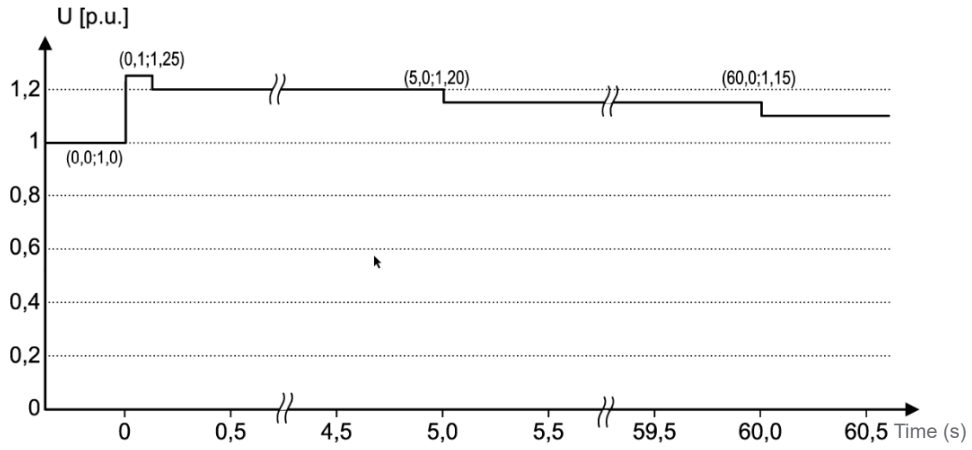
Reinforced lacing

On machines where the stator is wound with flat copper wire, Nidec Power requires the winding coil head to be reinforced with the use of lacing.

Transient overvoltage:

This is the counterpart of the voltage dip. For an undefined length of time, the mains voltage increases suddenly. The equipment should therefore stay connected for a minimum period of time.

The physical phenomenon behind this constraint is sudden disconnection of a load. As the grid can be capacitive, reactive energy is sent and the voltage increases.



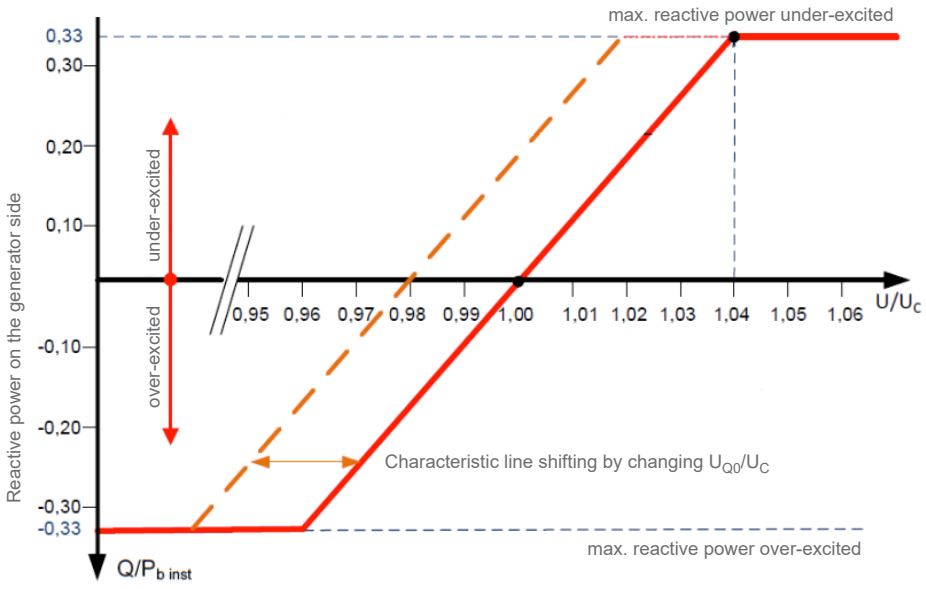
Extract from EN 50549

REGULATION MODES

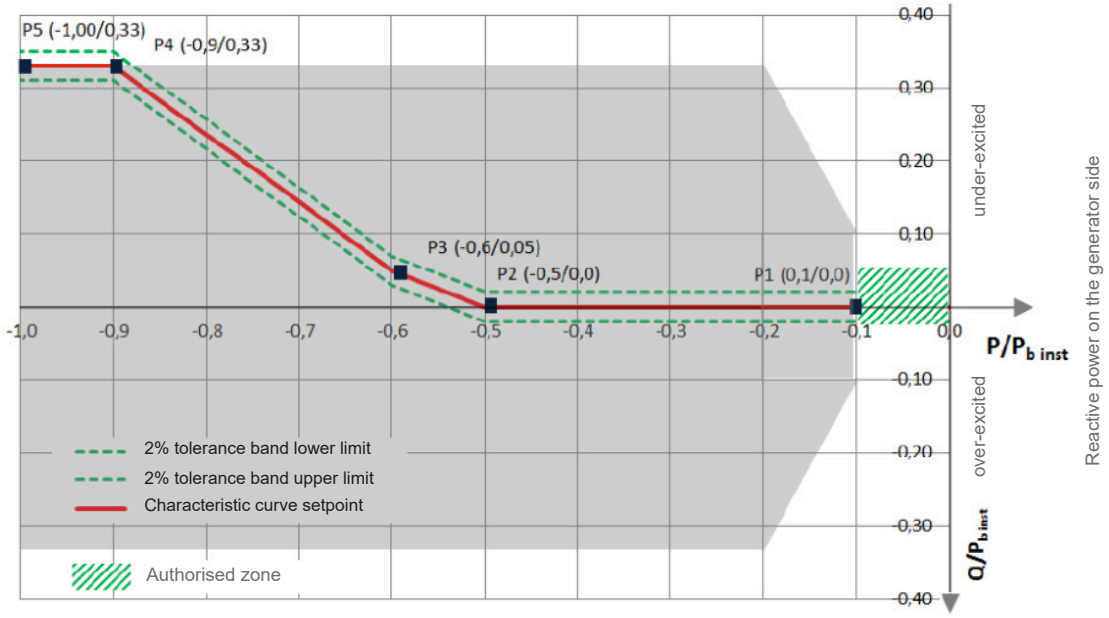
The new digital regulations platforms D550 and D700 offer a Grid Code functionality, making them compatible with the standards of numerous countries rules for connecting production plants to the grid. This section lists all the functions that can be used to ensure energy is generated in compliance with the standards while guaranteeing the integrity of the different components of the power plant.

• REACTIVE POWER REGULATION FUNCTIONS

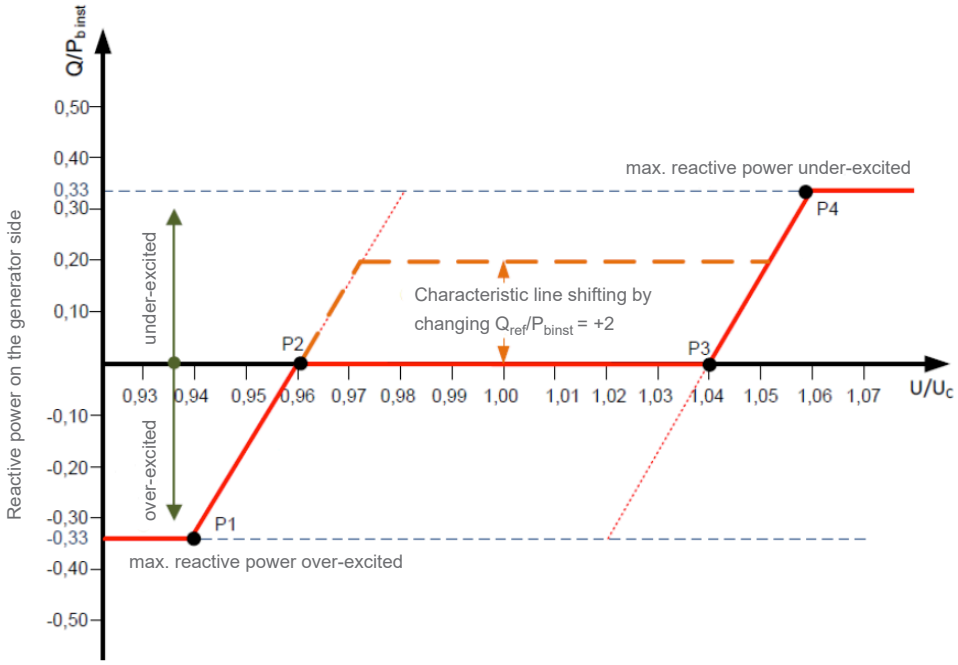
Supply or absorption of reactive power Q(U) according to the voltage at the measurement point for the electrical values: this can support the grid to maintain the setpoint value of the voltage at the measuring point.



Configurable curve that defines the reactive power to be regulated according to the active power Q(P): used to adjust the regulated power factor when the active power delivered by the primary energy source drops below its nominal value.



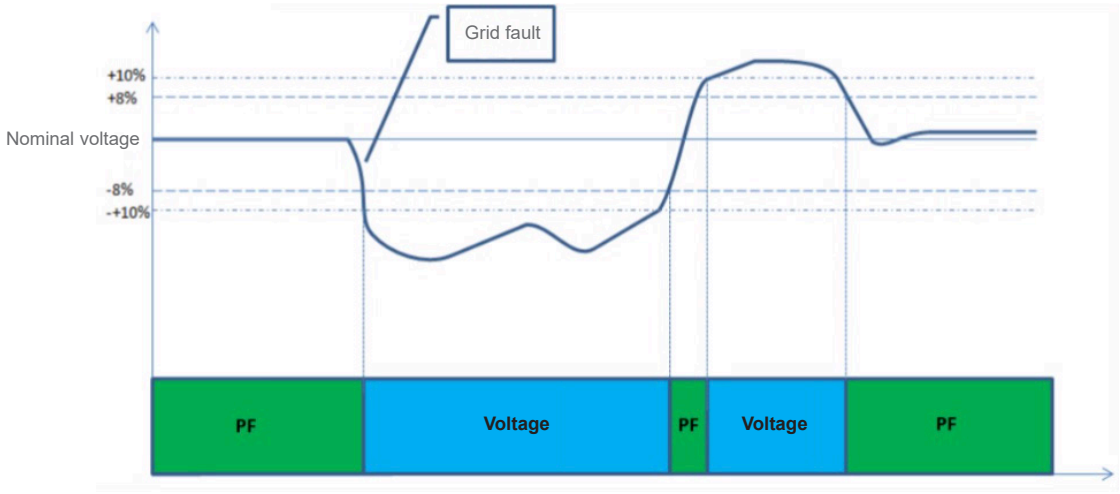
Configurable regulation of reactive power Q(U) at the measurement point for the electrical values with limitation according to the measured voltage: used to set a fixed reactive power so that the voltage does not deviate too much from its nominal value. Otherwise, the production plant supports the grid to limit changes in voltage.



Power factor regulation: used to maintain a constant power factor at the measurement point for the electrical values.

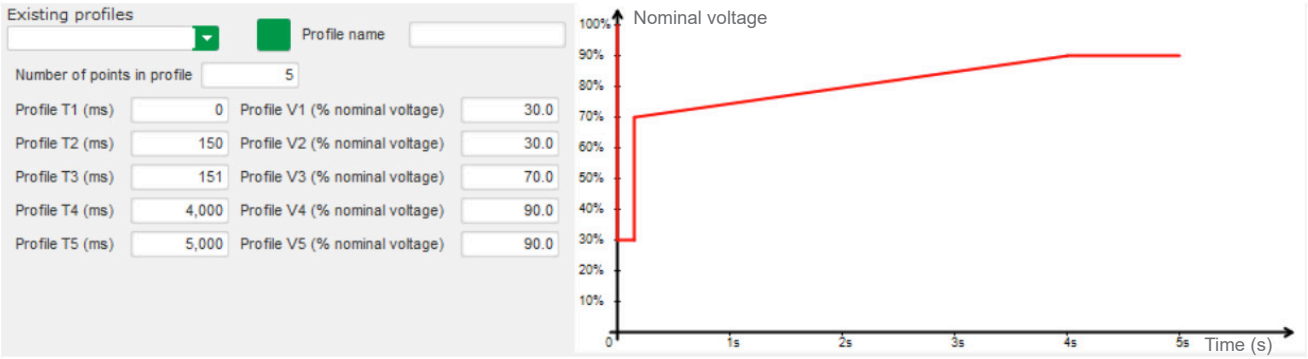
CHANGING THE REGULATION MODE

This configurable function allows switching between power factor (or kVAr) regulation and voltage regulation when the voltage at the measurement point falls or rises above a certain percentage of its nominal value.
A hysteresis is present in order to prevent incessant switching when the voltage is close to the trip threshold. In addition, switching during overvoltages can be activated or not according to user requirements.



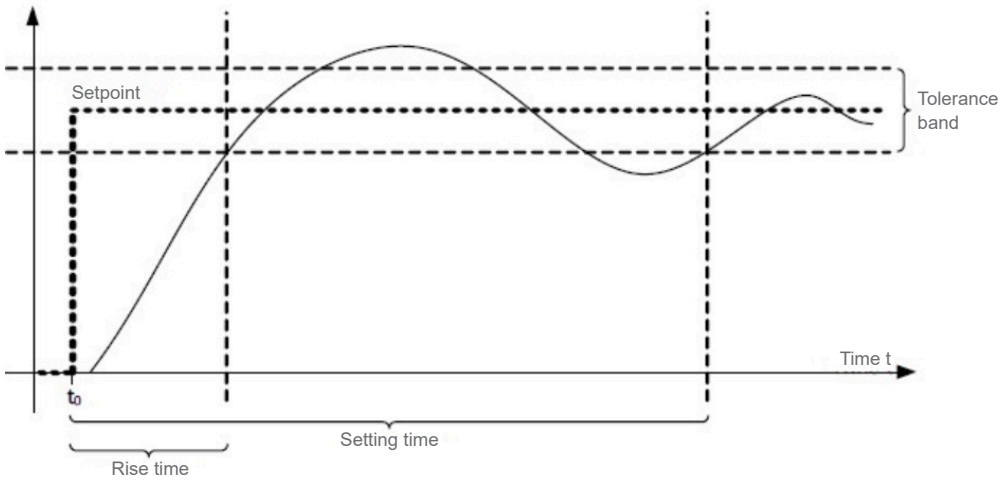
GRID CODE PROFILES

Used to define, using five configurable coordinate points, the voltage profiles to be considered during Grid Code events on the grid. Three profiles should be defined for transient overvoltages, balanced undervoltages and unbalanced undervoltages.



ADJUSTABLE SETPOINT VARIATION TIME

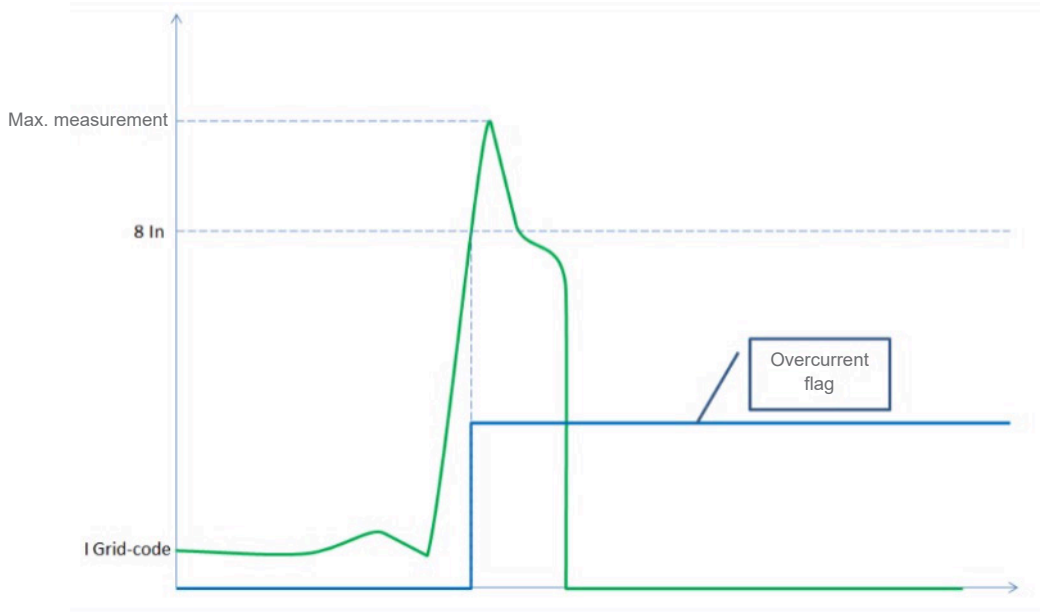
This function can be used to adjust the setpoint modification time when changes have been requested by the user or the control body. The setpoint change follows a first-order law, thus avoiding the strong transients that occur after sudden step changes.



In addition, the AVR offers other monitoring functions that can be used to guarantee the integrity of the equipment during operation. In particular they can replace the installation of additional equipment that increases the cost and complexity of the installation.

• MONITORING THE MAXIMUM STATOR CURRENT

Informs the user if a maximum configurable threshold is exceeded in order to ensure the integrity of the alternator.



• MONITORING THE ROTOR ANGLE

This configurable function is used to measure the angle between the rotor and stator and its distance from a critical angle where the risk of a pole slipping becomes extremely likely.

CERTIFICATION

According to the European code RfG, equipment must obtain a certificate of conformity from an approved certifying body. This certificate of conformity can include models verified on the basis of a series of tests.

The RfG code also mentions the technical documentation for the power plant that the owner of a power generation facility should send to the appropriate system operator for type B and C plants. The purpose of this documentation is to demonstrate that the installation conforms to the regulations applicable to this facility.

Organisations such as the TÜV or DNV GL can be asked by facility owners to certify their installation. This is especially the case in Germany.

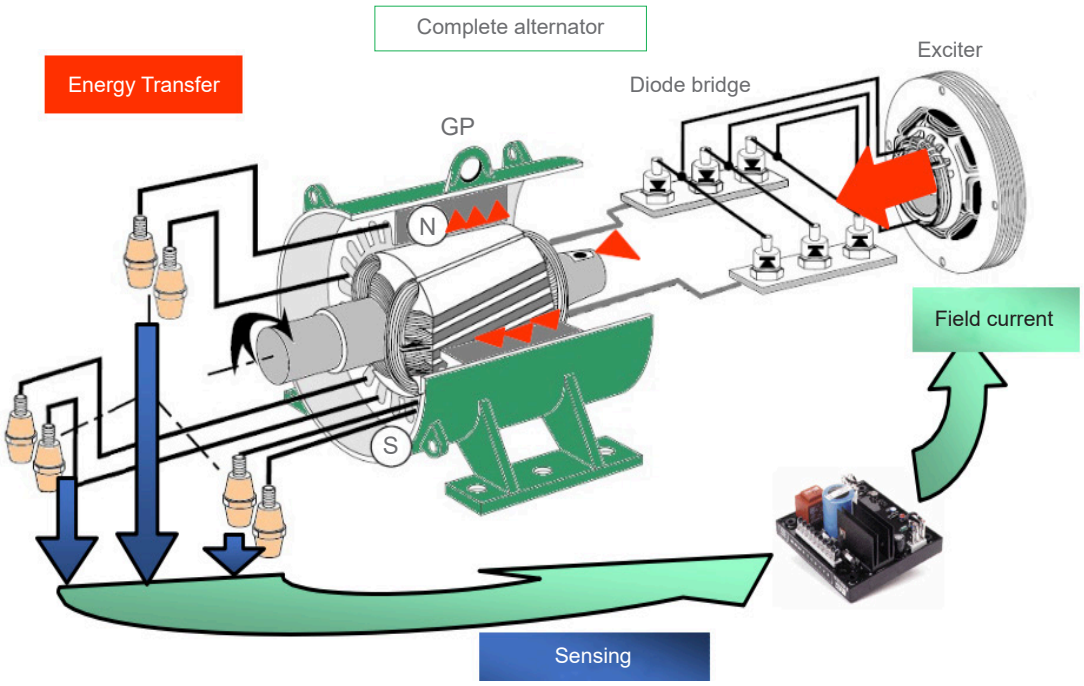
MODELLING

• OVERVIEW OF THE ALTERNATOR

A synchronous machine is defined as being an alternating current machine in which the frequency of the generated voltages and the speed of the machine are in a constant ratio (Def. IEV 411-31-08). We talk about an alternator when energy conversion results in capture of electricity.

These machines can have smooth or salient poles but it should be noted that at Nidec Power, production is primarily focused on designing synchronous generators with salient poles and wound rotor, consisting of a notched stator and a rotor with several poles.
Depending on market requirements, Nidec Power is also able to design alternators with permanent magnets. The power range is between 10 kW and 25 MW for a three-phase voltage range between 380 V and 15 kV.

Designing alternators involves sizing the machine's geometric parameters. The machine dimensions are the subject of theoretical studies to ensure it can withstand operational stress as per the specification. Thermal stress is studied to ensure the alternator works at optimum efficiency and that the equipment is safe.



• EXCITATION MODES

The alternator comprises two combined generators: a main generator (stator/rotor) and an exciter generator (exciter + diode bridge). An AVR (Automatic Voltage Regulator) can be added to this. To excite the machine, the idea is to draw sufficient energy from the machine output terminals to self-prime the machine. There are several different excitation modes for this:

- AREP + PMI: here, two auxiliary windings on the main machine stator provide the exciter field power supply energy (Nidec Power standard excitation system). The magnets inserted in the exciter field supply the regulation system with power during the alternator starting phase.

- PMG: here, the exciter field power supply energy is provided by a permanent magnet generator (PMG).

• ALTERNATOR MODEL

The basic machine model most commonly used to study the characteristics of the synchronous machine with wound rotor is the Park model resulting from changing the three-phase code abc to the two-phase code dq, whose values are constant over time.

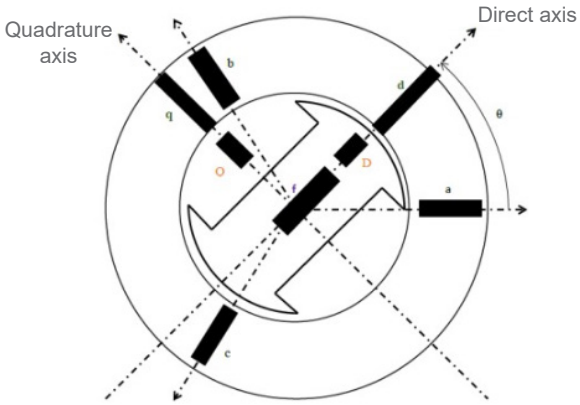
Limited by certain assumptions such as linearity of the magnetic circuit, this model is improved by taking saturation into account correctly thanks to calculation tools using finite elements and theoretical analytical models validated by bench tests.

A data set containing different reactance values and time constants is proposed for every operating mode (permanent, transient and sub-transient).

The model should be adapted to each machine use case.

Note that the majority of professional simulation programs require different data sets on the same interface.

Illustration of DQ model



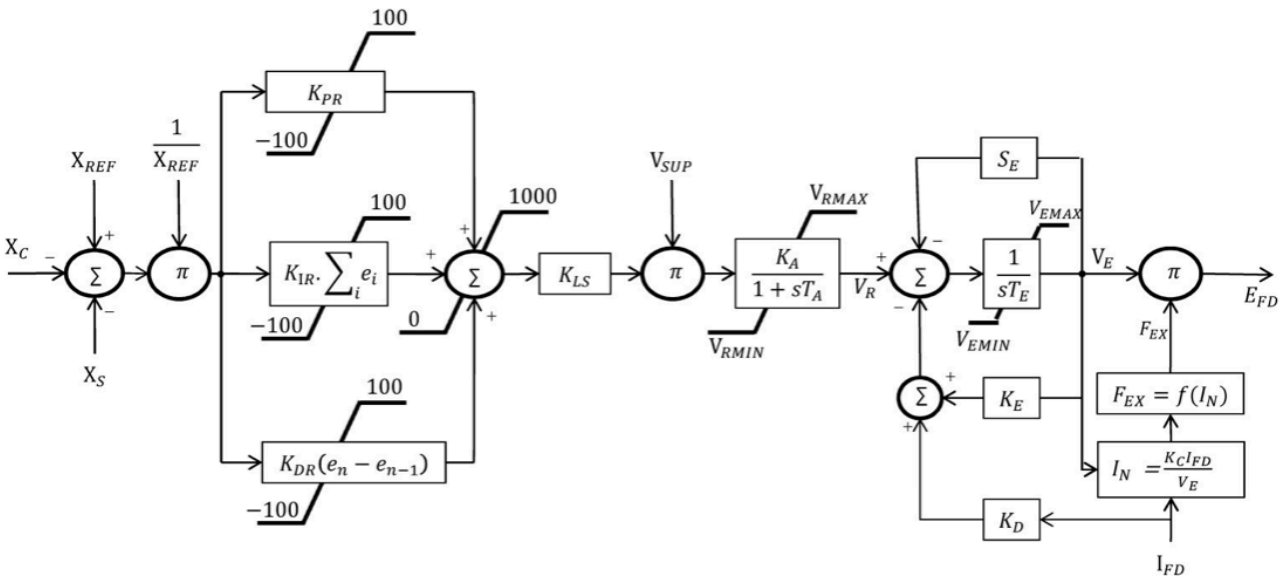
GRID CODE MODEL

This is intended to model the “Exciter generator + Diode bridge + Main generator” assembly in order to run simulations in accordance with the Grid Code regulations and standards. As a general rule, the Grid Code specifies the behaviour required of a generator connected to the grid during system disturbances. Compliance to Grid Code requirements involves complying with a number of conditions on voltage regulation, frequency ranges, power factor limits, etc. To do this, advanced studies are conducted on alternator behaviour during transients, especially short-circuits and/or voltage dips on the grid.

So that we can model how our alternator will fit into the customer’s installation, Nidec Power provides the following documents on request when creating the order (see “Generate report” if you are the model owner):

- Electrical characteristics (reactance, time constants, etc)
- No-load curve
- IEEE exciter model (AC8B according to IEEE421)
- Model of auxiliary windings (AREP)
- AVR operating modes and settings

Example of D600 regulation diagram



DESIGN ADVICES

• REMINDERS

Grid regulations (grid codes) are not alternator standards, i.e. they are not intended to describe how the alternator and AVR shall be built, but the guidelines of the electric utilities must be followed to gain access to the market, our customer has to translate his requirements into technical specifications. All in all, it's the production facility that will be defined as compliant.

• WHAT SHOULD WE ASK THE CUSTOMER?

The information needed in addition to that for a conventional offer is:

- The voltage range
- The frequency range
- The short-circuit ratio (written as Scr)
- The operating power factors in under-excited and over-excited modes (leading and lagging as per the convention for generators)
- The voltage to comply with for each power factor (eg: Un-5% at pf 0.95 under-excited)
- The characteristics of the voltage templates (voltage dips - LVRT, overvoltage - HVRT)
  - Minimum voltage
  - Maximum voltage
  - Duration of time slots

The purpose here is to be able to alert on a potential risk that Leroy Somer would detect in relation to his experience on the subject.

For information:

- Ask for the Grid Code applied (in the form of a standard or regulation) and provision of the documents (or extracts) if Nidec Power does not have a copy
- Ask whether or not a transformer with an on-load tap changer is present

For qualification tests:

When qualification tests are planned and the genset uses an AVR of Leroy-Somer™ (D550 or D700 in this case), the R&D department needs to know certain details regarding the use of the genset.

The document containing all the questions to be asked to the customer on this subject is available on the Nidec Power intranet.

• WHAT SHOULD BE DONE IF INFORMATION IS MISSING?

If information is missing, Nidec Power will determine the size on the basis of the following characteristics:

- Temperature rise class F
- Voltage range +/-10%
- Frequency range +/-5%
- Minimum short-circuit ratio 0.4
- Leading power factor at 0.95 for Un -10%
- If Nidec Power is the supplier, type AVR D550 or D700 is used as standard - unless otherwise specified - depending on the alternator power output.

However, Nidec Power guarantees that its alternators can withstand 100 sudden short-circuits. For dynamic requirements, Nidec Power cannot position itself.

In both cases, it is the responsibility of the facility owner (power plant operator) to validate the facility's compliance with current regulations.

The blank questionnaire to be completed so that the R&D department can design the synchronous alternator which is attached to this document as well as examples for the German, British and French grid codes.

In the absence of information, the previous clause is also presented in the same form in the Annex.

APPENDIX A: ALTERNATOR DESIGN QUESTIONNAIRE

Questionnaire for designing a generator connected to the grid		
Country of installation*		
Grid code directive to be applied*		
Type following RfG code EU 2016/631*		*A, B, C or D*
Grid operator		
If Leroy-Somer™'s AVR isn't used, please indicate the manufacturer and type of AVR		
Apparent power*		kVA
Temperature class (IEC)*		
Rated voltage*		V
Voltage range*		*± x%*
Rated frequency*		Hz
Frequency range*		*± x%*
Rated lagging power factor*		
Short circuit ratio**		
Leading power factor**		
Voltage to be applied at leading power factor**		*Un ± x%*
Low Voltage Ride Through		
Value and duration of each stage		
High Voltage Ride Through		
Value and duration of each stage		
Rated voltage at connection point of installation		V
Transformer with tap changer on load		*Yes/No*

** : required*
*** : short circuit ration OR leading power factor to indicate*

The values provided are only indicative and do not replace the customer's specifications, which must take into account its own gridcode constraints.

APPENDIX B: DESIGN WITHOUT CUSTOMER INFORMATION QUESTIONNAIRE

Questionnaire for designing a generator connected to the grid		
Country of installation*		
Grid code directive to be applied*		
Type following RfG code EU 2016/631*		*A, B, C or D*
Grid operator		
If Leroy-Somer™'s AVR isn't used, please indicate the manufacturer and type of AVR		
Apparent power*		kVA
Temperature class (IEC)*	**F**	
Rated voltage*		V
Voltage range*	**±10%**	*± x%*
Rated frequency*		Hz
Frequency range*	**±5%**	*± x%*
Rated lagging power factor*		
Short circuit ratio**	**≥ 0.4**	
Leading power factor**	**0.95**	
Voltage to be applied at leading power factor**	**-5%**	*Un ± x%*
Low Voltage Ride Through		
Value and duration of each stage		
High Voltage Ride Through		
Value and duration of each stage		
Rated voltage at connection point of installation		V
Transformer with tap changer on load		*Yes/No*

** : required*
*** : short circuit ration OR leading power factor to indicate*

The values provided are only indicative and do not replace the customer's specifications, which must take into account its own gridcode constraints.

APPENDIX C: DESIGN QUESTIONNAIRE FOR GERMANY VDE 4105: 2018-11

Questionnaire for designing a generator connected to the grid		
Country of installation*		
Grid code directive to be applied*		
Type following RfG code EU 2016/631*		*A, B, C or D*
Grid operator		
If Leroy-Somer™'s AVR isn't used, please indicate the manufacturer and type of AVR		
Apparent power*	**Active power sum <135kW**	kVA
Temperature class (IEC)*	**Sizing for multiple faults following DIN EN 60034-1**	
Rated voltage*		V
Voltage range*	**±10%**	*± x%*
Rated frequency*	**50**	Hz
Frequency range*	**±2%**	*± x%*
Rated lagging power factor*		
Short circuit ratio**		
Leading power factor**	**0.95 @U_N -5%**	
Voltage to be applied at leading power factor**	**-5% or +10%**	*Un ± x%*
Low Voltage Ride Through	0.3 / 0-150ms 0.7 / 150-700ms 0.85 / 1500-5000ms (linear extrapolation between 700 and 1500ms)	
Value and duration of each stage		
High Voltage Ride Through	1.25 / 0-150ms 1.2 / 150-5000ms	
Value and duration of each stage		
Rated voltage at connection point of installation	Low-voltage network <1kV (typically 400V)	V
Transformer with tap changer on load		*Yes/No*

** : required*
*** : short circuit ration OR leading power factor to indicate*

Type 1 generating units with a maximum total active power of less than 135 KWe, regardless of the connection voltage level.

The values provided are only indicative and do not replace the customer's specifications, which must take into account its own gridcode constraints.

APPENDIX D: DESIGN QUESTIONNAIRE FOR GERMANY VDE 4110: 2018-11

Questionnaire for designing a generator connected to the grid		
Country of installation*	Germany	
Grid code directive to be applied*		
Type following RfG code EU 2016/631*		*A, B, C or D*
Grid operator		
If Leroy-Somer™'s AVR isn't used, please indicate the manufacturer and type of AVR		
Apparent power*	**Active power sum <135kW**	kVA
Temperature class (IEC)*	**Sizing for multiple faults following DIN EN 60034-1**	
Rated voltage*		V
Voltage range*	**±10%**	*± x%*
Rated frequency*	**50**	Hz
Frequency range*	**±2%**	*± x%*
Rated lagging power factor*		
Short circuit ratio**		
Leading power factor**	**0.95 @U_N -7.5%**	
Voltage to be applied at leading power factor**	**-7.5% or +10%**	*Un ± x%*
Low Voltage Ride Through	0.3 / 0-150ms 0.7 / 150-700ms 0.85 / 1500-5000ms (linear extrapolation between 700 and 1500ms)	
Value and duration of each stage		
High Voltage Ride Through	1.25 / 0-100ms 1.2 / 100-5000ms	
Value and duration of each stage		
Rated voltage at connection point of installation	Middle-voltage network 1kV to 60kV	V
Transformer with tap changer on load		*Yes/No*

** : required*
*** : short circuit ration OR leading power factor to indicate*

Delivery of a certificate of component (AVR) and generating unit are required.

Type 1 generating units with a maximum total active power of less than 135 KWe, regardless of the connection voltage level.

The values provided are only indicative and do not replace the customer's specifications, which must take into account its own gridcode constraints.

APPENDIX E: DESIGN QUESTIONNAIRE FOR GERMANY VDE 4120: 2018-11

Questionnaire for designing a generator connected to the grid		
Country of installation*		
Grid code directive to be applied*		
Type following RfG code EU 2016/631*		*A, B, C or D*
Grid operator		
If Leroy-Somer™'s AVR isn't used, please indicate the manufacturer and type of AVR		
Apparent power*		kVA
Temperature class (IEC)*	**Sizing for multiple faults following DIN EN 60034-1**	
Rated voltage*		V
Voltage range*	**+15.5% / -13%**	*± x%*
Rated frequency*	**50**	Hz
Frequency range*	**±2%**	*± x%*
Rated lagging power factor*		
Short circuit ratio**		
Leading power factor**	**Variant 1: 0.974** **Variant 2: 0.950** **Variant 3: 0.925**	
Voltage to be applied at leading power factor**	**-6.5% and +15.5%**	*Un ± x%*
Low Voltage Ride Through	0 to 0 / 0-150ms 0.25 to 0.7 / 150-300ms 0.7 to 0.85 / 500-1500ms 0.85 to 0.85 / 1500-60000ms	
Value and duration of each stage		
High Voltage Ride Through	1.3 / 0-100ms 1.25 / 100-60000ms	
Value and duration of each stage		
Rated voltage at connection point of installation	High-voltage network 60kV to 150kV (typically 110kV)	V
Transformer with tap changer on load	**Mandatory**	*Yes/No*

** : required*
*** : short circuit ration OR leading power factor to indicate*

Delivery of a certificate of component (AVR) and generating unit are required.

Type 1 generating units connected to a step-up transformator.

The values provided are only indicative and do not replace the customer's specifications, which must take into account its own gridcode constraints.

APPENDIX F: DESIGN QUESTIONNAIRE FOR FRANCE

Questionnaire for designing a generator connected to the grid		
Country of installation*		
Grid code directive to be applied*		
Type following RfG code EU 2016/631*		*A, B, C or D*
Grid operator		
If Leroy-Somer™'s AVR isn't used, please indicate the manufacturer and type of AVR		
Apparent power*		kVA
Temperature class (IEC)*		
Rated voltage*		V
Voltage range*	**±10%**	*± x%*
Rated frequency*	**50**	Hz
Frequency range*	**+3% / -5%**	*± x%*
Rated lagging power factor*	**0.8**	
Short circuit ratio**		
Leading power factor**	**0.936**	
Voltage to be applied at leading power factor**	**-5%**	*Un ± x%*
Low Voltage Ride Through		
Value and duration of each stage		
High Voltage Ride Through	130% 50 ms 125% 2500 ms 110% 30000 ms	
Value and duration of each stage		
Rated voltage at connection point of installation		V
Transformer with tap changer on load		*Yes/No*

** : required*
*** : short circuit ration OR leading power factor to indicate*

APPENDIX G: ALTERNATOR DESIGN QUESTIONNAIRE FOR UK

Questionnaire for designing a generator connected to the grid		
Country of installation*	**UK**	
Grid code directive to be applied*	**ENAC_EREC_G99**	
Type following RfG code EU 2016/631*		*A, B, C or D*
Grid operator		
If Leroy-Somer™'s AVR isn't used, please indicate the manufacturer and type of AVR		
Apparent power*		kVA
Temperature class (IEC)*		
Rated voltage*		V
Voltage range*	**±10%**	*± x%*
Rated frequency*	**50**	Hz
Frequency range*	**+4% / -6 % (+2% / -2% continuous)**	*± x%*
Rated lagging power factor*	**Type A&B : 0.95** **Type C&D : 0.92**	
Short circuit ratio**		
Leading power factor**	**Type A&B : 0.95** **Type C&D : 0.92**	
Voltage to be applied at leading power factor**	**-5%**	*Un ± x%*
Low Voltage Ride Through		
Value and duration of each stage		
High Voltage Ride Through		
Value and duration of each stage		
Rated voltage at connection point of installation		V
Transformer with tap changer on load		*Yes/No*

** : required*
*** : short circuit ration OR leading power factor to indicate*

The values provided are only indicative and do not replace the customer's specifications, which must take into account its own gridcode constraints.

APPENDIX H: QUESTIONNAIRE FOR TESTS AND REGULATION

Preliminary questions for Grid Code tests			
PLANNED DATE FOR THE TEST: / /			
Steady-state operation			
What regulation mode will be configured in the regulator during the experimental tests?			
		Y/N	**Details**
Reactive power according to voltage Q(U)			Slope
Reactive power according to voltage Q(U) with limitation (Q(U)2)			Limits, slopes
Reactive power kVAr			
Power factor cosφ			
Grid power factor cosφ			Measurement location
Voltage U			
What kind of external BIAS setting will be used to adjust the setpoint?			
	Y/N	**Details**	
Analogic		+-10V, 0-10V, 4-20mA, potentiometer	
Digital(+-)			
CAN		Length of cables, time between two successive transmissions	
Will the regulator be cascaded with the controller?			
Yes		No	
If yes, what regulation mode will be undertaken by the controller?			
	Y/N	**Details**	
Voltage regulation		Regulation type, command refreshment delay, …	
Power factor cosφ regulation		Regulation type, command refreshment delay, …	
Reactive power kVAr regulation		Regulation type, command refreshment delay, …	
Dynamic Grid Support			
What functions will be used and by which device will they be executed?			
	AVR	Controller	Not used
Under voltage regulation switching			
Over voltage regulation switching			
Under voltage profile monitoring			
Over voltage profile monitoring			
Maximum stator current monitoring			
Internal angle monitoring			
Other limitations and protections in the AVR			
Are there limitations that will be used during the tests?			
	Y/N	**Details**	
Over excitation		Limit value	
Under excitation		Limit value	
Reactive power limitations		Limit value	
Stator current limitation		Limit value	
Are there protections that will be used during the tests?			
	Y/N	**Details**	
Over voltage		Auto-reset, action after fault	
Under voltage		Auto-reset, action after fault	
Over frequency		Auto-reset, action after fault	
Under frequency		Auto-reset, action after fault	
Diode fault		Auto-reset, action after fault	
Motor start		Auto-reset, action after fault	
Reverse active power		Auto-reset, action after fault	
Reverse reactive power		Auto-reset, action after fault	
Loss of sensing		Auto-reset, action after fault	
Short-circuit fault		Auto-reset, action after fault	
Unbalanced voltage		Auto-reset, action after fault	
Unbalanced current		Auto-reset, action after fault	
Battery under voltage		Auto-reset, action after fault	
IGBT fault		Auto-reset, action after fault	
Power bridge overload		Auto-reset, action after fault	
Temperature protection		Auto-reset, action after fault	

APPENDIX I: EQUIVALENCE TABLE [Voltage Range/Leading Power Factor/Short Circuit Ratio (SCR)]

For a synchronous alternator designed for a nominal operating point at a lagging power factor of 0.8:

Voltage Range (Un - XX%)	Leading Power Factor	Short Circuit Ratio (SCR)
10	0.98	≥ 0.29
15	0.98	≥ 0.33
10	0.95	≥ 0.37
7.5	0.95	≥ 0.43
10	0.925	≥ 0.475
10	0.9	≥ 0.52
15	0.9	≥ 0.63