Standards for Connection of Generator Based REG systems

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1 REFERENCE DOCUMENTS

[1] Development of a Regulatory Framework for Distributed Renewable Generation in the Kingdom of Saudi Arabia (this document referred to as "WERA Regulations")
[2] The Saudi Arabian Distribution Code – Issue 03 – Revision 02 – October 2018 (in this document referred to as "Distribution Code")
[3] The Saudi Building Code Electrical Requirements (SBC401) – 2007
[4] DS3: Rate of Change of Frequency (ROCOF) Workstream, EirGrid 2011.
[5] Technical Standards for the Connection of small-scale solar PV systems to the LV and MV Distribution Networks of SEC – Version 3.2.
[6] IEC TS 62862-2-1:2021 Solar thermal electric plants - Part 2-1: Thermal energy storage systems - Characterization of active, sensible systems for direct and indirect configurations.
[7] IEC 62862-3-2:2018 Solar thermal electric plants - Part 3-2: Systems and components - General requirements and test methods for large-size parabolic-trough collectors.
[8] IEC TS 62862-3-3:2020 Solar thermal electric plants - Part 3-3: Systems and components - General requirements and test methods for solar receivers.
[9] IEC 60953-1:1990 Rules for steam turbine thermal acceptance tests. Part 1: Method A - High accuracy for large condensing steam turbines
[10] IEC TS 62862-1-1:2018 - Solar thermal electric plants - Part 1-1: Terminology.
[11] IEC TS 62862-1-1:2018(E) contains the main terms and definitions used by the solar thermal electric (STE)
[12] IEC TS 62862-1-2:2017 - Solar thermal electric plants - Part 1-2: General - Creation of annual solar radiation data set for solar thermal electric (STE) plant simulation.
[13] IEC TS 62862-3-3:2020 - Solar thermal electric plants - Part 3-3: Systems and components - General requirements and test methods for solar receivers
[14] IEC 60045-1:2020 - Steam turbines - Part 1: Specifications
[15] IEC 60953-1:1990 - Rules for steam turbine thermal acceptance tests. Part 1: Method A - High accuracy for large condensing steam turbines.
[16] IEC 60953-2:1990 - Rules for steam turbine thermal acceptance tests. Part 2: Method B - Wide range of accuracy for various types and sizes of turbines.
[17] IEC 60953-3:2001 - Rules for steam turbine thermal acceptance tests - Part 3: Thermal performance verification tests of retrofitted steam turbines.
[18] ISO 10494:2018 - Turbines and turbine sets - Measurement of emitted airborne noise - Engineering/survey method-

2 SCOPE OF CONNECTION STANDARDS

This connection standards is developed with the purpose to define technical rules and requirements to connect all types of Renewable Energy Generator Based Systems, referred as "Generator Based REG Systems" in this document, which intend to operate in parallel with the LV & MV distribution networks of Saudi Electricity Company (SEC) in the Kingdom of Saudi Arabia (KSA). The Generator Based REG systems will include different types of technologies that for the scope of this activity will be limited to:

1. CSP Plants connected to the distribution grid via Synchronous Generator.
2. Waste to Energy Plants connected to the distribution grid via Synchronous Generator.
3. Biomass Plants connected to the distribution grid via Synchronous Generator.

All Generator Based REG systems shall in first place be designed by experts that are capable of guaranteeing the safe operation of the Generator Based REG system and fulfil the needed requirements established by the connection standards to avoid jeopardizing the stability and the security of the distribution network.

The connection standards is not intended to provide guidelines or recommendations in designing Generator Based REG systems, it instead focus on the safe operation of the distribution network, and based on that the connection standards establishes certain requirements to fulfil regardless the presence of loads in the Consumer's installation, such as:

- Requirements to support the frequency and voltage stability of the power system when it is subject to disturbances.
- Requirements for the start-up, the operation and the disconnection of Generator Based REG systems.
- Requirements to prevent the Generator Based REG Systems from causing disturbances and damages either to the distribution network and to the other Consumers connected to the same distribution network.

The present document should not contradict with any requirement already established by other national & international standards, network codes or specific technical requirements of SEC, and which may apply for the connection of Generator Based REG Systems, in particular:

- The Regulatory Framework for Distributed Renewable Generation in the Kingdom of Saudi Arabia – WERA regulations for 2021 (This document will be referred as "WERA regulations"), and
- The Saudi Arabian Distribution Code – Issue 03 – Revision 02 – October 2018 (This document will be referred as "Distribution Code").

The Distribution Code is applicable to all users of the distribution system and still represents the main technical document to refer to for the connection of a new Consumer or for the modification of the connection of an existing Consumer. The present Connection Standards shall apply in case the new installation (or the modified one) that includes a new Generator Based REG System as defined in WERA Regulations and shall be intended as an extension of the Distribution Code for what not directly ruled by the code itself. For all the aspects not covered by the present document, reference shall be made to the Distribution Code.

It is not within the scope of the present document to:

- define the process to be followed for the selection and evaluation of the Connection Point.
- define the process to be followed for the assessment of the impact of connecting Generator Based REG Systems to SEC distribution network.
- define the process to be followed for the assessment of a connection application and its compliance with the present standards.

This information can be found in other companion documents that will be delivered within the Scope of the "Consultancy Service for Distributed Renewable Energy Generation" project.

DISCLAIMER

It is not under the purpose of these standards to define technical rules for the generators that operate without a grid connection or in off grid mode or as emergency mode generators able to supply user plants when the main grid id not present. This document however is intended to define the technical requirements needed to connect the above-mentioned technologies safely to the distribution network via synchronous generators.

2.1 Important Notes to users

Users should be aware that this document may be superseded at any time by the issuance of new editions or may be amended from time to time through the issuance of amendments, corrigenda, or errata. These Connection Standards at any point in time consist of the current edition of the document together with any amendments, corrigenda, or errata then in effect. All users should ensure that they have the latest edition of this document, uploaded on SEC website.

Additionally, even if it is not directly within the scope of the present standards, it is important to stress and remind the fundamental importance and necessity for these systems to be built in a workmanlike manner, which means the use of products and their assembly in accordance with the national and international standards commonly used for the planning, design, installation, operation and maintenance of all Generator Based REG Systems.

Finally, the user shall refer to Saudi Building Code SBC as well as any applicable SASO Standards or International Standards mentioned in these SEC documents, unless differently indicated in other SEC documents related to Generator Based REG Systems Regulations.

2.2 SEC Limitation of Liability and Consumer's undertaking

SEC disclaims liability for any personal injury, property or other damage, of any nature whatsoever, whether special, indirect, consequential, or compensatory, directly or indirectly resulting from inappropriate design of the Generator Based REG systems. Consumers are responsible for observing or referring to the applicable laws and regulatory requirements.

It is the responsibility of the Consumer to determine that the interconnection equipment's specifications and confirmed performance satisfy the technical needs of SEC Distribution system and to be compatible with the present and any other applicable SEC standards. All equipment in an installation connected to SEC Distribution network shall be designed, manufactured, tested and installed in accordance with all applicable statutory obligations and shall conform to the relevant SEC standards current at the time of the connection of the installation to SEC Distribution network.

The Consumer shall undertake to comply with the following:

- Arrange all necessary requirements and systems to connect Generator Based REG systems to SEC Distribution network including compliance with security and safety requirements and providing necessary equipment.
- Terms and conditions of offer to connection, connection agreement, connection conditions, and any other relevant requirement adopted by SEC.
- Not to exceed the authorized Maximum Connected Capacity for exporting to SEC Distribution network.
- Not to conduct any action impacting the safety and efficiency of SEC Distribution network.
- Cooperate with SEC staff in all matters related to electricity exported to the system.

- All costs associated with the connection of Generator Based REG systems to SEC Distribution network shall be borne by the Consumer.
- Any excess electricity generated by Generator Based REG systems above the electricity consumed in the Consumer's premises shall be exported to SEC Distribution network in accordance with the provisions of the connection agreement.
- If there is a risk for the safety or the security of the grid and the public electricity network, SEC is entitled to either disconnect or to require immediate disconnection of the Generator Based REG System from the Distribution network.

3 TERMS AND DEFINITIONS

Active Power - Active Power is the real component of the apparent power, expressed in watts or multiples thereof (e.g. kilowatts (kW) or megawatts (MW)). In the text this will be generically referred as P or Pnom in case of nominal active power of equipment.
Apparent Power - Is the product of voltage (in Volt) and current (in Ampere). It is usually expressed in kiloVolt-Ampere (kVA) or MegaVolt-Ampere (MVA) and consists of a real component (Active Power) and an imaginary component (Reactive Power). In the text this will be generically referred as S or Sn in case of rated apparent power of equipment.
Auxiliary Supply Power – Electricity supply to auxiliary systems and services such as Interface Protection or circuit breaker and contactor opening coils.
Maximum Available Active Power Output – Is the Active Power Output determined by the primary resource (for example, sun irradiance, wind, etc.) and by the maximum steady-state efficiency of the Generator Based REG System for this operating point.
Connection Point – The physical point at which Consumer's Plant or apparatus is joined to the SEC Distribution System.
Consumer – Any Person supplied with electricity services for his own consumption. In this context, this term will also be used to refer to a User owning a Generator Based REG System. This term has also the same meaning of Customer, as defined in the Distribution Code. As per WERA Regulations, a Consumer is considered Eligible when it meets both the requirement of the same Regulations and the Connection Conditions as defined in the Distribution Code.
Delay time (of a protection relay) – Indicates the minimum duration of a fault detected by the protection relay before the output of the protection relay is triggered.
Distribution System / Network – The system which consists of electric lines, electric plant, transformers and switchgear and which is used for conveying electricity to final Customers / Consumers. It can be either a Medium or Low Voltage system, for the scope of the present document and in accordance with international standards:

- A Low Voltage (LV) Distribution System is a network with nominal voltage lower than 1kV AC or 1.5 kV DC. The LV Distribution System nominal voltages in KSA are 400/230V, 380/220V and 220/127V.
- A Medium Voltage (MV) Distribution System is a network with nominal voltage included in the range from 1kV AC up to 69 kV. The MV Distribution System nominal voltages in KSA are 13.8, 33 and 69kV.

For avoidance of doubt, the term Distribution Network will be preferred in this document in place of Distribution System.
Interface Protection (IP) - The electrical protection required to ensure that either the Generator Based REG System and/or any Generating Unit is disconnected for any event that could impair the integrity or degrade the safety and reliability of the distribution network.
Islanding - Situation where a portion of the distribution network, containing generating plants, becomes physically disconnected from the rest of the distribution network and one or more generating plants maintain a supply of electrical energy to such isolated part of the distribution network.
Loss Of Mains (LOM) – Represents an operating condition in which a distribution network, or part of it, is on purpose or in case of fault separated from the main power system with the final scope of de-energization. This denotes also the protection which detects this condition, and it is also known as anti-islanding.
Main Meter - Is the bidirectional device installed at the Connection Point which measures the amount of electric energy actually exchanged (either in import or in export) by the Consumer with the distribution network.

Maximum Connected Capacity - The Eligible Consumer maximum installed generation capacity which SEC allows to operate in parallel to the Distribution Network. The Maximum Connected Capacity shall not exceed for any reasons the limits set forth by WERA Regulations.
Generator Meter - Is the device installed at the common output point of any Generator Based REG System and which measures the total energy produced from the Generating Units.
Rated active power – Represents the sum of the nominal active power of all the Generating Units which compose the Generator Based REG System; it is generally referred as Pnom.
Reactive power capability – Defines the reserves of inductive/capacitive reactive power which can be provided by a generating system/unit. The reactive power capability usually varies with the active power and the voltage of the generating system/unit.
Reactive Power - Represents the imaginary component of the apparent power, usually expressed in kilovar (kVAr) or Megavar (MVAr).
Generator Based REG System – Are Distributed Renewable Energy Generation System which can include different type of RES technologies (e.g. CSP, Biomass power plants or Waste to Energy plants) connected to either LV or MV network by means of generating units.
Generating Unit – An electrical generator and its associated prime source, together with all associated Plant and apparatus and any generator transformer, which relate exclusively to the operation of that generator, which in the case of:

- a steam turbine will include the boiler and heat exchanger and in addition in the case of a solar concentrator the solar collectors,
- a gas turbine will include the gas generator/combustion turbine, and
- a fuel engine will include the engine any gearbox and the prime mover.

Switch – Mechanical device capable of making, carrying and breaking currents in normal circuit conditions and, when specified, in given operating overload conditions. In addition, it is able to carry, for a specified time, currents under specified abnormal circuit conditions, such as short-circuit conditions.
Synchronism - Synchronism occurs when two a.c. voltages are of the same frequency and magnitude and have zero phase difference.
THD (Total Harmonic Distortion) – With reference to an alternating quantity, it represents the ratio of the r.m.s. value of the harmonic content to the r.m.s. value of the fundamental component or the reference fundamental component.
Chartered Engineer - An engineer registered with the Engineering Council. Chartered Engineers are degree-qualified and have gained the highest level of professional competencies through training and monitored professional practice experience. In KSA the registration is made before the Saudi Council of Engineers.
Charter – the Founding Charter of the Electricity and Cogeneration Regulatory Authority
Certified Consultant/Contractor – A legal entity that has been certified by the Certification Committee to carry out design and Electrical Installations work specific to DRG systems.

4 GLOSSARY

The following acronyms and symbols are used throughout the document:

cos φ	Power factor
WERA	Water & Electricity Regulatory Authority
IP (or I.P.)	Interface Protection
LOM	Loss Of Mains
LV	Low Voltage (namely 220/127 Vac or 380/220 Vac or 400/230 Vac)
LVRT	Low Voltage Ride Through
MV	Medium Voltage (namely 13.8kV or 33 kV)
P	Active power
Pnom	Nominal active power of equipment
p.u. (or pu)	per unit
PV	(Solar) Photovoltaic
Q	Reactive Power
ROCOF	Rate Of Change Of Frequency expressed in Hz/s.
S	Apparent Power
Sn	Nominal Apparent Power
SEC	Saudi Electricity Company
V	Voltage
Vnom	Nominal Voltage
REG	Renewable Energy Generation

5 TECHNICAL REQUIREMENTS FOR GENERATOR BASED REG SYSTEMS

5.1 General requirements

All Generator Based REG Systems shall be designed in such a way to guarantee the performance expected by the current standards. It is the responsibility of SEC to design a suitable connection process for all kind of technologies of REGs, assessing the capacity of the network to host the connecting Generator Based REG System at that point whilst maintaining a stable and reliable operation of the system for all operating conditions.

According to the Distribution Code, if the results of such process highlight that the connecting Generator Based REG System is likely to cause the network to possibly operate outside of SEC statutory performance standards, SEC has the right to ask for design alternation/modifications and in some extreme cases might reject the application. The Maximum Connected Capacity of the Generator Based REG System to be proposed by the Consumer, will be verified according to the Distribution network hosting capacity available and in accordance with WERA Regulations.

The upcoming paragraphs reports several requirements for all Generator Based REG Systems, the technologies can vary based on primary source of energy, for instance these standards will set several technical requirements for:

- CSP plant.
- Waste to Energy plants.
- Biomass power plants.

5.2 Connection schemes

The connection scheme does differ depending on plenty of factors. These standards wouldn't define a scheme that fits each technology or each Generator Based REG system, because each Chartered Engineer should be free do take the necessary measures that himself retain feasible for the plant he is designing. All Generator Based REG systems must coordinate the protection schemes and settings with those of the distribution network; they shall therefore be agreed between SEC and the Consumer with the following purpose:

- faults and malfunctions within the Generator Based REG System shall not impair the normal operation of SEC distribution network. In particular, any faults that including earth-faults with leakage current internal to the Consumer's installation will be detected and cleared below or at the connection point before any SEC protection operates.
- the ability of the Generator Based REG system to generate power shall not be affected at any time by random trappings of a protection device cause by a bad selectivity. For instance, if the IP protection trips due to a fault in the network, once the disturbance is cleared, no other device should prevent the Generator Based REG system from generating power but the IP protection itself, hence, all components in the Generator Based REG system shall be ready once the IP protection commands the reclosure of the IP switch.
- the protection schemes coordination between SEC distribution network and the Generator Based REG system shall guarantee the correct operation of the protection devices in case of faults either within the Generator Based REG System or within the distribution network.

In order to satisfy the above requirements, Figure 1 and Figure 2 present the typical equipment which shall be at least installed for a safe and reliable interconnection of a Generator Based REG System to the LV and MV distribution network respectively:

- A Main Switch shall be installed as close as possible to the Connection Point and shall be operated by a protection system in case of internal faults, in accordance with the Distribution Code [1]. If agreed with SEC, it is possible to install more than one main switches in order, for example, to have two separate circuits, one dedicated to the Consumer's loads and one dedicated to the Generator Based REG System.
- The Interface Switch, operated by an Interface Protection, shall be envisaged in the Consumer installation to separate the portion of it containing one or more Generating Units from both the remaining part of the Consumer's installation containing only loads and SEC distribution network. For Generator Based REG Systems whose power exceeds 20kW, a backup is necessary in case of failure on this switch opening.
- The Generator Unit Switch shall be installed as electrically close as possible to the terminals of each Generating Unit, for the protection and the connection/disconnection of that unit. For the protection issues, the recommendations and requirements of the Manufacturer of the equipment shall apply.

5.3 Choice of Switches

The correct choice of switches and the dimensioning of the equipment is ultimately the responsibility of the chartered engineer. In this chapter, this document is providing some generic technical rules to follow in selecting the switches. For each of the above-mentioned switches, the choice of the type to be installed (circuit breaker, contactor, disconnecting switch with fuses, etc.) shall be based on:

- the functions the switch shall carry out.
- the characteristics of the Consumer's installation.
- the characteristics of SEC Distribution Network at the Consumer's Connection Point.

Especially, the following criteria shall be adopted:

- the switches, panels and switchgear shall be compliant with the requirements of the Distribution Code,
- the switch(es) of the Generating Unit(s) shall be compliant with the Manufacturer requirements,
- For Generator Based REG Systems connected to the MV Distribution Network and with the Interface Switch on the MV side of the plant, the Interface Switch shall consist of:
    - three-pole withdrawable automatic circuit breaker operated by an undervoltage release, or
    - three-pole automatic circuit breaker operated by an undervoltage release along with a Line isolator (either upstream or downstream the circuit breaker)

  In any case, the circuit breaker shall be motorized, to allow automatic reclosure once the network disturbances that have led to the trip of the Interface Protection have been cleared. The consensus to the reclosure of the Interface Switch shall be given by the Interface Protection itself, which has then to sense the voltages on the network side and not on the Generator Based REG System side of the Interface Switch.
- For Generator Based REG Systems connected to the MV Distribution Network and with the Interface Switch on the LV side of the plant or for Generator Based REG Systems connected to the LV distribution network (see schemes, the interface switch shall consist of either:
    - motorized automatic circuit breaker or switch disconnector operated by an undervoltage release, or
    - AC3 contactor which operates on all the poles (i.e. phases and neutral).

  in order to allow automatic reclosure once the network disturbances that have led to the trip of the Interface Protection have been cleared. The consensus to the reclosure of the Interface Switch shall

[1] For the definition of the requirements of the protection system against faults within the Consumers' installations, please refer to The Saudi Arabian Distribution Code, Issue: 03, Revision:02/October 2018

be given by the Interface Protection itself, which has then to sense the voltages on the network side and not on the Generator Based REG System side of the Interface Switch.

- any switch shall have a breaking and making capacity coordinated with the rated values of the Consumer's installation, taking into consideration both the generating plant and the contribution to short circuit from the Distribution Network.
- the short time withstand current of the switching devices shall be coordinated with the maximum short circuit power at the Connection Point[2];
- in case of loss of auxiliary supply power to the switchgear, a secure disconnection of the Interface Switch is required immediately.

The function of the Interface Switch can be combined with either the Main Switch or the Generating Unit Switch in a single switching device[3]. In case of a combination of these, the single combined switching device shall be compliant with both the requirements of the interface switch and of either main switch or Generating unit switch, according to the combination chosen. As a consequence, at least two switches in series shall be always present between a Generator Based REG System and the Connection Point.

5.4 Protection of the installation against faults

The electrical protections required for the connection of a Generator Based REG System to SEC Distribution networks are of concern in the present document. These additional protections shall be checked and approved by DPED-SEC. Other protections shall also be installed to protect the Consumer's electrical assets as per SEC protection policy. All protections shall be graded and co-ordinated with SEC upstream protections and downstream protections within the Generator Based REG installation. Any faults down to the Connection Point shall be cleared at the same point or below, without impacting SEC distribution network.

Where overcurrent protection is required for the safety of the equipment, whether this be part of the Generator Based REG System or not, automatic disconnection of the faulted circuit shall be accomplished. The maximum braking current of any protection device must consider both the short circuit value coming from SEC Distribution network and the short circuit contribution from the Generator Based REG system which varies from one technology to another, for instance, for technologies e.g. CSP or WtE the short circuit contribution is higher than PV and Wind.

Hence, the Chartered Engineer or a Certified Contractor/Consultant must take into consideration all the factors that will lead to the right selection of the protection rating capacity to guarantee the safe operation of Generator Based REG systems.

[2] Information about the maximum prospective short-circuit level of SEC distribution networks is reported in 4.5.1 of the Distribution Code.

[3] For connection schemes using a single main switch, the combination of the interface switch with the main switch will lead to the disconnection of the overall Consumer's facility when the interface switch is opened, that is a lack of supply will also affect the Consumer load.

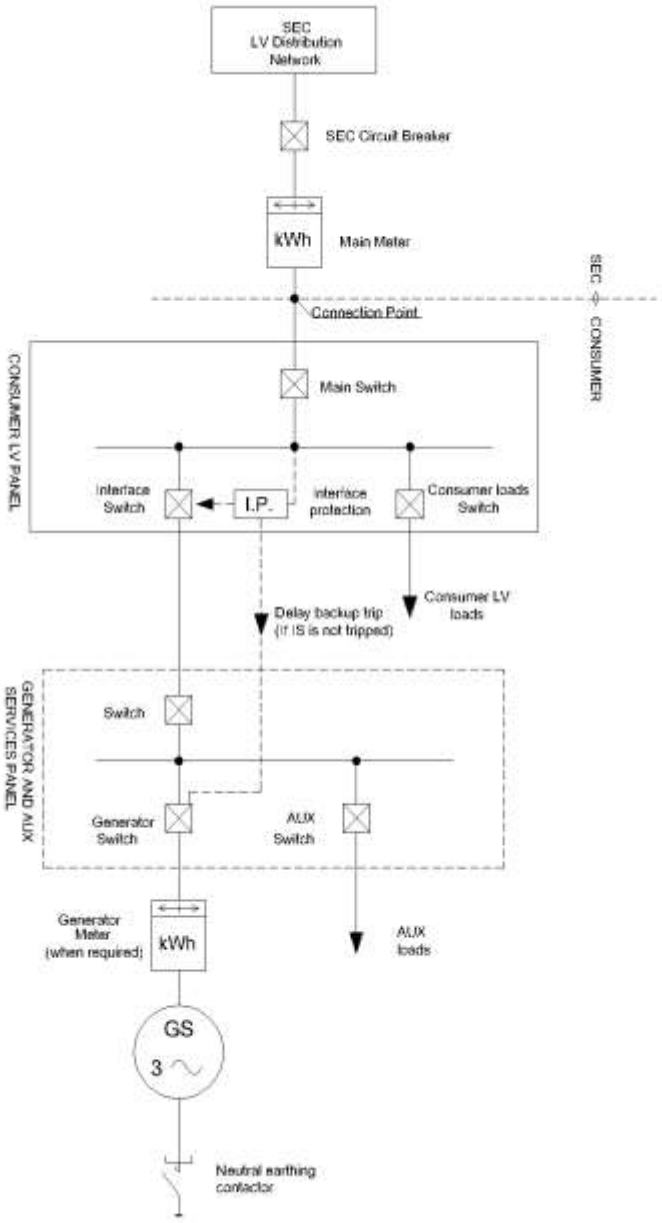

Figure 1 - Schematic representation for the interconnection of a Rotating Generator Based Technology with SEC LV Distribution Network

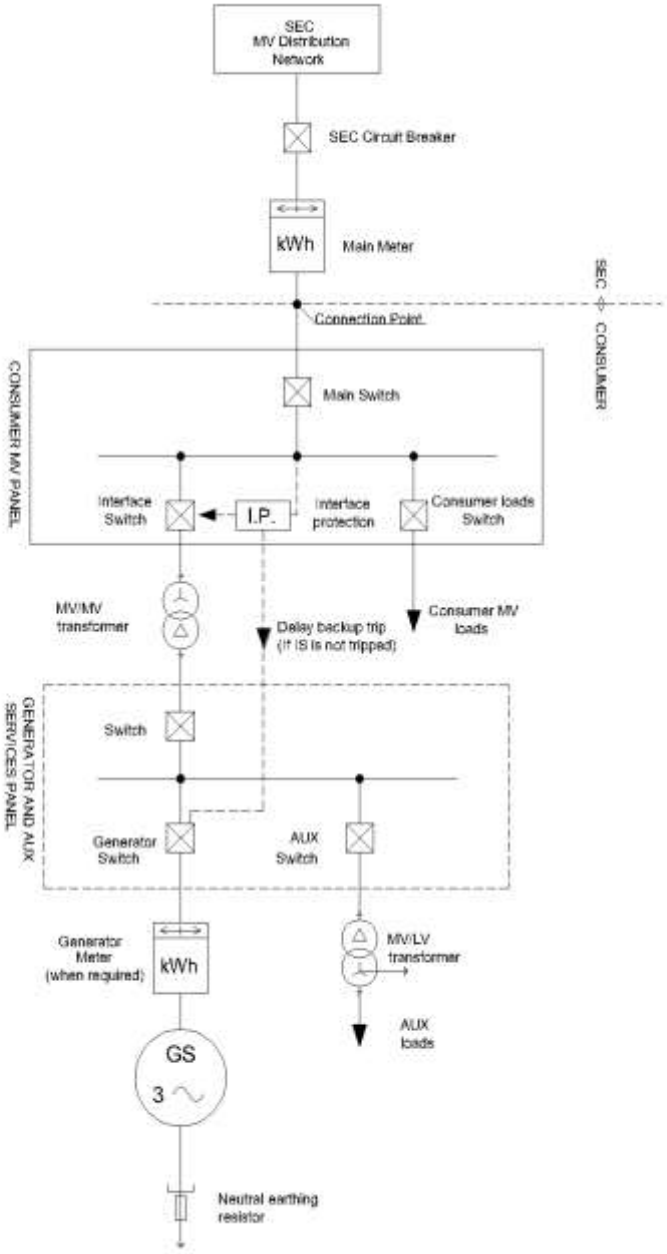

Figure 2 - Schematic representation for the interconnection of a Rotating Generator based Technology with SEC MV Distribution Network (either 13.8, 33 or 69kV)

5.5 Operating ranges

Generator Based REG Systems shall be capable of remaining connected to the Distribution Network and of operating stably, as specified in this document, in the frequency and voltage ranges for the time periods specified in the tables below, regardless of the type and settings of the protection systems:

Table 1: Frequency operating range

Below Nominal Frequency (Hz)	Above Nominal Frequency (Hz)	Operation Requirement
58.8 – 60.0	60.0 – 60.5	Continuous
57.5 – 58.7	60.6 – 61.5	for a period of 30 minutes
57.0 – 57.4	61.6 – 62.5	for a period of 30 seconds

Table 2: Voltage operating range

Voltage range at the Connection Point	Operation Requirement
90-110% Nominal Voltage	Continuous

5.6 Immunity to disturbances

5.6.1 Low Voltage Ride Through (LVRT) capability

All types of Generator Based REG Systems within a power plant greater than 11 kW shall contribute to the stability of the overall power system by providing immunity towards dynamic voltage changes, especially those due to faults on the higher voltage level networks. The requirements below apply to all kind of disturbances (1ph, 2ph and 3ph faults) and are independent of the Interface Protection settings (see 5.10.4) which overrule the technical capabilities of a Generator Based REG System. Therefore, whether the Generator Based REG System will stay connected or not will also depend on settings of the Interface Protection and Generator characteristics.

For Generator Based REG Systems the LVRT curve is different due to the fact that Rotating Generators are different from their characteristics compared to the inverters as they shall be capable to stay connected to the distribution network if the voltage at the Connection Point remains above the voltage-time diagram shown in Figure 3.

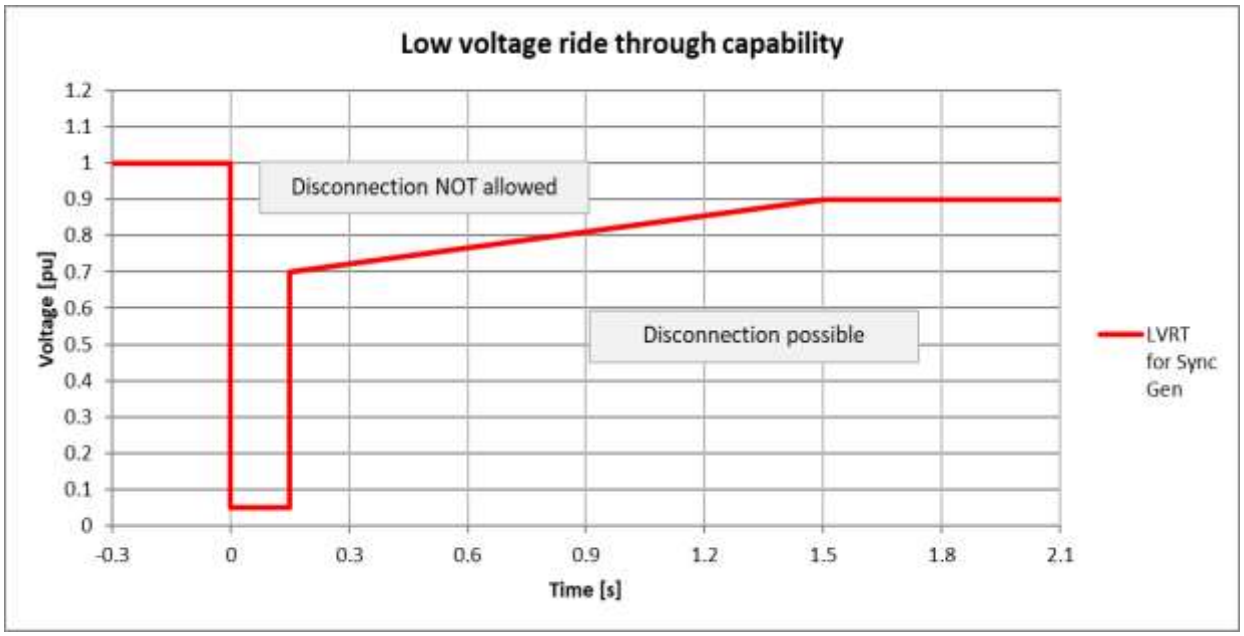

Figure 3 - LVRT characteristic for REG Sync Generator Based Systems > 11kW

The p.u. voltage shall be calculated with respect to the nominal voltage at the Connection Point. For three-phase generating systems, the smallest phase to phase voltage shall be evaluated. The compliance to such LVRT requirement shall apply to all equipment that might cause the disconnection of the Generator Based REG System, i.e. Interface Protection and generator protections, control systems, auxiliary supply, etc.

After the fault is cleared and the voltage returned within the voltage normal operating range (see 5.5), the pre-disturbance operating conditions (active & reactive power) shall be recovered as fast as possible and with a tolerance of ±10% of the Generator Based REG System rated power.

5.6.2 ROCOF withstand capability

All Generator Based REG Systems, when generating power, shall be able to go through frequency transients with frequency within the normal operating range (see 5.5) and with ROCOF value up to 2.5 Hz/s, this value should be similar to the values respected by other REG technologies [12] [13]. In the case the Loss Of Mains (LOM) protection, as described in 5.10.4, implements a ROCOF-based method, the threshold of the LOM function shall not cause the intervention of the protection within the immunity ranges as specified in this paragraph.

5.7 Requirements for the frequency stability of the power system

5.7.1 Active power response to frequency variations for Generator Based REG Systems exceeding 2 MW

All Generator Based REG Systems exceeding 2 MW shall be capable of activating the provision of active power response to over-frequency transients according to the curve of Figure 4, with frequency threshold and droop settings adjustable and to be specified by SEC;

- the frequency threshold shall be settable at least between 57 Hz and 62 Hz inclusive; if not differently specified by SEC, the threshold shall be set to 59.8 and 60.2Hz.
- the generated active power Pgen shall be referred to the actual active power value Pact when the threshold is reached, and the active power response is activated.
- the droop settings shall be between 2% and 8% in steps of a maximum of 1 %; if not explicitly specified by SEC, the droop shall be set to 3.83%.
- The response to under-frequency transients shall be available and activated according to SEC request. If requested, Generator Based REG system shall keep a 10% of its generation capacity available to be used when frequency drops below 59.8 Hz.

The resolution of the frequency measurement shall be ±10mHz or less. The active power response shall be activated as fast as possible and shall be delivered with an accuracy of ±10% of the nominal power.

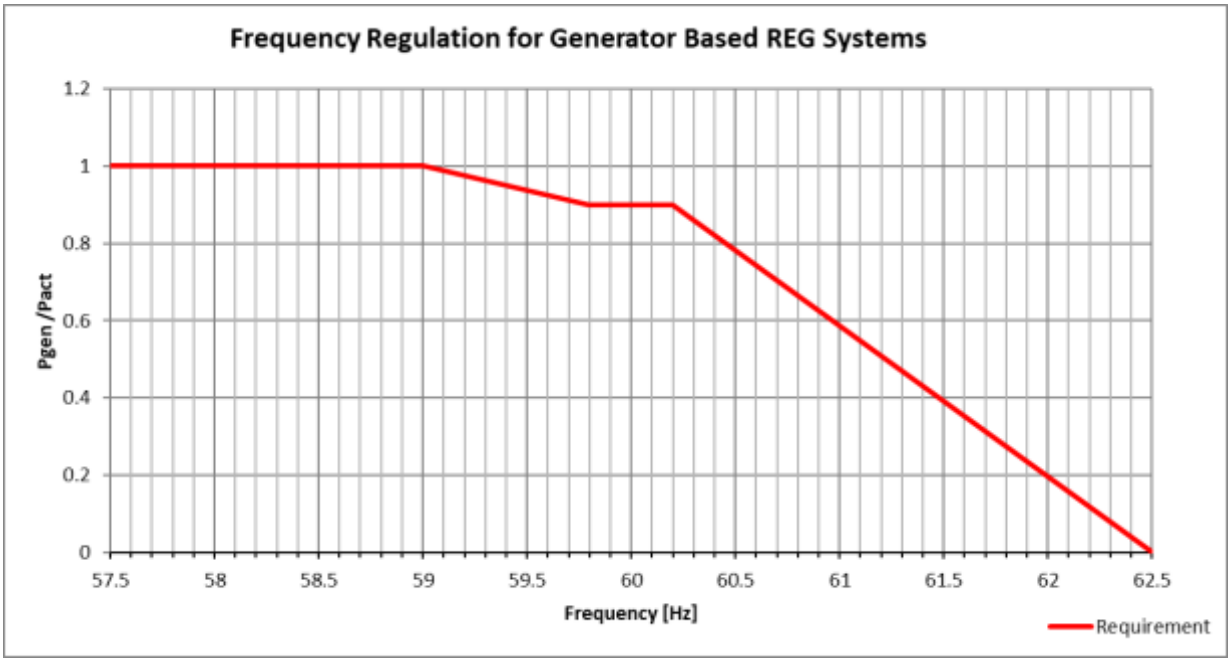

Figure 4 – Frequency regulation requirement for Generator Based REG Systems > 2 MW

5.7.2 Active power response to frequency variations for Generator Based REG Systems below 2 MW

For Generator Based REG systems less than 2 MW only over frequency control is required. These systems shall be capable of reducing their Pgen once frequency exceeds 60.2 Hz threshold according to the graph shown in Figure 5**.**

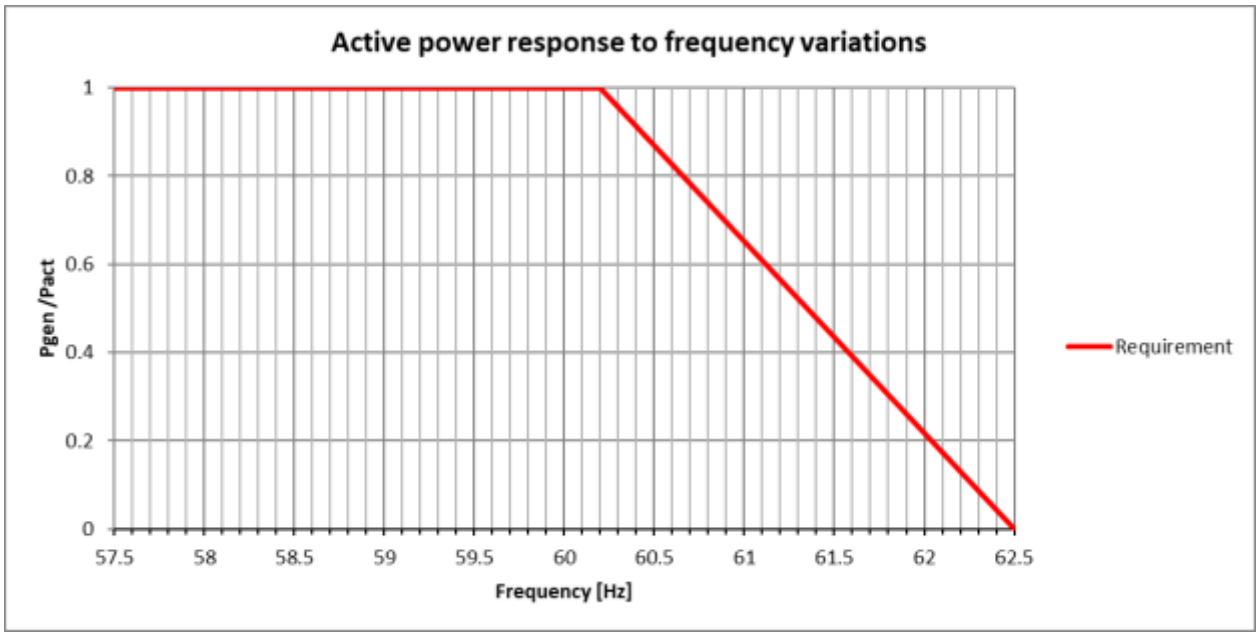

Figure 5 – Over-frequency requirement for Generator Based REG Systems < 2 MW

For Generator Based REG System they are not allowed to reduce their active power in under frequency regime, however if they have to reduce their active power due to technical limits this reduction in power shall be limited to the characteristics of the generator as much as possible. This limited tolerance is given for Generator Based REG systems below 2MW which are not accounted for power reserve.

5.8 Remote limitation of active power

A Generator Based REG System with a Maximum Connected Capacity greater than 11kW shall be equipped with an interface (input port) which is able to receive, from a remote-control center, an instruction requiring the reduction of the active power output. The reduction of active power shall be carried out as fast as possible and with an accuracy greater than 5% of the nominal active power of the Generator Based REG System.

In accordance with the provisions set forth in 5.10.6, SEC shall have the right to specify further requirements in terms of equipment, communication protocol, information to be exchanged and/or time of execution, which allow to integrate such feature into the control systems of its distribution network and which allow to remotely limit the active power output of the REG Generating Units connected to its network.

5.9 Requirements for the voltage stability of the power system

5.9.1 Reactive power capability

When voltage and frequency at the Connection Point are within their normal operating ranges, a Generator Based REG System shall be able to provide reactive power in any operating point within the boundaries of the reactive power capability curves defined in Figure 6[4].

According to this capability, the Generator Based REG System will be able to either generate or absorb inductive reactive power from the Distribution Network, in order to participate to voltage support at the Connection Point, for any of the values of active power generated by the Generator Based REG System.

The red stripes area is indicating the capability limits of a typical Synchronous Generator as shown in Figure 6:

- Turbine Pmax Limit: indicate the maximum active power limit for the turbine behind the generator.
- Stator Current Limit: Indicate the maximum current flow that the stator winding can withstand.
- Rotor Current Limit: Indicates the maximum current flow the rotor winding can withstand.
- Stability Limit: is the maximum limit for the generator before going out of step and losing synchronism with the network.

For Generator Based REG Systems their ability regulate voltage is wider and more flexible compared to the REG Invert Based Systems. The presence of a conventional synchronous generators provides the ability to absorb or inject reactive power based on the machine limitations e.g. Stator Current limitation, Rotor current limitation, Turbine Max power limitation and Stability limit for under excitation.

Each Generator Based REG System will have its capability limits based on the machine characteristics provided by the manufacturer and generally these characteristics will be aligned with the below figure.

[4] The active power 1 p.u. shall refer to the nominal active power value of the Generator Based REG System: at 1 p.u. of active power, the reactive power capability of a Generator Based REG System corresponds to a power factor.

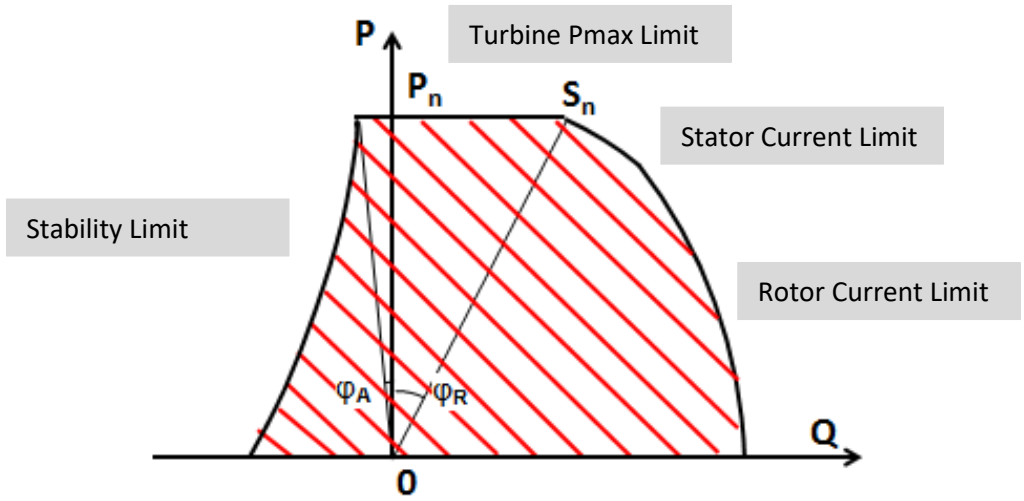

Figure 6 - Capability Curve for Generator Based REG Systems

5.9.2 Reactive power control modes

All Generator Based REG Systems shall be capable of operating in the control modes stated below, within the limits of its reactive power capability as expressed in 5.9.1:

- fixed Q: the reactive power is controlled in order to have a fixed value.
- fixed cos φ: the reactive power is controlled in order to have a fixed power factor.
- cos φ (P): the reactive power is controlled in order to have a power factor function of the actual active power delivery.
- Q=f(V): the reactive power is controlled as a function of the local voltage, according to a characteristic curve.

The above control modes are exclusive; only one mode may be active at a time. The activation, deactivation and configuration of the control modes shall be field adjustable. It is the responsibility of SEC to communicate to the Generator Based REG System's owner which of the above-mentioned reactive power control mode shall be activated.

5.9.2.1 Fixed control modes

When operated with fixed Q or fixed cos φ control mode, the REG Generating Unit shall control the reactive power or the cos φ of its output according to a set point set in the control system of the Generator Based REG System. If not explicitly specified by SEC, the default set point values shall be 0 for fixed Q control mode and 1 for fixed cos φ control mode.

For a Generator Based REG System with a Maximum Connected Capacity greater than 11kW, the Generating Unit shall also be able to receive the set-point from a remote control center in accordance with the provisions set forth in 5.10.5.

5.9.2.2 Power related control mode

The power related control mode cos φ (P) controls the cos φ of the output as a function of the active power output. A characteristic with a minimum and maximum value and three connected lines according to Figure 7 shall be configurable within the control systems of the Generator Based REG System; a change in active power output results in a new cos φ set point according to the characteristic.

The parameters A, B, C and D shall be field adjustable, and their settings are the responsibility of SEC. If not explicitly specified by SEC, these parameters shall be set as indicated below:

- A P = 0 Pnom cos φ = 1
- B P = 0.5 Pnom cos φ = 1
- C P = Pnom cos φ = 0.95 Lag
- D P = Pnom cos φ = 0.95 Lead

where Pnom is the active nominal power of the REG Generating Unit.
The response to a new cos φ set point value shall be as fast as technically feasible after the new value of the active power is reached. The accuracy of the control to each set point shall be in accordance with the requirements of 5.9.1.

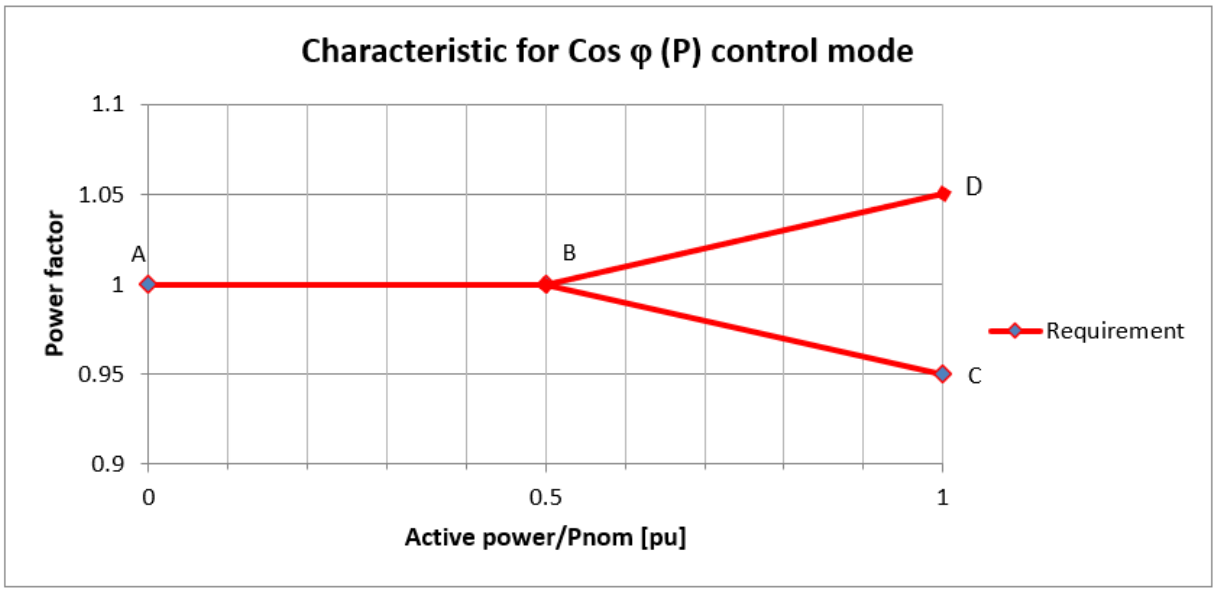

Figure 7 - Characteristic for Cos j (P) control mode

The implementation of a lock-in and lock-out voltage level shall be configurable, each in the range 90% to 110% of the nominal voltage at the Connection Point: the contribution is activated when the voltage at the Connection Point exceeds the lock-in voltage and is deactivated when the voltage at the Connection Point drops below the lock-out voltage. When the contribution is not activated, the Generator Based REG System shall be controlled with a unity power factor (cos φ = 1).

5.9.2.3 Reactive power support as a function of the voltage Q(V)

For Generator Based REG Systems with a Maximum Connected Capacity greater than 11kW, for such control mode, a characteristic with a minimum and maximum reactive power value and three connecting lines according to Figure 8 shall be configurable.
It is SEC responsibility communicate the parameters to be configured in case this support is required from Generator Based REG Systems.

For Generator Based REG Systems, the values shall be assigned according to the generator characteristics, therefore the parameter ranges available in the Generator Voltage Regulator shall not exceed the technical limits imposed by the characteristics of the Generator Based REG system, for instance:

- Qmax and –Qmax correspond to the maximum rotor current limit and stability limit as shown in Figure 6
- V1 > [27<] threshold of Interface Protection

- V4 < [59>] threshold of Interface Protection
- V2< Vnom <V3

Possible default values can be the following, unless differently agreed with SEC:
V1 = 0.9 Vnom
V4 = 1.1 Vnom
V2=0.95 Vnom, V3=1.05 Vnom

where Vnom is the nominal Voltage at the Connection Point.

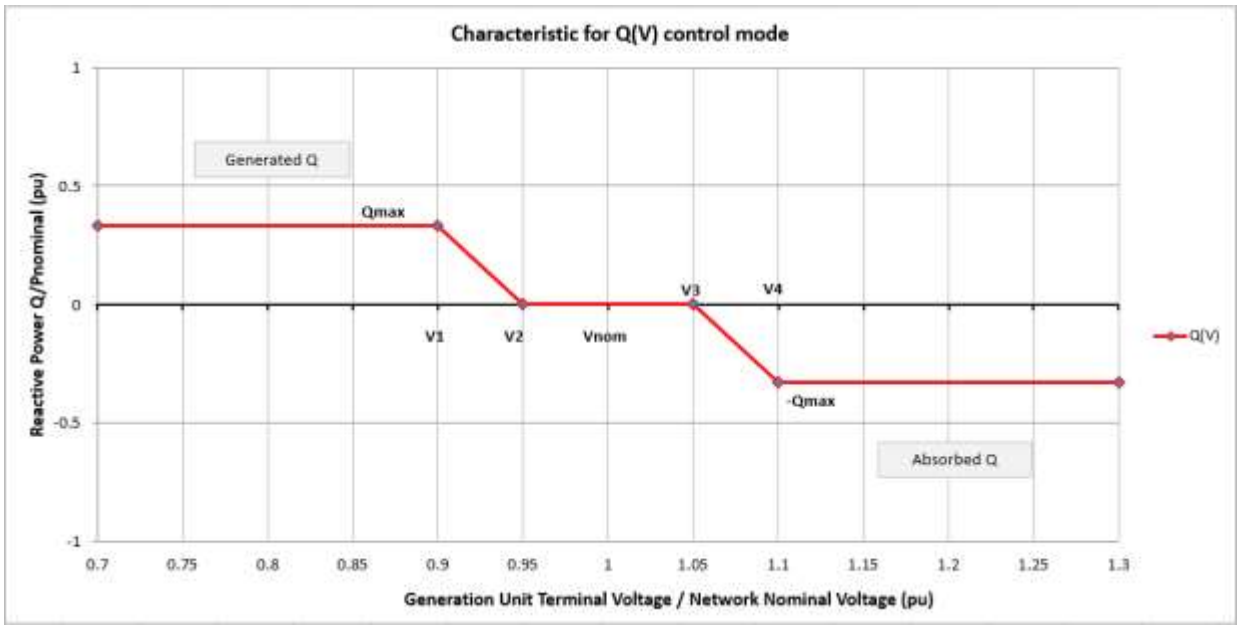

Figure 8 - Characteristic for Q(V) control mode

5.9.3 Power reduction at increasing voltage

In order to avoid the disconnection due to overvoltage protection, a Generator Based REG System is allowed to reduce its power output (active and/or reactive power) as a function of the rising voltage at the Connection Point. The implemented logic can be chosen by the Manufacturer/Consumer. Nevertheless, the implemented logic shall not cause steps or oscillations in the power output of the system.

5.10 Requirements for the management of the power system

5.10.1 Connection conditions

A Generator Based REG System is allowed to be connected to the network and to start to generate electrical power due to normal operational start-up, when the voltage and frequency are within the following range for at least the observation time:

- Frequency range 59.5 Hz ≤ Frequency ≤ 60.05 Hz.
- Voltage range 95% Vnom ≤ Voltage ≤ 105% Vnom (Vnom= nominal voltage at the Connection Point).
- Minimum observation time 30s.

Synchronizing a Generator Based REG System with the distribution network shall be fully automatic, that is it shall not be possible to manually close the switch between the two systems to carry out the synchronization[5].

The synchronization of a Generator Based REG System to the distribution network shall not create a transient voltage variation at the Connection Point of more than 4% of nominal voltage. After the connection, a Generator Based REG System shall follow its target active power value with a variation rate not greater than 10% Pnom/min, where Pnom is the nominal active power of the Generator Based REG System.

The active power target shall be the maximum available active power output that the Generator Based REG System can generate, taking into account the all technical constrains and limitations of the Generator Based REG system, except for the operating conditions when the power output shall follow changes due to the provision of some of the services specified in this document (see 5.7.1, 5.8 and 5.9.3).

For Generator Based REG Systems that can be programable, the active power target shall match the dispatchment program provided by the DSP and according to the connection agreement.

5.10.2 Remote disconnection

A Generator Based REG System with a Maximum Connected Capacity greater than 11kW shall be equipped with a logic interface (input port) in order to disconnect from the network following an instruction received at its interface.

In accordance with the provisions set forth in 5.10.5, SEC shall have the right to specify further requirements in terms of equipment, time of execution, communication protocol and/or data to be exchanged, to integrate such feature into the control systems of its distribution network and to allow the remote disconnection of the Generator Based REG Systems connected to its network.

5.10.3 Automatic reconnection after tripping

After the trip of the interface protection, a Generator Based REG System is allowed to reconnect to the network only if the voltage and frequency are within the following range for at least the observation time:

- Frequency range 59.5 Hz ≤ Frequency ≤ 60.05 Hz.
- Voltage range 95% Vnom ≤ Voltage ≤ 105% Vnom (Vnom= nominal voltage at the Connection Point).
- Minimum observation time 300s.

After reconnection, the Generator Based REG System shall return to its target active power value with a variation rate not greater than 10% Pnom/min, where Pnom is the nominal active power of the Generator Based REG System.

[5] It means that the switch used for the synchronization with the network cannot be a manual switch.

5.10.4 Interface Protection

The purpose of the interface protection is to:

- disconnect the Generator Based REG System from the Distribution Network in the following cases
  - the Distribution Network (or the feeder) the Generator Based REG System is connected to is de-energised from the main source of supply. De-energisation can happen automatically due to protection system operation or manual/electrical disconnection. Electrical/manual disconnection in the Distribution Network can happen either remotely by SEC SCADA system or by local switching.
  - the voltage and/or frequency values at the Connection Point are out of the normal operating ranges as defined in 5.5.
- prevent the Generator Based REG System, when generating power, to cause over-voltages in the distribution network it is connected to.

It is not the purpose of the interface protection to:

- disconnect the Generator Based REG System from the Distribution Network in case of faults within the Consumer's installation; for such issues, the requirements for the connection of passive customers shall apply (refer to Distribution Code).
- prevent damages to the Consumer's equipment (generating units or loads) due to faults/incidents (e.g. short circuits) in the Distribution Network or in the Consumer's installation; for such issues, the recommendations and requirements of the manufacturers of the equipment shall apply.

The interface protection shall be a dedicated device which acts on the interface switch. The interface protection shall command the interface switch; for a all Generator Based REG System, unless explicitly agreed by SEC, only one interface protection and one interface switch shall be used.

For a Generator Based REG System with a Maximum Connected Capacity greater than 20kW, the interface protection shall additionally act on another switch (backup switch) with a proper delay in case the interface switch fails to operate. The backup switch may consist of a dedicated switch or an already existing switch[6] e.g. the Generating unit switch. When the back-up switch is triggered because the interface switch has failed to open, only manual reclosure shall be possible[7], hence the backup switch can't be motorized in any circumstances.

For a Generator Based REG System with a Maximum Connected Capacity greater than 11kW, the power supply of the interface protection shall include an uninterruptible power supply. The loss of the auxiliary voltage on either the interface protection or on the Generator Based REG System's control system shall trigger the interface switch without delay.

The protection functions required in the Interface Protection are the following:

- Under voltage [27]
  - One threshold [27<] in the range [20%; 100%] of the nominal voltage at the Connection Point adjustable by steps of 5%, and delay time in the range [0.1s;100s] adjustable in steps of 0.1s;
  - One threshold [27<<] in the range [0%; 100%] of the nominal voltage at the Connection Point adjustable by steps of 5%, and delay time in the range [0.1s;5s] adjustable in steps of 0.05s.
- Over voltage [59]
  - One threshold [59>] in the range [100%; 120%] of the nominal voltage at the Connection Point adjustable by steps of 1%, and delay time in the range [0.1s;100s] adjustable in steps of 0.1s;

[6] It is anyway recommended not to use the main switch as back-up switch since it could lead to the disconnection of the overall Consumer's facility in the case the interface switch fails to open, with the consequence of the power supply also being removed to Consumer's loads.

[7] The reasons are that it is required that the plant operator first acknowledges and checks the reasons why the interface switch failed to open, then remedies the technical issues and finally resumes operation.

  - One threshold [59>>] in the range [100%; 130%] of the nominal voltage at the Connection Point adjustable by steps of 1%, and delay time in the range [0.1s;5s] adjustable in steps of 0.05s.
- Over frequency [81>]
  - One threshold [81>] in the range [60Hz; 63Hz] adjustable by steps of 0.1Hz, and delay time in the range [0.1s;100s] adjustable in steps of 0.1s.
  - One threshold [81>>] in the range [60Hz; 63Hz] adjustable by steps of 0.1Hz, and delay time in the range [0.1s;5s] adjustable in steps of 0.05s.
- Under frequency [81<]
  - One threshold [81<] in the range [57Hz; 60Hz] adjustable by steps of 0.1Hz, and delay time in the range [0.1s;100s] adjustable in steps of 0.1s.
  - One threshold [81<<] in the range [57Hz; 60Hz] adjustable by steps of 0.1Hz, and delay time in the range [0.1s;5s] adjustable in steps of 0.05s.
- Loss Of Mains (Anti-Islanding):

  for the Loss Of Mains (LOM) protection function, a wide variety of approaches can be used: besides the passive observation of voltage and frequency, other active and passive methods are available and used to detect unintentional islanding situations. The present document does not intend to specify the method to be used to achieve the goal but rather its efficacy; for such a reason, the only requirement on LOM protection is that the protection function shall be tested in accordance with SASO IEC 62116 or other equivalent standard and to have the possibility to deactivate the LOM feature whenever is required.

The present standard recognizes that it may not be straightforward for IP manufacturers to define settings of the LOM protection which can be efficient for all the current and future operating conditions of SEC distribution networks. This is especially the case of the most common passive methods currently used for the implementation of such function within a dedicated protection device (i.e. ROCOF and vector jump).

Usually a generator unit doesn't come with the LOM functionality, however in any case, the LOM protection, irrespective of its actual position, i.e. either integrated in a dedicated Interface Protection or built-in in the generator unit, shall detect island operating conditions and cease to energize the Distribution Network within two seconds of the formation of the island, unless differently specified by SEC on the basis of MV feeder auto-reclosure time. Furthermore, for LOM embedded in the generator units, the manufacturers in this case shall propose the best operational mechanism that satisfy the above requirement.

The protection functions for under-voltage [27] and over-voltage [59] shall be fed by all the line voltages, whereas the protection functions for under-frequency [81<] and over-frequency [81>] shall be fed by at least one line voltage.

Appropriate settings shall be applied to the interface protection and shall ensure the correct tripping of the Generator Based REG System under specific conditions. The settings shall be chosen so that, in case a fault within the distribution network triggers the network protection systems (which in turn disconnect the faulty feeder), all Generator Based REG Systems are disconnected before the attempt of reclosure in the MV distribution network takes place.

0 proposes default settings for 27, 59 and 81 protection functions. Such settings shall be actually applied to the Interface Protection of a Generator Based REG System only in case no other settings have been explicitly specified and communicated by SEC. Moreover, the Interface Protection shall have at least two configurable digital inputs which may be used in the future[8] by SEC for transfer trip, remote tripping or

[8] In a scenario of growing penetration level of distributed generation in the distribution networks of the KSA

any other function that may be necessary to increase the capacity of the distribution networks to host distributed generation while keeping an acceptable level of reliability and security.

5.10.5 Protection and Control Ranking Priority

All Generator Based REG Systems shall be designed and manufactured in a way that respects the priority ranking for the protections provided in this section. The purpose of introducing the priority ranking is to avoid the confliction between 2 or more functions that has to be implemented at the same time.

For instance, if there is an internal fault within the Generator Based REG Systems and at the same time there is an under frequency problem in the network that indicates that the Generator Based REG Systems that is generating power towards the network shall maintain its operation and stay connected, if not even provide the required power reserve.

In this case which of the 2 function should prevail over the other? According to the below priority ranking the internal fault inside a Generator Based REG Systems has the priority and the disconnection shall take place. the protection and control devices of a Generator Based REG Systems shall be organized in accordance with the following priority ranking (from highest to lowest):

1. Protection of the Generator Units
2. Protection against faults within the Consumer's installation
3. Protection of the distribution network (Interface Protection)
4. Remote disconnection
5. Active power response to frequency variations
6. Remote limitation of active power
7. Remote reactive power control modes
8. Local reactive power control modes

5.10.6 Monitoring, remote control and information exchange

Adequate information concerning the Consumers connected to the Distribution Networks is a prerequisite for enabling SEC to maintain the stability, reliability and security of its networks. SEC needs to have a continuous overview of the state of the network, which may require, in some cases, updated information on the operating conditions of the Generator Based REG Systems connected to its Distribution Networks, as well as the possibility to communicate with these plants in order to direct the operational instructions set forth by the provisions of the present document.

Such requirements are usually needed in case of growing penetration level of the Generator Based REG Systems in the distribution networks; they may also be introduced in the framework of other initiatives dedicated, for example, to the optimization of the control performances of the network.

A Generator Based REG System with Maximum Connected Capacity greater than 11kW shall therefore have provision for bi-directional communication exchange which can be used for the exchange of information with SEC. Once actually needed for the operation of the network, in accordance with a cost/benefit approach, SEC shall have the right to specify additional requirements concerning especially:

- data, which shall be collected and sent to SEC in real-time or periodically, related to the operating conditions of the Generator Based REG System.
- operational instructions sent by SEC which shall be executed by the Generator Based REG System; such instructions shall be compliant with the requirements indicated in the present standards (especially the requirements of 5.8 and 5.10.2);
- Communications channels and protocols to be used for the above requirements.

If technically possible, SEC may take advantage of already existing communication channels, such as smart metering infrastructure, in order to facilitate the integration of the monitoring activities into its ICT architecture and reduce the costs of implementation.

5.10.7 Power factor

Any installations containing a Generator Based REG System shall comply with the power factor limits, as measured at the Connection Point, indicated in the Distribution Code[9] (amended to date).

5.10.8 Power quality

5.10.8.1 Voltage deviation

Under normal operating conditions, the connection and operation of a Generator Based REG System shall not cause the voltage at its Connection Point and at the Connection Point of any other Consumers connected to the same Distribution Network, to vary from the system rated voltage by more than ±5%.

The values of the voltages will then range in the following intervals as specified in the Distribution Code:

Table 3: Voltage range under normal operating conditions for the different voltage level

Nominal Voltage	Lowest Voltage	Highest Voltage
220/127 V	209/120 V	231/134 V
380/220 V	360/209 V	400/231 V
400/230 V	380/218.5 V	420/241.5 V
13.8 kV	13.1 kV	14.5 kV
33 kV	31.4 kV	34.7 kV
69KV	65.5KV	72.5KV

5.10.8.2 Rapid voltage changes

Connection and disconnection of a Generator Based REG System from the distribution networks shall not give rise to voltage variations exceeding 3% of the system rated voltage at the Connection Point.

5.11 Metering System

The metering system to be installed at Consumer Premises shall be in agreement with the requirements of WERA Regulations (Chapter 8 as per the date of the release of this document), that is:

- a first digital meter (Main Meter) supplied and installed by SEC at the Connection Point, to measure both the energy injected into the Distribution Network and consumed from this one. For this reason, the meter must be bidirectional.
- a second digital meter (Generator Meter) supplied and installed by SEC at the Connection Point only in case the Maximum Connected Capacity of the Generator Based REG System exceeds 100kW.

The Main Meter measures the net energy at the Connection Point, whereas the Generator Meter measures the energy produced by only the Generator Based REG System.

The Generator Meter will be installed outside, close to the Main Meter, until remote reading capability from SEC of this meter will be available. From that time on, Generator Meters shall be installed within the Consumer Premises, as close as possible to the Generating Unit.

[9] Specifically DPC2.4

6 COMPLIANCE

The Consumer shall ensure that its Generator Based REG System complies with the requirements defined in the present standards throughout the overall lifetime of the facility. The Consumer shall notify to SEC any incident, failure or planned modification of its Generator Based REG System which may affect the compliance with the requirements defined in the present standards.

The Consumer shall provide SEC with all the documents, studies and measurements useful to demonstrate the compliance of its Generator Based REG System to the requirements defined in the present standards. If deemed necessary, SEC shall have the right to request the Consumer to carry out additional tests or studies with the scope to demonstrate the compliance of the Generator Based REG System with the provisions of the present document. Such activities may be requested not only during the connection process, but at any time throughout the lifetime of the Generator Based REG System, and more specifically after any failures, modifications or replacements of any equipment that may have an impact on the compliance of the System with the present standards.

ANNEX A. DEFAULT SETTINGS OF INTERFACE PROTECTION

The following table reports the default settings to be implemented in the Interface Protection of Generator Based REG Systems when no other settings have been communicated by SEC.

Table 4: Default settings for the protection functions of the IP

Protection function	Settings	
	Threshold	Time delay
27<	90% Nominal Voltage	1.5 s
27<<	40% Nominal Voltage	0.8 s
59>	110% Nominal Voltage	3 s
59>>	120% Nominal Voltage	0.2 s
81>>	62.5 Hz	0.1 s
81<	57.5 Hz	4 s
81<<	57 Hz	0.1 s
50	DT: current setting 7 pu	0.15 s
51	SI, current setting 1.2 pu	time dial 0.1s
50N	DT: 0.8PU A	0.0 s
51N	SI, current setting 0.1 pu	time dail 0.1 s

Table 5 LOM settings

Vector Shift (VS)	**12 degrees**	**0.0s**
Rate of Change of Frequency (RoCoF)	**2.5 Hz per second**	**0.0s**

NOTE: LOM functionality must have the possibility to be excluded if requested by SEC.