REPORT TO THE CREG

COST-BENEFIT ANALYSIS ON REQUIREMENTS FOR GENERATORS APPLICABLE ON EXISTING AND NEW GENERATING UNITS BETWEEN 1 AND 25 MW

DÉCISION (B)658E/79 OF 14 JULY 2022

Preliminary report

Phase 1: preparation of work

26/05/2023

1. Introduction

1.1 Description of the incentive

The objective of this incentive is to perform a cost-benefit analysis on the oportunity of applying one or more requirements currently applicable only to new Type B power generating units (hereinafter PGMs) to PGMs considered as existing with an installed capacity between 1 and 25 MW (not included) and connected to the Elia grid. The requirements to be assessed are the requirements applicable to new type B PGMs (PPM and SPGM). They are listed in the document "Requirements of General Application of the RfG" (hereinafter GR RfG), following Article 7(4) of the European Commission Regulation (EU) 2016/631 of 14 April establishing a network code on requirements for grid connection of generators (hereinafter: NC RfG).

The cost-benefit analysis will evaluate, for a given set of requirements applicable to new type B PGMs:

- on the one hand the benefits for the transmission system of applying one or more of these requirements to existing PGMs with a capacity between 1 and 25 MW connected to the transmission system and
- on the other hand the costs associated with the application of these requirements that would fall on the owners of these existing PGMs.

1.2 Context and justification

Following the adoption of the Third Energy Package, different network codes have been drafted (NC RfG, NC DCC, NC HVDC). The purpose of these codes is, on the one hand, to create a level playing field between EU Member States and, on the other hand, to ensure greater robustness of electricity networks by defining criteria for connection to these networks that take into account the evolving energy landscape.

The NC RfG defines the requirements for the connection of new PGMs.

At the Belgian federal level, these requirements are detailed in the Royal Decree establishing a Grid Code for the management of and access to the electricity transmission system of 22 April 2019 (Part 3, Book 1, Title 4, Chapter 3 & 6).

At the Belgian regional level, the document "Requirements of General Application of the NC RfG", details the requirements applicable to new PGMs.

Although the requirements in the NC RfG are applicable to new PGMs, Article 4 of the NC RfG defines the framework for the application of these requirements to existing PGMs:

- Article 4.1 foresees the application of all or part of the requirements of the NC RfG to existing PGMs in the following cases:
    - art 4.1, a) in case of substantial modernisation for type C and D units

- art 4.1, b) when the regulatory authority or a Member State decides to apply, on the proposal of the TSO, certain requirements of the NC RfG to an existing PGM after carrying out a cost benefit analysis
- Article 4.3 allows the TSO to propose to the competent regulatory authority the application of all or part of the requirements of the NC RfG code to a set of existing PGMs also after a cost-benefit analysis.

Articles 4.3, 4.4, 38 and 39 of the NC RfG specify how the cost-benefit analysis is supposed to be conducted.

In the future, this cost-benefit analysis will serve as an objective basis for the regulator's decisions regarding:

- the application of articles 4.1, b) and 4.3 of the NC RfG to existing PGMs with an installed capacity of between 1 and 25 MW (not included)
- a possible extension of the existing derogation from the application of the principle of substantial modernization to PGMs considered as existing, with a maximum installed capacity of less than 25 MW and a voltage at the point of connection greater than or equal to 110 kV (which are by definition considered as type D).
- evaluate the opportunity to extend the concept of substantial modernisation to units with a power between 1 and 25 MW

2. Type B PGMs inventories

In this section, the amount of existing and new PGMs is quantified. It is important to know this information in order to quantify the potential benefits for the system of some requirements.

2.1 Definition of a criteria

The date of entry into force of the RfG is 26 May 2016. According to the article 4 of the RfG, a PGM shall be considered as existing if it is already connected to the network on the date of entry into force of the RfG (or if the PGM owner has concluded a final and binding contract for the purchase of the main generating plant by two years after the entry into force of the RfG).
The federal grid codes specifies the definition of existing PGM versus new PGM in article 35.
At the regional level, different decisions specify the definition of existing PGM versus new PGM[1].

However, for this study, we separated differently the PGMs in existing and new categories.
Indeed, the RfG provides a legal framework for the requirements but leaves (via Art 7) to the TSOs the definition of requirements of general application.
At the federal level, the requirements are included in the Federal Grid Code (Part 3, Book 1, Title 4, Chapter 3 & 6), which was published on 27 April 2019.
At the regional level, the regional regulators approved the Requirements of General Application of the RfG in September and November 2019 for application 2 months later [2].
The content of the requirements is the same at federal and regional level.

Considering that the new requirements were officially published on 27 April 2019 via the Federal Grid Code, Elia kept communicating the old requirements to the Grid Users until that date.
For this reason, we used the date of the 27 April 2019 as a key date for the split betwwen the existing PGMs from the new PGMs. The PGMs for which the detailed study was delivered before the 27 April 2019 are considered as existing. The PGMs for which the detailed study was delivered after the 27 April 2019 are considered as new.

2.2 Results

The amount of type B PGMs considered as existing and connected to the Elia network is equal to 112 (figures from early February 2023). There are also 24 new type B PGMs which are already sconnected (13) or which will probably be connected to the Elia network considering that they are either under construction (4) or in an engineering/permitting phase (7).

[1] VREG: Beslissing 2019-06; CWaPE: CD-18j25-CWaPE-0233; Brugel: Décision 20190424-91
[2] BESL-2019-39 (VREG), CD-19h28-CWaPE-0347 (CWaPE), DECISION-20190904-117 (Brugel)

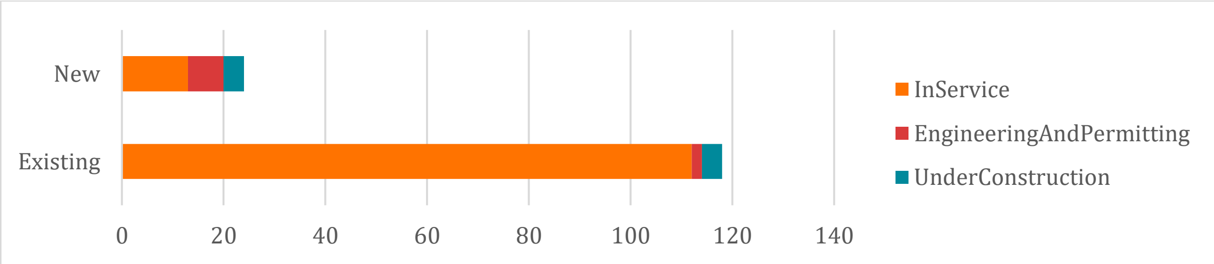


Figure 1 Amount of new and existing PGMs connected to the Elia network

If we consider the power repartition, we can see at the Figure 2 that 86,5% of the installed power for type B PGMs are existing PGMs.

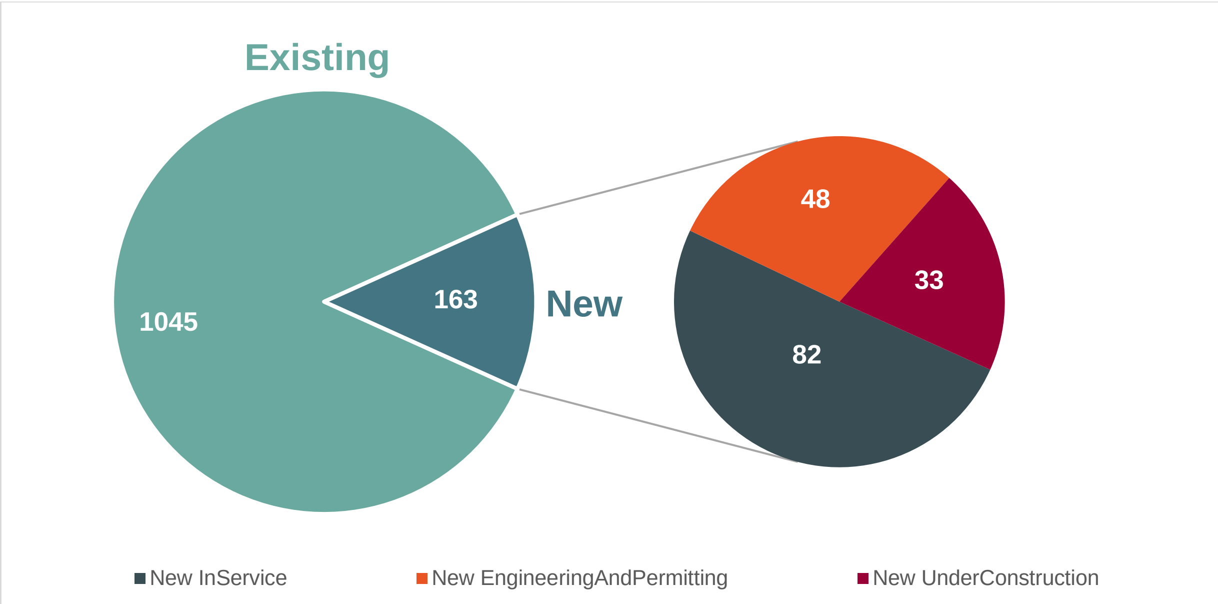


Figure 2 Repartition in power [MW] of the existing and new PGMs

The 1045 MW of existing type B PGMs are made of different technologies as described at the Table 1 and at the Figure 3. One can see that the three most important technologies of type B existing PGMs are Cogeneration units, Wind Turbines and Incineration Stations.

Table 1 Distribution of existing type B PGMs per production type

PRODUCTION TYPE	INSTALLED POWER (MW)
Classical (Steam Turbine)	53,4
Diesel	45,6
Hydro Unit - Run Of River	21,8
Incineration Station	164,318
Solar	59,63
STEG - Steam Turbine	20
Turbojet	108
Wind Onshore	216,6
WKK	355,783
TOTAL	**1045,131**

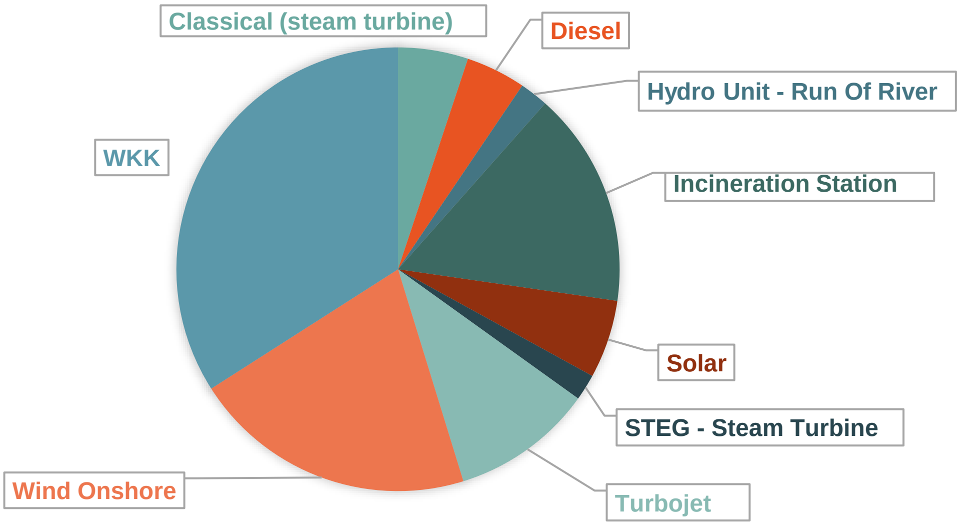


Figure 3 Distribution (in power) of per technology of the type B PGMs

More generally, existing type B PGMs are mainly Synchronous Power-Generating Modules (SPGMs) where new type B PGMs are mainly Power Park Modules (PPMs).

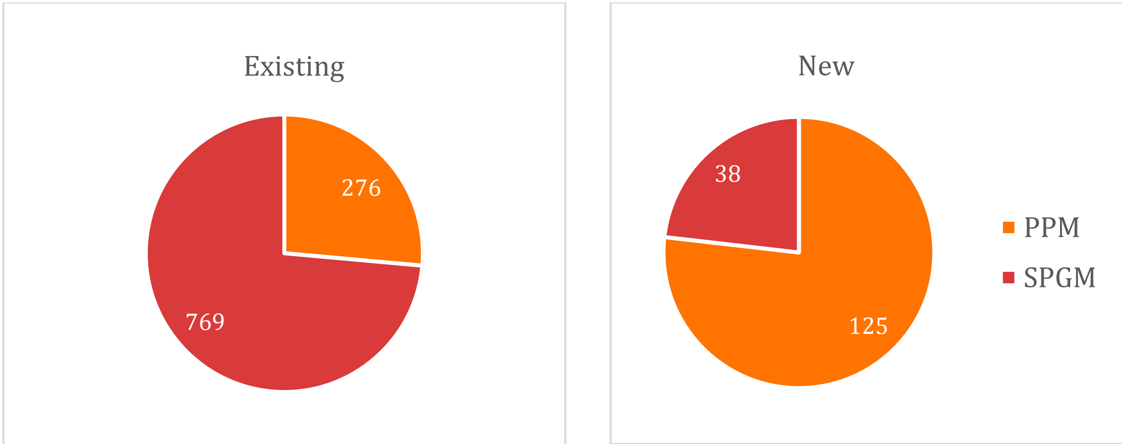


Figure 4 Distribution (in MW) of PPMs and SPGMs for existing and new PGMs

It is also interesting to know which proportion of the existing PGMs between 1 and 25 MW are connected to the transport grid (Federal competence) and to the local transport grid (Regional competence). This information is given in the table below.

Authority	Percentage of PGMs (in Installed Power)
Federal level	21%
Regional level	79%

Proportion (in installed power [MW]) of the PGMs between 1 and 25 MW connected to the Federal and Regional level

3. Comparison of the requirements applicable to new and existing type B PGMs

3.1 Introduction

The requirements for PGMs type B are sorted in different categories:

Category 1: Data questionnaire and models

Category 2: Internal compliance proof (RGIE) , equipments capabilities & protection scheme agreement

Category 3: Voltage & Frequency requirements

Category 4: Information exchange / telecom requirements

Category 5: Balancing/Congestion management requirements

Category 6: Power Quality requirements

Category 7: Emergency & Restoration requirements

Category 8: Protections requirements

3.2 Category 1 : Data questionnaire and models

3.2.1 Data questionnaire

I) Requirement applicable to existing PGMs

According to Article 354 of the FGC the grid user should provide Elia with the required filled data questionnaire.
The installation document (or data collection questionnaire) is provided by Elia and must be filled by the grid user.
The information provided through this data questionnaire must be in accordance with the other relevant requirements listed further in this document.

II) Requirement applicable to new PGMs

According to article 30 of the NC RfG :

the power-generating facility owner shall ensure that the required information is filled in on an installation document obtained from the relevant system operator […].

This installation document (or data collection questionnaire) is provided by Elia and must be filled by the grid user.
The information provided through this data questionnaire must be in accordance with the other relevant requirements listed further in this document.

III) Comparison

The data questionnaire requirement is similar for new and existing PGMs (or slightly more stringent for new PGMs).

3.2.2 Simulation models

I) Requirement applicable to existing PGMs

The PGM Owner had to submit a model including the functional block diagrams.

II) Requirement applicable to new PGMs

The PGM Owner shall submit the static and dynamic models of each PGM units-including transformers, cables or other relevant assets and control system and protection with an appropriate guidance note to ELIA. The documentation shall be submitted in DIgSILENT PowerFactory format and the documentation and data collection in the format defined in coordination with ELIA during connection process.

III) Comparison

The requirement is more severe for new PGMs than for existing ones. For existing PGMs, the grid users had to provide the functional block diagram. For the new PGMs, the model files must be submitted to Elia.

3.3 Category 2 : Internal compliance proof (RGIE), equipment's capabilities & protection scheme agreement

3.3.1 Internal compliance proof – RGIE

The existing and new PGM must be compliant with the RGIE. The requirement is as consequence considered as similar for new and existing PGMs.

3.3.2 Equipment Capabilities - Annex 1 - Icc max

The values set out in the tables in Annex 1 of the relevant grid code apply to facilities, regardless of their voltage level. All PGMs, load facilities or CDS connected to the transmission system must, at the voltage level of the interface point, comply with the values set out in the tables in Annex 1.
Installations at the first voltage level below the voltage level of the interface point shall be sized so that they do not limit the maximum permissible short-circuit power at the connection point, this maximum permissible short-circuit power at the connection point being the value given in Annex 1 respectively for this voltage level.

I) Requirement applicable to existing PGMs

This requirement is detailed in the appendix 1 A of the Federal or Regional Grid Code. This appendix summarizes the requirements regarding the short-circuit currents.

1A. Caractéristiques techniques d'une installation considérée comme existante existante conformément à l'article 35, §§ 7, alinéa 1[er], 8 et 9

Niveau de tension (kV)	Um Equipement (kV)	LIWV Uw (kV)		Disjoncteurs	Autres équipements		
				Isc (kA)	I thermique		I dynamique (kA)
					Durée	(kA)	
380	420		1550 ou 1425 (*)	50 ou 63 (*)	>= 1 s	50	125
220	245		1050	40	>= 1 s	40	100
150	170		750	40 ou 50 (*)	>= 1 s	40	100
70	82.5	Hors Zone Liège	380	20	>= 1 s	20	50
		Zone Liège	380	31.5	>= 1 s	31.5	80
36	40.5		200 ou ≥ 170 (*)	31.5	>= 1.2 s	31.5	80
30	36		170	31.5	>= 1.2 s	31.5	80
26	30		145	25	>= 2 s (1)	25	63
15	17.5		95	20	>= 2 s (1)	20	50
11-12	17.5		95	25	>= 2 s (1)	25	63
10	12		75	25	>= 2 s (1)	25	63
6	7.2		60	25	>= 2 s (1)	25	63
					Duur	(kA)	

(*): suivant décision gestionnaire du réseau.

(1): correspondant au temps de déclenchement de la protection en réserve

II) Requirement applicable to new PGMs

This requirement is detailed in the appendix 1 B of the Federal or Regional Grid Code. This appendix summarizes the requirements regarding the short-circuit currents.

1B. Caractéristiques techniques d'une installation considérée comme nouvelle conformément à l'article 35, §§ 7, alinéa 1er, 8 et 9

Niveau de tension (kV)	Um Equipement (kV)	LIWV Uw (kV)	I dynamique (kA)	Disjoncteurs	Autres équipements travées haute tension		Liaison en câble souterrain / ligne aérienne	
				Isc (kA)	I thermique		I thermique (3φ et 1φ)	
					Durée	(kA)	Durée	(kA)
380	420	1425	160 ou 125 (*)	63 ou 50 (*)	>= 1 s	63 ou 50 (*)	0,6 s	50
220	245	1050	125 ou 100(*)	50 ou 40 (*)	>= 1 s	50 ou 40 (*)	0.6 s	40
150	170	750	125 ou 100 (*)	50 ou 40 (*)	>= 1 s	50 ou 40 (*)	0.6 s	40
110	123	550	100	40	>= 1 s	40	0.6 s	Cable: 40 Ligne: 40 ou 31,5 (*)
70	82.5	380	100 ou 80 ou 50 (*)	40 ou 31.5 ou 20 (*)	>= 1 s	40 ou 31.5 ou 20 (*)	0.6 s	Cable: 25 Ligne: 25 ou 20(*)
36	40.5 (42)	200 ou ≥ 170 (*)	100 ou 80(*)	40 ou 31.5 (*)	>= 1.2 s	40 ou 31.5 (*)	3φ: 1.2 s 1φ: 1,2 s	3φ: 31,5 1φ: 4
30	36	170	100 ou 80 (*)	40 ou 31.5 (*)	>= 1.2 s	40 ou 31.5 (*)		
26	30	145	80 ou 63 (*)	31.5 ou 25 (*)	>= 2 s (1)	31.5 ou 25 (*)		
15	17.5	95	63	25	>= 2 s (1)	25	3φ:2 s 1φ: 3,3 s	3φ: 25 1φ: 4
11-12	17.5	95	63	25	>= 2 s (1)	25		
10	12	75	63	25	>= 2 s (1)	25		
6	7.2	60	63	25	>= 2 s (1)	25		

(*): suivant la décision du gestionnaire du réseau

(1): correspondant au temps de déclenchement de la protection en réserve

III) Comparison

The requirements is more stringent for new installations. However, this requirement is part of Demand Connection Code. As consequence, we propose not to include this requirement in the eligible requirements for this incentive.

3.3.3 Equipment Capabilities - Annex 2 – Protections

The bays of the connection facilities are equipped with protections, in order to selectively eliminate a fault within an interval of time determined as the maximum allowable, including the time of operation of the protection, operation of the circuit breaker and extinction of the arc. The values to be respected are mentioned in Annexes 2 of the relevant grid codes.

I) Requirement applicable to existing PGMs

This requirement is detailed in the appendix 2 A of the Federal or Regional Grid Code:

2A. Temps maximal d'élimination d'un défaut par protections pour une installation considérée comme existante existante conformément à l'article 35, §§ 7, alinéa 1er, 8 et 9.

Niveau de tension (kV)	LIGNES, CABLES, TRANSFO *									Défaut JEUX DE BARRES		
	Base (ms)	Refus Protect (ms)	Refus Disj. (ms)	Refus Disj. (ms)	Réserve ligne/ câble suivant (ms)	Réserve jeux de barres suivants (ms) ****		Réenclenchement ligne (ms)		Base (ms)	Réserve du couplage (ms)	
			déf. mono	déf. poly		Déf. mono	déf. poly	mono.	Poly_ phasé		déf. mono.	déf. poly
380	100	100	300	170	1000	500	250	1	10	100	250	170
220	120	120	-	-	1000	600	600	1	***	100	300	300
150	120	120	-	-	1000	600	600	1	***	100	300	300
70	120**	2250	-	-	1000	600	600	-	***	600	-	-
36	120	2250	-	-	1200	1200	1200	-	***	600	-	-
30	120	2250	-	-	1200	1200	1200	-	***	600	-	-
15	1100	3100	-	-	-	1800	1800	-	***	1800	-	-
12	1100	3100	-	-	-	1800	1800	-	***	1800	-	-
10	1100	3100	-	-	-	1800	1800	-	***	1800	-	-

* Transformateur: niveau de tension = tension nominale max. du transformateur

** Pour les lignes, cette valeur est d'application pour l'extrémité située le plus proche du défaut; pour l'autre extrémité, un temps d'élimination de 500 ms est autorisé.

*** A déterminer par le gestionnaire du réseau en fonction des paramètres de réglage des protections des installations avoisinantes

**** Aussi applicable pour défaut entre transformateur de courant et disjoncteur

Remarque: Tous les temps sont les valeurs maximales permises.

II) Requirement applicable to new PGMs

This requirement is detailed in the appendix 2 B of the Federal or Regional Grid Code:

2B. Temps maximal d'élimination d'un défaut par protections pour une installation nouvelle au sens de la législation applicable et de l'article 71, § 2.

Niveau de tension (kV)	LIGNES, CABLES, TRANSFO * Base (ms)	Refus Protect (ms)	Refus Disj.(ms) ***** déf. mono	Refus Disj.(ms) ***** déf. poly	Réserve ligne/câble suivant (ms)	Réserve jeux de barres suivants (ms) **** Déf. mono	déf. poly	Réenclenchement ligne (s) mono.	Pol ypha sé	DEFAUT JEUX DE BARRE S Base (ms)	Réserve du couplage (ms) déf. mono.	déf. poly
380	100	100	300	250	1000	500	270	1	10; 16	100	170	170
220	120	120	300	300	1000	600	600	1	***	100	330	330
150	120	120	300	300	1000	600	600	1	***	100	330	330
110	120**	2250	300	300	1000	600	600	-	***	100	330	330
70	120**	2250	-	-	1000	600	600	-	***	600	-	-
30-36	120**	2250	-	-	1200	1200	1200	-	***	600	-	-
10-29,9kV	1100	3100	-	-	-	1800	1800	-	***	1800	-	-

* Transformateur: niveau de tension = tension nominale max. du transformateur

** Pour les lignes, cette valeur est d'application pour l'extrémité située le plus proche du défaut; pour l'autre extrémité, un temps d'élimination de 500 ms est autorisé.

*** A déterminer par le gestionnaire du réseau en fonction des paramètres de réglage des protections des installations avoisinantes

**** Aussi applicable pour défaut entre transformateur de courant et disjoncteur; ces valeurs sont valables pour les deux extrémités des lignes connectées au jeu de barre concerné

***** Seulement pour les disjoncteurs des barres haute tension raccordées aux jeux de barre

Remarque: Tous les temps sont les valeurs maximales permises.

III) Comparison

The requirements is rather equivalent for new installations. However, this requirement is part of Demand Connection Code. As consequence, we propose not to include this requirement in the eligible requirements for this incentive.

3.3.4 Specific protections scheme agreement

In certain cases, the detailed study (EDS) or the minor change letter indicates that the Grid user must implement some changes in the settings of his protections.

This requirement is defined in point 4.2.1 in the GR RfG for the new PGMs or in article 46 in the Federal Grid code for new and existing PGMs. Consequently, this requirement is identical for new and existing PGMs.

3.4 Category 3 : Voltage and frequency requirements

3.4.1 Frequency withstand capability

I) Requirement applicable to existing PGMs

A power generation unit or nLon-synchronous storage considered as existing in accordance with Article 56, must be able to operate in synchronous mode with the transmission system

The proposed frequency range for existing units are as following:

Frequency Range	Duration
< 48,0 Hz	Islanding
48,0 Hz – 48,5 Hz	Mutual Agreement
48,5 Hz – 51,0 Hz	Unlimited
51,0 Hz – 52,5 Hz	Mutual Agreement
> 52,5 Hz	Islanding

Figure 5: Minimal Frequency withstand capability for existing generating units

II) Requirement applicable to new PGMs

A production unit of type B must be able to stay connected to the grid for a certain time even if the frequency of the grid deviates from 50 Hz. The applicable regulation for this requirement is the article 13.1 (a) of the NC RfG. Elia has defined requirements in line with this regulation in the section 3.1.1 of the GR RfG (see Requirements section) and the article 83§1 of the Federal Grid Code.

Proposed frequency range and minimum time period are as following:

Frequency Range	Duration
[47,5 Hz – 48,5 Hz[	30 minutes
[48,5 Hz – 49,0 Hz[	30 minutes
[49,0 Hz – 51,0 Hz]	Unlimited
]51,0 Hz – 51,5 Hz]	30 minutes

Figure 6 Minimal frequency withstand capability

III) Comparison

This requirement is similar for new and existing PGMs.

3.4.2 Rate of Change of Frequency (ROCOF)

I) Requirement applicable to existing PGMs

This requirement is not applicable for existing unit.

II) Requirement applicable to new PGMs

Regarding the rate of change of frequency withstand capability of a production unit, the RfG states, at the article 13.1(b), the following:

With regard to the rate of change of frequency withstand capability, a power-generating module shall be capable of staying connected to the network and operate at rates of change of frequency up to a value specified by the relevant TSO, unless disconnection was triggered by rate-of-change-of-frequency-type loss of mains protection. The relevant system operator, in coordination with the relevant TSO, shall specify this rate-of-change-of-frequency-type loss of mains protection.

The RoCoF limit was defined by Elia at the section 3.1.2 of the RG for RfG and at the article 83§2 of the Federal Grid Code :

The proposed RoCoF withstand capability is defined considering frequency against time profile as depicted in the Figure 7 with explicit measurement technique taking into consideration 2 Hz/s for a duration of 500 ms. For PGM connected to Transmission Network and relying on Loss Of Main (LOM) detection based on RoCoF measurement, the protection settings should not be conflicting with RoCoF withstanding capabilities requirements unless in case of local event detection (and not an overall power system event).

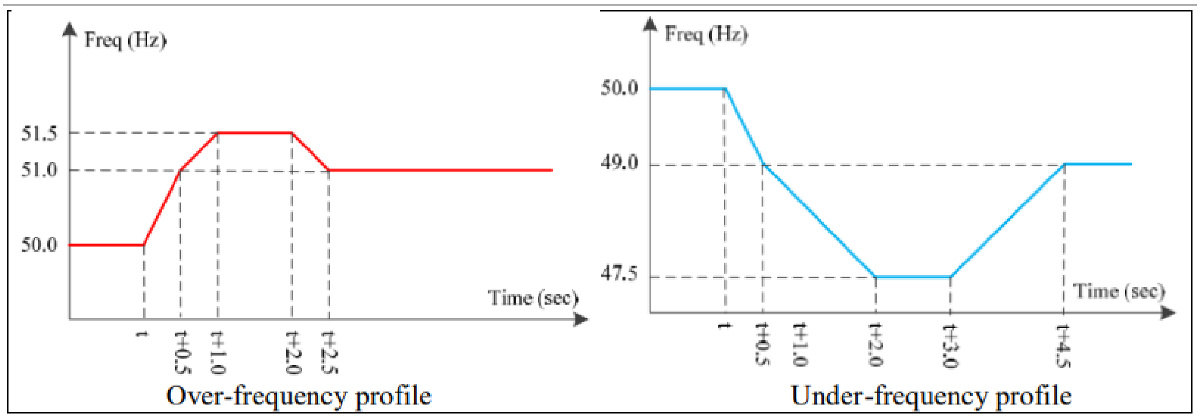


Figure 7 Frequency against time withstanding capabilities

III) Comparison

This requirement is not applicable to existing PGMs. It is then more severe for new PGMs than for existing PGMs.

3.4.3 Maximum allowable power reduction

I) Requirement applicable to existing PGMs

In Accordance with the Article 59 of the FGC, in the event of a sudden change or significant deviation in frequency, no device of a power generation unit or a non-synchronous storage or a non-synchronous storage facility considered as existing, may interfere with the primary control of the system.

II) Requirement applicable to new PGMs

Regarding the maximum allowable power reduction of a production unit, the RfG states, at the article 13.1(b) the following:

§4 : The relevant TSO shall specify admissible active power reduction from maximum output with falling frequency in its control area as a rate of reduction falling within the boundaries, illustrated by the full lines in Figure 8:

I) below 49 Hz falling by a reduction rate of 2 % of the maximum capacity at 50 Hz per 1 Hz frequency drop;

II) below 49,5 Hz falling by a reduction rate of 10 % of the maximum capacity at 50 Hz per 1 Hz frequency drop.

§5 : The admissible active power reduction from maximum output shall:

a) clearly specify the ambient conditions applicable;

b) take account of the technical capabilities of power-generating modules.

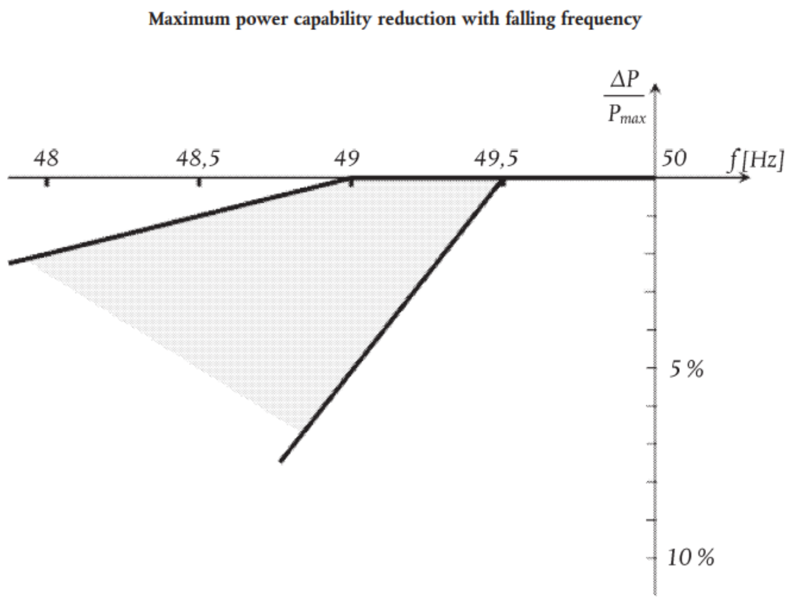


Figure 8 Maximum power capability reduction with falling frequency

The diagram represents the boundaries in which the capability can be specified by the relevant TSO.

The capability was defined by Elia at the section 3.1.5 of the GR RfG and at the article 83§4 of the Federal Grid Code.

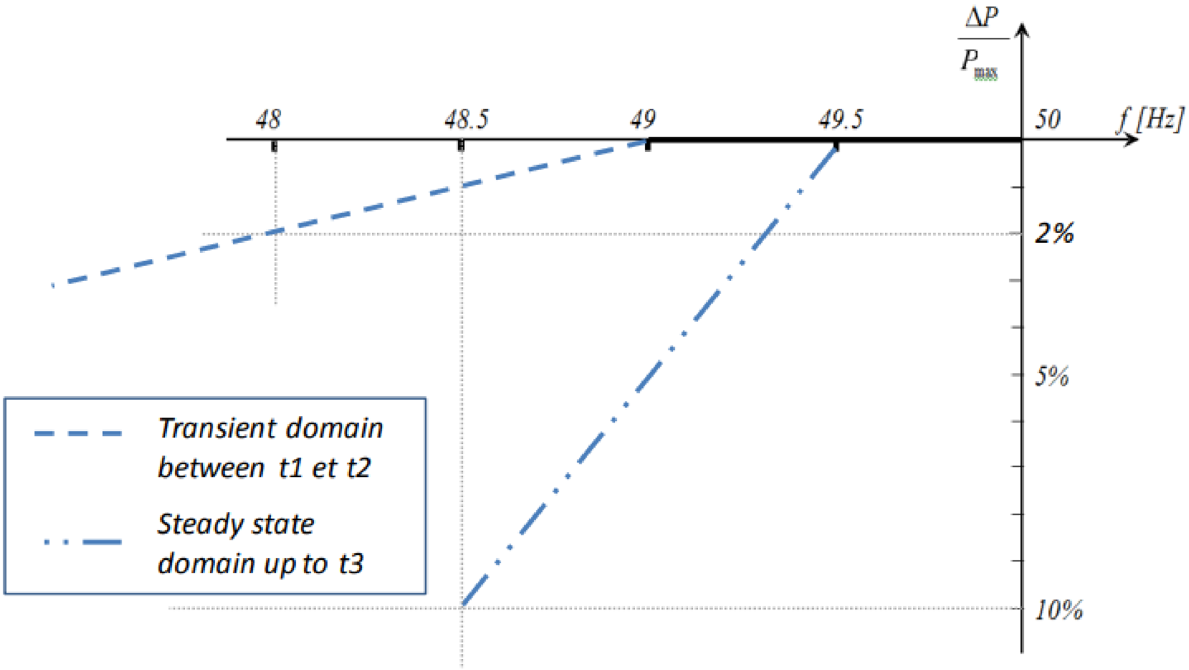


Figure 9 Maximum admissible active power reduction from maximum output for transient and steady state domains

In the case of PPM, no active power reduction is admissible above 49 Hz, below 49 Hz a maximum active power reduction of 2%/Hz is admissible (although it is not expected as PPMs have no specific technology limitation within this range).

In the case of SPGM, in order to take into consideration system needs and technology limitations, two profiles are covering separately transient domain and steady state domain. In case no technical limitation to maintain active power are existing, active power reduction should be avoided. Figure 10 covers the requirement during the transient period where the PGM are expected to respect the limit of 2 % active power reduction per Hz from maximum output for a duration up to 30 seconds this would allow other frequency control means to act. During the steady state period, the PGM are allowed if needed to reduce the active power from maximum power output respecting the limit of 10% / Hz.

	Parameter	Requirement
Transient domain	Frequency threshold	49 Hz
	Slope	2 % / Hz
	t 1	≤ 2 seconds
	t 2	30 seconds
Steady state domain	Frequency threshold	49.5 Hz
	Slope	10 % / Hz
	t 3	30 minutes

Figure 10 Maximum admissible active power reduction from maximum output

The standard applicable ambient conditions are defined as following:

- Temperature: 25 °C
- Altitude between 400 m and 500 m
- Humidity: between 15 and 20 g H2O/Kg

Compliance will be based on homologation certification or on a case-by-case base with the power generator facility owner.

III) Comparison

This requirement is less severe for new PGMs than for existing PGMs.

3.4.4 Voltage withstand capability

I) Requirement applicable to existing PGMs

In alignment with Article 65 §2, for any connection point voltage between 0.9 and 1.05 of the normal operating voltage, the generating unit considered as existing must ensure an unlimited time period for operation, except in the case of a limitation due to restrictions on the generator voltage or the generator stator current. A limitation on the stator current may not intervene in the fast voltage setting.
The limitation on the voltage at the generator terminals must be in alignment with rules described in other articles mainly during Faults or Voltage dips.

II) Requirement applicable to new PGMs

The voltage withstand capability requirement is described at the section 2.1.1 of the GR RfG.
This requirement should be met at the connection point. Voltage withstand capabilities are only mentioned in NC RfG for type D PGMs (art 16.2), similar capabilities (cfr. Table 1) are necessary for other PGMs, in order to guarantee safe operation of the grid.

	Voltage Range	**Time period for operation**
Voltage ranges below 300kV	0.85 pu – 0.90 pu	60 minutes
	0.90 pu – 1.118 pu	Unlimited
	1.118 pu – 1.15 pu	To be agreed between the TSO and the facility owner in the connection agreement
Voltage ranges above 300kV	0.85 pu – 0.90 pu	60 minutes
	0.90 pu – 1.05 pu	Unlimited
	1.05 pu – 1.10 pu	To be agreed between the TSO and the facility owner in the connection agreement

Table 1: Voltage withstand capabilities

The following base values are to be considered as reference for the pu values reported in the Table 1 for PGM connected to TSO network:

400kV
220kV
150kV
110kV
70kV
36kV

In case broader or longer voltage withstand capabilities are technically and economically feasible, the power-generating facility owner shall not unreasonably refuse to put them at disposal of the relevant system operator.

III) Comparison

This requirement is more severe for new PGMs than for existing PGMs. It is now asked to the PGMs to stay connected longer to the network during voltage deviations.

3.4.5 LFSM-O

I) Requirement applicable to existing PGMs

This requirement is not defined nor applicable for existing generating unit

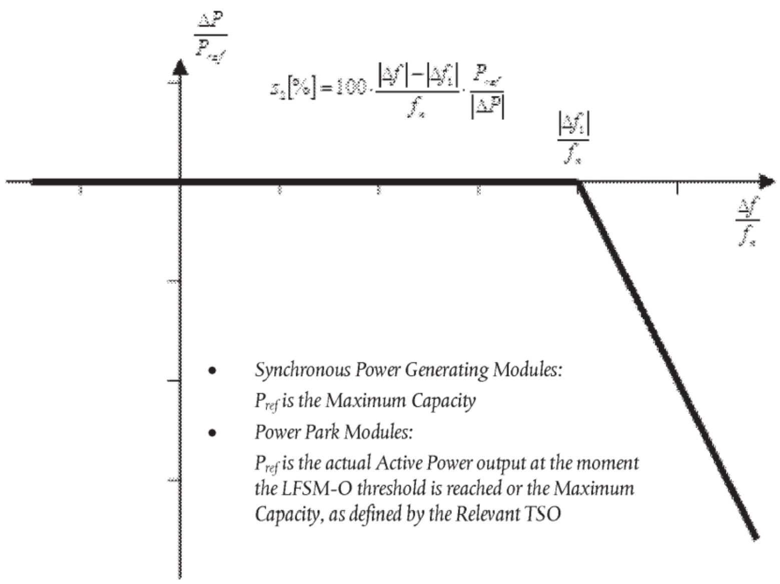
II) Requirement applicable to new PGMs

The LFSM-O requirement is described at the section 3.1.4 of the GR RfG and at the Article 88§1 of the Federal Grid Code.

Presentation of the active power response to frequency variations

[…] the power-generating module shall be capable of activating the provision of active power frequency response according to figure 1 at a frequency threshold and droop settings specified by Elia[…]

Active power frequency response capability of power-generating modules in LFSM-O



P_{ref} is the reference active power to which ΔP is related and may be specified differently for synchronous power-generating modules and power park modules. ΔP is the change in active power output from the power-generating module. f_n is the nominal frequency (50 Hz) in the network and Δf is the frequency deviation in the network. At overfrequencies where Δf is above Δf_1, the power-generating module has to provide a negative active power output change according to the droop S_2.

The NC RfG also mentions that :

[…]

- the power-generating module shall be capable of activating a power frequency response with an initial delay that is as short as possible. If that delay is greater than two seconds, the power-generating facility owner shall justify the delay, providing technical evidence to the relevant TSO

[...]

- the power-generating module shall be capable of operating stably during LFSM-O operation. When LFSM-O is active, the LFSM-O setpoint will prevail over any other active power setpoints. [...]

Definition of the parameters of the response of the PGM

The response of the PGM takes the following aspects in consideration. They are represented at the figure 11.

- The dead time (Td) covers the time from the frequency change event until the beginning of the response;
- The step response time (Tsr) covers the time from the frequency change event until the instant until the response reaches the tolerance range for the first time;
- The settling time (Ts) covers the time from the frequency change event until the instant, from where on the corresponding response remains within the tolerance band of the set value.

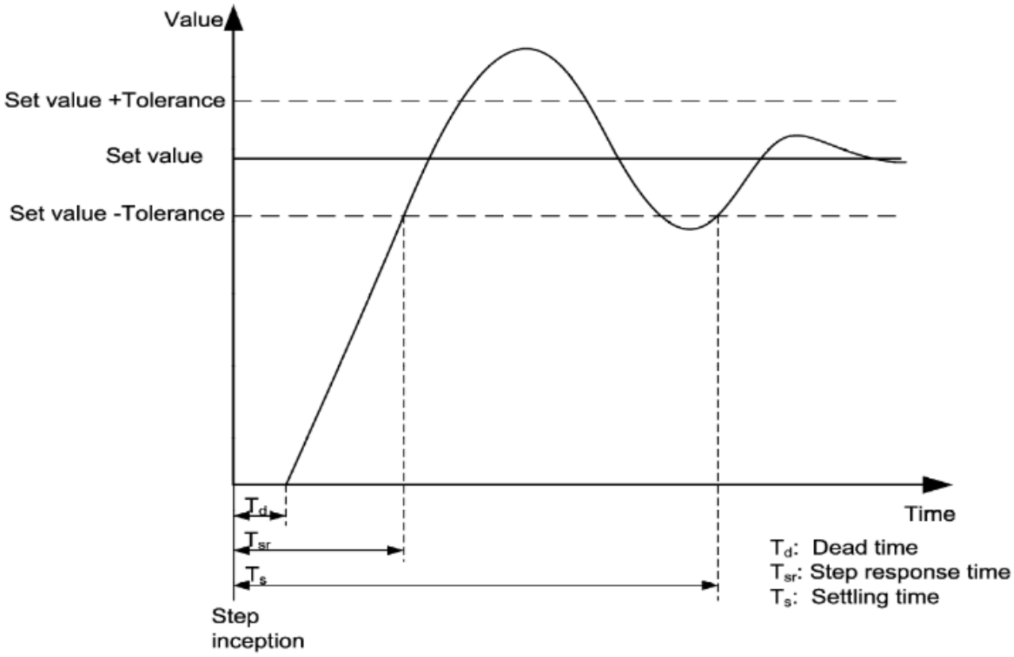


Figure 11: Definition of PGM response parameters

Definition of the droop

The droop is defined as per the following formula:

$$s[\%] = 100.\frac{|\Delta f| - |\Delta f1|}{fn}.\frac{Pref}{|\Delta P|}$$

Where ΔP is the change in active power output from the power-generating module. f_n is the nominal frequency (50 Hz) in the network and Δf is the frequency deviation in the network. At over frequencies where Δf is above Δf_1, the power-generating module has to provide a negative active power output change according to the droop s.

NC RfG allows two options for defining Pref for power park modules: either Pmax or the actual active power output at the moment the LFSM threshold is reached. In order to achieve an equitable active power response to a high or low frequency event (regardless of the number of power generating modules in operation) the reference active power Pref is therefore assigned based on the expected capacity operation:

- Pref is by default the actual active (at the moment of activation) for PPM;
- Pref can be alternatively defined as Pmax for PPM expected to operate mostly at or near maximum capacity (example for offshore wind farms connected to Elia Network).

The automatic disconnection and reconnection as referred in 13-2(b) of the NC RfG are not allowed by default. The below requirements are common for all PGM:

- The droop setting is 5% and selectable within the range 2% and 12%.
- Frequency activation threshold : 50.2 Hz;
- Dead time : by default as fast as technically possible (no intentional delay), specific provisions could be applicable in agreement with the TSO;
- Once the minimum regulating level is reached, the operation mode shall be continued at the same level (no further decrease for further frequency increase).

The requirements for SPGM units are the following:

Parameters (SPGM)	For power increase	For power decrease
Step response time	≤ 5 minutes for an increase of active power of 20 % Pmax (note that the response shall be as fast as technically possible, for example a slow reaction is not applicable in the case of an increase shortly – a few seconds – following a decrease phase)	≤ 8 seconds for a decrease of active power of 45% Pmax
Settling time	≤ 6 minutes for an increase of active power (note that the response shall be as fast as technically possible, for example a slow reaction is not applicable in the case of an increase shortly – a few seconds – following a decrease phase)	≤ 30 seconds for a decrease of active power

The requirements for PPM units are the following:

Parameters (PPM)	For power increase	For power decrease
Step response time	*For wind generation:* ≤ 5 seconds for an increase of active power of 20 % Pmax (note that the response shall be as fast as technically possible, for example for operational points lower than 50% of Pmax, a reaction can be slower but shall remain faster than 5 seconds) *For the rest:* ≤ 10 seconds for an increase of active power of 50 % Pmax	≤ 2 seconds for a decrease of active power of 50 % Pmax
Settling time	≤ 30 seconds for an increase of active power	≤ 20 seconds for a decrease of active power

For gas turbines and internal combustion engines whose technical specifications do not allow to follow the default requirements described above, the following alternative requirements are applicable:

- If Pmax ≤2 MW, at least 1.11% Pmax per second (increasing or decreasing frequency)
- If Pmax> 2 MW, at least 0.33% of Pmax per second (increasing or decreasing frequency)

III) Comparison

This requirement is only applicable to new PGMs.

3.4.6 Reactive Power Capability

I) Requirement applicable to existing PGMs

In alignment with Article 65 §1, every power generation unit considered as existing, for any value of active power likely to be injected into the transmission system between the technical minimum and the maximum connection power, at the normal operating voltage must be able to produce or to absorb at the connection point a reactive power of at least -0.1 Pmax and 0.45 Pmax.

II) Requirement applicable to existing PPMs

For PPMs in accordance with Article 58§2 that refers to the Elia requirements, any generating units considered as existing, for any value of the active power between Min and Maximum at nominal Voltage, they must be able to respectively absorb or supply at the point connection, reactive power includes at least,

- -0.2 Pmax and 0.35 Pmax.
- -20%<Q<+35% on-shore WF
- -25%<Q<+25% offshore WF

III) Requirement applicable to new PPMs

The requirement was described by Elia at the section 4.4.2 of the GR RfG and at the Article 89 of the FGC.
The required reactive capabilities should be met at the HV side of the step up transformer if existing; otherwise they should be met at the inverter terminals.
For PPMs of type B, the requirement for the reactive power provision capability is determined by the Q-P profile represented in Figure 11 where the limitations are based on nominal current at high active power output and by a power factor (cos(phi)) defined by the 2 points at Q= -33% and +33% of PD, where PD is the maximum active power that can be produced in case of the maximum requested reactive power output (hence equal to 0.95*Snom).
With respect to voltages different from 1pu, the required U/Uc-Q/PD profile is represented in Figure 12.
Note that the effective resulting available capability of the PPM at the connection point (that can be different than the one at the PPM terminal) should be communicated, demonstrated and put at disposal of the relevant system operator during the connection procedure.
In case the PPM unit has the capability of voltage regulation for wider values than the minimum requirement area shown in Figure 11, the PPM owner shall not unreasonably withhold consent to put them at disposal of the RSO, taking account of their economic and technical feasibility. The unit is therefore expected to not limit its capabilities to comply with the minimum requirement but to use the full capability to support the system stability as stated in its agreement.
In this case, the settings of the controllers should be agreed with the relevant system operator

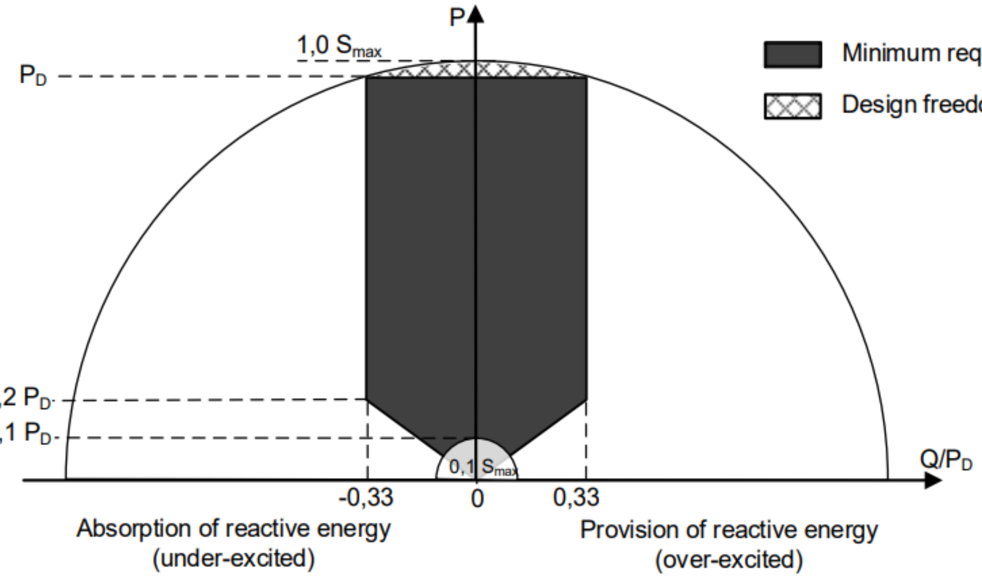


Figure 11 : Capability curve for PPM type B

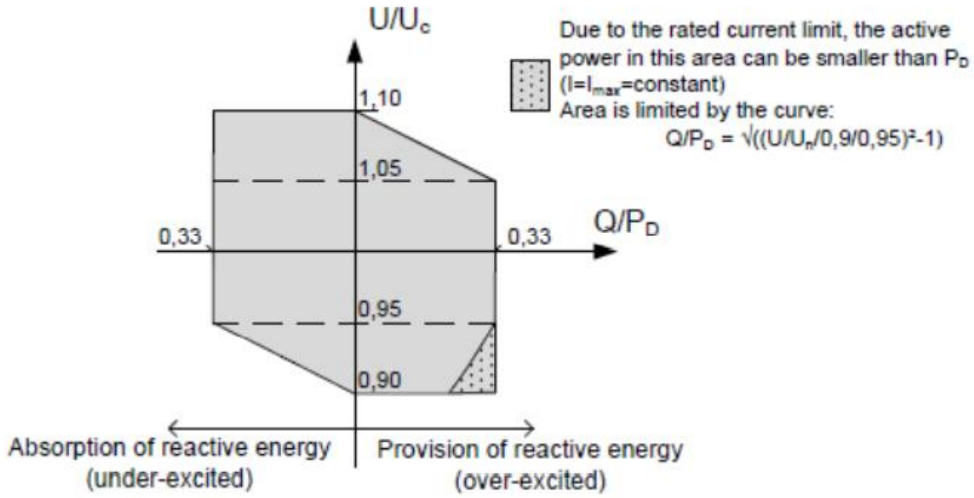


Figure 12 U/U_c – Q/P_D profile for type B PPM in order to visualize reactive power requirements for voltages different from 1 pu.

IV) Requirements applicable to new SPGMs

The required reactive capabilities should be met at the HV side of the SPGM step up transformer if existing; otherwise it should be met at the alternator terminals. The requirements apply to SPGM connected to the Elia network. For SPGMs of type B, the requirement for the reactive power provision capability is determined by the Q/P profile represented in Figure 13 where the limitations are based on nominal current at high active power output and by a reactive power (Q) limited to -33% and +33% of PD, where PD is the maximum active power that can be produced in case of the maximum requested reactive power output (hence equal to 0.95*Snom).

With respect to voltages different from 1pu , the required U/Uc-Q/PD profile is represented in Figure 14.

Note that the effective resulting available capability of the SPGM at the connection point (that might be different than the one at the SPGM terminals) should be communicated, demonstrated and put at disposal of the relevant system operator during the connection procedure. The SPGM owner shall not unreasonably withhold consent to use wider reactive capabilities, taking account of their economic and technical feasibility. The unit is therefore expected to not limit its capabilities to comply with the minimum requirement but to use the full capability to support the system stability as stated in its agreement.

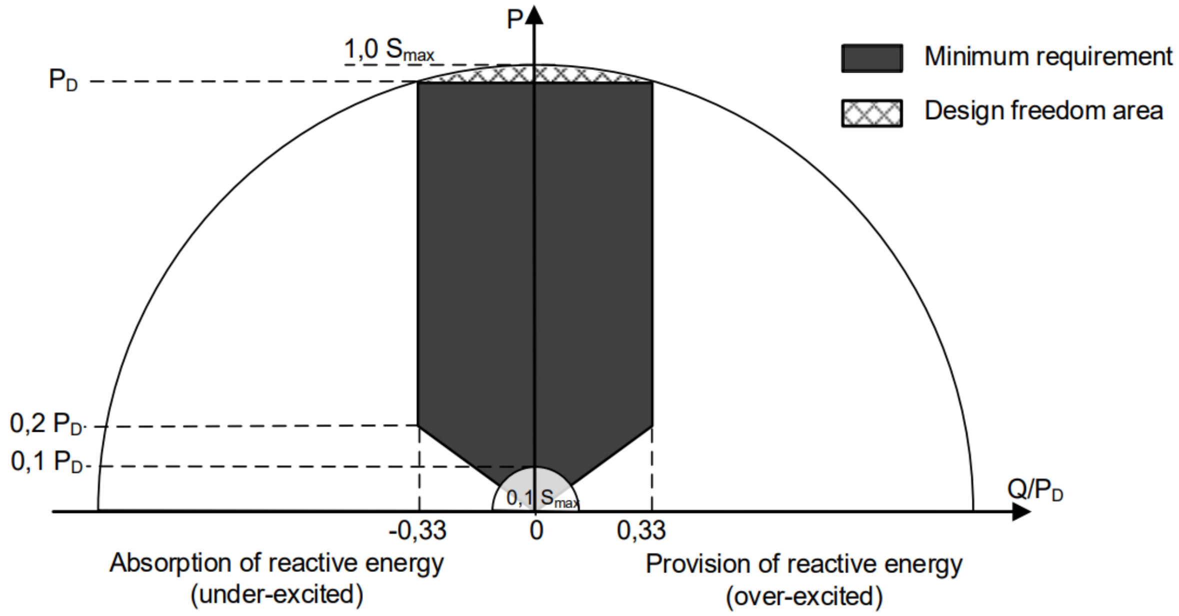


Figure 13 Capability curve for SPGM type B

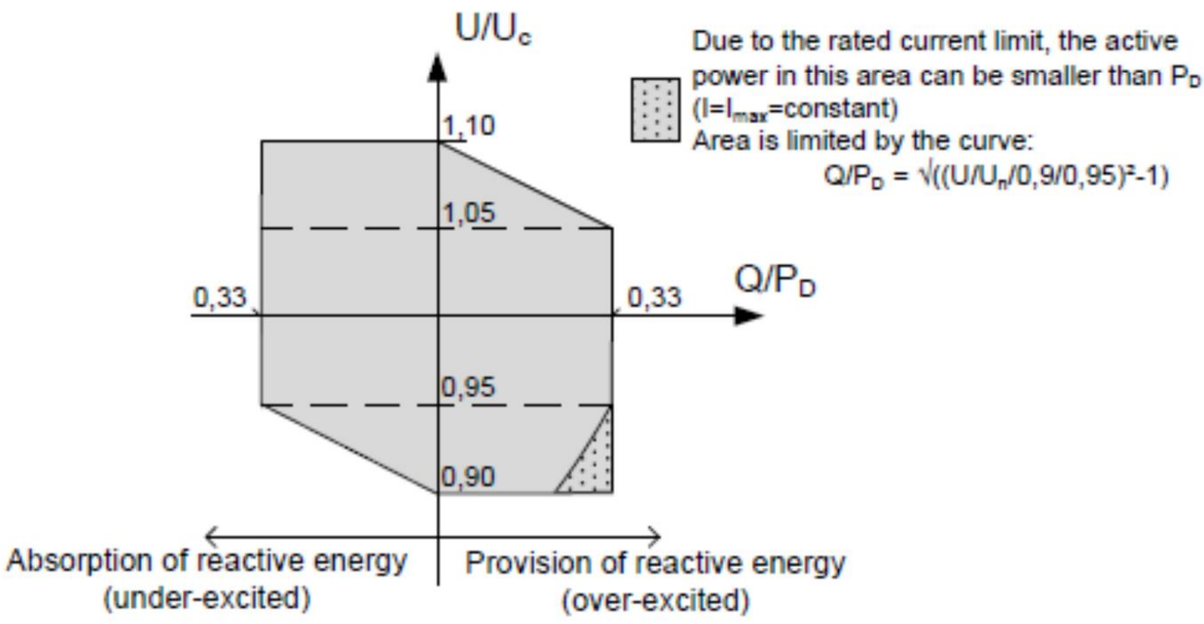


Figure 14 U/Uc – Q/PD profile for type B SPGM in order to visualize reactive power requirements for voltages different from 1 pu.

V) Comparison

This requirement is considered as more stringent for both new PPMs and SPGMs.

3.4.7 Voltage control

I) Requirement applicable to existing PGMs

In accordance with Art. 69 of the FGC, a PGM with a Pmax lower than 25 MW and which does not have a MVAr contract should operate at a reactive power setpoint of 0 MVAr.

II) Requirements applicable to new PGMs

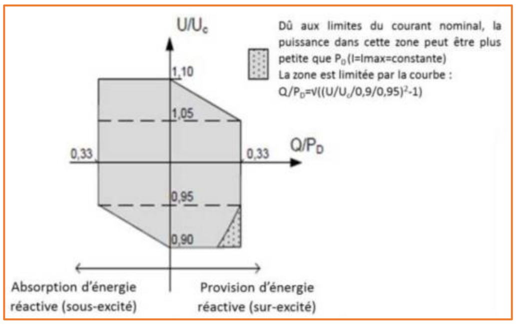
This requirement is optional for PPMs.
In line with the article 17-2(b) of the RfG :

> *with regard to the voltage control system, a synchronous power-generating module shall be equipped with a permanent automatic excitation control system that can provide constant alternator terminal voltage at a selectable setpoint without instability over the entire operating range of the synchronous power-generating module.*

Elia completed the requirement at the article 89§2 of the FGC and at the section 4.3.2 of the Requirements of General Application.

According to the article 89§2 of the FGC, an SPGM must be able to operate in one of the two following modes :

- Qfix : maintain a constant reactive power within the P/Q capabilities
- Q(U) : maintain a constant voltage at the terminals of the alternator



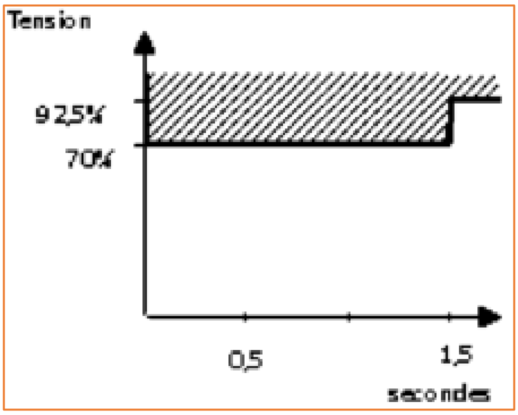
III) Comparison

This requirement is more stringent for new SPGMs. For PPMs, this requirement is not applicable

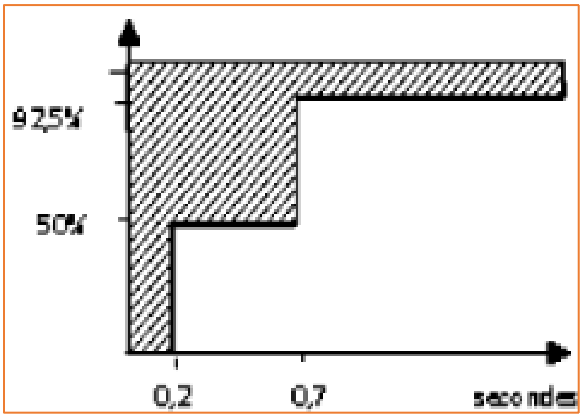
3.4.8 Fault Ride Through

I) Requirement applicable to existing PGMs

In Accordance with Article 58§1 of the federal grid code, a generating unit considered to be existing must be able to operate in its entire operating range in synchronous mode with the transmission system, when the voltage at the connection point, expressed as a percentage of the nominal voltage at this point, during a voltage dip of limited of limited magnitude, remains within the hatched area of the diagram below.



In Accordance with Article 58§1, a generating unit considered to be existing must be capable of operating throughout its operating range in synchronous mode with the transmission system when the voltage at the connection point, expressed as a percentage of the nominal voltage at this point, remains, during a voltage dip of significant magnitude, within the hatched area of the diagram below.:



II) Requirement applicable to new PPMs

In line with the NC RfG, Elia defined the fault-ride-through profile for PPMs at the section 4.4.1 of the GR RfG and at the Article 94 of the FGC:

This requirement defined by Elia as TSO should be met at the connection point.

The PPM unit should be able to support the network during fast transient voltages and network short-circuits for which the profile of the voltage versus time is referred as Fault-Ride-Through (FRT). PPM shall fulfil the requirements in Figure 15 (the evolution of the minimum voltage at the Connection Point), where the PPM shall remain connected to the grid as long as the voltage of the phase having the lower voltage is above the profile of Figure 10. It is recommended however to remain connected as long as the technical capability of the PPM would allow it. The same profile applies for asymmetrical faults. The proposed fault-ride-through parameters are presented in Table 4. A voltage U=1 pu represents the rated voltage (phase-to-phase) at the connection point.

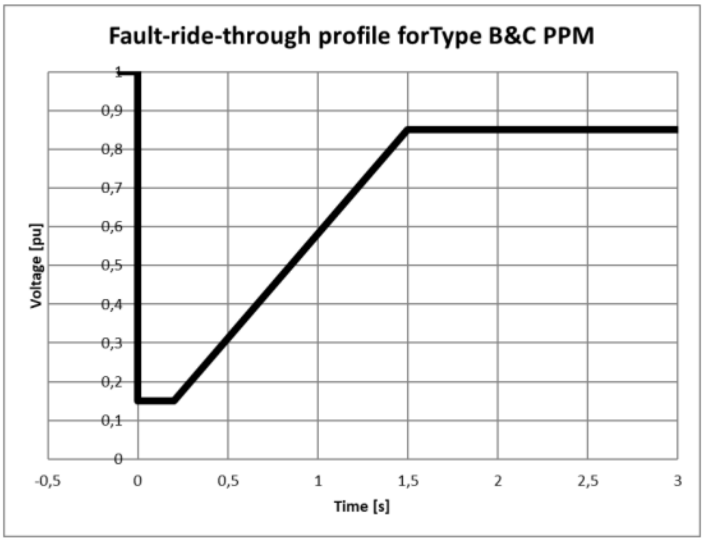


Figure 15 FRT requirement for PPM type B and C

Table 4: Parameters of the FRT requirements for PPM of type B and C.

Voltage parameters [pu]	Time parameters [seconds]
Uret=Uclear=Uret1= 0.15	tclear=trec1=trec2= 0.2
Urec2 = 0.85	t_{rec3}=1.5

III) Requirement applicable to new SPGMs

In line with the NC RfG, Elia defined the fault-ride-through profile for PPMs at the section 4.3.3 and at the Article 90 of the FGC:

This requirement defined by Elia as TSO should be met at the connection point.

The SPGM should be able to support the network during fast transient voltages and network short-circuits for which the profile of the voltage versus time is referred as Fault-Ride-Through (FRT). SPGM shall fulfil the requirements in the figure below, where the SPGM shall remain connected to the grid as long as the voltage of the phase having the lower voltage is above the profile.

It is recommended however to remain connected as long as the technical capability of the PGM would allow. The same profile applies for asymmetrical faults. The proposed Fault-Ride-Through parameters are presented in the figure below. A voltage U=1 pu represents the rated voltage (phase-to-phase) at the connection point.

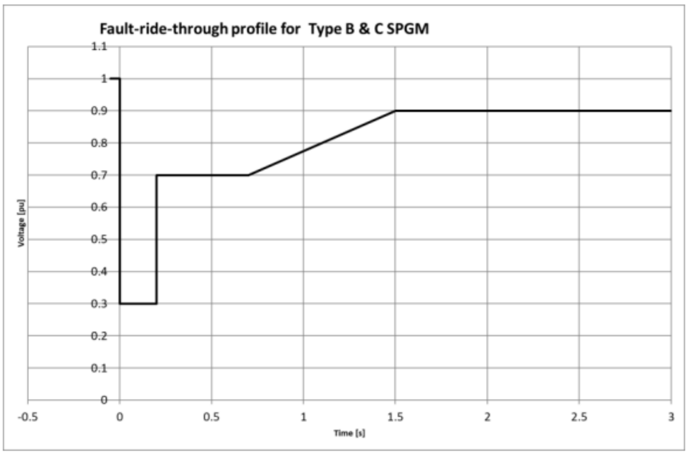


Figure 9: FRT requirement for SPGM type B and C.

Table 3: Parameters of the FRT requirements for SPGM of type B and C.

Voltage parameters [pu]	Time parameters [seconds]
Uret = 0.3	tclear = 0.2
Uclear = 0.7	Trec1=tclear
Urec1 = 0.7	trec2=0.7
Urec2 = 0.9	trec3 = 1.5

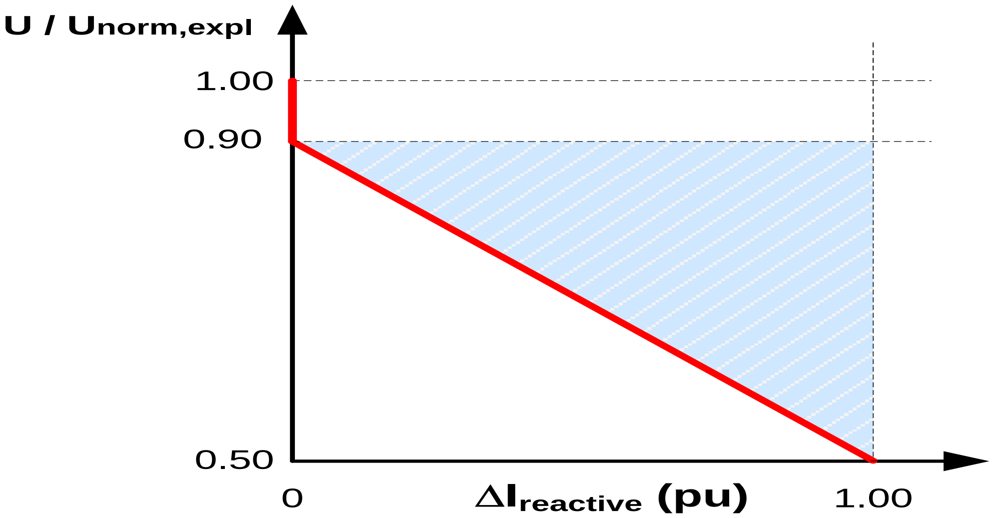
IV) Comparison

This requirement is **less** severe for new PGMs than for existing ones.

3.4.9 Fault current & dynamic voltage support

I) Requirement applicable to existing PGMs

In accordance with Article 58§2 that refers to the Elia requirements, any generating units considered as existing is ensure an injection of additional reactive current determined by the figure below, where for voltages between 1 and 0.9 in pu of $U_{nom,expl}$, the wind park should follow the normal voltage droop control mode



The magnitude of the additional reactive current injection ($\Delta I_{reactive}$) shall be determined as a linear function of the positive or negative voltage change (ΔU) with respect to the pre-disturbance value with total reactive current injection limited to 100% of rated current

II) Requirement applicable to new PGMs

This requirement is described at the section 4.4.3 of the GR RfG and at the Article 93§3 of the FGC and only applies to the Power Park Modules (PPMs).

The PPM unit shall be able to inject/absorb additional reactive current compared to the pre-fault state during low and high voltage conditions up to the maximum of its capability. The additional injected/absorbed reactive current shall be function of the positive sequence voltage at the connection point depending on the available capability of the PPM. The resulting fast current injection at the point of connection should be calculated and shared with the TSO by simulation in terms of active and reactive current components. The requested additional reactive current characteristic injection is illustrated in Figure 13. For voltages within the deadband [$\Delta V- act$, $\Delta V+ act$], the PPM unit should follow the normal voltage control mode. The injection or absorption of additional reactive current shall be delivered by the PPM with a minimal delay from the detection of the over/undervoltage, $tIq\ act$ .The functionality should remain active for a minimum time of $tIq\ on$ and can be deactivated if the voltage returns and remains within [$\Delta V- act$, $\Delta V+ act$] for a time longer than $tIq\ off$. The parameters of this functionality lying within the normal operational range of the installation as well as the delays of activation, dead band and duration of the activation are to be agreed during the connection process on a case by case level and fixed in the individual connection contract with the relevant system operator (it might be the DSO or Elia) in coordination with the relevant TSO. The parameter setting of this functionality is therefore site specific.

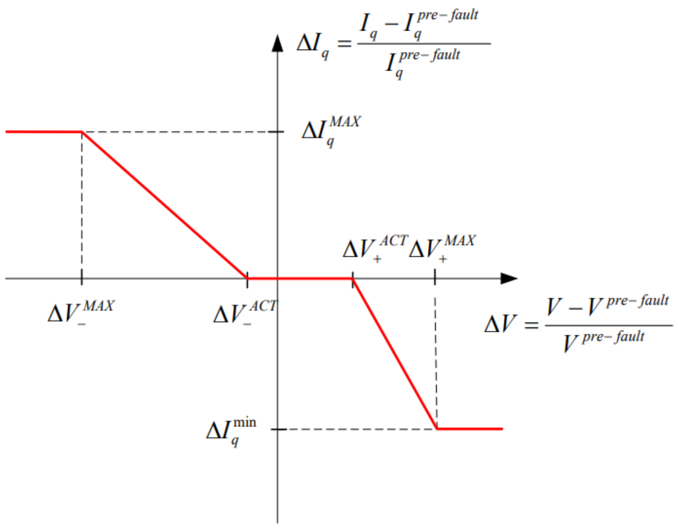


Figure 13: Injection of additional reactive current.

For the reliable detection of asymmetric faults, the PPM unit shall contribute to the fault with positive, negative and zero-sequence current. The short-circuit contribution is to be agreed during the connection process on a case by case level and fixed in the individual connection contract with the relevant system operator in coordination with the relevant TSO. The parameter setting of this functionality is therefore site specific

III) Comparison

This requirement is more severe for new PGMs than for existing PGMs.

3.4.10 Oscillation and damping Control

I) Requirement applicable to existing PGMs

In alignment with Art. 69 § 1. the transmission system user and the transmission system operator shall agree on the minimum general technical requirements, control parameters and specifications for aspects that are directly related to the safety, reliability and efficiency of the transmission system the minimum general technical requirements, control parameters and functional specifications to be adopted with respect to the transmission system user's facilities, including in particular for power system stabilizer as well as dynamic and static stability

II) Requirement applicable to new PGMs

Same requirements is applicable as for existing PGMs.

III) Comparison

The requirement is identical for new and existing PGMs.

3.4.11 Post-fault active power recovery

I) Requirement applicable to existing PGMs

In accordance to the Article 58§2 that refers to the Elia requirement, any generating unit considered as existing must follow an active power recovery, after fault clearance, with a gradient of at least 0.2 p.u/s

II) Requirement applicable to new PPMs

This requirement is defined at the article 20-3 of the NC RfG :

Type B power park modules shall fulfil the following additional requirements in relation to robustness:

a) the relevant TSO shall specify the post-fault active power recovery that the power park module is capable of providing and shall specify:
   - i. when the post-fault active power recovery begins, based on a voltage criterion;
   - ii. a maximum allowed time for active power recovery; and
   - iii. a magnitude and accuracy for active power recovery;

b) the specifications shall be in accordance with the following principles:
   - i. interdependency between fast fault current requirements according to points (b) and (c) of paragraph 2 and active power recovery;
   - ii. dependence between active power recovery times and duration of voltage deviations;
   - iii. a specified limit of the maximum allowed time for active power recovery;
   - iv. adequacy between the level of voltage recovery and the minimum magnitude for active power recovery; and
   - v. adequate damping of active power oscillations.

This requirement was completed by Elia at the section 4.4.4 of the GR RfG and at the Article 95 of the FGC:

For PPMs, the parameters of this functionality should be agreed during the connection process with the relevant TSO on a case-by-case approach and fixed in the individual connection contract. These parameters are thus site specific requirement.

III) Requirement applicable to new SPGMs

This requirement is defined at the article 17-3 of the NC RfG :
With regard to robustness, type B synchronous power-generating modules shall be capable of providing post-fault active power recovery. The relevant TSO shall specify the magnitude and time for active power recovery.

This requirement was completed by Elia at the section 4.3.4 of the GR RfG and at the Article 91 of the FGC:
It is required that SPGM of Type B are able to provide post-fault active power recovery as the unit remains connected to the network.
For SPGMs, the values of the magnitude and time for the active power recovery will be a site specific specification: it is to be agreed during the connection process with the TSO on a case by case level and fixed in the individual connection contract.

IV) Comparison

It is considered that the requirements applicable to new PGMs are similar to the requirements applicable to existing PGMs.

3.5 Category 4: Information exchange

I) Requirement applicable to existing PGMs

This requirement is not defined nor applicable for existing generating units

II) Requirement applicable to new PGMs

This requirement was defined by Elia at the section 4.2.2 of the GR RfG. According to this document, at least the following signals must be communicated to Elia by the GU :

- position of the circuit breakers at the connection point (or another point of interaction agreed with the Elia);
- active and reactive power at the connection point (or another point of interaction agreed with the Elia); and
- net active and reactive power of power generating facility in the case of power generating facility with consumption other than auxiliary consumption.

III) Comparison

This requirement is more stringent for new PGMs.

3.6 Category 5: Balancing/Congestion management requirements

Remote Control reduction of Active Power

I) Requirement applicable to existing PGMs

This requirement is not defined nor applicable for existing generating units

II) Requirement applicable to new PGMs

The description of this requirement is given at the article 14.2 of the NC RfG.

Type B power-generating modules shall fulfil the following requirements in relation to frequency stability:

a) to control active power output, the power-generating module shall be equipped with an interface (input port) in order to be able to reduce active power output following an instruction at the input port; and
b) the relevant system operator shall have the right to specify the requirements for further equipment to allow active power output to be remotely operated.

The GR RfG also includes a reference to this requirement at the section 4.1.1 :

Respecting the applicable regional regulatory provisions, the right to request additional equipment to allow active power to be remotely operated will be asserted by Elia as relevant system operator in due time.

III) Comparison

This requirement is more stringent for new PGMs.

3.7 Category 6 : Power quality requirements

The power quality requirements are currently described in the connection contract for both existing and new PGMs. There is, as consequence, no difference between the requirements applicable to new or existing PGMs.

3.8 Category 7 : Emergency & restoration requirements

3.8.1 Automatic Connection

I) Requirement applicable to existing PGMs

This requirement is not applicable to existing PGMs

II) Requirement applicable to new PGMs

The conditions to allow a PGM of type B to connect to the network are the following:

1) Frequency to be within 49.9 Hz and 50.1 Hz; and
2) Voltage to be within 0.85 Un and 1.10 Un; and
3) Minimum observation time where the above conditions are satisfied of 60 seconds.

III) Comparison

This requirement is more stringent for new PGMs.

3.8.2 Automatic Reconnection

I) Requirement applicable to existing PGMs

This requirement is not applicable to existing PGMs

II) Requirement applicable to new PGMs

The conditions to allow a PGM of type B to connect to the network are the following:

1) Frequency to be within 49.9 Hz and 50.1 Hz; and
2) Voltage to be within 0.85 Un and 1.10 Un; and
3) Minimum observation time where the above conditions are satisfied of 60 seconds.
4) Presence of a signal from Elia allowing the PGM to inject power on the grid.

III) Comparison

This requirement is more stringent for new PGMs.

3.9 Category 8 : Protection requirements

3.9.1 Loss of Main by ROCOF

I) Requirement applicable to existing PGMs

This requirement is not applicable to existing units.

II) Requirement applicable to new PGMs

Elia described this requirement in the article 3.1.3 of the GR RfG and at the article 83 of the Federal Grid Code. For all PGM, a LOM based on RoCoF may be allowed and defined by the RSO in coordination with the TSO as per the provisions in Article 13. (1) b. In this case, the RoCoF measurement used for LOM protection is used to detect islanding and is not to be confused with the RoCoF immunity requirement defined in the section 3.1.2.

For PGM connected to Elia Network and relying on LOM detection based on RoCoF measurement, the threshold should be higher than 2 Hz/s for a duration of 500 ms. Note that other alternative LOM detection settings should not conflict with frequency withstand capabilities requirements unless in case of local event detection (and not an overall power system event). For technical and safety reasons, lower thresholds can be discussed on a case-by-case basis.

For the type B, C and D production units, a LoM by RoCoF protection can be implemented to avoid islanding of a part of the network. However, this is not required by Elia.

III) Comparison

This requirement is not mandatory for type B PGMs and, as consequent, it is not stricter for new PGMs than for existing ones.

3.9.2 Verification of the presence of a decoupling protection (Elia standards)

I) Requirement applicable to existing PGMs

For existing type B PGMs, the requirements are described in the following table :

	Threshold	Temporization

Frequency relay		
f<	47.5 Hz	0 ms
f>	51.5 Hz	0 ms
Voltage relay		
U>	110% Un or 100% Umax	0-100 ms
U<t	70% Un	1.5 - 3 s
U<<t	30% Un	300 ms
Uo>[3]	5 - 25%	2 - 5 s

II) Requirement applicable to new PGMs

For new type B PGMs, the requirements are described in the following table :

	Threshold	Temporization
Frequency relay		
f<	47.5 Hz	0 ms
f>	51.5 Hz	0 ms
Voltage relay		
U>	110% Un	100 ms
U<t	70% Un	1.5 - 3 s
U<<t	15% Un	300 ms
Uo>[4]	5 - 25%	2 - 5 s

III) Comparison

This requirement is very similar for new and existing PGMs.

[3] optional
[4] optional

3.10 Summary of the gap analysis

The gap analysis between type B requirements applicable to existing and PGMs can be summarized in the table below:

Category of requirements		Sub category	GAP analysis	Remark	Eligible for incentive
Category 1	Data questionnaire & Models	Data questionnaire	Small changes		
		Models	More stringent		X
Category 2	Internal compliance proof (RGIE) & protection scheme	RGIE	Identical		
		Annex 1 : Icc max	More stringent	Not in the scope : DCC	
		Annex 2 : Protections	Small changes	Not in the scope : DCC	
		Protection schemes	Identical		
Category 3	Voltage & frequency requirements	Frequency withstand capability	Small changes		
		Rate of change of frequency (ROCOF)	More stringent		X
		Maximal allowable power reduction	Less stringent		
		LFSM-O	More stringent		X
		Voltage withstand capability	More stringent		X
		Voltage control (SPGM)	More stringent		X
		Reactive power capability	More stringent		X
		Fault Ride Trough	Less stringent		
		Fault current & dyn. Voltage support (PPM)	More stringent		X
		Oscillation and damping control	Small changes		
		Post-fault power recovery (PPM)	More stringent		X
Category 4	Information exchange / Telecom requirements	Information exchange	More stringent		X
Category 5	Balancing/congestion man. requirements	Remote control reductions	More stringent		X
Category 6	Power quality requirements		Identical		
Category 7	Emergency & restoration requirements	Automatic connection	More stringent		X
		Automatic reconnection	More stringent		X
Category 8	Protections requirements	Loss of main protection by RoCoF	Identical		
		Decoupling protection	Small changes		

Figure 16 : gap analysis between type B requirements applicable to new PGMs compared to requirements applicable to existing PGMs

We considered as eligible for this incentive the requirements applicable to new PGMs type B being new or more stringent compared to the requirements applicable to existing PGMs type B

We also excluded the two requirements coming from the Demand Connection code.

The requirements eligible for this incentive are summarized in the table below:

Category of requirements		Sub category	GAP analysis	Eligible for incentive
Category 1	Data questionnaire & Models	Models	More stringent	X
Category 3	Voltage & frequency requirements	Rate of change of frequency (ROCOF)	More stringent	X
		LFSM-O	More stringent	X
		Voltage withstand capability	More stringent	X
		Voltage control (SPGM)	More stringent	X
		Reactive power capability	More stringent	X
		Fault current & dyn. Voltage support (PPM)	More stringent	X
		Post-fault power recovery (PPM)	More stringent	X
Category 4	Information exchange / Telecom requirements	Information exchange	More stringent	X
Category 5	Balancing/congestion man. requirements	Remote control reductions	More stringent	X
Category 7	Emergency & restoration requirements	Automatic connection	More stringent	X
		Automatic reconnection	More stringent	X

Figure 17 : summary of the requirements eligible for this incentive

4. Qualitative assessment of Type B requirements application to new and existing PGMs

4.1 System needs

The secure and stable operation of an AC power system is highly related to its voltage and frequency stiffness capability[5], usually referred as system strength and its ability to be operated within its voltage, frequency and current limits.

Historically, this system strength was ensured nearly exclusively by the large synchronous power generating modules (SPGM) connected and distributed over the transmission system.

Indeed, these large SPGMs, by the nature of the physic used the produced electricity energy, act as voltage sources with natural inertia contributing to the system voltage and frequency stiffness. And thanks to their governor and automatic voltage controls, they provide capability to adjust the active and reactive power in order to control voltage and frequency in the system. Moreover, the nature of primary energy sources used the generate electricity allow of most of the case a controllability in the level of active power produced.

End of last century, the evolution in the power electronic technology led to the introduction of new solution to produce and inject in the AC transmission power system. The Power Park Modules (PPM) are in fact using specific control-command of the power converters to transform primary energy source into an AC power in the power system. By nature, these sources of energy do not provide natural voltage or frequency stiffness to the system without specific application in their control-command strategy and might present a high level of volatility in function of its primary energy source (wind, solar)

Since about a decade, due to technology, environmental and political evolution and decision, (ex: phase out nuclear power generation completely, decarbonization of the power sector), we are observing a tendency of replacement of these large centralized SPGMs towards either:

- Small SPGMs or PPMs decentralized towards in the HV or MV transmission systems or industrial sites;
- Large PPMs decentralized toward the extremity of the EHV transmission system (offshore) or far away from load centers.

This evolution is affecting seriously the voltage and frequency stiffness of the transmission system and then the ability of system operators to fulfill their objective and obligation in term of operation in normal, emergency and restoration conditions.

[5] Stiffness capability refers to the "characteristic of an electrical power system that relates to the size of the change in voltage or frequency following a fault or power imbalance on the power system"

Moreover, the introduction and evolution of the European electricity market together with the volatile nature of some of the primary energy sources is leading to more and more variation in the current flowing through the transmission system. This increases the risk of overloading the capacity of the grid elements and triggering their uncontrolled (cascading) disconnection.
In this respect, for the perspective of ensuring secure, stable and good quality of power energy transmission, it is of upmost importance than small SPGM and PPM sources are contributing to the voltage and frequency stiffness of the transmission system and provide sufficient capability to modify active power injection via the requirements established in the European and Belgian grid codes.

4.2 Classification of Type B requirements

The TYPE B requirements where a gap between existing and new PGMs (see **Error! Reference source not found.**) has been identified can be classified into the categories related to the way they will contribute to the voltage and frequency stiffness of the transmission system and to the capability to modify active and reactive power injection via the requirements established in the European and Belgian grid code:

1. Voltage vs Frequency vs Current
   a. In the "Voltage" category, we will find requirements contributing to the voltage stiffness of the transmission system
      i. Voltage withstand capability = capability to remain connected to the grid in a certain voltage range and for a certain time
      ii. Reactive Power capability = capability to generate or absorb a certain quantity of reactive power within a voltage and active power range
      iii. Voltage control = capability to automatically adjust reactive power in function of voltage variation at the connection point
      iv. Fault current and dynamic voltage support = capability to quickly inject reactive power to the grid during voltage drop at the connection point as a result of a large grid event (usually short-circuit)
   b. In the "Frequency" category, we will find requirements contributing to the frequency stiffness of the transmission system
      i. Frequency control = capability to automatically adjust active power in function of small or large variation of the frequency at the connection point
      ii. RoCoF = capability to remain connected to the grid in case of rate of change of the frequency at the connection point up to a minimum value
      iii. LFSM-O = activating the provision of active power frequency response according to figure 1 at a frequency threshold and droop settings
      iv. Post-fault power recovery = follow an active power recovery, after fault clearance, with a gradient of at least 0.2 p.u/s
      v. Automatic connection and reconnection = condition to connect to the grid or to reconnect to the grid
   c. In the "Current" category, we will find requirements contributing to the capability to adjust active power in order to limit risk of overloading grid elements:
      i. Active Power controllability/remote control reduction = capability to request a fast reduction of the produced active power

Requirements not entering in these 3 categories were classified as "Other".

2. Normal state vs Emergency/Restoration state application
    a. Normal state contribution = contribution which shall be required to ensure capability of the system operation to meet his obligation to operate the grid in normal frequency and voltage ranges
    b. Emergency/Restoration state contribution = contribution that will be needed to allow the system operator to stabilize and restore the system when going out of the normal operation state.

3. Be robust vs Give Robustness
    a. Be robust = capability necessary for the power plant module to stay connected to the grid following voltage or frequency variation at his connection point as a result of small or large grid event
    b. Give robustness = contribution of the power generating module to limit voltage or frequency variation at his connection point as a result of small or large grid event

The eligible requirements have been classified according to the above categories:

				Frequency vs voltage vs Current vs Other	Normal state vs Emergency	Be robust vs give robustness
	Category of requirements	Sub category	GAP analysis	Classification	Classification	Classification
Category 1	Data questionnaire & Models	Models	More stringent	Other	Normal	Give robustness
Category 3	Voltage & frequency requirements	Rate of change of frequency (ROCOF)	More stringent	Frequency	Emergency	Be robust
		LFSM-O	More stringent	Frequency	Emergency	Give robustness
		Voltage withstand capability	More stringent	Voltage	Normal	Be robust
		Voltage control (SPGM)	More stringent	Voltage	Normal	Give robustness
		Reactive power capability	More stringent	Voltage	Normal	Give robustness
		Fault current & dyn. Voltage support (PPM)	More stringent	Voltage	Normal	Give robustness
		Post-fault power recovery (PPM)	More stringent	Frequency	Normal	Give robustness
Category 4	Information exchange / Telecom requirements	Information exchange	More stringent	Other	Normal	Give robustness
Category 5	Balancing/congestion man. requirements	Remote control reductions	More stringent	current	Emergency	Give robustness
Category 7	Emergency & restoration requirements	Automatic connection	More stringent	Frequency	Emergency	Be robust
		Automatic reconnection	More stringent	Frequency	Emergency	Be robust

Figure 18 : classification of the eligible requirements

4.3 Impact and benefit for the Belgian/European transmission system

In function of their category, fulfilling the gap of type B requirements might have different impact and benefits for the security and stability of operation of the system. Below is a qualitative assessment of the impact/benefit in function of the category :

- Frequency vs Voltage vs Current:
    - By nature, frequency is a characteristic of the transmission system influencing a whole synchronous area. Lack of performance or robustness in term of frequency related requirements might then endanger the security and even expose to black-out the whole synchronous area. In this respect, they are considered a MUST for the gap assessment.
    - By nature, voltage and current are considered as local characteristic of the transmission system influencing/being influenced by a limited perimeter. Lack of performance or robustness in term of voltage or current related requirements might endanger limited part of the system in first instance and might only evolve toward more global consequences if it evolves in cascading events. In this respect, it might be seen as a NICE to HAVE for the gap assessment.

- Normal vs emergency/restoration state:
  - Normal state is considered as the state where the system is operated within the operational limits and being able to face any normal or exceptional contingency. By definition, moving outside normal state will not directly means that energy will not be supplied or delivered or lead to black-out but means that the system might be exposed to reduced power quality and impacting costly measures. In this respect, it might be seen as a NICE to HAVE for the gap assessment.
  - Emergency/restoration state are states where (part of) the system is operated out of its normal operational limits and is highly exposed to a risk of black-out or is already in black-out. Lack of performance of requirements related to Emergency/restoration state exposes directly the system to a risk of black-out or increases the time to restore it to normal state. In this respect, they are considered a MUST for the gap assessment.
  -
- Be Robust vs Give Robustness:
  - Lack of robustness of an installation means that the risk is increase that the installation will disconnect unexpectedly and might directly or as a cascading result degrade the system state with as potential consequence a risk of partial or global black out. In this respect, they are considered a MUST for the gap assessment.
  - Giving robustness shall contribute to mitigate impact for the system and might be seen as a way to support the system operator in his objective and obligation to develop and operate the system in a secure and stable way. Most of the time alternative solutions might exist and should be considered in term of technical and cost efficiency. In this respect, it might be seen as a NICE to HAVE for the gap assessment.
  -
- The models and information exchange related requirements, these requirements have been classified as giving robustness to the grid in normal state.

<u>Qualitative analysis of the benefits :</u>

Based on the above, the Impact/benefit of each requirement shall be considered as HIGH if at least 2 MUST are linked to the requirement. Otherwise, the score shall be considered as MEDIUM. The qualitative analysis of the benefit for the grid can be summarized in the following table.

	Category of requirements	Sub category	GAP analysis	Impact/benefit
Category 1	Data questionnaire & Models	Models	More stringent	MEDIUM
Category 3	Voltage & frequency requirements	Rate of change of frequency (ROCOF)	More stringent	HIGH
		LFSM-O	More stringent	HIGH
		Voltage withstand capability	More stringent	MEDIUM
		Voltage control (SPGM)	More stringent	MEDIUM
		Reactive power capability	More stringent	MEDIUM
		Fault current & dyn. Voltage support (PPM)	More stringent	MEDIUM
		Post-fault power recovery (PPM)	More stringent	MEDIUM
Category 4	Information exchange / Telecom requirements	Information exchange	More stringent	MEDIUM
Category 5	Balancing/congestion man. requirements	Remote control reductions	More stringent	MEDIUM
Category 7	Emergency & restoration requirements	Automatic connection	More stringent	HIGH
		Automatic reconnection	More stringent	HIGH

Figure 19 : qualitative analysis of the benefit for the grid per eligible requirement

4.4 Cost and effort for Customer to fill the gap

A qualitative exercise has been done in order to estimate the cost and effort it would represent for the existing PGM type B to fill their gap compared to new PGM type B requirements.

Three categories of costs have been considered:

- low = some minor adjustments (such as settings adjustments) have to be implemented
- medium = replacement of some elements of the PGM or addition of new elements have to be implemented
- high = replacement of major elements of the PGM have to be implemented

The RfG (Art. 39) specifies the categories of costs that have to be taken into account:

- direct costs
- costs associated to loss of opportunity
- costs associated to change in maintenance and operation

For this costs analysis, further inputs from market parties will be crucial in order to assess more precisely the costs estimation and costs categories.

4.4.1 Type B SPGM :

- RoCoF : By definition, TYPE B SPGMs are small size generators and are able to withstand higher RoCoF than large SPGMs. For existing TYPE B SPGM, the limitation is most of the time coming from the application and setting of decoupling protection relay. The gap between existing and new requirements related to minimum RoCoF is then mainly linked to adjusting the setting of this decoupling protection. In this respect, the cost is considered as LOW.
- LFSM-O : LFSM-O is a function of the governor control. Most of the time, every SPGMs use a governor control to work, those governor control provides the possibility to adjust active power in function of the frequency/speed. In this respect, the cost is considered as LOW.
- Voltage withstand capability: the voltage withstand capability is related to the sizing of every element part of the power plant and the settings of protection. In the case the limit of operation is defined by element capacity, the effort and cost to increase it might by high but in the case the limitation is the result of a conservative protection setting, the effort and cost to change the settings can be considered as low. In this respect, the cost is considered a HIGH/LOW.
- Voltage control : SPGM needs an excitation system to work. In case the excitation system does not have an AVR, the cost is considered MEDIUM otherwise, excitation systems are controlled by an Automatic Voltage Controller (AVR) that will provide different possibilities to adjust excitation current and impact produced reactive power. Voltage control is usually common control on top of constant reactive power and power factor. In this respect, the cost is considered as LOW
- Reactive power capability : by its design, an SPGM has a reactive power capability which usually is in line with the expected requirement. Seen from the applicable point, this capability can be shifted by the impedance of the step-up transformer. In that case, additional device (capa/self) might be needed to meet the requirement. In this respect, the cost is considered as MEDIUM/LOW
- Remote control reduction: every SPGM is equipped with a Governor control which usually has the capability to receive an active power setpoint. However, existing SPGMs were considered as non-coordinable units and then were not equipped with the ability to receive directly this setpoint from a remote location, especially from the SCADA of the system operator. In this respect, the cost is considered as MEDIUM.

- Automatic connection: In order to connect safely to the grid, any SPGM need to ensure that voltage amplitude , frequency and voltage angle are as close as possible towards the ones of the grid at the connection point. The installation is then equipped with necessary device and operated with adequate procedures to do it. The setting used by the devices and in the procedures might differ from the ones defined by the system operator and would benefit to be aligned. In this respect, the cost is considered as LOW.
- Automatic reconnection: Being not coordinable, most the Type B unit are not equipped with the ability to receive directly this setpoint from a remote location, especially from the SCADA of the system operator. In this respect, the cost is considered as MEDIUM.

4.4.2 Type B PPM :

- RoCoF : PPMs able to withstand high RoCoF. For existing TYPE B PPM, the limitation is most of the time coming from the application and setting of decoupling protection relay. The gap between existing and new requirements related to minimum RoCoF is then mainly linked to adjusting the setting of this decoupling protection. In this respect, the cost is considered as LOW.
- LFSM-O : LFSM-O is a function of the control-command of the inverter used by the Power generating unit. Most of the inverter propose the functionality by default and its activation is just a question of settings. In this respect, the cost is considered as LOW.
- Voltage withstand capability: the voltage withstand capability is related to the sizing of every element part of the power plant and the settings of protection. In the case the limit of operation is defined by element capacity, the effort and cost to increase it might by high but in the case the limitation is the result of a conservative protection setting, the effort and cost to change the settings can be considered as low. In this respect, the cost is considered a HIGH/LOW.
- Reactive power capability: by design, a PPM has the possibility to use part of its current capability to generate or absorb reactive power as required by the requirement. Nevertheless, seen from the connection point, this capability can be shifted by the impedance of the step-up transformer. In that case, additional device (capa/self) might be needed to meet the requirement. Moreover, providing specific reactive power value from the global power plant might require the presence of a Power Park Controller. In this respect, the cost is considered a HIGH/MEDIUM.
- Fault current & dynamic voltage support: by design, a PPM inverter control-command which usually allows specific controlling option in case of large voltage dip seen from the voltage at its terminal. If the option is available, it is then question of setting adjustment. If not, it will require to change the inverter. In this respect, the cost is considered a HIGH/LOW.
- Post fault power recovery: By design, existing PPMs already have active post fault power recovery. If this function is settable, it is then a question of setting adjustment. If not, it will require to change the inverter. In this respect, the cost is considered a HIGH/LOW.
- Remote control reduction: For PPM, remote control reduction will require to have the option configurable in the inverter control-command. If not, it will require to change the inverter Moreover, existing PPMs were considered as non-coordinable units and then were not equipped with the ability to receive directly this setpoint from a remote location, especially from the SCADA of the system operator. In this respect, the cost is considered as HIGH/MEDIUM.
- Automatic connection: In order to connect safely to the grid, a PPM need to ensure that voltage amplitude , frequency and voltage angle are as close as possible towards the ones of the grid at the connection point. The installation is then equipped with necessary device and operated with adequate procedures to do it. The setting used by the devices and in the procedures might differ from the ones defined by the system operator and would benefit to be aligned. In this respect, the cost is considered as LOW.
- Automatic reconnection: Being not coordinable, most the Type B unit are not equipped with the ability to receive directly this setpoint from a remote location, especially from the SCADA of the system operator. In this respect, the cost is considered as MEDIUM.

The costs associated to the models and information exchange related requirements, have been classified as low for the models and medium for the information exchange as a component to allow exchange of information between the existing PGM and Elia have to be implemented.

The qualitative analysis of costs related to each eligible requirements can be summarized in the following table:

Category of requirements		Sub category	GAP analysis	Impact/benefit	Costs
Category 1	Data questionnaire & Models	Models	More stringent	MEDIUM	LOW
Category 3	Voltage & frequency requirements	Rate of change of frequency (ROCOF)	More stringent	HIGH	LOW
		LFSM-O	More stringent	HIGH	LOW
		Voltage withstand capability	More stringent	MEDIUM	HIGH/LOW
		Voltage control (SPGM)	More stringent	MEDIUM	LOW
		Reactive power capability	More stringent	MEDIUM	MEDIUM (SPGM) HIGH/MEDIUM (PPM)
		Fault current & dyn. Voltage support (PPM)	More stringent	MEDIUM	HIGH/LOW
		Post-fault power recovery (PPM)	More stringent	MEDIUM	HIGH/LOW
Category 4	Information exchange / Telecom requirements	Information exchange	More stringent	MEDIUM	MEDIUM
Category 5	Balancing/congestion man. requirements	Remote control reductions	More stringent	MEDIUM	MEDIUM (SPGM) HIGH/MEDIUM (PPM)
Category 7	Emergency & restoration requirements	Automatic connection	More stringent	HIGH	LOW
		Automatic reconnection	More stringent	HIGH	MEDIUM

Figure 20 : qualitative analysis of costs per eligible requirement

4.5 Summary table

Based on the above qualitative assessment of costs and benefit for each eligible requirement, we can then identify which ones of the Type B SPGMs and PPMs requirements might benefit to be further investigated as potential application to existing PGMs.

				Frequency vs voltage vs Current vs Other		Normal state vs Emergency		Be robust vs give robustness		Impact/benefit	Costs
Category of requirements		Sub category	GAP analysis	Classification	Benefit	Classification	Benefit	Classification	Benefit		
Category 1	Data questionnaire & Models	Models	More stringent	Other	Nice to have	Normal	Nice to have	Give robustness	Nice to have	MEDIUM	LOW
Category 3	Voltage & frequency requirements	Rate of change of frequency (ROCOF)	More stringent	Frequency	MUST	Emergency	MUST	Be robust	MUST	HIGH	LOW
		LFSM-O	More stringent	Frequency	MUST	Emergency	MUST	Give robustness	Nice to have	HIGH	LOW
		Voltage withstand capability	More stringent	Voltage	Nice to have	Normal	Nice to have	Be robust	MUST	MEDIUM	HIGH/LOW
		Voltage control (SPGM)	More stringent	Voltage	Nice to have	Normal	Nice to have	Give robustness	Nice to have	MEDIUM	LOW
		Reactive power capability	More stringent	Voltage	Nice to have	Normal	Nice to have	Give robustness	Nice to have	MEDIUM	MEDIUM (SPGM) HIGH/MEDIUM (PPM)
		Fault current & dyn. Voltage support (PPM)	More stringent	Voltage	Nice to have	Normal	Nice to have	Give robustness	Nice to have	MEDIUM	HIGH/LOW
		Post-fault power recovery (PPM)	More stringent	Frequency	MUST	Normal	Nice to have	Give robustness	Nice to have	MEDIUM	HIGH/LOW
Category 4	Information exchange / Telecom requirements	Information exchange	More stringent	Other	Nice to have	Normal	Nice to have	Give robustness	Nice to have	MEDIUM	MEDIUM
Category 5	Balancing/congestion man. requirements	Remote control reductions	More stringent	current	Nice to have	Emergency	MUST	Give robustness	Nice to have	MEDIUM	MEDIUM (SPGM) HIGH/MEDIUM (PPM)
Category 7	Emergency & restoration requirements	Automatic connection	More stringent	Frequency	MUST	Emergency	MUST	Be robust	MUST	HIGH	LOW
		Automatic reconnection	More stringent	Frequency	MUST	Emergency	MUST	Be robust	MUST	HIGH	MEDIUM

Figure 21 : qualitative cost-benefit analysis per eligible requirement

As a result of the qualitative cost and benefit analysis, we can summarize the key finding as followed:

- Requirements with a **HIGH impact/benefit** and a **NON-HIGH Costs** lead most probably to a positive CBA
- Requirements with a **MEDIUM impact/benefit** and **LOW costs** have a positive CBA
- **Other requirements should be further investigated through a quantitative CBA**

Category of requirements		Sub category	GAP analysis	Impact/benefit	Costs	Results of the CBA
Category 1	Data questionnaire & Models	Models	More stringent	MEDIUM	LOW	positive CBA
Category 3	Voltage & frequency requirements	Rate of change of frequency (ROCOF)	More stringent	HIGH	LOW	positive CBA
		LFSM-O	More stringent	HIGH	LOW	positive CBA
		Voltage withstand capability	More stringent	MEDIUM	HIGH/LOW	CBA to be performed
		Voltage control (SPGM)	More stringent	MEDIUM	LOW	positive CBA
		Reactive power capability	More stringent	MEDIUM	MEDIUM (SPGM) HIGH/MEDIUM (PPM)	CBA to be performed
		Fault current & dyn. Voltage support (PPM)	More stringent	MEDIUM	HIGH/LOW	CBA to be performed
		Post-fault power recovery (PPM)	More stringent	MEDIUM	HIGH/LOW	CBA to be performed
Category 4	Information exchange / Telecom requirements	Information exchange	More stringent	MEDIUM	MEDIUM	CBA to be performed
Category 5	Balancing/congestion man. requirements	Remote control reductions	More stringent	MEDIUM	MEDIUM (SPGM) HIGH/MEDIUM (PPM)	CBA to be performed
Category 7	Emergency & restoration requirements	Automatic connection	More stringent	HIGH	LOW	positive CBA
		Automatic reconnection	More stringent	HIGH	MEDIUM	positive CBA

Figure 22 : selection of eligible requirements for a quantitative CBA analysis