UPPSALA
UNIVERSITET

UPTEC STS 20008
Examensarbete 30 hp
Juni 2020

Compliance with the EU Regulation Requirements for Generators in the Swedish Electricity Sector

A Study of how Compliance with the New Requirements can be Facilitated

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Abstract

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Andreas Hedström

The EU regulation Requirements for Generators (RfG) was fully in force in Sweden in April 2019. With RfG, which contains requirements on the grid connection of new power-generating modules (PGMs), the EU aims to ensure a further market integration within the union, increase the security of supply and facilitate a continuous integration of renewable energy production. With the purpose of ensuring that the capabilities required in RfG are installed in new PGMs, compliance with the requirements must be shown before commissioning a new PGM via either on-site tests, simulations or both. However, the information RfG provided regarding how compliance is to be shown is vague. This has introduced ambiguity to the Swedish electricity sector with regards to what is required to show compliance. Therefore, in this study, an investigation of the Swedish compliance landscape with regards to RfG has been performed, with the objectives of shining light on obstacles that relevant actors in the industry experience and examining which incentives they have to comply with RfG today. Furthermore, the study gives a contribution to how compliance can be shown via templates of simulations for the requirements on wind power parks with a cumulative installed power of 10 MW to have the capability of delivering frequency regulation. The results indicate that the industry needs procedures of best practice and further guidelines or rules with regards to how compliance is to be shown to be able to achieve cost-effectiveness. Moreover, the templates provided in the study illustrate what types of guidelines that are demanded.

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ISSN: 1650-8319, UPTEC STS 20008
Tryckt av: Uppsala

Populärvetenskaplig sammanfattning

EU-förordningen Requirements for Generators (RfG) trädde i full kraft i Sverige i april 2019. Det nya regelverket ställer tekniska krav på nyanslutning av elproducerande enheter såsom vindkraftparker, solkraftsparker och kraftvärmeverk att bidra med olika förmågor för att säkerställa elsystemets fortsatta funktionalitet. Dessutom har EU målsättningen att, genom RfG, öka leveranssäkerheten av el, möjliggöra för en fortsatt utbyggnad av vind- och solkraft samt integrera de europeiska elmarknaderna. I syfte att visa att nya elproducerande enheter överensstämmer med den nya lagstiftningen kräver RfG att överensstämmelsetest- och simuleringar ska genomföras mot kraven i RfG innan enheten ansluts. Hur dessa test och simuleringar praktiskt ska gå till framstår dock som svårt att tyda för elbranschens aktörer. I flertalet andra EU-medlemsländer har de ytterst ansvariga organisationerna för elsystemets funktionalitet tagit fram regelverk eller riktlinjer kring hur överensstämmelse med kraven i RfG ska visas. Sådana regelverk eller riktlinjer saknas dock i Sverige, vilket lett till en osäkerhet i branschen kring hur arbetet med RfG ska fungera.

Bland de tekniska krav som RfG ställer på elproducerande enheter finns krav på vindkraftparker som ackumulerat kan producera mer än $10\ MW$ att kunna bidra till nätets kontinuerliga funktionalitet genom frekvensreglering. Ström och spänning i det svenska elnätet byter riktning med en specifik frekvens, $50\ Hz$, om produktion och konsumtion av el är i balans. Om en obalans mellan produktion och konsumtion sker så avviker frekvensen från $50\ Hz$. I syfte att hindra frekvensen från att avvika för mycket köps reserver upp i form av elproduktion som aktiveras när frekvensen avviker. Detta bidrar till att återställa frekvensen till den önskade nivån, genom så kallad frekvensreglering. Eftersom vindkraften byggs ut i snabb takt i Sverige så är det viktigt att förmågor som behövs för elnätets fortsatta funktionalitet kravställs på ny vindkraft. För att dessa förmågor, och andra viktiga förmågor i RfG, ska byggas in i elsystemet krävs dock att elbranschens aktörer kan tillämpa RfG på ett tillfredsställande sätt.

Denna studie undersöker därför om branschens relevanta aktörer, med nätbolag och kraftproducenter i fokus, har tillräckligt starka incitament för att överensstämma med RfG på ett korrekt sätt. För att besvara detta undersöks hur överensstämmelselandskapet fungerar idag, samt hur olika relevanta aktörer arbetar för att visa överensstämmelse med RfG i dagsläget. Utöver detta så lägger studien fokus på kraven för förmåga till frekvensreglering som RfG ställer på vindkraftparker som har en installerad effekt på minst $10\ MW$. Dessa krav agerar i studien som exempel på varför det är av vikt att de relevanta aktörerna överensstämmer med RfG. Dessutom bidrar denna studie med riktlinjer för hur överensstämmelse genom simuleringar praktiskt kan visas med kraven på frekvensreglering.

Resultaten i denna studie indikerar att det finns ett antal hinder för branschens relevanta aktörer när det kommer till att visa överensstämmelse med kraven i RfG. Avsaknad av praxis eller andra typer av riktlinjer och den osäkerhet detta medfört verkar ha påverkat branschens aktörer som väntar med att genomföra potentiellt kostsamma ändringar i arbetsmetoder tills sådana finns på plats. Dessutom bedrivs inte planlagd tillsyn av tillsynsmyndigheten angående ifall branschens aktörer faktiskt överensstämmer med RfG och således är det inte sannolikt att en organisation skulle råka ut för reprimander om organisationen inte skulle följa RfG. Detta betyder att Sverige riskerar att misslyckas med att bidra till EU:s mål om att öka leveranssäkerheten av el, möjliggöra för en fortsatt utbyggnad av vind- och solkraft samt integrera de europeiska elmarknaderna.

Utöver detta så ger denna studie ett bidrag till diskussionen om hur tidigare nämnda hinder kan undanröjas och hur tillvägagångssätten för att visa överensstämmelse med RfG kan förenklas genom förslag till mallar för överensstämmelsesimuleringar av frekvensregleringskraven för vindkraftparker med en installerad effekt på minst $10\ MW$. I utformandet av dessa mallar har hänsyn tagits till det arbete som bedrivs i branschen kring hur överensstämmelse med RfG ska visas, samt redan existerande testprogram från liknande frekvensregleringskrav författade av Svenska kraftnät. Dessutom har åsikter från relevanta respondenter som intervjuats i samband med studien vägts in.

Förord

Detta examensarbete har skrivits i samarbete med Sweco Energy AB. Jag vill rikta ett särskilt tack till min handledare Erica Lidström, men även till Katarina Yuen Lasson på Sweco för det värdefulla stöd och den rådgivning de bistått med under arbetets gång. Dessutom vill jag rikta ett tack till de respondenter som ställt upp på intervjuer till arbetet. Sist så vill jag rikta ett stort tack till min ämnesgranskare Valeria Castellucci, som med kunskap och stöd har bidragit till arbetet.

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Juni 2020

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Definitions

ACER - Agency for the Cooperation of Energy Regulators.

Deadband – A frequency interval that deliberately does not give frequency response.

Distribution system operator (DSO) - The owner and responsible party of a distribution system.

Droop settings - A way of describing the regulating power of a power-generating module. Droop is the frequency deviation in percent needed to change the power output of the power-generating module with 100 % of installed power, $s = \frac{\Delta f/50}{\Delta P/P_{max}}$. Measured in percent [%].

ENTSO-E - European Network for Transmission System Operators for Electricity.

Frequency response insensitivity - Refers to a feature of a control system allowing it to not react with a change in output power to frequency changes smaller than a specific value.

Frequency Sensitive Mode (FSM) - A way of operating a power-generating module where the active power is changed as a response to a change in system frequency in a way so that it contributes to restoring the target frequency.

Limited Frequency Sensitive Mode - overfrequency - Refers to an operating mode of a power-generating module that requires power output reduction to counteract a frequency change above a determined value.

Limited Frequency Sensitive Mode - underfrequency - Refers to an operating mode of a power-generating module that requires an increase in power output to counteract a frequency change below a determined value.

Power-generating module (PGM) - Either a synchronous power-generating module or a power park module.

Power-generating module document (PGMD) - A document containing information assuring compliance with relevant technical requirements in RfG. Is to be provided by the facility owner to the relevant system operator.

Power-generating facility - A facility converting primary energy into electricity consisting of one or several power-generating modules connected to a grid at one or several connection points.

Power park module (PPM) - One or several power-generating modules that are either asynchronously connected to the grid or connected via power electronics, and that have one common connection point to the grid.

Rated capacity (P_{max}) - A power generating facility's rated capacity is its highest active power production level measured at the connection point, at which power the facility can operate continuously without a time limit. Measured in Watts $[W]$

Relevant system operator (RSO) - Either a transmission system operator or a distribution system operator to whose grid the power-generating module is to be connected.

RfG – Commission Regulation (EU) 2016/631 of 14 April 2016 establishing a network code on requirements for grid connection of generators.

Swedish board for accreditation and conformity assessment (SWEDAC) - The national accreditation body of Sweden.

TSO - Transmission system operator.

1. Introduction

Commission Regulation 2016/631 Requirements for Generators (RfG) is a grid code imposed by the EU in 2016, defining requirements for grid-connected power-generating modules in all member states. With RfG, and seven other grid codes covering other areas of the electricity system, the EU aims to further integrate the energy markets but also to ensure the possibilities for continuous growth of renewable power generation in the European electricity systems. An increase of renewable power generation is desirable in order to mitigate climate change but comes with challenges of operational security and frequency stability. With the purpose of decreasing this risk, RfG includes requirements aiming to ensure continuous stable and robust grid operation as the integration of intermittent, non-synchronous power production continues to increase.

One EU member state that has seen a large increase in non-synchronous power penetration in the form of wind power, is Sweden. Being part of the Nordic synchronous area, the increase has occurred together with a phasing out of synchronous nuclear power plants in recent years. Simultaneously, deteriorated frequency stability has been observed over the last decade (Persson, 2017). The increase of wind power penetration is projected to continue, which increases the need of wind turbines and parks to contribute with ancillary services to ensure a continuously stable system in the future. In RfG, requirements of having the capability of delivering ancillary services like frequency regulation are put on wind power parks of type C and D, thus parks with an aggregated power of 10 MW or more.

Being fully implemented in Sweden since April 2019, there are still uncertainties related to how the actors in the electricity industry should practically apply parts of the grid code. One such part is how compliance with relevant requirements should be practically shown. RfG defines a framework for compliance tests on-site and computer simulations to the technical requirements but leaves room for interpretations when it comes to the practical execution. In addition to this, economic incentives and uncertainties might further decrease the motivation of actors in the industry to properly comply with relevant requirements in RfG. Therefore, this thesis will investigate the Swedish compliance landscape with regards to RfG with the purpose of shedding light on potential issues and challenges with showing compliance with the grid code on a general level. Furthermore, the thesis will specifically focus on the requirements for frequency regulation of wind power parks, thus capabilities to operate in Frequency Sensitive Mode (FSM) and Limited Frequency Sensitive Mode (LFSM). The thesis will investigate how compliance with these requirements could be shown in the Swedish context, to ensure that wind power has the capabilities of contributing with ancillary services and thus contributing to the robustness of the system.

1.1 Objective

The objective of this thesis is to investigate the Swedish compliance landscape with regards to Commission Regulation 2016/631 Requirements for Generators, with the purpose of identifying potential challenges that relevant actors in the electricity system might encounter. In addition to this, the thesis will specifically investigate the requirements related to the capability to operate in Frequency Sensitive Mode and

Limited Frequency Sensitive Mode as they are specified for wind power parks of type C and D. These requirements are investigated with the aim of describing the need of these capabilities for the functionality of the future electricity system, but also with the aim of describing how compliance with them can be shown, ensuring that the actors in the industry actually install the relevant capabilities in their parks. The aim is not to thoroughly describe all technical details in the process of showing compliance with these requirements, but rather to suggest an overview of how it could be done. By doing so, a contribution to the discussion of how compliance can be shown is made, while simultaneously light can be shone on potential issues with the current compliance landscape.

1.2 Research Questions

The objective has resulted in the following research questions:

- *How does the Swedish compliance landscape with regards to RfG function today?*
- *Are there sufficient incentives to facilitate relevant actors to comply with all relevant requirements in RfG?*
- *How can compliance be shown with the requirements for operation in FSM and LFSM for wind power parks of type C and D, and in which ways are these capabilities needed for the functionality of the future power system?*

1.3 Delimitations

RfG covers a large set of technical requirements for the grid connection of generators that could be subject for examination. However, due to the limited time during which this thesis is written, the choice of focusing on three related requirements was made. In addition to this, the focus was limited to on-shore power park modules of type C and D since these types of PGMs are among the most installed today. Furthermore, the requirements in RfG do not only apply to PGMs that are to be connected to the grid, but also to already connected PGMs that are modified to the extent that the connection contract needs to be renegotiated. However, this study is limited to the compliance process regarding new PGMs that are to be connected to the grid only.

1.4 Outline

This thesis is divided into six chapters in order to structure the content and guide the reader. The first chapter introduces a brief background to the subject and problematizes the topic. The second chapter describes the research method used to gather necessary information and how the result has been developed and analysed. The third chapter provides necessary background to understand the topic and the subsequent chapters of this thesis. In order for the reader to comprehend the results and discussion provided in this thesis, background is provided on a number of topics such as the contents of RfG, the capabilities of modern wind power and its integration to the electricity system and the implementation of RfG in Finland. In the fourth chapter the results are presented, followed by a discussion of these results in chapter five. Lastly, in chapter six, the conclusions of this thesis are presented.

2. Background

In this chapter, background on RfG and the actors relevant for the compliance with RfG is presented. Moreover, the compliance framework that RfG provides is explained, together with a review of power system stability and the requirements for FSM, LFSM and FCR. Lastly, the integration of wind power in Sweden and the current capabilities of wind turbines is explained.

2.1 European Network Codes

The third energy package was introduced by the EU in 2009, arranging a process for a set of EU-regulations to be developed with the purpose of harmonising the legal frameworks of the member states, increasing the cross-border energy trade, achieving better security of supply and ensuring the possibility of continuous integration of renewable energy sources. The eight regulations, that are now in force, have been developed by the European Network for Transmission System Operators for Electricity (ENTSO-E), the regulatory authorities of the member states, the Agency for the Cooperation of Energy Regulators (ACER) and the European Commission. Containing sets of rules for different parts of the electricity system, these network codes can be categorized into grid connection related codes, system operation related codes and market related codes, see Figure 3.1. The network codes affect many actors on the electricity market, for example electricity companies, electricity producers, electricity traders, electricity customers, and others (Swedish Energy Markets Inspectorate, 2016).

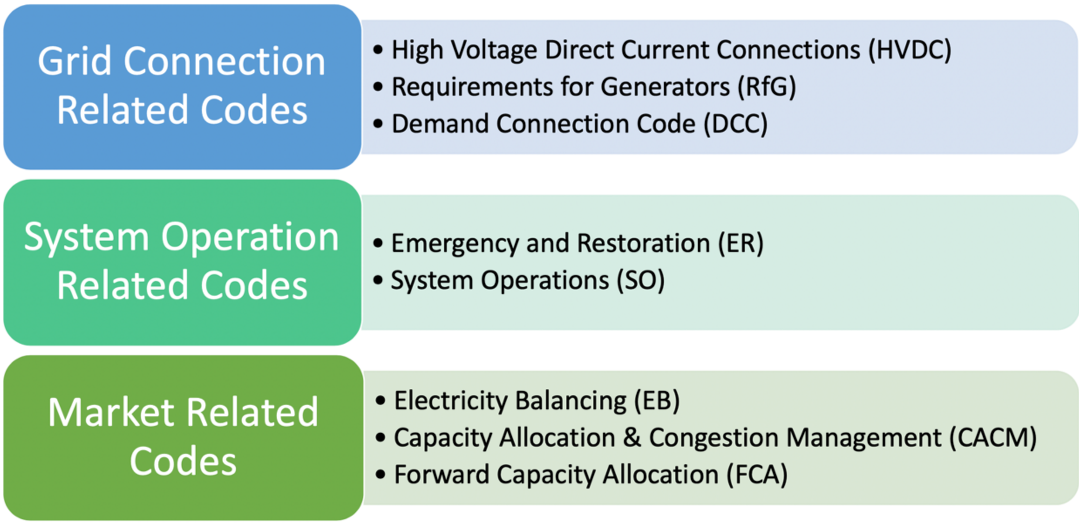

Figure 3.1. The eight network codes provided by the European Commission in the form of EU-regulations.

2.2 The EU Regulation Requirements for Generators

Commission Regulation (EU) 2016/631, known as Requirements for Generators (RfG) contains requirements for power-generating facilities (PGMs) to be connected to the European electricity system. As an EU regulation, the requirements in the network code directly enter into force in all EU member countries, including Sweden (Europeiska Unionen, 2020). In RfG, PGMs are categorized into three groups: synchronous power-generating modules (SPGMs), power park modules (PPMs) and offshore power park modules (OPPMs). All three categories fall under the general requirements in RfG, but separate sets of requirements that are specific for each category are also provided (European Commission, 2016). Figure 3.2 summarises the categorization of PGMs.

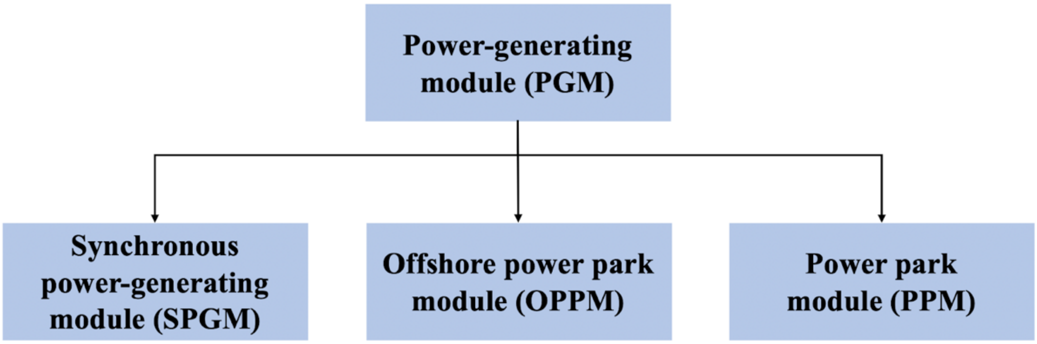

Figure 3.2. The division of power producing units in RfG.

The requirements apply to new PGMs to be connected to the grid, and type C and D PGMs that are already connected to the grid but have been modified to the extent that the connection agreement has to be renewed. In addition to this, PGMs are sorted in order of their significance for the system performance according to the definition in Table 3.1, with both separate and common sets of requirements for each category. Regarding PPMs, the rated capacity values in Table 3.1 refer to the park's aggregated power in the connection point to the grid (European Commission, 2016).

Table 3.1. Definitions of power-generating facilities in the Nordic synchronous area (Swedish Energy Markets Inspectorate, 2018 (a)).

	Power-generating facility	Voltage at connection point
Type A	Equal to or more than 0.8 kW	Lower than 110 kV
Type B	Equal to or more than 1.5 MW	Lower than 110 kV
Type C	Equal to or more than 10 MW	Lower than 110 kV
Type D	Equal to or more than 30 MW	Lower than 110 kV
Type D	All	Equal to or higher than 110 kV

When an already connected PGM is to be modified, the PGM owner has, according to RfG, to contact and inform the RSO who will decide if a new connection agreement has to be agreed. If a new connection agreement has to be agreed, the RSO is obliged to contact and inform the regulatory authority, the Swedish Energy Markets Inspectorate, that will assess which requirements that the modified PGM fall under (Swedish Energy Markets Inspectorate, 2020 (b)).

Furthermore, RfG consists of mandatory and non-mandatory requirements, both categories consisting of exhaustive and non-exhaustive requirements. The mandatory requirements shall be applied by all member states and can be exhaustive, in which case they are implemented as they are, or non-exhaustive, meaning that they are to be exhaustively implemented in each member state. The non-mandatory requirements also consist of exhaustive and non-exhaustive requirements. The non-mandatory requirements are to be applied by the relevant member country if the need for the requirement can be demonstrated. The reasons can among other things be the level of penetration of renewable power production, maintaining already existing requirements or other country-specific conditions. Typically, the non-exhaustive requirements provide an interval in which a parameter is to be nationally defined. Furthermore, the requirements that are to be nationally specified are referred to as requirements of general application and have in Sweden been specified by the Swedish Energy Markets Inspectorate after a proposal from Svenska kraftnät (Swedish Energy Markets Inspectorate, 2018(a)). For example, the requirements for operation in FSM and LFSM-O/U contain requirements of general application that accordingly have been specified by the Swedish Energy Markets Inspectorate. An illustration of the structure of the different types of requirements in RfG can be seen in Figure 3.3.

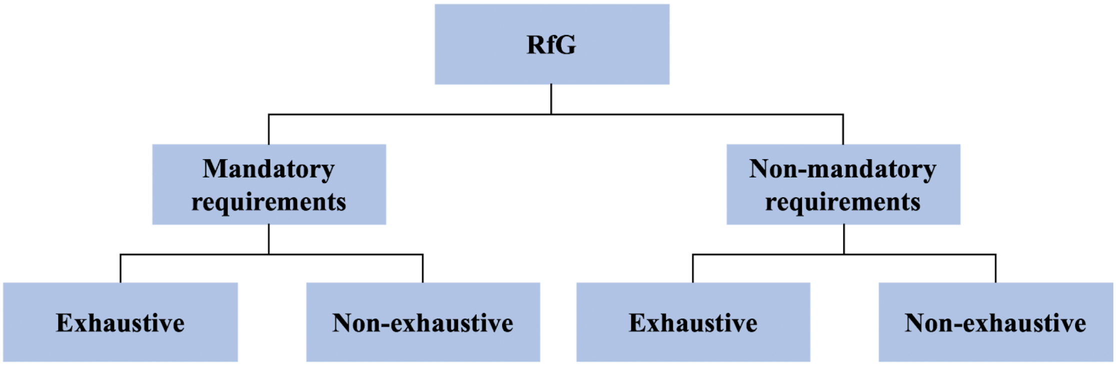

Figure 3.3. The different types of requirements in RfG.

2.3 Hierarchy of Norms

Rules is a unifying term for provisions in laws, regulations and general recommendations. Not all rules are binding, such as recommendations for how to comply with binding rules. Binding rules are laws and regulations. The different types of rules relate to each other in a specific hierarchy. In Sweden, highest in this hierarchy is the constitutional law. Second are other laws, legislated by the parliament. Third are regulations decided by the government, with authorisation from the parliament. Fourth in the hierarchy is national regulations authored by the responsible government body, typically in order to further specify details in a matter. Last in the hierarchy are the non-legally binding general recommendations. In some areas, non-legally binding standards and handbooks exist, provided by professional organisations for example, to help interpret and practice legal frameworks. In addition to this, the EU can affect Swedish rules by directives, that are to be implemented in the law in such a way that specified purposes are fulfilled, and by regulations, that are binding directly as they are. Any Swedish rule that is in conflict with an EU-regulation is no longer valid when the regulation becomes effective (Wetter-Ryde, 2020). RfG is an EU-regulation and thus takes precedence before any Swedish rule that might conflict with it.

A legal framework formulated by TSO Svenska kraftnät in 2005, SvKFS 2005:2, covers requirements for the grid connection of generators. However, SvKFS 2005:2 is currently only valid for PGMs that were connected to the grid from 2005 until requirements in RfG became applicable since RfG, as an EU-regulation, takes precedence over any conflicting national legal framework.

2.4 Compliance with Requirements

When new power-generating modules are to be connected to the grid, compliance tests on-site and simulations in a software carried out by the facility owner have to take place as stated by the relevant system operator (RSO) and according to the requirements in RfG. For some requirements only compliance tests - meaning practical on-site tests - are required, and for some only simulations. Others require both tests and simulations. The purpose of the tests and simulations is to ensure that the PGM complies with all relevant requirements. In a case where the facility owner wants to demonstrate compliance in a different way than suggested by the RSO, the RSO may accept this as long as the alternative approach will demonstrate compliance with relevant requirements. RfG also opens the possibility to show compliance by providing a certificate issued by an authorised certifier (more about this in section 3.4.1) (ENTSO-E, 2017(b)).

Also, after the PGM has been connected to the grid, the RSO has the right to request that compliance tests and simulations are carried out according to a repeat plan to ensure that the PGM complies with the relevant requirements during its whole lifetime. This process is called compliance monitoring (European Commission, 2016). Compliance tests and simulations should also be carried out in the case of a failure or modification of the unit that might impact the PGM's compliance with relevant RfG requirements (ENTSO-E, 2017(b)). However, this thesis will focus on the compliance procedure for the commissioning of new PGMs only.

In addition to this, RfG specifies several operational notifications that are to be issued by the RSO to an owner of a PGM, specifying the allowed connection and operation of a PGM. The operational notifications range from allowing the energisation of the internal network to allowing the connection and full operation at the relevant grid point. In different stages in the compliance procedures, different operational notifications are to be issued. However, the operational notifications and their use will not be in further focus in this thesis.

2.4.1 Compliance by Certificates

An authorised certifier is an entity with the purpose of issuing equipment certificates and power-generating module documents with accreditation from the national affiliate of the European cooperation for Accreditation (EA), which in Sweden is the Swedish Board for Accreditation and Conformity Assessment (SWEDAC) (European Accreditation, 2019). In Sweden there is currently no authorised certifier, since SWEDAC has not accredited any organisation for this purpose (Calestam, 2020). Consequently, there is no actor that can issue equipment certificates.

Equipment certificates are documents issued by an authorised certifier for equipment used by a PGM. The scope of the certificate might be defined on different levels, selected from an allowed range at a European level (ENTSO-E, 2017(b)). The purpose of the certificate is to avoid repeated resource-demanding compliance tests and simulations and instead certify standardized parts of PGMs through fewer tests. RfG leaves it open for the compliance of all requirements to be shown via different types of equipment certificates (European Commission, 2016). Equipment certificates are divided into unit certificates and components certificates, see Figure 3.4. The unit certificate is a type of equipment certificate, showing a whole unit's compliance with certain requirements. A unit could for example be a heating plant system or a wind turbine. Unit certificates must also include verified electric simulation models (ENTSO-E, 2017(b)). Furthermore, a component certificate is also a type of equipment certificate referring to a component of a unit or another component that is used in a facility for generation, demand or HVDC. The component certificate verifies compliance with certain requirements. The component certificate can be applied in a unit certification process or applied to show compliance with specific parts when a compliance test is carried out for a whole facility (ENTSO-E, 2017(b)).

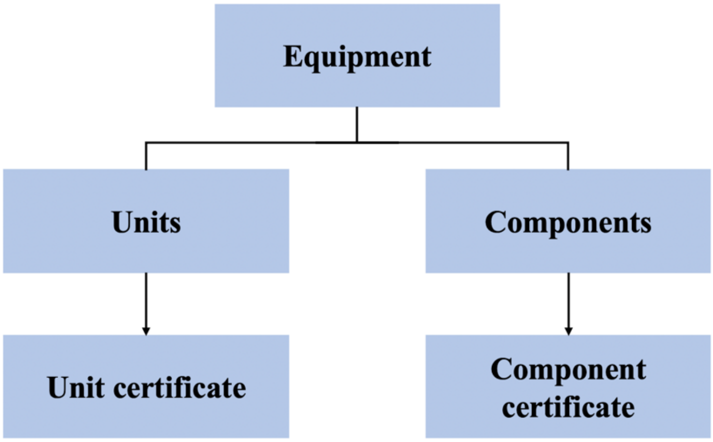

Figure 3.4. The certificate types.

2.5 Responsibilities of Relevant Actors

RfG imposes new roles, new responsibilities and new work procedures for actors in the electricity markets. In several other countries, guidelines or rules regarding work procedures and how compliance tests and simulations are to be carried out have been provided to the industry, typically by the TSO (Fingrid, 2018; VDE FNN, 2020). No such guidelines or rules have been designed yet in Sweden, and thus the relevant actors have to relate to RfG and EIFS 2018:2 directly to understand their responsibilities. Article 40.1 in RfG states that it is the responsibility of the owner of the PGM to make sure that the PGM will comply with the relevant requirements during its whole lifetime (European Commission, 2016).

In addition to this, article 40.4 states that the owner of the PGM is obliged to inform the RSO of how compliance is planned to be shown in good time before commissioning compliance tests. On the other side, the RSO is responsible for assessing the compliance tests and for informing the owner of the PGM of the results of these assessments. The RSO is also responsible for informing the owner of the PGM of the requirements that the PGM needs to comply with and what documentation that is to be provided. This should be made publicly available as a list. Furthermore, the RSO has the responsibility of informing the PGM owner of the division of responsibilities between them with regards to how compliance tests and simulations are to be carried out. If the owner of the PGM cannot show that the PGM complies with all relevant requirements, the RSO should deny connection of the PGM. Also, RfG states that the compliance assessment can be left to a third party (European Commission, 2016). Figure 3.5 illustrates the responsibilities of the relevant actors in the compliance process. No requirements of compliance testing or simulation include type A PGMs and consequently the above-mentioned procedures and responsibilities will not apply to them

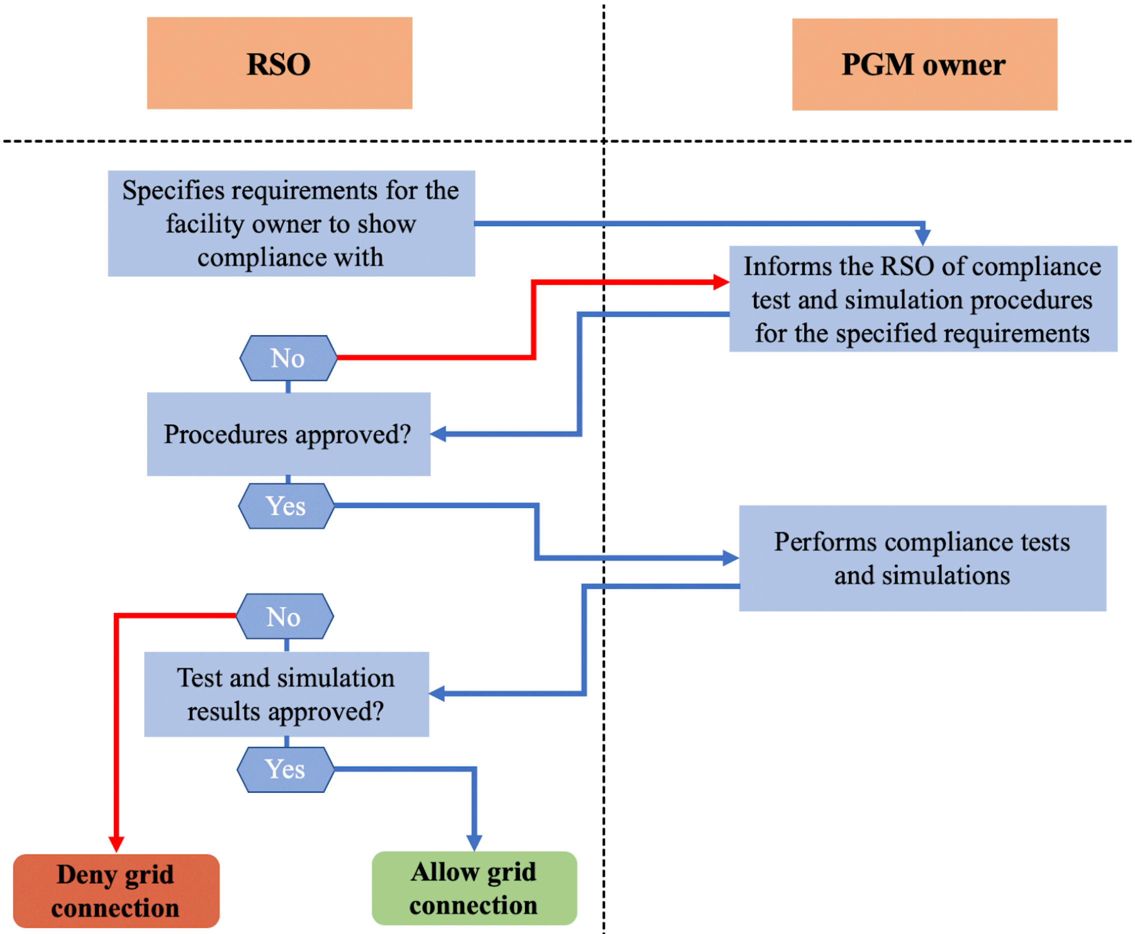

Figure 3.5. A flow chart illustrating the responsibilities of the RSO and facility owner when compliance with RfG and EIFS 2018:2 is to be shown.

With regards to what documentation the RSO shall require and publish as a list, RfG specifies some minimum criteria. At least, the RSO shall publish all documentation and certificates to be provided by the RSO, along with technical data of relevance to the grid connection. Also, the RSO should state requirements for models to be provided for dynamic and steady-state studies, together with a timeline specifying the provision of required data. Furthermore, the RSO shall require studies by the PGM owner with the purpose of showing compliance with relevant requirements in RfG. Lastly, conditions, procedures and scope for the use of equipment certificates should be included (European Commission, 2016).

2.5.1 Supervision by the Regulatory Authority

Compliance with RfG is to be ensured by the regulatory authority in each member state, as stated in Article 71:

"Regulatory authorities shall ensure that national agreements between system operators and owners of new or existing power-generating facilities subject to this Regulation and relating to grid connection requirements for power-generating facilities, in particular in national network codes, reflect the requirements set out in this Regulation." (European Commission, 2016)

The regulatory authority for energy markets in Sweden is the Swedish Energy Markets Inspectorate. The Swedish Energy Markets Inspectorate conducts supervision in two ways: according to a planned scheme or according to indication, which means that supervision is conducted based on events such as complaints or reports (Swedish Energy Markets Inspectorate, 2020 (a); Jaakonantti, 2020).

2.6 Power System Frequency Stability

The Nordic synchronous area has a nominal frequency of $50\ Hz$, meaning that power production and consumption is in balance when the frequency remains stable at $50\ Hz$. In a situation with a production surplus, the frequency increases above $50\ Hz$ and in a situation with a demand surplus, the frequency decreases under $50\ Hz$ (ENTSO-E, 2016).

The frequency stability of the power system is dependent primarily on three characteristics: system inertia (or rotational energy), reserves and the dimensioning fault, meaning the largest single fault contingency (Svenska kraftnät, 2019 (a)). The system inertia is the total kinetic energy of directly connected synchronous generators, turbines and motors connected to the power system. The inertia works as a brake for frequency change when faults, or other events causing a frequency deviation from the nominal frequency in the system, occur. As an example, the frequency change due to disturbances in a system with high kinetic energy is slower and thus easier to control than in a system with low kinetic energy. The inertia in the system might vary between hours, days and seasons as a consequence of, for example, the strength in the wind and thus the wind power penetration in the system (Svenska kraftnät, 2019 (a)).

Moreover, the reserves consist of power resources ready to be activated in order to achieve balance between production and demand at contingency. If the disturbance is smaller than the dimensioning fault, then the ancillary services for primary regulation are automatically activated within 5 to 10 seconds in order to stabilize the frequency. The frequency is then restored to the nominal value with secondary regulation. The primary regulation makes out the fundamental reserve for maintaining the desired frequency quality. However, the primary regulation is not dimensioned to manage disturbances larger than the dimensioning fault. If frequency reserves should be insufficient, protective functions such as fast power support via HVDC-connections or load disconnection are used. The dimensioning fault of a power system determines the maximum imbalance that the system sustains without ending up outside allowed operational limits for frequency, current and voltage (Svenska kraftnät, 2019 (a)).

2.7 Frequency Response

Fundamentally, the primary and secondary regulations are activated by increasing or decreasing the active power output of predetermined PGMs. In Sweden, these regulations consist primarily of the services FCR-D and FCR-N, which belong to the primary regulation and have the purpose of stabilizing the frequency after a frequency deviation, while the automatic Frequency Restoration Reserves (aFRR) belong to the secondary reserve and manual Frequency Restoration Reserves (mFRR) to the tertiary reserve, having the purpose of restoring the frequency back to its nominal value (North European Energy Power Perspectives, 2019). Subsection 3.9.4 further explains the FCRs. In Sweden, the TSO Svenska kraftnät has the balance responsibility. In order to ensure sufficient system balance in every moment, Svenska kraftnät utilizes a balance market where above mentioned balance services can be sold by power producers and consumers.

For PGMs of type C and D, RfG and EIFS 2018:2 require capabilities for operation in Frequency Sensitive Mode (FSM). In this operational mode, PGMs contribute with primary regulation of frequency by increasing production during a demand surplus and decreasing the production during a production surplus. The aim with building these capabilities into every PGM of type C and D is to ensure the robustness of the power system and that enough capabilities to deliver the FCR-products continuously exist (Svenska kraftnät, 2019 (d)). In addition to FSM, RfG defines requirements for PGMs to have the capability to respond with increased or decreased production when the power system is in emergency state, with operation in Limited Frequency Sensitive Mode (LFSM) (ENTSO-E, 2018).

2.7.1 FSM

In RfG, Frequency Sensitive Mode (FSM) is defined as a way of operating a PGM so that it changes its active power output as a response to the grid frequency deviating away from its nominal value, thus contributing to frequency recovery to nominal frequency. FSM capabilities are to be shown in the frequency range $49.5 - 50.5\ Hz$, with a deadband of $\pm\ 100\ mHz$, see Figure 3.6. The purpose of the requirements is to ensure that technical capabilities for ensuring a robust power system are built into the system, such as enabling PGMs to deliver FCRs. However, a PGM should only operate in FSM if the RSO orders it to do so (European Commission, 2017). Operating in FSM, a PGM is supposed to respond to a disturbance within $2\ s$ and deliver full active power output, according to defined parameters, within $30\ s$ (Swedish Energy Markets Inspectorate, 2018(a)).

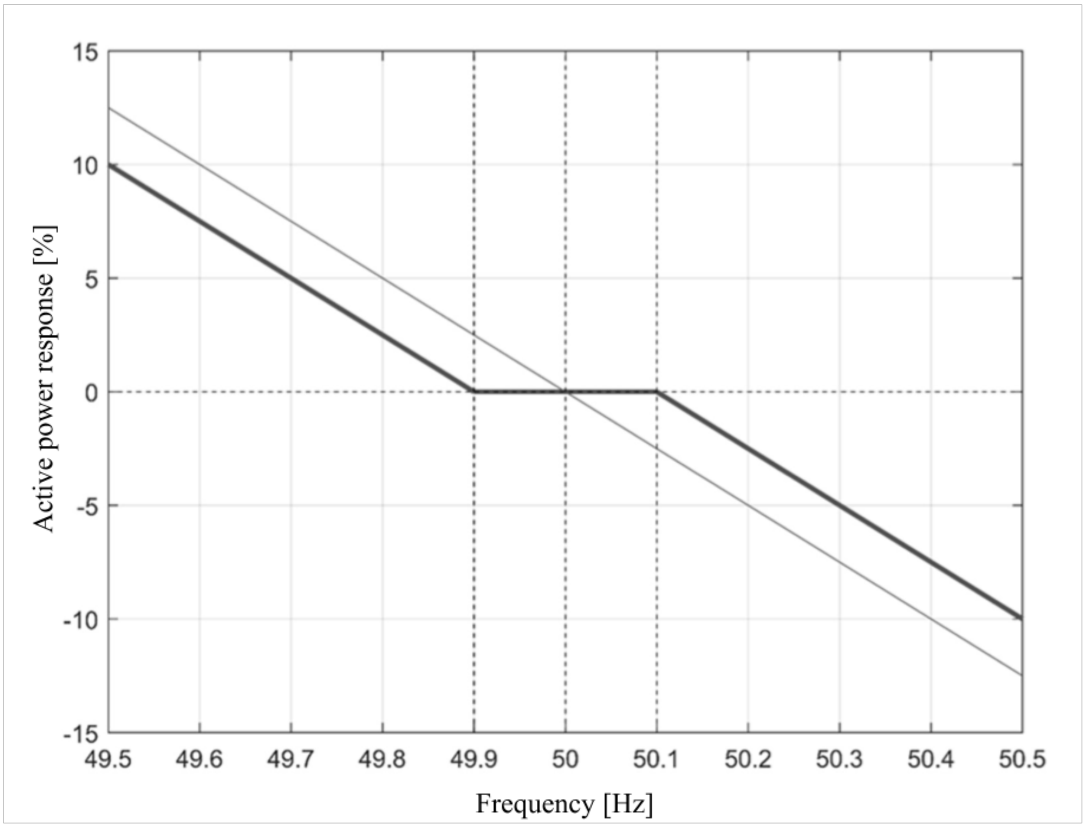

Figure 3.6. The frequency area where operation in FSM must be guaranteed for all PGMs of type C and D. The thin line represents frequency response without deadband and insensitivity and the thick line represents frequency response with deadband and insensitivity (Swedish Energy Markets Inspectorate, 2018(a)).

The minimum frequency response is given by the following relations between active power output, frequency and droop (Swedish Energy Markets Inspectorate, 2018 (a)):

$$\frac{\Delta P}{P_{ref}} = 100 * \frac{f_n + f_{deadband} - f}{f_n} * \frac{1}{s_1}, \text{ when } 50.1 \leq f \quad (1)$$

$$\frac{\Delta P}{P_{ref}} == 0, \text{ when } 49.9 < f < 50.1 \quad (2)$$

$$\frac{\Delta P}{P_{ref}} = 100 * \frac{f_n - f_{deadband} - f}{f_n} * \frac{1}{s_1}, \text{ when } f \leq 49.9 \quad (3)$$

where P_{ref} is the maximum continuous power of the PGM, and P is the change in active power of the PGM. f_n is the nominal frequency and f is the current actual frequency. $f_{deadband}$ is the deadband, a frequency interval where no response is required. s_1 is the droop, which determines the response to frequency deviations, defined to be within the interval $2 - 12$ %. The parameter ranges and values that have to be fulfilled by a PGM to comply with the requirements for FSM are presented in Table 3.2 (Swedish Energy Markets Inspectorate, 2018(a)).

Table 3.2. Parameters defining requirements for FSM and their intervals.

Parameters	Interval

Active power range related to maximum capacity $\frac{\Delta P_1}{P_{max}}$	$5 - 10$ %
Frequency response insensitivity Δf_i	10 mHz
Frequency response insensitivity $\frac{\Delta f_i}{f_n}$	$0.02 - 0.06$ %
Deadband for frequency response	100 mHz
Droop s_1	$2 - 12$ %
Initial delay t_1	2 s
Full activation time t_2	30 s
Full frequency response endurance	15 min

Figure 3.7 illustrates the initial and final activation delay of which the PGM must deliver the specified active power response.

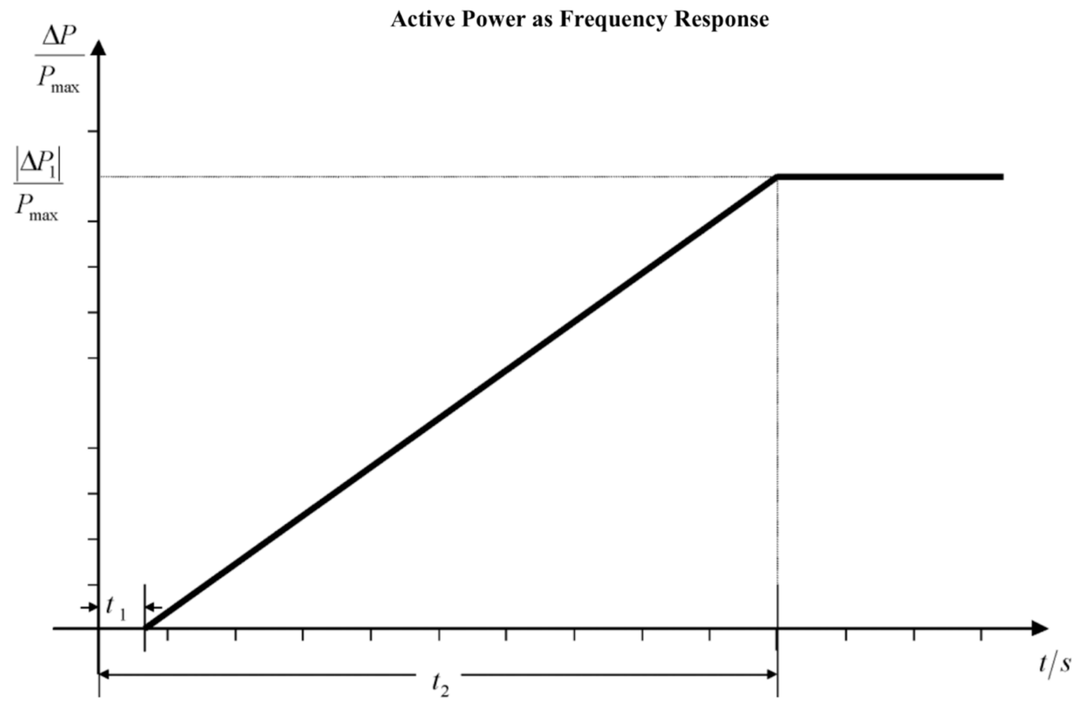

Figure 3.7. Illustration of the initial and final allowed delay in active power response and the active power response related to maximum capacity (European Commission, 2016).

2.7.2 LFSM-O

Limited Frequency Sensitive Mode at Overfrequency (LFSM-O) is to be activated when the power system is in emergency state, in need of quick reduction of active power output and all frequency containment reserves with the purpose of decreasing the frequency have already been deployed. The activation of LFSM-O is not sold on the balance market, however, it should according to EIFS 2018:2 be activated when the frequency threshold for LFSM-O, 50.5 Hz, is surpassed. When the lowest regulation capacity is reached, the PGM should continue to operate on that level. During LFSM-O operation, the primary droop setting should be 8 %. The LFSM-O/U droop is defined as:

$$s[\%] = 100 * \frac{|\Delta f| - |\Delta f_1|}{f_n} * \frac{P_{ref}}{|\Delta P|} \quad (4)$$

f_1 is the frequency threshold for LFSM-O/U. When the minimum regulating level is reached, the PGM should continue to operate on that minimum level. Furthermore, the reference value for active power P_{ref} should be the maximum continuous power of the PGM. Also, automatic disconnection of PGMs is not accepted as an alternative to active power reduction. These requirements apply to PGMs of type A, B, C and D (European Commission, 2016).

2.7.3 LFSM-U

Limited Frequency Sensitive Mode at Underfrequency (LFSM-U) is to be activated when the power system is in emergency state, in need of a quick increase of active power output and all FCRs with the purpose of increasing the frequency have been deployed. The activation of LFSM-U is not sold on the balance market, however, it should according to EIFS 2018:2 be activated when the frequency threshold for LFSM-U, 49.5 Hz, is surpassed. When a PGM is operated in LFSM-U, the primary droop setting should be 8 %. The PGM should be able to increase the active power output until its maximum continuous active power. These requirements apply to PGMs of type C and D (European Commission, 2016).

Regarding the actual active power output by a PGM during operation in LFSM-U, consideration is to be taken to the access to primary energy sources (European Commission, 2016) If this means, for example, that a wind power park does not need to contribute with LFSM-U if the frequency decreases below 49.5 Hz, is not clear. According to the Swedish Energy Markets Inspectorate however, this is to be interpreted as not requiring wind turbines to operate in a deloaded mode in order to be able to increase the active power output in case of operation in LFSM-U is needed (Jaakonantti, 2020). Consequently, it is unlikely that wind turbines will actually contribute with LFSM-U.

In Table 3.3, a summary of the different operational modes and which PGMs that are obliged to have the corresponding capabilities can be seen.

Table 3.3. The different types of requirements for operational modes and the PGM-types that they apply to.

	Type A	Type B	Type C	Type D
LFSM-O	**X**	**X**	**X**	**X**
FSM			**X**	**X**
LFSM-U			**X**	**X**

2.7.4 FCR

In order to ensure sufficient system balance in every moment, Svenska kraftnät utilizes a balance market where balance reserves can be sold by power producers and consumers. The balance services Frequency Containment Reserve-Normal (FCR-N) and Frequency Containment Reserve-Disturbance (FCR-D) are two of the products sold on this market. In the Nordic synchronous area, the standard frequency range is $49.9 - 50.1\ Hz$, which is the frequency interval where FCR-N is automatically deployed in order to ensure that the frequency keeps within certain determined values based on a reference incident. Svenska kraftnät requires that FCR-N must be deployed with $63\ \%$ within 60 seconds and $100\ \%$ within 3 minutes and is a symmetrical product which means that the reserve must be able to regulate both up and down. The minimum bid size on the balance market for FCR-N is $0.1\ MW$ and the total volume requirement in Sweden is $237\ MW$ (Svenska kraftnät, 2019 (c)).

FCR-D is used for frequency containment in the range of $49.9 - 49.5\ Hz$ and must be deployed with $50\ \%$ within 5 seconds and $100\ \%$ within 30 seconds. The minimum bid size on the balance market for FCR-D is, like FCR-N, $0.1\ MW$ and the total volume requirement in Sweden is $573\ MW$ (Svenska kraftnät, 2019 (c)). See Table 3.4 for a summary of the parameters for the FCR-products.

Table 3.4. FCR requirements in Sweden.

	Initial delay	Full activation time
FCR-N	$63\%\ within\ 60\ s$	$180\ s$
FCR-D	$50\%\ within\ 5\ s$	$30\ s$

2.8 Wind Power Integration in Sweden

2.8.1 The Wind Power Development

Sweden has seen a large integration of wind power into the power system in recent years. The total installed power has gone from $585\ MW$ year 2006 to $7300\ MW$ year 2018, see Figure 3.9 (Swedish Energy Agency, 2020). Prognoses show that the wind power production could increase to 60 TWh and $18\ 500\ MW$ of installed power by 2030, and $90\ TWh$ production and $25\ 000\ MW$ installed power by 2040 (Swedish Wind Energy Association, 2020).

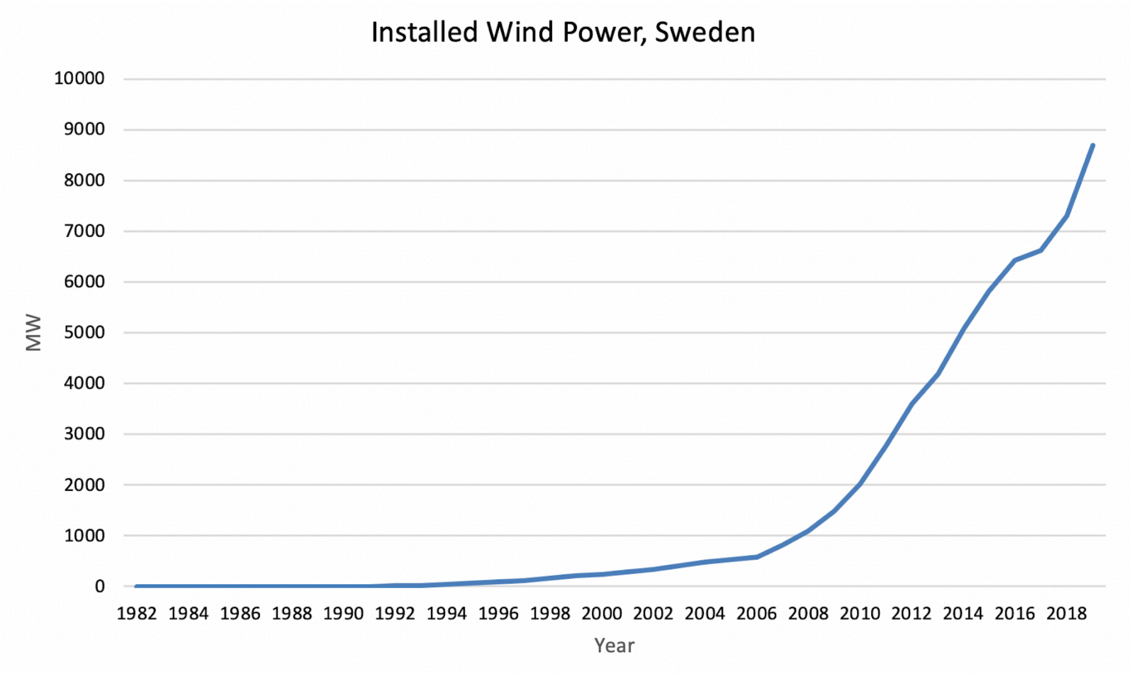

Figure 3.9. The development of installed wind power during 1992-2018.

2.8.2 Full Power Converter Wind Turbines

Most wind turbines used today are equipped with full power converters. When a full power converter is used, all power from the wind turbine goes through the power converter. This creates an mechanical decoupling between the generator and the grid (see Figure 3.10), with the result that the rotational energy stored in the rotation of the blades will not automatically contribute to the grid inertia in the way that synchronous generators do. In addition to this, the full power converter makes it possible to control frequency, current and voltage according to what fits the connecting grid. On the generator side of the power converter the stator current and rotational speed of the turbine can be controlled, and on the grid side of the power converter the balance between active and reactive power can be controlled (Yingcheng & Nengling, 2011).

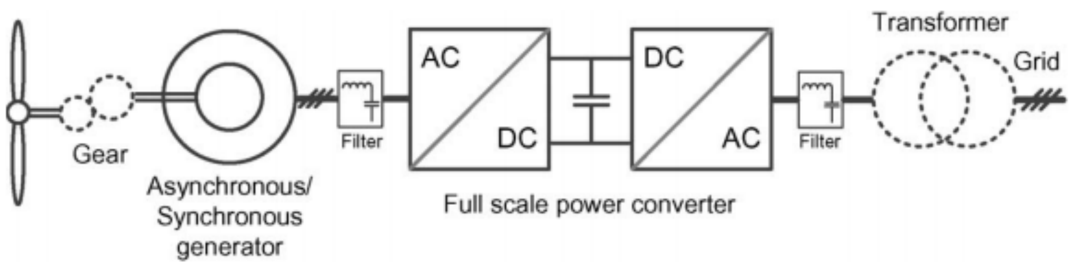

Figure 3.10. A variable speed wind turbine with a full-scale power converter. Figure modified from Blaabjerg et al., 2012.

2.8.3 Wind Power Capabilities

Before RfG, no requirements of having capabilities for frequency regulation existed for wind turbines and farms in Sweden. With RfG, and the requirements on capabilities for operation in FSM and LFSM, this has changed. Type A and B PGMs should be able to operate in LFSM-O, while type C and D should also be able to operate in LFSM-U and

FSM regardless of primary energy source. Wind turbines with full power converters have the technical possibility of operating in FSM and LFSM-O/U through different algorithms deployed in the software. However, the different algorithms all accomplish this by operating the turbine with regulation margins. The power regulation can be achieved based on the following derivation.

The wind power resource in an area A can be estimated by:

$$P_{wind} = \frac{1}{2}\rho A v^3 \qquad (5)$$

where is the air density and v is the wind speed. The power extracted by the turbine can be estimated by:

$$P_{turbine} = \frac{1}{2}C_p \lambda A v^3 \qquad (6)$$

where C_p, the power coefficient, usually is given as a function of the blade pitch angle and the tip speed ratio, the angle between the plane of rotation and cross section chord of the blade which are dependent on the specific turbine. Thus, the power extracted from the wind turbine is maximized when C_p is maximized, which is at a specific value for the tip speed ratio. For a given wind speed, the tip speed ratio is then maximized for a specific turbine rotor speed and thus C_p, and the extracted power, can be controlled by controlling the turbine rotor speed (Kesraoui et al, 2011). Conventional wind generators operate at maximum power point (MPP), which means continuously maximizing C_p, and do not contribute with frequency regulation.

Generally, there are two methods to control the active power output of a wind turbine: pitch angle control and rotor speed control (Bao and Li, 2014). Pitch angle control involves optimizing the pitch angle of the rotor blade in different wind speeds. When maximum production is achieved, the pitch angle is 0 degrees. The power production is suboptimal whenever the pitch angle deviates from 0 degrees. The second method, rotor speed control, involves optimizing the rotor speed instead and keeping the pitch angle fixed.

A wind turbine has the possibility of operating in a deloaded mode, at lower than maximum power, in order to ensure sufficient reserve power to contribute with upwards frequency regulation. It is normal that a wind turbine operates in $80 - 90\ \%$ of MPP in order to ensure a margin for upwards frequency control. In a situation where the frequency decreases, the operating mode is changed from the deloaded mode to MPP and thus the turbine can contribute with frequency regulation (Bao and Li, 2014). Requirements on participating in frequency regulation both upwards and downwards already exist in Denmark, where some wind turbines operate in a deloaded mode in order to ramp up production as frequency response on decreasing frequency (Energinet, 2016).

Furthermore, the droop method has been suggested as a way for wind turbines to contribute with the primary frequency regulation needed in a power system with low inertia (Arani & Mohamed, 2018). Implementing this method in the control system results in wind turbines emulating how conventional synchronous, directly connected generators respond to a frequency change, thus changing the power output as a result of frequency deviations. This is achieved by controlling the power output of the wind turbine via the converter. Droop is in RfG defined as the frequency deviation in percent needed to change the power output of the PPM with 100 % of installed power, $s = \frac{\Delta f/50}{\Delta P/P_n}$. Droop control makes the PPM increase and decrease its power generation according to changes in frequency. To increase the power generation, the wind turbine needs to be operated in a deloaded mode and deviate from MPP according to the reasoning above.

2.9 PPM Compliance with FSM and LFSM Requirements

Compliance with the FSM-requirements has to be shown via both tests and simulations, or via equipment certificates provided by an authorised certifier. Regarding how compliance with the FSM-related requirements in RfG are to be shown, article 48 in RfG provides a framework (European Commission, 2016). With regards to compliance tests, the technical capability of the PGM to contribute with frequency regulation should be shown from maximum continuous power to the minimal regulating level, while showing compliance with all relevant parameters. Frequency steps and ramps large enough to cause the whole defined interval of active power as frequency response should be simulated and provided to the park. The tests should be assessed as approved if the following conditions are satisfied:

1) No longer activation time for the whole interval in frequency response as a consequence of a frequency step change than t_1 and t_2, see Table 3.2.

2) Undamped oscillations do not occur after the response on the frequency step change.

3) The initial delay is no longer than t_1, see Table 3.2.

4) The parameter values of the droop and deadband are fulfilled.

5) The insensitivity for active power frequency response is not higher than f_i, see Table 3.2.

When it comes to tests of the LFSM requirements, the tests are similar to the tests of the FSM requirements with the difference that the frequency steps and ramps are to be large enough to cause a change of 10 % of maximum continuous power. Also, for the LFSM-U requirement, the starting point should be no higher than 80 % of maximum continuous power (European Commission, 2016).

Regarding compliance simulations of the FSM-related requirements, the simulation should, with frequency steps and ramps, show the capability of the PGM to modulate active power according to defined parameters for droop and deadband in the whole frequency area defined in Table 3.2, thus $5 - 10$ %. The simulations should be assessed as successful if both following conditions are satisfied:

1) The simulation model is validated against the compliance tests described above.

2) Compliance is shown with the FSM-related requirements.

Compliance simulations of LFSM-O should be carried out by simulating frequency steps and ramps at high frequencies until the lowest possible regulating capacity. The simulation should be assessed as successful if the model and the results are validated against the compliance tests for LFSM-O. Regarding compliance simulations of LFSM-U, frequency steps and ramps at low frequencies could be performed, fulfilling the requirements of LFSM-U. The simulation should be assessed as successful if the model and its results are validated against the compliance tests for LFSM-U (European Commission, 2016).

2.10 Fingrid's Implementation of RfG

In Finland, RfG has been implemented by the TSO Fingrid in the document "*Grid Code Specifications for Power Generating Facilities VJV2018"*, henceforth referred to as *VJV2018* (Fingrid, 2018). The document contains a compilation of necessary information for PGM owners and DSOs in Finland to show compliance with relevant requirements in RfG, compared with the Swedish situation where RfG and EIFS 2018:2 have to be followed in parallel and guidelines, rules or best practices of how to show compliance are lacking. In *VJV2018*, Fingrid has included the requirements in RfG, the requirements of general application and clarifications. Fingrid has also made sure that data from new PGMs are obtained by Fingrid or the RSO with the purpose of acquiring necessary information and data for being able to plan and maintain a stable grid operation.

Regarding the specifications of compliance tests of the FSM and LFSM requirements for PPMs of type C and D, *VJV2018* contributes with some additional procedures in comparison to RfG of how to show compliance. For LFSM-O, it adds a suggestion that an interfering signal of $+0.7\ Hz$ can be introduced in the frequency measurement. For LFSM-U, it suggests an interfering signal of $-0.7\ Hz$ and that the starting point for the PPM is no higher than 80 % of rated power. With regards to FSM, *VJV2018* specifies an initial power generation of at least 30 % of rated power. It also suggests that the tests could be carried out through 2 scenarios with minimum and maximum droop, 4 and 6 %, introducing signals of $+0.1\ Hz, +\ 0.5\ Hz, -0.1\ Hz$ and $-0.5\ Hz$ through both steps and ramps. The tests should consist of no less than 10 minutes measurement. For testing the deadband, *VJV2018* suggests setting the deadband to the defined value and measuring the frequency for 5 consecutive minutes. Also, both droop and deadband should be set to both minimum and maximum value of the respective setpoint range (Fingrid, 2018). With regards to compliance simulations for the requirements for FSM and LFSM, *VJV2018* gives no additional information or specifications of how these are to be carried out (Fingrid, 2018).

3. Method

In this chapter, the research method of this study is presented. The choice of performing interviews, which literature that has been reviewed and how conclusions have been drawn is further explained.

3.1 Research Method

The initial research of this thesis was dedicated to studying the content of RfG and the appurtenant collection of national regulations from the Swedish Energy Markets Inspectorate, EIFS 2018:2. After that, contact was initiated with people in the electricity industry deemed to have insight in how the relevant actors in the industry currently relate to RfG. The different contacts initiated resulted in 15 interviews that were performed during the 20 weeks this thesis was written. Also, a literature review was carried out with the purpose of describing the possibilities for wind turbines to contribute with primary frequency regulation. From the information gathered from the initial research and interviews, the current compliance landscape was described and characterized together with a description of the motivations for requiring the capabilities of operating wind power parks of type C and D in FSM and LFSM-O/U. From these results, an analysis was made with the purpose of proposing possible consequences of the current compliance landscape for the future power system, with focus on the requirements for FSM and LFSM-O/U. Incentives for complying with RfG and the impact of future guidelines were also discussed.

3.2 Design of Compliance Simulation Templates

Templates of compliance simulations in a calculation software for the requirements for capability to operate in FSM and LFSM-O/U by PPMs of type C and D, are provided in this thesis. The templates were based on the type of guidelines that the relevant respondents of this study demanded, the Finnish transmission system operator (TSO) Fingrid's grid code *VJV2018* (Fingrid, 2018) and the Swedish TSO Svenska kraftnät's test programmes for delivery of Frequency Containment Reserves (FCRs) (Svenska kraftnät, 2018). Fingrid's approach was chosen since future national guidelines in Sweden, currently being developed by Svenska kraftnät together with the industry based on Fingrid's work, are to be provided some time in the future. Furthermore, Svenska kraftnät's test programmes for delivery of FCRs were chosen since the requirements for FSM and LFSM are much alike the requirements for delivery of FCRs. Also, the reason for requiring capability to operate in FSM is for the PGM to be able to deliver FCRs (ENTSO-E, 2017 (a)). Lastly, the opinions of respondents were taken into consideration in order to shine light on the type of guidelines that are demanded from the industry.

The relevant respondents expressed a need for more detailed guidelines with regards to the compliance tests and simulations than what Fingrid's grid code provides. Therefore, the templates for compliance simulations were developed using the following methodology. First, the minimum requirements on compliance simulations stated in RfG were included. Second, additional information from Fingrid's grid code was included. Third, in areas where neither RfG or Fingrid's grid code provided any guidelines or specifications of how to show compliance, Svenska kraftnät's test programmes for the FCRs were examined to see which type of details and specifications they could provide. Lastly, in the matters that remained unspecified, the author of this thesis has contributed with suggestions of how compliance can be shown.

3.3 Interviews

A part of this thesis was carried out as a qualitative study. A qualitative study is conducted with the purpose of characterizing, describing or finding models that best describe a given phenomenon in relation to its surroundings (Olsson & Sörensen, 2011). In this thesis, a qualitative study was performed in the form of semi-structured interviews with actors in the electricity industry that were deemed to have important and relevant roles with regards to the compliance with RfG. This includes respondents from the Swedish TSO Svenska kraftnät, the Swedish Energy Markets Inspectorate, Swedenergy AB and respondents from Swedish distribution system operators (DSOs) and PGM owners. These respondents were chosen with the aim of characterizing the situation for the relevant actors in the industry when it comes to the compliance with RfG and to specify obstacles and issues with regards to complying with the regulation. Primarily, the supervisors of this thesis have contributed by providing the contacts of people with relevant competences, but the respondents themselves have in a few cases recommended other relevant respondents. The people that were interviewed are listed in Table 1, and with further motivations to why they have been interviewed in the Appendix.

4. Results

In this chapter, a description of the current Swedish compliance landscape and incentives for complying with RfG is presented, based on research and interviews. Furthermore, the motivation for requiring capabilities for operation in FSM and LFSM of wind parks is provided. Finally, a suggestion of how to show compliance with the requirements for FSM and LFSM is presented.

4.1 The Swedish RfG Implementation Structure

The EU regulation 2016/631 Requirements for Generators entered fully into force in April 2019 (Swedish Energy Markets Inspectorate, 2018 (b)). Svenska kraftnät have, in accordance with article 7.4 in RfG, provided suggestions regarding the specification of the requirements of general application. The suggestions were then handed to the Swedish Energy Markets Inspectorate for ratifying. The Swedish Energy Markets Inspectorate are, according to Regulation (1994:1806), authorised to provide national regulations in this matter. The result is a collection of regulations, EIFS 2018:2, containing non-exhaustive requirements made exhaustive, and non-mandatory requirements made mandatory (Bobadilla-Robles, 2020). An illustration of the implementation structure in Sweden can be seen in Figure 4.1.

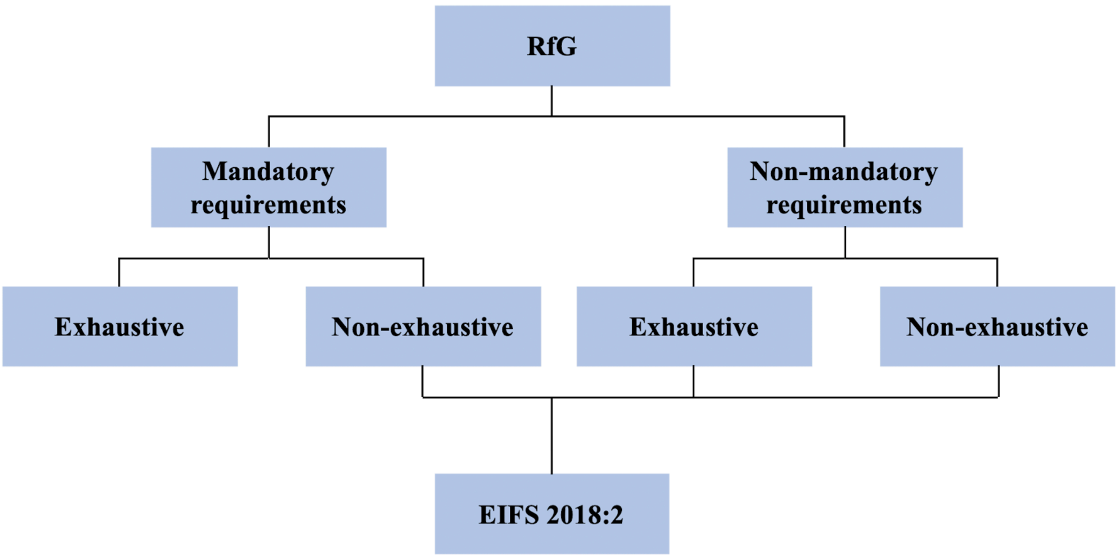

Figure 4.1. The structure of the implementation of RfG in Sweden.

With the implementation of RfG, there are three legal frameworks in force in Sweden concerning the grid connection of PGMs. These three are RfG, the national specification of requirements of general application in the legal framework EIFS 2018:2 and a legal framework formulated by TSO Svenska kraftnät in 2005, SvKFS 2005:2. However, SvKFS 2005:2 covers only PGMs that were connected to the grid from 2005 and until RfG became applicable. This is because RfG, as an EU-regulation, takes precedence over any conflicting national legal framework and only concerns PGMs that either are to be connected to the grid, or that are already connected but are to be substantially modified.

4.2 The Current Swedish Compliance Landscape

Several respondents express that most actors in the industry have not implemented work procedures ensuring compliance with RfG yet, although the aim is to do so (Respondent 1, 2020; Agneholm, 2020; Berglöf, 2020). The reasons for this seem to be several. Firstly, the implementation of RfG infers new responsibilities and new work procedures for actors in the electricity sector. Among other things, DSOs are given a more active role than before. The DSOs are now responsible for providing which requirements the PGMs that are to be connected to their grid should fulfil and assessing compliance tests and simulations, which is a large and costly change from the work procedures before RfG when this was the responsibility of the owner of the PGM. Assessing compliance tests and simulations will require heavy documentation handling and specific competence, and likely many companies will need to recruit personnel dedicated for this (Adolfsson, 2020).

Furthermore, with the implementation of RfG, owners of PGMs have to respond to more comprehensive technical requirements for PGMs and likely more complex procedures for guaranteeing compliance with the new requirements. Before RfG entered into force, when complying with grid codes was the responsibility of the PGM owner only, it was not always the primary concern of the PGM owner to show compliance with all requirements in the preceding grid code SvkFS 2005:2. Rather, the primary concern was to ensure a stable and secure grid operation after the connection of the PGM from the perspective of the DSO. With RfG in force, and the more complex work procedures it implies, this behaviour seems to remain to some extent (Ogiewa, 2020; Lindroth, 2020).

In addition to this, several respondents point out the lack of planned supervision by the regulatory authority as another circumstance creating a situation that is not facilitating motives to fully implement work procedures as required by RfG. At the same time, the same respondents see no purpose in detailed supervision during a learning period when the actors in the industry are trying to implement the new work procedures (Ogiewa, 2020; Lindroth, 2020; Respondent 1, 2020). The regulatory body has the responsibility of ensuring that actors in the energy sectors comply with relevant legal requirements, where RfG is one of them (Swedish Energy Markets Inspectorate, 2019). However, the Swedish Energy Markets Inspectorate exercise no planned monitoring of the actors in the electricity sector in order to ensure that new PGMs that are to be connected to the grid comply with RfG and EIFS 2018:2. For the moment, the supervision is based on indication, but the Swedish Energy Markets Inspectorate will start to conduct planned supervision sometime in the future (Jaakonantti, 2020).

Another factor that decreases the incentives for actors in the sector to properly implement the work procedures required by RfG is, according to several respondents, the unclear landscape and following ambiguity with regards to how compliance is to be shown with RfG that exists in Sweden (Ogiewa, 2020; Adolfsson, 2020; Respondent 1, 2020;

Tykeson, 2020). According to RfG, compliance is to be shown via either tests, simulations or both, depending on the requirement, or equipment certificates issued by an authorised certifier. However, there is no compliance scheme or guidelines set out in Sweden defining how compliance is to be practically shown, which leaves the involved actors in a resource-demanding situation. In each new project, owners of PGMs and DSOs have to orient in the new RfG landscape and how compliance is to be shown for each requirement. Some requirements are perceived as difficult to interpret, and the compliance procedures in RfG are vaguely described which leaves owners of PGMs and DSOs in an uncertainty with regards to what is required to actually show compliance with requirements in RfG. This is appointed as a major obstacle for working effectively with RfG. Other EU member states, for example Finland (Fingrid, 2018) and Germany (VDE FNN, 2020), have via their TSOs provided compliance schemes for the actors in the electricity sector consisting of guidelines of how to show compliance, in order for them to be able to show compliance in a cost-effective manner that is suited to their specific national context.

Svenska kraftnät and the Swedish Energy Market Inspectorate states that the compliance landscape in Sweden should be designed in a cost-effective way (Bobadilla-Robles, 2020; Lund, 2020). At the same time, the current situation, lacking guidelines or a national best practice for compliance testing and simulation and where the involved actors in each new project have to orient in the new RfG landscape, is not assessed to be cost-effective. Svenska kraftnät states that they are working together with the different actors in the electricity market towards designing a compliance scheme for the Swedish electricity sector. It is an extensive legislation requiring major work to fulfil and maintain. Svenska kraftnät is currently defining the different roles and responsibilities in their organization to be able to secure the transition and fulfil the future requirements (Lund, 2020).

In order to accomplish a cost-effective compliance scheme that makes sure that compliance with relevant requirements can be shown, Svenska kraftnät have together with the professional organisation of system operators and power producers in Sweden, Swedenergy AB, initiated what is called the Four Parties Conversation, where they together with the Swedish Energy Markets Inspectorate among other things discuss how to move forward to accomplish a cost-effective compliance scheme in Sweden (Lund, 2020). The participants from Swedenergy have expected Svenska kraftnät to take a leading role in the mission to design a compliance scheme but have experienced that the initiation of a working group with this purpose has taken time. Therefore, Swedenergy initiated a working group that met the first time in February, so far without Svenska kraftnät's participation, with the hope that Svenska kraftnät would join the group later on (Berglöf, 2020; Agneholm, 2020). The primary objective of this working group has been to examine the implementation of a compliance scheme in the neighbouring country Finland.

The Finnish TSO Fingrid has designed a compliance scheme consisting of information and guidelines about relevant requirements, requirements of general application, compliance tests and compliance monitoring. This information is integrated in the national grid code (Fingrid, 2018). Svenska kraftnät expressed in April that they have started developing national compliance procedures based on Fingrid's *VJV2018* but adjusted for the Swedish implementation of the requirements of general application (Modig, 2020; Piva, 2020). It is therefore likely that the outcome of the compliance scheme being developed by Svenska kraftnät will result in a similar document to VJV2018, with regards to content and how compliance tests and simulations are specified (Adolfsson, 2020; Berglöf, 2020; Agneholm, 2020). However, several respondents express a demand for a more detailed document than VJV2018 when it comes to the requirements and guidelines for compliance tests and simulations (Speychal, 2020; Lindroth, 2020; Adolfsson, 2020; Respondent 1, 2020). For example, clearer and more detailed scenarios and parameter values for testing both LFSM-O/U and FSM have been desired.

4.3 The Need of FSM and LFSM Capabilities in the Future Power System

4.3.1 Wind Power Integration and Frequency Quality

Wind power is a technology with power electronic converter interfaced electricity generation. The continuous integration of wind power into the power system increases the average level of wind power penetration, which means that the system inertia, or rotational energy, decreases which increases the risk of system frequency instability. Too large frequency deviations may cause tripping of generators and load-shedding. It has been reported that the Nordic synchronous system frequency stability has deteriorated during the last decade (Persson, 2017). As can be seen in Figure 4.2, a higher number of minutes outside the normal frequency band, that is 49.9 -50.1 Hz, has been observed in the period 2010-2016 compared to the period 2001-2010. The goal is to keep the number of minutes outside the normal frequency band below 10 000 minutes per year.

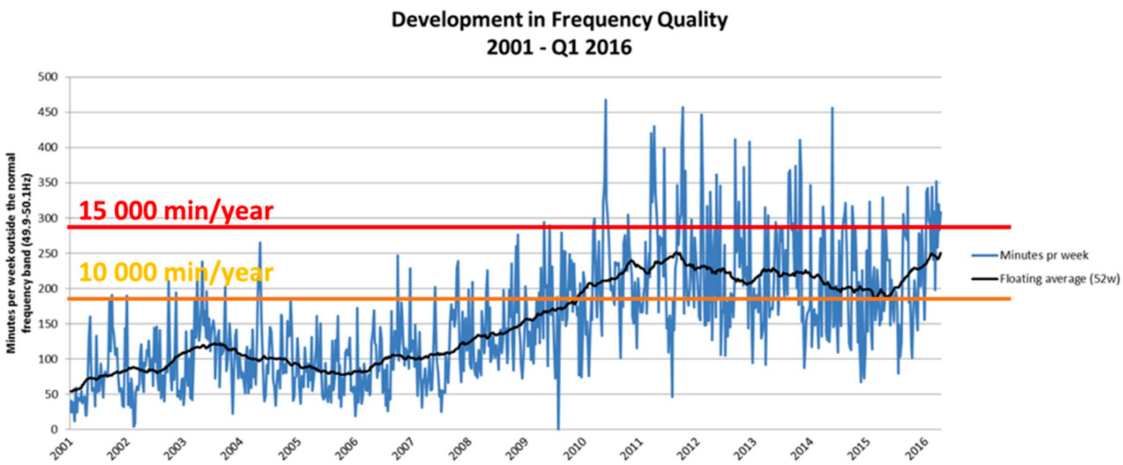

Figure 4.2. The blue line represents the number of minutes outside the normal frequency band (ENTSO-E, 2016).

Consequently, the Nordic TSOs are concerned about the future system frequency stability, as the development of higher penetration of primarily wind power in the Nordic power system shows no sign of mitigating and all Swedish nuclear power plants are planned to be phased out by 2040 (ENTSO-E, 2016; Persson, 2017).

In addition to this, the costs for balance services, primarily the automatic reserves FCR-D, FCR-N and aFRR have increased in recent years. This has further implications for the actors involved in the power system. The tariffs for the transmission grid have increased, as have the charges for the balance responsible parties in order for Svenska kraftnät to cover the increased costs for balance services. Also, Svenska kraftnät emphasizes the need of increasing the number and technology diversity of suppliers of FCR in order to increase the competition on the market and lower the prices. Today, hydro power supplies the vast majority of balance services (Svenska kraftnät, 2019 (b); Modig, 2020).

Thus, there is a need for PGMs to support the frequency stability more to keep the historical stability and robustness (ENTSO-E, 2018). As wind turbines do not traditionally contribute with ancillary services such as inertia or frequency control, the need for regulation of wind turbines with the purpose of reducing frequency instabilities is increasing. This can be done with the most common wind turbines of today with full power converters (ENTSO-E, 2016; Persson, 2017).

4.3.2 Possible Contribution to Power System Robustness by Operation in FSM and LFSM

The FSM capabilities are mainly required in order to ensure that PPMs of type C and D have the possibility of delivering FCR-products (ENTSO-E, 2017 (a)). If a PPM fulfils the FSM requirements, then technical possibilities with regards to activation times of delivering the balance service FCR-N on Svenska kraftnät's balance market is ensured within the required regulation area of $5 - 10$ % of maximum continuous power. Also, delivery of FCR-D is possible in the same regulation area if 50 % of change in active power can be achieved within $5\ s$.

Today, the large majority of the bids on the balance market come from the easily regulated hydro power. However, wind power might need to contribute with frequency regulation in future scenarios. Situations with low system inertia and greater need of balance services are more likely to happen as nuclear power is phased out and more wind power keeps being installed (Persson, 2017). Also, wind power, with its low marginal cost, might replace hydro power in the energy production mix in future scenarios to an extent that there is a need for wind power to contribute with FCRs to ensure the stability of the grid. Because of this, situations where it is profitable for wind power to contribute with primarily the FCR products are likely to appear in the future. Also, Svenska kraftnät deems it desirable that wind power contributes with FCR in the future in order to diversify the balance portfolio (Modig, 2020).

Furthermore, operation in LFSM-O/U is deemed to be needed very rarely (Modig, 2020; Jaakonantti, 2020). However, building the capabilities into the system increases the system robustness and the possibilities to manage a situation when the power system is in emergency state. Also, it is assessed as reasonable that all power-producing technologies contribute to help the system in the case of emergency state (Modig, 2020).

4.4 Compliance with Requirements for FSM and LFSM

When a wind power park of type C or D is to be connected to the grid, it has to show compliance with relevant requirements in RfG as stated in section 3.9. Furthermore, RfG requires that the compliance with capabilities to operate in FSM and LFSM-O/U is to be shown by performing both tests and simulations. Hereafter, templates of compliance simulations for the requirements to have capability to operate in FSM and LFSM-O/U is presented. The templates have been developed using the methodology described in section 2.2.

4.4.1 Simulations

The compliance simulations for showing capabilities for operation in FSM and LFSM-O/U should be carried out in a software suitable for performing power system studies. The software should be able to create a model that realistically reproduces the main functionalities and characteristics of the PPM (Fingrid, 2018). In order to create a realistic model of the park, turbine models have to be provided by the manufacturer (Speychal, 2020; Lindroth, 2020; Respondent 1, 2020).

4.4.2 FSM

The compliance simulation is to be based on a series of frequencies being fed to the park as suggested in *VJV2018*, after which relevant parameter responses can be measured. The sequence of frequencies suggested to be fed to the frequency measurements of the wind turbines can be seen in Table 4.2. By setting the deadband to $100\ mHz$ and ensuring that the interval it covers is passed through by the series of frequencies being fed to the park, the deadband requirement could be tested. At the start of the test, the PPM needs to produce energy at least at $30\ \%$ of its rated capacity. Also, the simulation is to be carried out with minimum and maximum droop, see Table 4.1 (Fingrid, 2018). Moreover, an additional specification can be added based on Svenska kraftnät's test programmes for the FCRs. The active power should be measured with a maximum sampling time of $1\ s$, as requested in the test programmes (Svenska kraftnät, 2018).

From this point, where *VJV2018* or the test programmes provide no additional guidelines on how compliance with the remaining requirements presented in section 3.7.1 can be shown, my own suggestions will be presented. First, the sampling time of the frequency should be Δf_i, $10\ mHz$. In that way the lowest acceptable frequency insensitivity required by RfG is tested. Furthermore, for every frequency change, the following parameters should be measured: the initial delay t_1, the full activation time t_2 and for maximum and minimum regulating level, thus 49.5 and $50.5\ Hz$, the frequency signal should be applied for at least $15\ min$ to test the endurance. In addition to this, in order to determine if undamped oscillations appear, a tolerance level of P_{tol} from the steady state value for the frequency response is proposed, which should not be passed after the time t_3. Defining these parameters requires further studies not addressed in this thesis, however, the concept can be used if agreed upon between the DSO and the PGM owner. A currently ongoing project between the Nordic countries is developing requirements for ensuring that undamped oscillations do not occur when delivering FCRs (Modig, 2020). Eventually, the results of this project could also be applied to the tests of undamped oscillations.

Furthermore, simulations should be performed with minimum and maximum droop and with both frequency steps and ramps. The ramps are suggested to be carried out with a rate of change of frequency of $2.0\ Hz/s$, since EIFS 2018:2 requires all PGMs to manage a maximum rate of change of this magnitude. However, other rates of change of frequency can be used for the purpose of showing compliance with the requirements for FSM. Lastly, the active power response in relation to maximum continuous power should be measured so that the droop can be calculated for each frequency change by using equation 1 and 3. The result of this is four different sets of simulations, according to chapter 4.2.

Table 4.1. A matrix representing the four sets of simulations.

Scenario	$s = 2$ [%]	$s = 12$ [%]
Steps	☐	☐
Ramps	☐	☐

Table 4.2. A table with frequency steps or ramps and values to be measured with the simulations.

Scenario	$\frac{\|\Delta P\|}{P_{ref}}$ [%]	t_1 [s]	t_2 [s]	t_3 [s]	√ / X
$\mathbf{50.00\ Hz \rightarrow 50.10\ [Hz]}$					
$\mathbf{50.10\ Hz \rightarrow 50.50\ [Hz]}$					
$\mathbf{50.50\ Hz \rightarrow 50.10\ [Hz]}$					
$\mathbf{50.10\ Hz \rightarrow 49.90\ [Hz]}$					
$\mathbf{49.90\ Hz \rightarrow 49.50\ [Hz]}$					

4.4.3 LFSM-O

The compliance simulation is again to be based on a series of frequencies being fed to the park, after which relevant parameter responses can be measured. *VJV2018* states that a change of 10 % of maximum continuous power shall be caused during the test (Fingrid, 2018).

From this point, where *VJV2018* or the test programmes provide no additional guidelines on how compliance with the remaining requirements presented in section 3.7.1 can be shown, my own suggestions will be presented. Svenska kraftnät's test programmes for the FCRs suggests a series of frequencies being fed to the park, including changes in frequencies both up and down in the interval that is being tested. However, none of the test programmes cover the frequency range that constitutes LFSM-O. RfG states that a PPM should be able to keep producing energy at its lowest regulation capacity, which is an individual characteristic for every PPM. Thus, the series of frequencies cannot be generalised. However, a suggestion of a series of frequencies is provided in Table 4.4, which can then be modified to find the lowest regulation capacity of the specific PPM. Moreover, the parameters t_1, t_2 and t_3 are to be measured as in the previous section, 4.4.2. and the active power response in relation to maximum continuous power should again be measured so that the droop can be calculated for each frequency change by using equation 4.

The frequency sequence in Table 4.4 is suggested for the simulation, performed through both steps and ramps according to Table 4.3.

Table 4.3. A Table representing the two sets of simulations.

Scenario	$s = 8$ [%]
Steps	☐
Ramps	☐

Table 4.4. A table with frequency steps or ramps and values to be measured with the simulations.

Scenario	$\frac{\|\Delta P\|}{P_{ref}}$ [%]	√ / X
$\mathbf{50.50}\ \boldsymbol{Hz} \rightarrow \mathbf{51.00}\ [\boldsymbol{Hz}]$		
$\mathbf{51.00}\ \boldsymbol{Hz} \rightarrow \mathbf{51.50}\ [\boldsymbol{Hz}]$		
$\mathbf{51.50}\ \boldsymbol{Hz} \rightarrow \mathbf{51.00}\ [\boldsymbol{Hz}]$		
$\mathbf{51.00}\ \boldsymbol{Hz} \rightarrow \mathbf{50.50}\ [\boldsymbol{Hz}]$		

4.4.4 LFSM-U

The compliance simulation is again to be based on a series of frequencies being fed to the park, after which relevant parameter responses can be measured. *VJV2018* states that a change of 10 % of maximum continuous power shall be caused during the test, with a starting point of maximum 80 % of rated capacity (Fingrid, 2018).

From this point, where *VJV2018* or the test programmes can provide no additional guidelines on how compliance with the remaining requirements presented in section 3.7.1 can be shown, my own suggestions will be presented. Svenska kraftnät's test programmes for the FCRs suggests a series of frequencies being fed to the park, including changes in frequencies both up and down in the interval that is being tested. However, none of the test programmes covers the frequency range that constitutes LFSM-U. However, a suggestion of a series of frequencies is provided in Table 4.6, based on the concept in the test programmes but adjusted for frequencies below 49.5 Hz. Moreover, the parameters t_1, t_2 and t_3 are to be measured as in section 4.4.2. and the active power response in relation to maximum continuous power should again be measured so that the droop can be calculated for each frequency change by using equation 4.

The frequency sequence in Table 4.6 is suggested for the simulation, performed through both steps and ramps according to Table 4.5.

Table 4.5. A table representing the two sets of simulations.

Scenario	s = 8 [%]
Steps	☐
Ramps	☐

Table 4.6. A table with frequency steps or ramps and values to be measured with the simulations.

Scenario	$\frac{\lvert\Delta P\rvert}{P_{ref}}$ [%]	√ / X
$\mathbf{49.50}\ \boldsymbol{Hz} \rightarrow \mathbf{49.00}\ [\boldsymbol{Hz}]$		
$\mathbf{49.00}\ \boldsymbol{Hz} \rightarrow \mathbf{48.50}\ [\boldsymbol{Hz}]$		
$\mathbf{48.50}\ \boldsymbol{Hz} \rightarrow \mathbf{49.00}\ [\boldsymbol{Hz}]$		
$\mathbf{49.00}\ \boldsymbol{Hz} \rightarrow \mathbf{49.5}\ [\boldsymbol{Hz}]$		

4.4.5 Tests

The tests are suggested to be performed by injecting the same frequency sequences into the frequency measurement of the park as suggested for the simulations, since the tests are to validate the model. When performing the tests, the same parameters are to be measured as for the simulations. If the test results comply with the relevant requirements and validates the simulation model, compliance for the PPM has been shown.

5. Discussion

In this chapter, the results of the study are discussed with the purpose of answering the research questions of this thesis.

5.1 Functionality of the Swedish Compliance Landscape

The Swedish compliance landscape seems to carry obstacles and challenges for the relevant actors to overcome in order to properly implement work procedures with the purpose of fully complying with RfG. First of all, it is clear that economic short-term incentives exist for not implementing new resource-demanding work procedures and carrying out expensive compliance tests and simulations. For DSOs, implementing these work procedures involves additional work with documentation, test and simulation result assessment and acquiring knowledge regarding the content of RfG and how compliance tests and simulations can be carried out. Likely, this involves hiring new personnel with competence in these areas (Adolfsson, 2020). For owners of PGMs, a major objective when planning a PGM is to minimize the Levelized Cost of Energy (LCOE). Complying with RfG involves new technical requirements on PGMs to be connected to the grid, and the need of acquiring competence for carrying out - in many cases - new and more extensive compliance simulations and tests. These tasks will most likely increase the LCOE for any new project (Respondent 1; Ogiewa, 2020).

Thus, the factors presented above motivates the relevant actors to not fully comply with RfG. However, those factors do not necessarily have to constitute major obstacles for ensuring that the relevant actors in the industry comply with RfG. If other strong incentives for complying with RfG exist, they might outdo these factors. One such incentive could be supervision or monitoring by the regulatory authority, and reprimands in case of not complying with RfG. However, indicative supervision, that is performed today, requires a formal report to be made and neither PGM owners nor DSOs have clear incentives to report the other part in case of suspecting that the other part does not fully comply with RfG. Instead, their interests lie in agreeing with the other part on work procedures that benefit both parts and do not necessarily involve the regulatory authority.

Not complying fully with RfG implies, consequently, no immediate consequences for either PGM owner or DSO, if the connection and operation of the PGM is functioning sufficiently in the eyes of both parties. This approach to grid codes seems, to some extent, have been present also before RfG, which might further decrease the speed of change among the relevant actors in this matter. This raises an issue related to the contents of Article 71 in RfG, that specifies the objective of the regulatory authority as ensuring that the relevant actors comply with RfG. The evidence from this study implies that the industry has problems showing compliance with RfG. It is likely that the actors in the industry would experience stronger incentives to comply with RfG if the Swedish Energy Markets Inspectorate would change the supervision by indication to planned supervision. However, before doing this, it would be reasonable to notify the industry and leave space for implementing necessary work procedures.

In addition to this, Sweden's lack of national guidelines or best practices with regards to how compliance with relevant requirements is to be shown further aggravates the situation for the relevant actors. Being among the first actors to implement potentially costly work procedures and design tests and models for showing compliance might not be seen as attractive - especially not since national rules or guidelines will be made official sometime in the future. Instead, many actors wait with the costly changes until these guidelines are published.

A situation with incentives to *not* properly implement work procedures that ensures compliance with RfG risks that important features and capabilities as specified by the regulation are not built into the power system. With the imposition of RfG, the European Commission is aiming for further market integration, achieving better security of supply and ensuring the possibility of continuous integration of renewable energy sources. These objectives are risked to not be achieved if the industry lacks incentives to fully implement work procedures to comply with RfG.

5.2 Motivation for Frequency Regulation Requirements for Wind Power Parks

The need for wind power parks to contribute with ancillary services from operation in FSM seems to be increasing. The reasons for this seem to be several. First of all, situations with large wind power penetration in the system, and thus low system inertia, already occur and will likely increase in frequency and magnitude in the future as the wind power integration in Sweden shows no sign of mitigating. In addition to this, the low marginal costs for energy production by wind turbines might entail the pushing aside of energy production from hydro power in future scenarios. Since hydro power today almost has a complete monopoly on the balance market for FCR products, this would entail a decrease of both the system inertia and conventional suppliers of FCR products. It is important to note that scenarios with low wind power penetration also are likely to happen frequently in the future. In these situations, hydro power might continue to play a similar role to the one it plays today. However, the scenarios with high wind power penetration might open up possibilities for wind power to compete on the balance market in a profitable way. Thus, incentives for wind power to contribute with FCRs are likely to increase in the future.

Ensuring capabilities for frequency regulation in wind power parks might not be of primary concern of project owners today, given that conventional operation of wind power parks does not include contributing with frequency regulation. However, the capabilities might be needed for the system stability in the future. Thus, a future scenario where wind power is occupying a large proportion of the momentarily power production but having little capabilities of contributing with frequency regulation is not unlikely, if capabilities for, for example, frequency regulation were not required already today. In this context, the system robustness with a future perspective is increased as a result of the requirements in RfG of PPMs of type C and D to have the capabilities for operation in FSM.

The operations in LFSM-O/U are to be activated when the power system is in an emergency state, a situation that is assessed to be extremely rare (Modig, 2020). Thus, the importance of these capabilities for the robustness of the power system is difficult to assess. In addition to this, wind power will likely not be able to contribute with LFSM-U if operated in the conventional way of MPP tracking. However, there is no obstacle for wind power to contribute with operation in LFSM-O. Consequently, ensuring these capabilities in PPMs of type C and D is deemed to increase the system robustness by some extent.

Furthermore, capabilities for FSM and LFSM-O/U are risked to not be sufficiently installed in PPMs of type C and D if the current situation with few and weak incentives for fully complying with all requirements in RfG continues. If this continues, it might result in a future scenario where the robustness of the Swedish power system is decreased as a consequence of few built-in resources with the possibility of delivering FCRs. Therefore, these requirements function as an example of the potential consequences for the future power system derived from the current compliance landscape in Sweden.

5.3 The Future Compliance Landscape

For the relevant actors to have clear and strong incentives to fully comply with RfG, some kind of guidelines or a manual of best practices for compliance tests and simulations is required, declaring the responsibilities of the relevant actors and procedures for the tests and simulations. This would facilitate the compliance with RfG by clarifying expectations, responsibilities and test procedures and, as a result, no actor has to spend time and resources on orienting in the new landscape alone. However, the relevant actors seem to request more detailed suggestions for these procedures than Fingrid's *VJV2018* in order to be able to work efficiently with RfG. To emphasize what is requested, a compliance simulation for the requirements for capabilities to operate in FSM and LFSM-O/U providing a more detailed structure is suggested in this report.

One way of taking the requests of more detailed guidelines into consideration is to provide instructions for a test or simulation that would ensure that all relevant minimum requirements are being tested. The test design in section 4.5 is of such character. RfG leaves the possibility for the DSO to accept alternative sets of tests than as outlined by RfG, as long as the alternative tests can show compliance with the relevant requirements.

Accordingly, the tests do not have to be compulsory, but can be provided as suggestions of how tests can be designed and performed with the addition that tests can be designed in alternative ways. This could significantly reduce the workload of both DSOs and PGM owners. DSOs could request the tests to be of the suggested design or a similar outline, while assessments of the test could be simplified if the suggested tests or simulations can be compared with. For PGM owners, if difficulties of ensuring that all relevant requirements are being tested arises when designing a compliance test or simulation, the suggested test designs can provide helpful information and guidelines. Alternatively, the suggested tests or simulations can be performed completely. Thus, by introducing guidelines or a manual of this sort, the incentives for fully complying with RfG can be strengthened.

Furthermore, several respondents agree that the use of certificates might benefit the cost-effectiveness when showing compliance with RfG (Adolfsson, 2020; Speychal, 2020; Ulvgård, 2020). Primarily the compliance of mass-produced units, like wind turbines, can be simplified. The lack of authorised certifiers in Sweden, however, makes this impossible today. If a demand exists in the industry, it might be an attractive role for foreign certifiers or organisations in Sweden with fitting competence to take. Using certificates could potentially lower the costs for both DSOs and PGM owners. DSOs could leave the task of defining requirements for the PGM owner to comply with to an authorised certifier, as well as the assessment of the tests. The PGM owner on the other hand could leave the task of designing tests and simulations and carrying these out to an authorised certifier.

5.4 A Successful Compliance Procedure

A successful compliance procedure, focused on the compliance process regarding a type C or D PPM requested to show compliance with the requirements for capability to operate in FSM and LFSM-O/U, should work in the following way. First, when the DSO and PGM owner have agreed that an attempt to connect a specific PPM should be made, the DSO should ensure that the necessary competence for specifying the relevant requirements that the park must fulfil according to RfG and EIFS 2018:2 is available. Since these tasks are new to the DSOs, this might imply the need of hiring new personnel or outsourcing the tasks. Thereafter, the minimum criteria for documentation along with the requirements needs to be specified and made available to the PGM owner.

From this point, it is the responsibility of the PGM owner to design plans for how the compliance tests and simulations are to be carried out. Since the requirements in RfG are more comprehensive and in some cases more complex than SvKFS 2005:2, the PGM owner might need to acquire additional competence or outsource this task. For ensuring compliance with the requirements for capability to operate in FSM and LFSM-O/U, the test design provided in section 4.4.1 can be used as a template. Thereafter, the procedures should be suggested to the DSO which approves if the minimum requirements are met. When this is done, the PGM owner can carry out the tests and simulations and provide the results in the way required by the DSO. Lastly, the DSO assesses the results of the compliance procedures, and since this is a new responsibility of the DSO, it might need to acquire additional competence or outsource this task. However, if the compliance template provided in this thesis is used, the result assessment can be easily checked and standardised. Figure 5.1 illustrates the process of a successful compliance procedure.

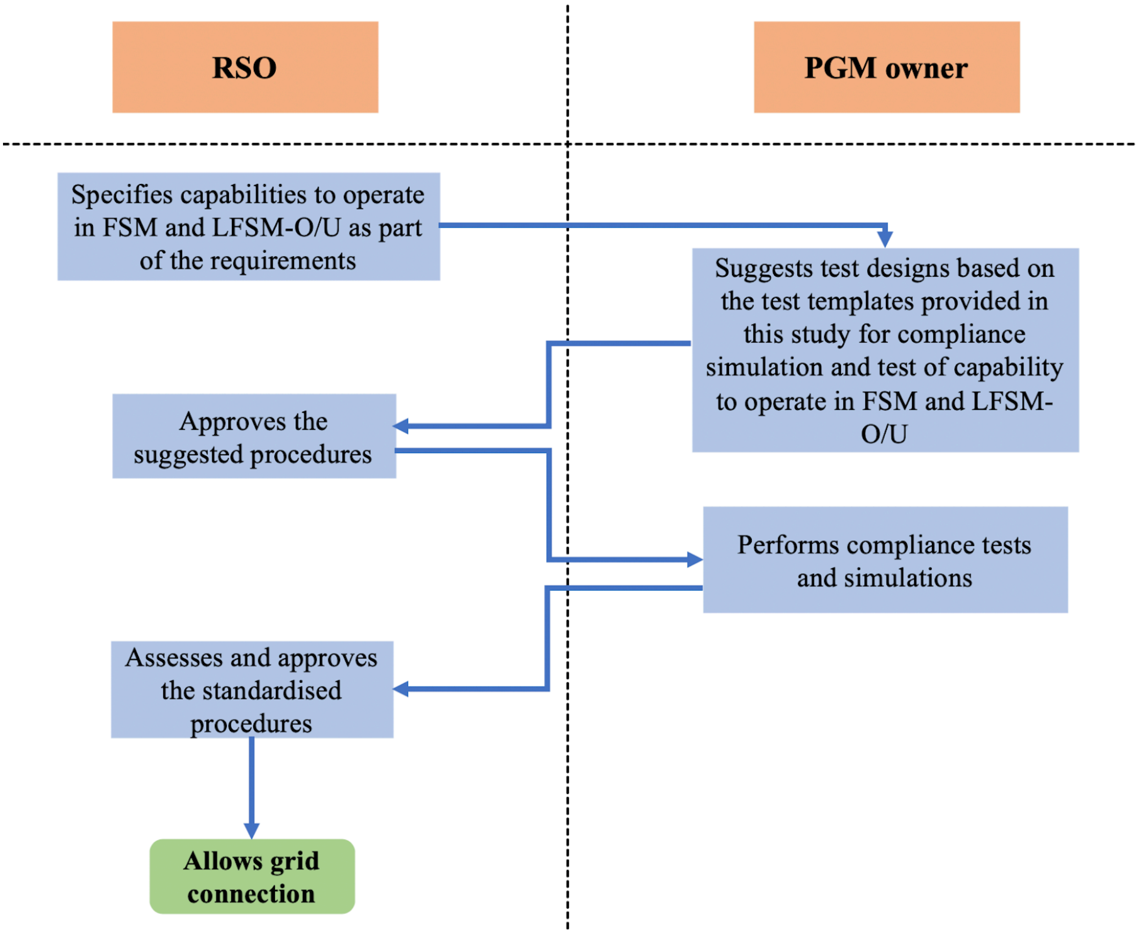

Figure 5.1. A flow chart over a successful compliance procedure.

6. Conclusion

The current Swedish compliance landscape carries some fundamental obstacles for the relevant actors. The most important obstacles are potential short-term economic losses of implementing costly work procedures in order to comply with RfG, ambiguity with regards to how compliance tests and simulations are to be carried out and the lack of clarifications and guidelines of how compliance procedures should function. In addition to this, the regulatory authority conducts no active supervision in this matter. Therefore, sufficient incentives to facilitate relevant actors to comply with all relevant requirements in RfG are not assessed to exist. The lack of clear and strong incentives to comply with RfG implies that Sweden risks to fail with contributing to the objectives of further market integration, achieving better security of supply and ensuring the possibility of continuous integration of renewable energy sources as stated by the European Commission.

Furthermore, it is likely that wind power will need to deliver FCRs in future scenarios with high wind power penetration from a power system stability perspective. Therefore, it is deemed to be reasonable to require capabilities for operation in FSM by PPMs of type C and D already today to ensure the robustness of the future power system. The requirements for LFSM-O/U are assessed to further improve the robustness of the power system. Moreover, in this thesis, a template of compliance simulations for the requirements for capabilities to operation in FSM and LFSM-O/U is presented, based on Fingrid's grid code, Svenska kraftnät's test programmes for delivery of FCRs and the type of guidelines demanded by relevant respondents in this study. Templates like this could significantly reduce the workload of both DSOs and PGM owners.

6.1 Further studies

In this thesis, the requirements for capability to operate in FSM and LFSM-O/U by PPMs of type C and D are in focus. Further studies could provide more breadth to this field by examining other types of PGMs and other requirements. Furthermore, a more thorough analysis of the economic consequences of complying with RfG could be carried out in order to decrease the uncertainty for the relevant actors.

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Interviews

Table 1. A compilation of the respondents being interviewed, their roles, which type of interview that was carried out and on which dates.

Name	Role	Interview type	Date
Carl Berglöf	Nuclear power and power grid expert at Swedenergy AB	Telephone	08-02-2020
Eskil Agneholm	Project manager at Ellevio AB	Telephone	12-02-2020
Mikael Calestam	Leader of Assessment at Swedac	Telephone	02-02-2020

Herlita Bobadilla-Robles	Analyst/engineer at the Swedish Energy Markets Inspectorate	In person	13-02-2020
Richard Ogiewa	Grid Integration Engineer at Enercon GmBH	Skype for Business	11-02-2020
Jens Lund	Head of Unit at Svenska kraftnät	Telephone	14-02-2020
Liselotte Ulvgård	Grid compliance engineer at DNV-GL	Skype for Business	19-02-2020
Anna Wetter-Ryde	Senior Researcher in law at SIEPS	Telephone	11-03-2020
Respondent 1	Manager at the Grid and Control Department at a company that develops, builds, finances and operates facilities for renewable energy in the Nordics	Microsoft Teams	02-04-2020
Andreas Adolfsson	Power system analyst at Vattenfall AB	Telephone	03-04-2020
Niklas Modig	Power system analyst at Svenska kraftnät	Skype for Business	03-04-2020
Santiago Piva	Acting Head of Unit at Svenska kraftnät	Telephone	27-04-2020
Simon Lindroth	Power System Analyst at Sweco AB	Skype for Business	14-02-2020, 02-04-2020
Magnus Speychal	Power Engineer at Sweco AB	Skype for Business	31-03-2020
Krister Tykeson	Power Engineer at Sweco AB	Skype for Business	11-02-2020

Meetings

Meeting with Technical Committee 8 for electrical energy supply of SEK Svensk Elstandard, 13-03-2020.

Email correspondence

Table 2. A compilation of the email correspondence.

Name	Role	Date
Lena Jaakonantti	Analyst/engineer at the Swedish Energy Markets Inspectorate	23-03-2020

Liselotte Ulvgård	Grid compliance engineer at DNV-GL	21-03-2020
Tobias Gehlhaar	Grid compliance engineer at DNV-GL	23-03-2020

Appendix

Motivations for Choosing Respondents

Simon Lindroth, Power System Analyst at Sweco AB - Chosen as respondent for his experience in grid code simulation studies. 2 interviews.

Magnus Speychal, Power Engineer at Sweco AB - Chosen as respondent for his experience in grid code simulation studies.

Krister Tykeson, Power Engineer at Sweco AB. Chosen as respondent for his experience in grid code studies.

Carl Berglöf, Nuclear power and power grid expert at Swedenergy AB - Chosen as respondent for his insight into the perspectives of DSOs and PGM owners with regards to the compliance of RfG.

Eskil Agneholm, Project manager at Ellevio AB - Chosen as respondent as suggested by Carl Berglöf. Participant in a working group trying to solve issues with regards to the compliance with RfG.

Mikael Calestam, Leader of Assessment at Swedac - Chosen as respondent for his knowledge about accreditation of certification bodies.

Herlita Bobadilla-Robles, Analyst/engineer at the Swedish Energy Markets Inspectorate - Chosen as respondent for her knowledge about the implementation of RfG in Sweden.

Richard Ogiewa, Grid Integration Engineer at Enercon GmBH - Chosen as respondent for his competence in the field of grid integration of wind turbines and farms.

Jens Lund, Head of Unit at Svenska kraftnät - Chosen as respondent for his general knowledge regarding Svenska kraftnät's work with the development of a national compliance scheme for RfG.

Liselotte Ulvgård, Grid compliance engineer at DNV-GL - Chosen as respondent for her experience and competence of certification of renewable energy sources against grid codes.

Anna Wetter-Ryde, Senior Researcher in law at SIEPS - Chosen as respondent for her experience and competence in EU law.

Respondent 1, Manager Grid and Control Department at a company that develops, builds, finances and operates facilities for renewable energy in the Nordics - Chosen as respondent for his experience as a PGM owner and project developer.

Andreas Adolfsson, Power system analyst at Vattenfall Eldistribution AB - Chosen as respondent for his experience as a DSO but also as a member in a working group trying to solve issues with regards to the compliance with RfG.

Niklas Modig, Power system analyst at Svenska kraftnät - Chosen as respondent for his competence within the field of FCR balancing.

Santiago Piva. Acting Head of Unit, Svenska kraftnät - Chosen as respondent for his competence with regards to the future guidelines being developed for the compliance with RfG.