SONI Grid Code Proposed Minimum Generation Studies Phase 1 Report

External Studies Support resulting from proposed Modification to CC.S1.1.3.8 and CC.S1.2.3.3 of the SONI Grid Code

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Executive summary

EP Kilroot, (a subsidiary of EP UK Investments), proposed an update to the SONI Grid Code Clauses CC.S1.1.3.8 and CC.S1.2.3.3 to modify the minimum generation (min gen) requirements for generation units in Northern Ireland (NI).

	Current	Proposed
CC.S 1.1.3.8 (CC.S1.2.3.3)	A generating Unit must be capable of remaining Synchronised to the NI System at an Output which is no greater than the lower of 80MW or 40% of its maximum continuous rating.	A generating Unit must be capable of remaining Synchronised to the NI System at an Output which is 40% of its maximum continuous rating

Jacobs has been contracted by SONI to provide support for the evaluation of the proposed Grid Code modification, and to help SONI gain a comprehensive understanding of the potential and impacts of modifying the Grid Code's min gen requirements.

This report presents the Phase 1 activities of the assessment which focused on investigating the proposed modification of the min gen requirements through comprehensive market research studies. This phase involved evaluating the requirements outlined in the Industrial Emissions Directive (IED) and Best Available Techniques (BAT), as well as examining the SONI Grid Code (specifically applicable to generators). Additionally, best practices from various Transmission System Operators (TSOs) and the technological capabilities of generator Original Equipment Manufacturers (OEMs) regarding min gen requirements were analysed.

The report assesses the suitability of the proposed min gen requirement and evaluates the overall impact of modifying these requirements in relation to the research undertaken.

Overall Summary

According to market research, the TSOs Grid Codes min gen requirements settings can be modified based on the specific needs of the electrical network, particularly to accommodate new connections and the increasing integration of renewable energy sources. However, it is crucial for the TSOs to consider the network's ability to handle fluctuations in generation and demand, ensuring the power system's security and stability. This consideration encompasses maintaining sufficient levels of inertia, which is essential for reliable power system operation.

The analysis of four TSOs, including SONI, suggests that min gen requirements may be modified based on the following observations:

- The historical changes in Finland show that the min gen levels for hydropower, combined cycle gas turbines (CCGTs), motor power plants, and combined heat and power plants were updated in 2013. These updates considered technological advancements that expanded the safe operating range of generation units, making it possible to decrease the min gen threshold to 10%.
- The research of Portugal showed that the TSO adopted the min gen criteria similarly by considering the capabilities of generation-turbine systems, as well as factors such as service quality, reliability, and network security. Consequently, Portugal implemented a min gen requirement of 40%.
- In contrast, the UK have implemented two different min gen levels, namely 65% and 55%. This dual approach allows for increased flexibility in regulating frequency during fluctuations in demand or generation, while also providing a safety margin for the operation of generator-turbines.

Based on the research findings, it is suggested that the min gen requirements can be modified. This is supported by the fact that some TSOs have already updated their min gen requirements to align with the evolving system needs and advancements in turbine capabilities.

However, the TSO (Grid Code's min gen requirements) may also need to consider the design limitation and capabilities of standard generator OEMs to comply with all the Grid Code requirements, the IED and the impact of other regulations across the entire loading range specified in the Grid Code. The IED evaluation has shown the following:

- To operate legally, a generator needs to obtain an appropriate permit from the relevant environmental regulator which is the Northern Ireland Environment Agency (NIEA) in Northern Ireland. This permit would include compliance with emission limit requirements set out in the IED and BAT documents.
- To obtain the permit the NIEA would also assess the overall efficiency (at the rated power) against the BAT requirements.
- The BAT emission limits requirements can be interpreted in two ways depending on the country of application. Each country can interpret the compliance with the BAT emission limits as either applied to the load range above 70%, as is the case in Finland, or to the full load range. The NIEA interprets the BAT emission limits as applied to the entire feasible generator-turbine operating load range specified in the Grid Code.
- There is no limit prescribed within the IED or BAT around the minimum or maximum load on a generator. The min gen is only addressed in the Grid Code.

This assessment considered the capabilities of three of the top global utility gas turbine OEMs: Siemens Energy, General Electric (GE), and Mitsubishi Power. The assessment utilized data gathered during market research phase. The initial project scope considered assessment of a broad range of turbine technologies and sizes. However, due to project time constraints the assessment focused on the utility gas/steam turbines only. It also focused on the 200-500MW power rating range since this range is affected by the proposed modifications to the min gen clauses. Furthermore, the OEMs' minimum emission compliant generation capability is obtained with respect to the full generator-turbine operating load range specified in the Grid Code, as required by the NIEA. The assessment found that:

- Siemens turbines can operate with a min gen of 40% for Open Cycle Gas Turbine (OCGT) applications and 45% for CCGT applications, within the emissions compliant load range. The OCGT can also operate with a reduced min gen of 35% using mitigation techniques such as Selective Catalytic Reduction (SCR)
- Mitsubishi turbines can operate at a min gen of 50% without, or possibly as low as 40% with mitigation techniques respectively.
- GE turbines can operate with a min gen of 30% - 35% for OCGTs and for CCGT applications, the min gen range is 40% - 48%.
- The OEMs' emissions compliant min gen levels align with the min gen requirements in the three TSO countries National Grid in UK, REN in Portugal, and SONI, NI. The only exception is the Finnish grid in Finland where the 10% min gen requirement is significantly lower than the OEMs' emission compliant load levels. The reason for this could be that Finland interprets compliance with the BAT emission limits requirements only for the load range above 70% and based on OEM research the turbines can comply with such requirements. For the 10% to 70% load range, it is possible that other domestic criteria apply. This means that although the 10% min gen requirement considers safety of turbines' operation, it may not consider the BAT emission limit compliance.

Assessment Findings

The analysis carried out indicates that the proposed modification, i.e., removal of the 80MW min gen limit, from the NI Grid Code clauses CC.S 1.1.3.8 and CC.S.1.2.3.3 does not pose significant obstacles. The assessment also indicates that the proposed modification is suitable based on evaluating requirements of four TSOs (including SONI), historical system changes, IED/BAT and Environmental Agencies' requirements (particularly NIEA in the NI system), and the capabilities of the generation-turbines. Also, the feedback received from generator OEMs suggests that there are no major obstacles in complying with other NI Grid Code clauses that could be affected by the proposed change in min gen requirements.

The assessment has highlighted the importance of considering the following observations/conclusions:

- The assessment has indicated that utility-scale turbines within the power rating range of 200-500MW can effectively operate with
    - min gen criteria of 40% for OCGT applications and 45%-50% for CCGT applications, without the need for any mitigation techniques.
    - with min gen criteria of 35% for OCGT applications and 40% for CCGT applications, with the application of the mitigation techniques.
- Increasing the min gen criteria above the proposed settings would reduce the ability of the electrical network to deal with the emerging issue of managing the minimum demand conditions.
- To meet the 40% min gen settings or a more stringent setting, the generator-turbines OEMs may need to apply the mitigation techniques (especially for CCGT plants). Based on Jacobs' experience, implementing such measures may bring some economic challenges for generators.
- The adoption of alternative min gen clause settings may be suggested based on the requirements of the system needs in the electrical network, as well as the assessment of risks, benefits, and other factors such as techno-economic considerations and market impacts.
- The NIEA plays a crucial role in prescribing the emission level constraints, as interpreted from BAT, which affects the min gen capability of generator units in Northern Ireland.

Study risks and limitations

This study was conducted using a variety of sources of information. Some OEMs were only able to provide high-level information, so the final min gen conclusions should be treated with some caution. Also, the OEMs cannot guarantee the min gen figures provided with reference to the use of the mitigation techniques. Further project by project basis studies must be conducted to confirm actual achievable min gen with mitigation techniques. This study also did not consider operators' business case, socio-economic effects, whole NI system pollution & environmental impact and any other regulatory aspects except one mentioned in the report on the min gen requirements. Additionally, the min gen assessment is based on a limited set of turbine technologies and power ranges (200-500MW), so it may not be representative of all turbines or OEMs. It is important to note that existing turbines below 200MW are not expected to be affected by the proposed min gen criteria of 40%.

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Acronyms and abbreviations

IED	Industrial Emissions Directive – Directive 2010/75/EU
NIEA	Northern Ireland Environment Agency
BAT	Best Available Techniques
BRef	BAT Reference Document
OCGT	Open Cycle Gas Turbine
CCGT	Closed Cycle Gas Turbine
TSO	Transmission System Operator
SNSP	System Non-Synchronous Penetration
OEM	Original Equipment Manufactures
GC	Grid Code

1. Introduction

1.1 Project background

A Modification to the Northern Ireland (NI) Grid Code has been proposed by EP Kilroot (subsidiary of EP UK Investments) in relation to minimum generation requirements. The proposal concerns the modification of the CC.S1.1.3.8 and CC.S1.2.3.3 clauses of the Grid Code and the details are given below:

	Current	Proposed
CC.S 1.1.3.8 (CC.S1.2.3.3)	A generating Unit must be capable of remaining Synchronised to the NI System at an Output which is no greater than the lower of 80MW or 40% of its maximum continuous rating.	A generating Unit must be capable of remaining Synchronised to the NI System at an Output which is 40% of its maximum continuous rating

Jacobs has been requested to evaluate this proposal and to help SONI obtain understanding of wider opportunities to modify the Grid Code minimum generation requirements.

1.2 Study aims

The minimum generation requirements concern a number of different TSO aspects such as security of the transmission system, the ability to maintain the balance between energy supply and demand, the ability to accommodate increasing penetration of renewable energy in the decarbonisation of the power system, etc. It also concerns the Original Equipment Manufacturers (OEMs) of generation equipment to comply with overall Grid Code requirements and to comply with the emission limits set out in the environmental regulatory documents.

Jacobs is supporting the evaluation process of the proposed minimum generation requirements by providing specialist service including technical expertise in the form of market research, data modelling and complex studies, which considers the aspects that may be affected by the modification of the min gen requirements as explained above. The aim of these studies is to evaluate the suitability of proposed minimum generation requirements, but also to help SONI gain a comprehensive understanding of the potential and the impacts of modifying the Grid Code's min gen Clauses CC.S1.1.3.8. and CC.S1.2.3.3.

1.3 Project scope

The project scope is divided into two phases:

Phase 1: Market Research:

a) Evaluation of Industrial Emissions Directive (IED) requirements

b) Evaluation of TSOs' requirements

c) Evaluation of OEMs' capabilities to comply with IEDs and Overall Grid Code requirements including OEMs' consultations.

Phase 2: Techno-economic studies using PLEXOS

Each of these is discussed in more detail in the following sections.

This report focusses on Phase 1 market research activities.

1.3.1 Phase 1a: Evaluation of IED requirements

This phase reviews the current constraints, limits and requirements under the relevant Environmental Legislation, for units fuelled by gaseous and liquid fuels as defined by EU legislation (e.g. natural gas, biogas, hydrogen-containing gas and syngas). The relevant constraints, requirements and limits are taken from Directive 2010/75/EU, which covers units where the aggregate thermal input is over 50MW; Directive 2015/2193, which applies to units with a thermal input above 1MW but below 50MW; and Best Available Technologies (BAT) conclusions detailed in Decision (EU) 2021/2326. Where there is any specific NI regulatory guidance, this is also reviewed and considered.

The outputs of the BAT review; regulatory guidance; and legislative reviews are used to prepare an overall 'minimum requirements' dataset. This dataset is used to evaluate the proposed minimum generation level. If the dataset demonstrates that the minimum generation level does not comply with all requirements, a clear statement will be prepared to explain whether the failure was on the basis of breaches of the requirements of the Directives or Decisions, or if the gap is related to regulatory interpretation breaches.

1.3.2 Phase 1b: Evaluation of TSOs requirements

This aim of this task is to summarize the best practice from a range of TSOs in relation to minimum generation requirements. The choice of the TSOs considers those operating systems with high penetration of non-synchronous generation, low inertia and weakly interconnected to other synchronous areas, similar to the Northern Ireland network. Three TSOs are considered and benchmarked against the SONI requirements.

The aim of this task is to inform SONI if other similar systems may have adopted different minimum generation requirements and to provide reasons. For this assessment, different TSOs are considered and consulted (where possible). This task is based on research/ data collection from the publicly available resources and the non-confidential data received from the TSOs .

1.3.3 Phase 1c: Evaluation of OEMs capabilities

This task evaluates feasible minimum generation considering a range of conventional generation technologies including steam turbines fed by boilers fired on a range of fuels, and gas turbines in open and combined cycle, from a range of OEMs and with reference to the evolving NI generation portfolio.

The following types of generators are considered in this task according to project proposal,

- Open and combined cycle gas turbine generators
- Steam turbines generators
- Biomass/waste turbine generators
- Nuclear (if available)

However, due to project time constraints only the open and combined cycle gas turbine plants are considered in the assessment. Also, only the 200-500MW generator-turbine power rating range is considered, since this power range may be affected by the proposed modification of the min gen requirements.

The aim of this task is to understand the generator OEMs capabilities to comply with both TSO Grid Codes and the IED requirements in relation to minimum generation. The assessment considers the OEM standard design limitations and opportunities using enhancement techniques/technologies. The aim is also to understand how the OEMs interpret the IED requirements including implementation of BAT techniques, and how they interpret Grid Code constraints in relation to minimum generation requirements (in the considered transmission systems). Lastly, the aim is to identify the Grid Code Clauses which may be affected by the proposed modification of min gen requirements and to identify any obstacles.

This assessment considers the resources such as generators data sheets, publicly available on the OEM's websites. Then, a set of questions are prepared and sent to different OEMs and the responses will be recorded and analysed further. The questions are prepared considering requirements reviewed as part of the IED and grid code evaluation task and the TSO consultation task. The assessment considers up to three OEMs.

The obtained information and responses from the OEMs will be compared against the obtained IED and Grid Code requirements and considered TSO practises. This will be part of the final combined assessment of the proposed minimum generation. The complete assessment will also consider detailed studies in PLEXOS explained in the following subsection.

1.3.4 Phase 2: Techno-economic studies using PLEXOS

This task will evaluate market impacts of changing the stipulated minimum generation level by performing studies in PLEXOS.

The following tasks are covered in this phase,

- PLEXOS model validation & development
- Establish the case scenarios & constraints
- Perform the studies
- This task will model and assess the system for years 2027 and 2030 only.

1.3.5 Conclusion on proposed Grid Code Minimum Generation assessment

Once all the relevant information is obtained regarding IED and Grid Code requirements, TSO practises and OEM capabilities, and findings from the PLEXOS studies, a combined assessment of the proposed minimum generation will be performed. This will provide a common conclusion as to the suitability of the proposed minimum generation and will provide insight into the most important considerations regarding wider opportunities to modify the CC.S1.1.3.8 and CC.S1.2.3.3 clauses of the NI Grid Code.

2. Market research - Evaluation of IED requirements

2.1 IED purpose

The Industrial Emissions Directive (IED), Directive 2010/75/EU, covers the integrated prevention and control of pollution, arising from industrial activities. It describes the rules designed to prevent, or where that is not practicable, reduce emissions to achieve a high level of protection to the environment as a whole.

The Directive has been implemented in Northern Ireland (NI) through the 'Pollution Prevention and Control (Industrial Emissions) Regulations (NI) 2013 (as amended). As this implementation predates UK's withdrawal from the EU, the Directive is still valid in NI and is applicable in Ireland.

2.2 IED scope

The IED includes a list of industrial activities which fall within its scope, laid out in Annex 1 of the Directive. These are separated out into 6 chapters or categories, with the first chapter being of relevance to this discussion, which is 'energy industries'. Within this are four sub chapters, with chapter 1.1. being applicable, for the '*combustion of fuels in installations with a total rated thermal input of 50MW or more*'.

With regard to combustion plant, although the Directive covers all combustion units with thermal inputs over 50MW in size, more prescriptive requirements apply to large combustion plant (LCP) that is units over 100MW thermal input. These requirements are laid out in Annex V of the Directive.

The Directive requires all plants falling within its scope to be operated in accordance with a permit or consent issued by the appropriate regulator, which includes the environmental limits and operating techniques appropriate to that plant. A number of derogations and applicability limits existed under the Directive, for combustion plant relating to the requirement to meet emission limits and operating hours. However, all these derogations and limits referred to existing plant only and were time limited. The applicable time limits have now expired and both existing and new plants must meet the required standards within the directive.

2.3 IED definitions

Under the IED, when considering the rules and requirements for combustion plant, the thermal input is the basis of the assessment, rather than the electrical or thermal output. The assessment is based around the combustion plant being operated at full load for a 24-hour period.

Plant may be aggregated together, specifically when two or more combustion unit stacks share a common windshield. In this instance, the plant would be classified based on the combined thermal input of all stacks within the windshield. Emission limits and other requirements are set on a per combustion unit basis, so each flue within a stack has a separate emission limit and each unit is assessed separately for efficiency.

When considering emission limits and other technical specifications, there are tighter requirements set for 'new' plants, than 'existing' plants. In the case of large combustion plant, for a plant to be 'existing' it needed to have been operational before 7th January 2013 or permitted before 7th January 2014. It has been assumed in this report that any plant considered would be deemed a 'new' plant.

2.4 Best Available Techniques

2.4.1 Definitions

Best Available Techniques (BAT) are defined as:

'the most effective and advanced stage in the development of activities and their methods of operation which indicates the practical suitability of particular techniques for providing the basis of emission limit values and

other permit conditions designed to prevent and, where that is not practicable, to reduce emissions and the impact on the environment as a whole:

a) 'techniques' includes both the technology used and the way in which the installation is designed, built, maintained, operated and decommissioned;

b) 'available techniques' means those developed on a scale which allows implementation in the relevant industrial sector, under economically and technically viable conditions, taking into consideration the costs and advantages, whether or not the techniques are used or produced inside the Member State in question, as long as they are reasonably acceptable to the operator;

c) 'best' means the most effective in achieving a high general level of protection of the environment as a whole'.

As techniques, BAT incorporates plant design including layout and technology; as well as management systems and operating practices.

BAT is set out for individual sectors in sector specific narrative BAT reference documents (BRef), which are accompanied by a BAT conclusions document, which only lists out the BAT requirements. These documents are subject to periodic review and updating.

2.4.2 Regulator

Large combustion plant, defined as those with a thermal input over 50MW, which fall within the scope of the IED, are regulated in Northern Ireland by the Northern Ireland Environment Agency (NIEA), part of the Department of Agriculture, Environment and Rural Affairs.

The NIEA website does not point to sector specific guidance for the IED, instead linking directly to the EU level BRef's and BAT guidance.

Operators need to apply to the NIEA for a permit to operate, under the IED. As part of their application, operators are expected to demonstrate how their plant will meet the requirements of BAT applicable to their plant. As part of the application for a combustion plant, an air dispersion model will be submitted, with the air dispersion model and permit being based around the worst case emission scenario, which will include modelling100% load on the plant, as well as a reduced load where the emissions of specific pollutants would be highest.

The air dispersion model uses standard software to demonstrate the impact of the emissions both short term and long term, at the release point and on nearby sensitive receptors such as residents and environmentally protected areas. The model takes into account the local meteorological conditions and background pollutant concentrations.

Permits are issued to the operator of the plant and they are the ones with the legal obligation to maintain compliance with any emission limits or other pollution minimisation requirements within the permit. The issued permit may include requirements to demonstrate that following commissioning of a new plant, the proposed emission values and plant efficiency within the application are achieved by the plant.

2.4.3 Emission Limits

Within BAT, emission limits are set for combustion plant, based on fuel type and combustion plant type, based on mg/Nm^3 measured at 15% of excess oxygen. Typically, these include limits for NO_x, CO and SO_2, although other species may be monitored dependent upon fuel. Specific additional rules apply for assessing emissions for dual fuelled or dual fired plant, as laid out in Article 40 of the IED.

Specified air emission limits are defined within the Directive and associated BAT. They are commonly stated as being set at 100% load for a plant, however, lower loads may give rise to higher emissions for some releases. As such, the emission limits are set and the operator must comply with them, whether at full load or a lower load. If the plant is operated at a reduced load, with increased emissions, there is no direct impact on the required emission limits, these remain as stated within the permit..

Note that CO_2 emission limits are not set under IED or BAT for any fuel. There is, however, a requirement on the operator to consider and provide feasibility study of having Carbon dioxide Capture and Storage (CCS) in future, where plants exceed 300MWth input. The application of CCS is limited to those plants where there are suitable storage sites; technically and economically feasible transport facilities; and it is technically and economically feasible to fit CCS equipment. There are no methods for CCS outlined in the BAT guidance.

When measuring gaseous emission concentrations, the measurement should take place on the exhaust flue, in a position after any abatement plant necessary to comply with the limits is located. The choice of abatement techniques is determined by the plant operator and may include combustion unit specification and / or post combustion gas treatment.

2.4.4 Annex V LCP

Annex V of the Directive relates to emission limits and other technical requirements for large combustion plant, i.e. those exceeding 100MW thermal input.

Part 2 of Annex V gives the emission limits for new combustion plant. These are specified based on fuel type and plant type (where appropriate). Gas engines and gas turbines have specific limits set. Limits are set for SO_2; NOx; CO and Dust for fuels, although dust limits do not apply to gas fuelled plants.

The emission limits stated in Annex V, Part 2 (6) for gas fuelled combustion plant have two caveats attached. One relates the NOx emission limit to the efficiency of single cycle gas turbines at ISO base load conditions. The other defines the stated emission limits as being applicable above 70% load. Note that the permit limits would still be set at the limits in the Annex, as the unit would be permitted as though it were operating at 100% load. This restriction has been removed within the more recent BRef and BAT conclusions and would not be applied to a new applicant, which has been confirmed through correspondence with NIEA. It is understood that this interpretation may differ within the EU, with some nations retaining the applicability load of >70%.

The emission limits set in Annex V, Part 2 (6) do not apply to plants for emergency use operated under 500 hours per annum. The operator would need to record the operating hours in order to demonstrate compliance with this requirement. The term 'emergency' is not defined in IED.

2.4.5 BAT ref. EU 2021/2326

The specific BAT conclusions document for large combustion plant, is Decision (EU) 2021/2326. It comprises 75 separate BAT entries, which may be applicable to LCP.

The BAT document can be considered to comprise two groups of BAT requirements. There is an initial group of BAT 1 – 17 which are applicable to all plants which meet the definition of LCP. The second group are specific BAT requirements, which apply to plants with a specific fuel type or a specific technology type.

The first grouping includes BAT requirements such as minimum standards for the environmental management system for the plant and requirements around noise and waste management. As these requirements are applicable irrespective of the specific plant under consideration, they are not considered further.

Table 2-1 BAT 40 – 45 relate specifically to natural gas fuelled units

BAT Number	Scope	Applicability
40	Increasing energy efficiency of natural gas combustion using an appropriate combination of the specified techniques	Yes – includes applicable emission limit values (ELV's)

BAT Number	Scope	Applicability
41	Prevention or reduction of NOx emissions in gas boilers by use of one or more of the specified techniques	No – applicable to boilers only
42	Prevention or reduction of NOx emissions from gas turbines by use of one or more of the specified techniques	Yes
43	Prevention or reduction of NOx emissions from gas engines by use of one or more of the specified techniques	No – applicable to engines only
44	Prevention or reduction of CO emissions by optimised combustion and/or use of oxidation catalysts	Yes
45	Reduction of non-methane volatile organic compounds and formaldehyde emissions from the combustion of natural gas in spark-ignited lean-burn gas engines by optimised combustion and/or use of oxidation catalysts	No – applicable to engines only

BAT 40 relates to energy efficiency and sets out a series of techniques which might be applicable. Point (a) relates to the use of combined cycle plants and includes a statement that combined cycle configurations are generally applicable (i.e. preferred) for new gas turbines and engines unless the plant is operating <1500 hrs per annum.

It is understood from correspondence with NIEA, that they would only permit a new OCGT as a limited operating hours plant, due to concerns around compliance with BAT 40.

For a new open cycle gas turbine fuelled by natural gas, the BAT associated energy efficiency levels (BAT-AEEL) limits are for plants operating >1500 hours per year:

Table 2-2 BAT associated energy efficiency levels (BAT-AEEL) limits

Plant type	Net electrical efficiency (%)	Net mechanical energy efficiency (%) (not applicable to electricity only plants)
OCGT ≥50MWth	36 – 41.5	36.5 - 41
CCGT (50-600MWth)	53 - 58.5	No BAT -AEEL
CCGT ≥600MWth	57 – 58.5	No BAT -AEEL

These efficiencies are measured at the plant operating at full (100%) load, in accordance with the General Considerations section of the BAT document. There are no specific requirements for the application of the efficiency requirements for loads levels below rated operating conditions. So, our assumption (checked with the OEM's and NIEA) it is that it is applied at full load only. This interpretation has been applied when interpreting data from the generation-turbine OEMs during the consultations reported in Section 4.2

For oil fuelled plant the BAT efficiencies are:

Table 2-3 Oil fuelled plant BAT efficiencies

Plant type	Net electrical efficiency (%)
Gas oil fired OCGT	>33

Gas oil fired CCGT	>40

The efficiencies given are applicable to CHP units whose design are orientated towards power generation, or units generating only power. There are no specified limits for net mechanical energy efficiency.

Efficiencies for other fuels are either specified as being applicable to boilers or combustion plant in general.

2.4.6 Natural Gas Fired Emission Limits

Emission limits for open cycle gas turbines are set within BAT 44. The relevant reference conditions are:

Dry Gas at a temperature of 273.15 K; pressure 101.3kPa. For gas turbines, the O2 concentration is 15%.

[The applicable oxygen concentration is the same for liquid and gaseous fuels for use in gas turbines, engines or integrated gasification combined cycles plant. However, it is different for solid fuels (6%); and gaseous and liquid fuels when combusted in plant other than gas turbines or engines, where it is 3%.]

Start up and shut down periods are excluded from the data utilised to demonstrate compliance with emission limits. Limits do not apply to plants operating <1500 hours per year.

Table 2-4 BRef emission limits

Plant type	NOx Yearly average (mg/Nm^3)	NOx Daily average (mg/Nm^3)	CO Yearly average (mg/Nm^3)
OGCT ≥50MWth	15 – 35	25 - 50	5 – 40
CCGT ≥50MWth	10 – 30	15 - 40	5 – 30

Although the emission limits with the BRef are stated as not being applicable for plant operating under 1500 hours per annum, it is expected that the NIEA would apply these limits to a new limited operating hour plant.

2.4.7 Other Fuels

Other fuels are covered by different BAT requirements, and their limits apply to specified types of combustion plant.

Table 2-5 Other fuel BAT efficiencies

Plant type	Net electrical efficiency (%)
Gas oil* fired OCGT ≥50MWth	>33
Gas oil* fired CCGT ≥50MWth	>40
Coal fired <1000MWth	36.5 – 41.5

* Gas oil is the term used in the BAT documents. It is the same as diesel.

These are not applicable where the unit is operated <1500 hours per annum

Table 2-6 Other fuel BAT emission limits

Fuel	Plant type	NOx Yearly average (mg/Nm^3)	NOx Daily average (mg/Nm^3)	CO (mg/Nm^3)	SO_2 Yearly average (mg/Nm^3)	SO_2 Daily average (mg/Nm^3)	Dust yearly average (mg/Nm^3)	Dust daily average (mg/Nm^3)
HFO / Gas oil	Reciprocating engine ≥50MWth	115 – 190	145 - 300	None set	45 – 100	60 -110	5 – 10	10 - 20
HFO / Gas oil	Gas turbine ≥50MWth	None set	50*	100*	35 - 60	50 – 66	5 – 10	10 - 20
Coal	<100MWth combustion plant	100 – 150	155 – 200	<30 - 140	150 – 200	170 – 220	2 – 5	4 – 16
Coal	100-300MWth combustion plant	50 - 100	80 - 130	<30 - 140	80 – 150	135 - 200	2 - 5	3 - 15

* Value taken from Annex V, Part 2 (5) of IED, for units using 'light and middle distillates as liquid fuels'.

Nb. Coal also has specified BAT emission limits for HCl; HF; Hg

Dust is defined as total particulate matter. There is no size fractionation.

2.4.8 Load

When considering gas turbine, both OGCT and CCGT, emission limit values are set for NOx and CO, there is a footnote that the limits are only applicable above 70% load. (see Annex V, Part 2 (6) of the IED). However, this restriction has been removed from the BRef and BAT conclusions, so the emission limits would be applicable across the range of loads. It is understood that this interpretation may differ within the EU, with some nations retaining the applicability load of >70%, although it has been removed in NI. This may be investigated in more detail, for completeness, as part of the TSO and OEM consultations, which is reported in the following Chapters.

The Directive and BAT conclusions make reference to 'start up' and 'shut down' periods, and the duration of these are both defined and excluded from consideration when assessing compliance with air emission limits.

The necessary environmental permit to operate, issued by NIEA, will be based on the turbine at 100% load. Although reducing the load will impact on the exact emissions of NOx and CO from the plant, the daily and annual average emission values specified in the permit for these substances, would remain applicable and would need to be met for permit compliance.

Within the assessment of the Grid Code, it has been assumed it is not necessary to consider the load on the turbine specifically for compliance with environmental consents, provided the emission limits set are complied with.

2.5 Summary- IED/BAT requirements

IED and its associated BAT requirements, set the maximum allowable gaseous emissions from a generator unit, based on both fuel and combustion plant type. For some plant, there may be additional limits set based on thermal input. In order to operate legally, a generator would need to obtain an appropriate permit from the relevant environmental regulator, which would include these emission limits. These limits would be applied to the plant by NIEA, as the appropriate regulator in NI. The same rules would apply to facility based in Ireland.

As part of the permit application process the generator would have its overall energy efficiency assessed against values in BAT, again on a fuel and combustion plant type basis. However, this efficiency would not be included within the issued permit. There is no limit set within IED or BAT, around the minimum or maximum load on a generator, only on the environmental impacts of that load. The requirements around efficiency and BAT, (specifically clause a of BAT40) would mean that NIEA would limit the operating hours of an OCGT plant to 1500 hours per annum due to its lower energy efficiency, whereas a CCGT plant would not face this limitation on operating hours.

The combustion plant operator must remain in compliance with the requirements of their permit and this requirement feeds into the maximum allowable emission values that the operator would require from a plant vendor. If vendors state the plant cannot meet these limits, it could not be permitted. Therefore, it needs to be confirmed that vendors can meet the relevant daily emission limits, as compliance with the annual emission limits is dependent upon the annual load on the plant.

3. Market research – Evaluation of TSOs requirements

3.1 Grid Code

Grid Codes (GCs) are normative documents that constitute an important tool that imposes specific performance conditions to be required to the power plants that form part of a power system. GCs have significantly evolved over recent years and have done so hand in hand with the emergence of renewable generation technologies, as these pose enormous challenges for the systems they connect onto and need to be managed accordingly.

It is of the upmost importance that the energy market is fully functional and interconnected to preserve security of energy supply, increase competitiveness, and ensure that all consumers can buy energy at affordable prices. GCs are a set of legally binding rules that help to govern the work of operators and determine how electricity is distributed across a network.

3.2 EU Network Code

3.2.1 Overview

The European Commission (EC) began developing, in 2010 and through the European Network of Transmission System Operators for Electricity (ENTSO-E), a new network code formulating two types of requirements: mandatory requirements for all countries, and optional technical requirements, adaptable by each country based on the characteristics of its national electricity network. Moreover, the European Network Code is divided into three families: i) connection; ii) operations; and iii) market. Each of these network code families is in turn divided into different specific grid codes. The document that specifically addresses the requirements set for generators, known as “Requirements for Generators” (RfG), was established in the Commission Regulation (EU) 2016/631.

The RfG document aims to harmonise, at the European level, a set of minimum technical design and operational requirements for generator connections of any kind, both synchronous and asynchronous. These harmonised standards aim to strengthen the market of generation technology and increase competitiveness across Europe. The regulation also offers a global structure that may be followed for compliance assessment of the requirements. Given that existing GCs were already developed prior to the RfG, the RfG is incorporated into national GCs as an extension to prevailing national requirements. Thus, country specific GCs are a function of the RfG and national requirements.

EU Directives

EU Level Directives set out the common rules and requirements for the generation, transmission, distribution and supply of electricity. These rules are applicable for all EU countries and the United Kingdom, noting that the latest EU Directive was brought in prior to Brexit. A particular focus is evaluating the emissions standard (mainly NOx, CO levels) from electrical transmission. Therefore, there is an emissions criterion linked to power plant efficiency which needs to be satisfied before these plants are connected onto the network.

As such, whilst there is no direct legislation between minimum generation and emissions standard, it is not possible to set a minimum generation at a level which fails to comply with the emissions standard as the country specific environmental regulator would not allow the power plant on the network. As such the minimum generation needs to work in sync with the EU Level Directives.

3.2.2 Process for Developing Pan-European Network Codes

It is the responsibility of the ENTSO-E, which is made up of all the TSOs in the EU to develop legally binding European Commission network codes. ENTSO-E comprises of national transmission operators who coordinate with each other and collectively contribute to the development of pan-European network codes. The process for developing network codes and guidelines is reviewed annually and begins with a request from the

European Commission to the Agency for the Cooperation of Energy Regulators (ACER) to submit a framework guideline of priority areas.

The Commission then works with the ENTSO-E and ACER to devise a proposal for related network codes aligned to ACER Framework Guideline, conducting detailed public consultation throughout the duration of the development process. Following this, the code subsequently enters a Comitology process (an Electricity cross-border committee of specialists from national energy ministries) where member states agree on the final text.

Once the text is agreed across member states, it is then put forward for approval by the Council of the European Union and the European Parliament. Once approved by the Commission, the network code becomes legally binding in accordance with existing legislation - Electricity Regulation (EC) No 714/2009. In some instances, new rules are adopted as guidelines or Directives and Decisions rather than GCs. These documents remain legally binding but are adopted under a different provision of the Electricity Regulation (EC) No 714/2009.

3.2.3 The Eight European Network Codes

Since 2017, there have been a total of eight network codes and guidelines, these consist of:

- Three market guideline codes:
  - The capacity allocation and congestion management guideline (CACM)
  - The forward capacity allocation guidelines (FCA)
  - The electricity balancing guideline (EBGL)
- Two system operation codes:
  - The electricity system operation guideline (SOGL)
  - The electricity emergency and restoration network code (E&R)
- Three grid connection codes:
  - The network code on requirements for grid connection of generators (RfG)
  - The demand connection network code (DCC)
  - The requirements for grid connection of high voltage direct current systems and direct current-connected power park modules network code (HVDC)

A breakdown of the three main sectors, associated grid codes and likely applicability is provided in Table 3-1[1]

Table 3-1 European Network Codes

Areas	Overview	Network Codes	Likely Applicability
Market Guidelines	Establishes a platform for managing capacity and flow around the interconnected system to facilitate the setup of a single EU market.	Capacity Allocation and Congestion Management (CACM)	Trading, Power Exchanges, Interconnectors, TSOs, DSOs, Generators, Demand, Balancing Services
		Forward Capacity Allocation (FCA)	
		Electricity Balancing Guidelines (EBGL)	
System Operation	Harmonises the processes TSOs have to manage their systems, including system restoration	System Operation Guidelines (SOGL)	Generators > 1mW, Transmission Connected Demand Facilities, TSOs, DSOs, Demand Side Response Services, HVDC systems
		Emergency and restoration (E&R)	
Grid Connection	Sets consistent technical requirements across EU for new connections of user equipment (e.g generation/interconnectors)	Requirement for Generators (RfG)	New generators ≥800W, Operators of new HDVC Links, new DC- connected offshore power park modules, new directly connected Demand Users, new providers of Demand
		Demand Connection Code (DCC)	

[1] European Network Code background information available at: https://www.nationalgrideso.com/industry-information/codes/european-network-codes-enc and https://www.nationalgrid.com/sites/default/files/documents/8589937860-Overview%20Factsheet.pdf

Areas	Overview	Network Codes	Likely Applicability
		High Voltage Direct Current (HVDC)	Side response, Equipment Manufacturers

EU Member states have a legal requirement to implement these codes at the national level no later than three years after their publication. This process helps to maintain a harmonised and single energy market across Europe.

3.3 Countries under review

3.3.1 Our approach

SONI requested Jacobs to identify the required minimum generation of synchronous generators for countries with a similar transmission network to Northern Ireland. The criteria used to identify similar transmission grids were:

- Number of interconnectors
- % of total electricity facilitated through interconnectors
- Size of country, and
- Generation mix.

Northern Ireland (NI) has a small transmission grid, which is part of the wider 'All Island' system, which includes Ireland. Therefore, based on the above listed criteria, Finland (FL) and Portugal (PT) were shortlisted. Great Britain (GB) was also chosen as it is directly adjacent to NI and has one interconnector that connects NI to Scotland (see Section 3.3.2.1 for further details). Other countries were considered as well, such as Lithuania but were excluded due to language barriers.

Figure 1 Countries under review

The following Section 3.3.2 summarises the findings from our regulatory research and discusses the main factors that led the TSOs into setting the minimum generation requirement.

3.3.2 Minimum generation of benchmarked countries

The minimum generation is not explicitly dictated at the EU level, instead it is the responsibility of the incumbent TSO to set minimum generation within the safe operating limits of the turbine and to which does not undermine the transmission network and that of the EU. Table 3-2 outlines the minimum generation levels of the countries that are under review.

Table 3-2 - Minimum generation levels

Country	Transmission Operator	Generation Technologies	Minimum Generation Requirement	
			Value	Clause
Northern Ireland	System Operator of Northern Ireland (SONI)	All	80MW or 40% of rated capacity (whichever is smaller)	SONI GC - CC.S1.1.3.8[2] and CC.S1.2.3.3
Great Britain	National Grid Electricity System Operator (NGESO)	All	**Minimum Generation:** 65% of rated capacity	GB GC - CC.A.3.2
			Designed Minimum Operating Limit: 55% of rated capacity	GB GC - CC.A.3.2

[2] Note that SONI GC CC.S1.2.3.3 applies the same minimum generation criteria for generating units connecting to the distribution system

Country	Transmission Operator	Generation Technologies	Minimum Generation Requirement	
			Value	Clause
Finland	Finish Grid (FINGRID)	Hydropower, CCGT, motor power plants	10% of rated capacity	FL VJV (2018) – 11.3.2.1[3]
		Combined Heat Power (CHP) and other motor generators	40% of rated capacity	FL VJV (2018) - 11.3.2.1[4]
Portugal	Redes Energéticas Nacionais (REN)	All	40% of rated capacity	PT GC – 4.1[5]

As seen in Table **3-2** there are certain differences in the requirements of the GCs developed in the NI, GB, FL, and PT.

The forthcoming sections highlight that minimum generation levels are set across shortlisted countries based on the technical requirements of generators and to ensure safe operation of the electricity network – known as primary factors. There are also a set of wider system benefits that have occurred as a result of setting minimum generation level which support system operations – known as secondary benefits.

3.3.2.1 Northern Ireland (NI)

With reference to the latest version of the Northern Ireland Grid Code[6], generating plant performance requirements grid code CC.S1.1.3.8 and CC.S1.2.3.3 states that:

> *"A Generating Unit must be capable of remaining Synchronised to the NI System at an Output which is no greater than the lower of 80 MW or 40% of maximum continuous rating"*

The NI electricity network is comparatively small, maximum demand is approximately 1.8GW[7]. The all island system comprises of:

- one HVDC interconnector Moyle Interconnector connecting Northern Ireland to Scotland
- one North-South AC interconnection linking Northern Ireland and the Republic of Ireland

There are 2 other AC connections with Republic of Ireland that are controlled to 0 MW flow due to being 110 kV connections at a weak part of both networks. A further North-South interconnector is currently being proposed and is expected to be fully operational by 2026[8].

[3] https://www.fingrid.fi/globalassets/dokumentit/en/customers/grid-connection/grid-code-specifications-for-power-generating-facilities-vjv2018-.pdf

[4] Ibid

[5] https://recipp.ipp.pt/bitstream/10400.22/12021/1/DM_MarceloNeves_2017_MEESE.pdf

[6] SONI Grid Code June 2019

[7] https://www.nienetworks.co.uk/documents/connections/statement-of-connection-charges-november-2022-v1-8.aspx#:~:text=1.3%20Under%20the%20Licence%20NIE,demand%20of%20approximately%201%2C800%20MW.

[8] https://www.soni.ltd.uk/the-grid/projects/tyrone-cavan/the-project/

The NI system is also lightly interconnected. Despite this, the size of the interconnectors are large with respect to the size of the NI system. Stability of the network has historically been largely dependent on conventional generators.

The 'All Island' System

Both NI and Ireland operate under a single electricity market (SEM) whereby the two electricity networks in NI and Ireland are physically connected, this is known as the all-island system. Operation of the SEM is facilitated by the Single Electricity Market Operator (or SEMO) which is a contractual joint venture between the two system operators on the island of Ireland – SONI in NI and EirGrid Plc in Ireland – and enables the financial coordination that underpins the SEM.

There are a set of all-island rules which ensures the safe operation of the all-island system. Separately there are a set of jurisdictional rules to ensure that NI and Ireland systems would safely operate in isolation should the all-island system no longer exist.

One example of all-island rule is for inertia, where inertia is defined as the energy stored in large rotating generators and some industrial motors, which allows the generating unit to remain rotating. The minimum inertia level is currently set at 23,000 MWs and requires 8 generators to be operating at all times.

Separately there are jurisdictional rules related to the minimum number of large generating units which must be operating at all times. In the case of NI, because there are only 6 large generating units, there is no minimum floor but the minimum set rule requires 3 large generators to be online at all times.

Factors Impacting Minimum Generation in NI

The primary reason that NI set its minimum generation level is based on a set of technical capabilities of generating units which ensures the safe operation of the electricity network.

Further, setting a low minimum generation level on conventional units has secondary benefits through supporting system operations.

In particular, the current minimum generation level provides increased flexibility and helps to ensure that the NI system is secure for the minimum demand scenario. Low minimum generation also helps in the maximisation of the Renewable Energy Systems (RES) as systems move to a lower carbon footprint. The minimum generation level is also reflective of the fact that a small set of conventional generators is required to facilitate inertia.

As outlined within Section 3.3.2.3, technological advancement within hydropower and Combined Cycle Gas Turbine (CCGT) allows generators to meet the minimum inertia level at lower minimum generation levels. As the future capabilities of generating technologies improve, this may allow SONI to reduce their minimum generation level whilst still maintaining safe operation of the power systems. There is also emerging evidence[9] to suggest that the inertia from conventional machines will have less importance as a means to ensure stable system operations in the future, instead some TSOs are looking at options to provide inertia through battery storage.

3.3.2.2 Great Britain (GB)

The minimum generation requirements in GB were first introduced in 2007. This was introduced following the Grid Code Review Panel's (GCRP) concern over the capacity terms used in the Grid Code. They stated that the:

[9] https://www.linkedin.com/posts/lars-stephan_inertia-study-activity-7047480911797309441-FvDM?utm_source=share&utm_medium=member_ios

"Generation Capacity and Registered Capacity are defined differently in the Balancing Settlement Code (BSC) and Grid Code respectively and the need has been identified to review the various capacity terms used in the Grid Code with a view to rationalisation".[10]

Responding to these comments National Grid Electricity Transmission (NGESO) decided to expand the remit to include capacity terms utilised in the Grid Code, which are reflective of minimum operational conditions. This refers to the design operating minimum level and the minimum generation level. The definitions as per the latest Grid Code are as follows:

Designed Minimum Operating Level:

"The output (in whole MW) below which a Genset or a DC Converter at a DC Converter Station (in any of its operating configurations) has no High Frequency Response capability."[11]

Minimum Generation:

"The minimum output (in whole MW) which a Genset can generate or DC Converter at a DC Converter Station or Electricity Storage Module can import or export to the Total System under stable operating conditions, as registered with The Company under the PC (and amended pursuant to the PC). For the avoidance of doubt, the output may go below this level as a result of operation in accordance with BC3.7." [12]

The difference between the two minimum generation levels is that the Designed Operating Minimum Level is the minimum technical generation limit the generation asset can lower to without risking damage to the asset, whilst the minimum generation level is the maximum minimum generation level at which the asset should operate at to allow for frequency response.

The two levels are designed to provide NGESO the ability to increase and decrease the frequency of the grid based on increasing and decreasing generation levels. For example, when the frequency is too high, which means its above 50Hz, then the ESO will request generators to lower their generation and vice versa. Creating a range for minimum generation stops, the generator from either turning the asset on (100%) or off (0%), thus forcing the generator to operate within a range so that the ESO can use the generator as a mechanism to balance the frequency.

Therefore, based on the GCRP's request, it was decided to include the following two minimum generation levels:

*"The **Minimum Generation level** may be less than, but must not be more than, **65% of the Registered Capacity**. Each generating unit and/or CCGT module and/or power park module and/or DC concert must be capable of operating satisfactorily down to the Designed Minimum Operating Level."*[1]

*"For the avoidance of doubt, under normal operating conditions steady state operation below **Minimum Generation** is not expected.**"**[1]*

*"The **Designed Minimum Operating Level** must not be more than **55% of registered capacity."***

Table 3-3 summarises the minimum generation requirements for the GB.

[10] Grid Code Development Issues May 2007 – 'Capacity terms used in the Grid Code pg2'

[11] Page 23, GB Grid Code, 5th January 2023

[12] Page 49, GB Grid Code, 5th January 2023

Table 3-3 - Minimum generation levels for the GB

Clause	Minimum Generation Requirement
CC.A.3.2	**Minimum Generation level:** May be less than, but must not be more than, **65% of the Registered Capacity**.
CC.A.3.2	**Designed Minimum Operating Level:** Must not be more than **55% of registered capacity**.

The percentage was issued in 2007 and has remained the same throughout the various grid code reviews and changes. There is no evidence to suggest that the ESO and/or Ofgem are looking to change the minimum generation percentage in the future.

The reason why they set the value at this level is still awaiting response from National Grid.

3.3.2.3 Finland (FL)

The minimum generation requirement dates back and has been in effect since the 1990s. The initial limit (Figure 2) was set at 20% for hydropower, CCGT, and motor power plants and 40% for Combined Heat and Power (CHP) and other power plants. However, the limit was revised in 2013 with the publication of the Specifications for the Operational Performance of Power Generating Facilities (VJV) 2013 and lowered to 10% for the first category of generation technologies.

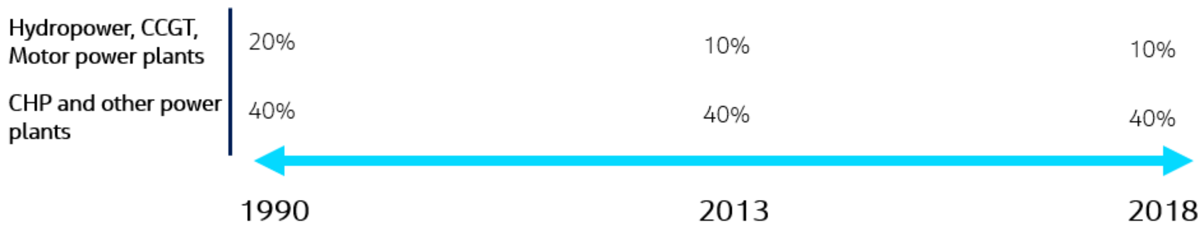

Figure 2 Minimum generation timeline

The minimum generation requirements as per the latest VJV 2018 is that:

"Hydropower, gas turbine and motor power plants need to maintain a minimum generation of 10% of rated capacity and that combined heat and power and other power generating facilities need to maintain a minimum generation of 40% of rated capacity."[13]

The new levels were set based on the current understanding about the safe operating limits of the generation technology. Technological advancement has increased the range in which generation units can operate safely. Consequently, the TSO has acted and reduced the threshold for minimum generation to align regulations with industry standards. The minimum generation levels have stayed the same with publication of the newest VJV in 2018[14] and remain at this level to date. The EU published a new large combustion BAT document in 2021, however, these documents tend to take a few years to publish with 2 to 3 rounds of drafts

[13] VJV, 11.3.2.1, 2018

[14] A new large combustion plant BAT was introduced in 2021, but earlier drafts may have been in circulation prior to 2021. It is possible that Finland considered this as part of its minimum generation criteria

being issued for comment. Therefore, it is possible that in 2018 a first document was circulated and FINGRID based their decision to reduce the minimum generation off of that document. However, we are not able to provide a guarantee on that statement.

There is no indication that FINGRID is looking to change the minimum generation levels in the future. This was confirmed after consulting with a specialist at FINGRID. The operating limits of the generation technology will be investigated in more detail as part of the OEM consultation.

3.3.2.4 Portugal (PT)

Portugal also began developing a new grid code based on the European regulation EU 2016/631. In particular, Portugal launched an ordinance, 'Portaria n.º 73/2020', in March 2020[15]. The RfG[16] document defines specific technical requirements for implementation by the member states, but also defines non-mandatory or non-exhaustive requirements, the specification of which depends on the decisions of each European country. Thus, regulation or ordinance 'Portaria n.º 73/2020' defines the non-exhaustive technical requirements for the connection of generation modules to the Public Electricity Supply Network, 'Rede Elétrica de Serviço Público', and identifies the facilities subject to the fulfilment of these requirements.

Thus, adding to the "Portaria n.º 73/2020' is the "Portaria n.º 596/2010, de 30 de Julho" which approves the Rede Nacional De Transporte (RNT) regulations and sets the current technical requirements. This sets the general technical conditions for connecting production facilities to the RNT, with the exception of wind installations (asynchronous). Based on this regulatory requirement Portugal's minimum generation level since 2010 has been set at 40%. The response below is a direct translation from the Portuguese GC:

> *"3.6.7 - **The technical minimum of the generator sets must not exceed 40% of the respective nominal power**.*

As expected, the regulatory document legislations mention that the specifications have been determined to safeguard the imperatives of quality of service, reliability, and security of the network. It is likely that the limits, similar to Finland, are set based on a reasonable assumption about the capabilities of technology currently available for different types of power plants. Based on the research of the generation-turbine OEMs capabilities in the next chapter which considers the three biggest utility OEMs, Siemens Energy, GE and Mitsubishi Power, the turbines are able to comply with the IED/BAT emission requirements in the generation load range from approximately 30% as the lowest obtained value up to the full load. This is higher than the 10% min gen requirement in case of the Finish grid.

So, it is possible that the Finish TSO set the requirements based on the technical capabilities of the turbines to operate safely and not based on capabilities to comply with the IED emission limits. It is possible that the Finish grid does not consider the IED emission limit requirements for load levels below 70% as discussed previously in section 2.4.8. Although, the lowest emissions compliant min gen was obtained for utility turbines only and this may be different for smaller industrial turbines which may be more common in Finland. Either way the main conclusion of the assessment of Finland and Portugal indicates that TSOs may choose to modify the min gen requirements based on the current and evolving turbine capabilities.

[15] https://dre.pt/dre/detalhe/portaria/73-2020-130273580

[16] The European Commission began developing, in 2010 and through the European Network of Transmission System Operators for Electricity (ENTSO-E), a new network code formulating two types of requirements: mandatory requirements for all countries, and optional technical requirements, adaptable by each country based on the characteristics of its national electricity network. Moreover, the European network code is divided into three families: i) connection; ii) operations; and iii) market. Each of these network code families is in turn divided into different specific grid codes. The document that specifically addresses the requirements set for generators, known as "Requirements for Generators" (RfG), was established in the Commission Regulation (EU) 2016/631.

3.4 Summary- TSO requirements

Grid codes will continue to play an important role for grid operators, since they constitute an important tool that can be revised with new response characteristics as well as new services to deal with the predicted necessities of the evolving power systems.

Our market research identified 2 reasons (Table 3-4) for which network operators have set a minimum generation level.

Table 3-4 – Primary reasons and benefits for setting a minimum generation.

ID	Reasons	Northern Ireland	United Kingdom	Finland	Portugal
		Primary	Primary	Primary	Primary
1	Turbines can operate within safe operating limits.	X	X	X	X
2	To safely respond to an increase or decrease in system frequency.	X	X		

- All network operators, consider safe operating limits when determining minimum generation levels. Further, countries such as Finland and Portugal have adjusted their GC to accommodate for advances in turbine technology.
- However, there are other network operators like NGESO that use generators as a mechanism to regulate frequency.
- Furthermore, another reason for setting a minimum generation level is to minimize the risk of oversupply in a minimum demand scenario. The grid system needs downward flexibility to ensure generation can be brought down to meet the demand level and manage any uncertainties in doing so. Larger countries, like GB, have more flexibility as there is a larger minimum demand, higher interconnectivity, and more flexibility options. Therefore, GB has options to reallocate excess supply. For example, NGED provided a case study[17] for how they were able to operate within a scenario where minimum demand was lower than minimum supply.

[17] https://www.nationalgrideso.com/document/186366/download

Case Study – National Grid Low Demand Operability Challenges from COVID 19

The Great Britain (GB) power system encountered unprecedented low demands due to the impact of COVID-19 restrictions in 2020. For significant periods during the COVID-19 restrictions, there was a risk that the available generation and supply mix did not allow for the reserve to manage the frequency second by second. Optional Downward Flexibility Management (ODFM) was a new commercial tool developed to provide necessary flexibility. As all our normal routes to accessing negative reserve such as the balancing mechanism, interconnector and bilateral trades were expected to be fully utilized, ODFM was created to give NGEDs control room an additional tool to operate the system safely and reliably, by reducing the amount of electricity (e.g. generation) supplied at the local distribution network level, rather than providing reserve generation.

Many embedded generators and demand consumers participated in ODFM as service providers which had not previously participated in any flexibility mechanism. They provided service information on a weekly basis including bid process, volumes, and availability window.

Source: https://www.nationalgrideso.com/document/186366/download

Overall, our review has identified that the minimum generation level is primarily based on system needs and the generating units technical capabilities. There is little evidence to suggest that regulatory and licensing requirements are a driving factor in determining minimum generation.

The conclusion that can be drawn from our research, is although it's rare, the minimum generation can be changed as shown by FINGRID. Finland has a similar network composition to SONI, where the majority of power is provided by CCGT, low levels of interconnection (especially after cutting its interconnector with Russia), and a relatively small grid. FINGRID did update its minimum generation levels in 2013 for hydropower, CCGT, motor power plants and combined heat and power plants. This was in response to technological advancements which increased the range in which generation units could operate safely and thereby provided scope to reduce the minimum generation threshold.

The assessment undertaken by Jacobs will ascertain the technical viability of any modifications to the maximum continuous rating of synchronous generating units connected to the NI system.

4. Market research – Evaluation of OEMs capabilities

4.1 Technical Evaluation Approach

4.1.1 Choice of OEMs

This Chapter presents the generation-turbine OEM data obtained from the Market research phase of the study. The obtained data considers the capabilities of turbines technologies based on which the feasibility of the proposed min gen requirements is evaluated. Three OEMs are considered for the assessment, Siemens Energy, General Electric (GE), and Mitsubishi Power. They represent the three of the biggest manufacturers of utility gas/steam turbines globally. They also provide solutions in the power range of 200MW – 500 MW which may be affected by the proposed modification of the min gen requirements as explained in the next section. Furthermore, Jacobs has contacts of the three OEMs relevant departments and some of our Jacobs colleagues have collaborated with their generation experts which facilitates the Market research phase of the study.

4.1.2 Turbine technologies and power requirements

The initial scope of the assessment considered a broad range of turbines technologies. However, due to project time restrictions, the assessment considered the following turbines only:

- Gas/steam turbines in OCGT and CCGT applications

Furthermore, due to time restrictions and the limited information that could be obtained from the OEM consultations, the assessment considered the turbines and their different configurations from 200MW to 500MW gross power generation range only. The reason for focusing on this power range is that the proposed minimum generation only affects generator-turbines with power rating above 200MW since the 40% limit and the 80MW limit are equal for this power rating. For example, for turbines with the power rating of 300MW, the current minimum generation would be the lower of the 40% of the power rating, or 80MW, which is 80MW, while the proposed limit would be the 40% which is 120MW. However, for a turbine with the power rating of 100MW the current limit and the proposed limit would both be the 40%. So higher power ratings above 200MW are of interest, and this mostly covers the utility turbine applications. An upper limit is also adopted to the power range of interest, the 500MW power rating limit which aligns with the NI largest single infeed.

4.1.3 Assessment parameters

To obtain a comprehensive understanding of the OEMs generator-turbine capabilities, the following parameters are researched:

- minimum (emissions compliant) generation load for single turbines and combined plant applications,
- emissions across the entire loading range
- efficiency at base power load
- Grid Code compliance across entire loading range
- the above parameters with and without mitigation techniques

These parameters are analysed against the IED/TSO requirements researched in the previous Chapters, and the SONI GC requirements, to assess the minimum feasible generation and the suitability of the proposed minimum generation requirement.

The three OEMs are investigated first using publicly available sources such as relevant websites, generator catalogues/brochures and technical specifications data base. Then the missing information is further explored through the OEM consultations.

4.1.4 Evaluation against IED/BAT

The generation-turbine parameter obtained in this chapter are compared against the following BAT requirements (obtained in Chapter 2):

- The BAT efficiency requirements, obtained in Table 22, for OCGT applications (>50MW input) are 36.1% - 41.5% efficiency, at base power load.
- The BAT efficiency requirements, obtained in Table 22, for CCGT applications 50-600 MWth (input) are 53 - 58.5% efficiency, and for CCGT applications ≥600 MWth (input) are 57% – 58.5% efficiency, at base power load
- The BAT emission limits requirements are obtained in Table 24 for gas turbines. As seen previously, for OCGT applications the daily average NOx emission limits are 25-50 mg/Nm^3 and CO yearly average emission limits are 5-40 mg/Nm^3. This is converted to 13- 26 ppm for NOx and 4-35 ppm for CO respectively. Note the unit conversion from mg/Nm^3 to ppm is on a high-level as it depends on gas content, molecular weight and temperature, and so it is indicative only.

4.1.5 OEMs Consultation

The three OEMs relevant departments were contacted as part of the consultation process using the Jacobs contacts. An OEM Questionnaire was written and sent to the OEMs with the aim of enquiring generation-turbine technical capabilities in relation to minimum generation levels as explained previously. Although all three OEMs responded only Siemens and Mitsubishi were able to provide detailed feedback, and only Siemens was able to comment on the Grid Code compliance questions.

The Questionnaire considers:

- Open cycle gas turbine generators
- Combined cycle gas turbine generators
- Steam turbine generators

The question related to IED documents consider compliance with:

- Directive 2010/75/EU,
- Decision (EU) 2021/2326
- Best Available Technologies

The question related to SONI Grid Code consider compliance with:

- System frequency and frequency change Clauses CC5.3.3, CC8.8.6.1, CC8.8.7.3, CC8.8.7.5,
- Response to system fault Clauses CC6.4.2, CC.S1.1.6.2
- Reactive power supply Clauses CCS1.1.3.2, CC.S1.1.3.3
- Voltage stability Clauses CC.S1.1.3.3 (e), CC.S1.1.3.3 (f)
- Control arrangements Clauses CC.S1.1.5.1, CC.S1.1.5.3

The questions related to Grid Code documents consider compliance with:

- Northern Ireland

Other countries of interest were also considered initially:

- Great Britain
- Finland
- Portugal

However, the OEMs were unable to cover information to such extent.

The Questionnaire puts focus on the generator power rating in the range 200MW – 500MW which may be affected by the proposed min gen modification.

The following sections provide the analysis of the obtained generator-turbine information and the OEMs responses to the Questionnaire, while the OEMs questions and the responses are presented in detail in the Appendices.

4.2 Siemens Energy evaluation

4.2.1 IED/BAT compliance

4.2.1.1 Turbine efficiencies and emission levels

The following information is obtained from the Siemens Energy public database:

- The efficiencies of the simple cycle gas turbines at rated power. This covers the power ratings range of interest 200MW-500MW but also a wider power range for completeness.
- The emission levels at rated power and ISO conditions. For some turbines, the emissions are given with mitigation techniques.
- What is missing is the emission levels at lower loads with or without mitigation techniques.

The obtained information is presented in Appendix A in Table A 1. The obtained data is compared against the BAT requirements, and it is evident that the Siemens turbines comply with the efficiency requirements and the emission limit requirments at the base load.

Further information obtained states that:

- SGT5-2000E turbines comply with the NOx and CO emission standards even at 50% part-load operation.
- SGT5-4000F turbines comply with the emission limits over a wide load range, but the minimum load is not specified.
- SGT5-8000H turbines use the can annular combustion system to successfully run in base and part-load operation while still complying with NOx and CO regulations.
- SGT5-900HL turbines have the lowest minimum environmental load (MEL) <30%.

Additional information is obtained for the above turbines in CCGT applications, and this is given in Table A 2. This provides efficiency at rated power but there is no information available for emissions. The obtained efficiencies are able to meet the BAT requirements at base power.

Three Siemens steam turbines are considered based on the power range of interest, the SST-3000, SST-4000 and SST-5000 turbines. The obtained information is presented in Table A 3. However, no information is available related to generation load below rated conditions and regarding emission limits.

4.2.1.2 Siemens consultations

The Siemens turbines were further evaluated based on the OEM consultations. The feedback from Siemens was the most comprehensive OEM response. The initial talks with Siemens helped us refine the Questionnaire to better suit the OEM's ability to respond. They advised us to consider few specific turbines only in our Questionnaire otherwise they would not be able to cover the capabilities of a broad range of technologies. Based on the input from Siemens, we revised the questions to consider only 2 gas turbines:

- SGT5-4000F
- SGT5-2000E

as this covers the power range of interest 200-500MW in both OCGT and CCGT application.

The following are the BAT compliance questions:

- What is the lowest minimum generation load level at which you can meet the NOx and CO emission limits (daily) specified in the BAT documents, without applying the mitigation/modification techniques?
- What is the lowest minimum generation load level at which you can meet the NOx and CO emission limits (daily) specified in the BAT documents, with applying the mitigation/modification techniques?
- What is the lowest minimum generation load level at which you can meet the net electrical efficiency specified in the BAT documents?
- If a Gas Turbine is part of a Combined Cycle Unit, would it have the same emissions as if it were an open cycle unit? This is not when considering the CCGT as a whole, but rather only giving consideration to the Gas Turbine. Is the minimum generation level of the GT impacted by being part of a CCGT?
- If possible, please provide the details of the emissions, efficiencies across the feasible loading range and mitigation techniques (if used).

Siemens responded to these questions by sending us a detailed data sheet extract. This covers the BAT emission limit requirements for OCGT and CCGT applications, and for natural gas operation and oil operation. The requirements were cross checked against the information obtained in Chapter 2 and they match. The received information is provided in Table A 4 - Table A 7 for convenience.

The obtained data sheets provide the detailed emissions and min gen information which is presented in Table A 8 and Table A 9. From the tables it is seen that the minimum generation load which complies with the BAT emission requirements is 40% for the OCGT application and 45% for the CCGT application, in case of the natural gas operation. This is the default capability of the turbine technologies. We are suspecting that with the use of the mitigation techniques lower minimum compliant load may be achieved since it is indicated that with the use of the SCR lower emission may be achieved. However, such techniques may not be economically viable for developers, operators and utilities to implement in the current marketplace. Siemens was enquired about the improved min gen turbine capabilities using such mitigation techniques but was not able to provide detailed answers. We understand that this information is project specific and would require further specific detailed studies. Furthermore, please note that the obtained min gen values are provided by Siemens as indicative values (given as approximate values in the data sheets) and so they should be treated with some caution.

4.2.2 Grid Code compliance

Siemen was also consulted on the Grid Code issues that may arise with respect to the change of the min gen requirements. Initially we wanted to know what sort of issues they experienced in the past and if they are able to meet all the GC requirements. They advised us that normally they are unable to meet of all the requirements and that we need to consider compliance with specific GC clauses. As a result, we obtained the most relevant NI GC clause requirements which may be affected by the change of the min gen requirement. The detailed questions and the Siemens responses are presented in Section A.2 of the Appendices.

From the obtained responses it is concluded that Siemens does not identify any major obstacles that would affect compliance with the requirements of the considered GC clauses, in relation to the current/proposed NI GC min gen requirement.

4.3 Mitsubishi Power

4.3.1 IED/BAT compliance

4.3.1.1 Turbine efficiencies, emissions levels, and turndown load

The utility gas turbine technical specifications were obtained similarly from the Mitsubishi Power public data base. This is presented in Table B 1 of the Appendices. Mitsubishi provides additional information, the Turndown load, which is the minimum emission compliant load based on the OEMs' definitions and based on similar values obtained from Mitsubishi during consultations (see section 4.3.1.2). Note that the turndown load is given for a single turbine, and it shall be different for CCGT applications depending on the configuration of the plant. The turndown load seems to be 50% for most turbines but it can be as low as 45% and as high as 60% for some turbines in the power range of interest 200-500MW.

The obtained efficiency and the emissions are similarly compared against the BAT requirements as for the Siemens turbines. Based on this it is evident that the Mitsubishi turbines are able to meet the requirements at the rated operating conditions.

4.3.1.2 Mitsubishi consultations

Similarly, as for Siemens, Mitsubishi had requested us to narrow down our Questionnaire to consider only a few specific turbine technologies. As a result, we considered the following turbine applications whose power output falls within the power range of interest 200-500MW:

- H-100 in 2x1 CCGT application
- M701F in both OCGT and 1x1 CCGT application
- M701JAC in OCGT application

The detailed Questionnaire and the responses from Mitsubishi are presented in Appendix B. From the responses it is concluded that Mitsubishi turbines are able to meet the BAT emissions requirements at the minimum generation levels of approximately 50% although with the use of mitigation techniques (such as catalysts prior discharging to stack) the achievable minimum compliant generation could be further reduced in the range of 40% and above.

Further comments from Mitsubishi note that the considered turbine systems are able to meet the minimum generation requirements of the rest of the considered countries of interest, so Great Britain (55% and 65%) and Portugal (40%) except for the Finish Grid where the 10% min gen requirement is far too low, but 40% would be achievable.

4.3.2 Grid Code compliance

The same detailed GC questions were shared with Mitsubishi as in case of Siemens. Unfortunately, they responded that the questions are project and scenario specific; it would require detailed engineering studies and deep studies of the country codes, which they would perform either during tendering stage or during construction activities.

4.4 General Electric evaluation

4.4.1 IED/BAT compliance

4.4.1.1 Turbine efficiencies and turndown load

The utility gas turbine technical specifications were obtained similarly from the GE public data base, and this is presented in Table C 1. The GE also provides the emission compliant turndown load, although this is given for the CCGT applications only. For 1x1 turbine CCGT the turndown load is in the range 28% - 48% for the power rating 200 - 500MW. Furthermore, the efficiency can just about meet the BAT requirements for most turbines, at the rated operating conditions. Unfortunately, there is no mention of the emission levels.

It is also seen that the turndown load for the 2x1 turbine CCGT configuration seems to be roughly half the value compared to the 1x1 configuration. However, the turndown load is not the same as the min gen load in this case. The turndown load is given on a plant level while the Grid Code min gen requirement and the BAT emission limits requirement apply to the individual turbines. This means that the individual turbines in a 2x1 configuration have a similar min gen capability as the one turbine in a 1x1 configuration. For example, in a 2x1 configuration, if the min gen emission compliant capability of one turbine is 40%, this is 20% on a plant level if the other turbine is disconnected. However, the 40% is still the capability of one turbine as prescribed by the Grid Code and with respect to the BAT emission requirements. Regardless, the 2x1 configuration is mostly not relevant for the NI system as the plant gross power output rating exceeds the 500MW of the NI largest single infeed.

4.4.1.2 GE consultations

GE was unable to provide responses to our Questionnaire in a similar level of detail as in case of Siemens or Mitsubishi and in time to meet the deadline of the OEMs consultations. This requires detailed studies of project specific scenarios especially in relation to detailed Grid Code compliance questions. However, GE was still able to provide useful information regarding the achievable emissions compliant min gen loads for OCGT applications, although on a high-level. This was obtained for turbines with power output in the 200-500MW range. The table below summarizes the obtained OCGT information including the relevant CCGT min gen loads obtained from open sources.

Table 4-1 Obtained GE turbines min gen levels

Turbines	OCGT application		1x1 CCGT application	
	Power	Min gen	Power	Min gen
9HA.01	448 MW	30%	680 MW	33%
9F.04	288 MW	35%	443 MW	48%
9E.04	147 MW	35%	218 MW	46%

GT13E2-210	210 MW	would unlikely be an option for the Irish market unless there was a very specific reason and request for that machine	305 MW	40%

As can be seen, the considered GE OCGTs may be able to operate down to 30-35% emission compliant min gen which is lower than the min gen obtained for Siemens or Mitsubishi turbines. This also seems to be quite lower than for the CCGT applications 40%-48% in the 200-500MW range or 46-48% excluding the GT13E2 turbines as indicated by GE.

4.5 Summary - OEMs capabilities

The following table summarises all the information obtained for each of the three OEMs. It also indicates all the information of interest that was not obtained. Note that we did not expect the OEMs to provide all the considered information as this request was not legally binding for them. Furthermore, the table below summarizes only the information obtained for the turbines in the power range of interest approximately 200-500MW.

Table 4-2 Summary of obtained OEM information against consider requirements.

OEM	Siemens		Mitsubishi		GE	
Single turbine parameter	OCGT	CCGT	OCGT	CCGT	OCGT	CCGT
Power	✓	✓	✓	✓	✓	✓
Minimum emission limits compliant generation without mitigation techniques	40%	45%	45% – 60% (mostly 50%)	50%	30% or 35%	40%-48% (46 – 48% excluding GT13E2 turbines)
Minimum emission limits compliant generation with mitigation techniques	35%	X	40%	40%	X	X
Efficiency at base power	✓	✓	✓	✓	✓	✓
Emissions at min gen	✓	✓	X	X	X	X

✓ - information obtained

X - information not obtained

So, the main takeaways from this chapter are:

- Generator-turbine specifications were obtained from the three OEMs, Siemens Energy, Mitsubishi Power and GE. This considered the minimum generation capabilities of the turbines to comply with the BAT requirements. It also considered the capabilities of the turbine to comply with the NI GC clauses affected by the proposed change of the min gen requirement. The information was obtained for the gas and steam turbines, for open cycle and combined cycle applications. However, focus was put on the power range 200-500MW, which covers utility turbines only, and which may be affected by the proposed change of the min gen requirement.
- The assessment obtained turbine efficiencies at the rated power. This indicated that the considered turbines may comply with the BAT efficiency requirements.

- The assessment also obtained emission levels. This indicated that the considered turbines may comply with the BAT emission limits although this was obtained for the rated operating conditions only.
- The evaluation of Siemens turbines indicated that in the OCGT applications the plants can operate at 40% min gen and in the CCGT applications at 45%. Although, we understand it may be possible to operate at lower min gen with the use of the mitigation techniques. However, the economic viability of such techniques has not been considered in this assessment. This information was not confirmed by Siemens but was indicated as achievable 35% min gen in case of one of the considered OCGTs.
- The evaluation of Mitsubishi turbines indicated an achievable min gen of 50% for both OCGT and CCGT utility applications. It also indicated that a 40% min gen could be achievable with the use of the mitigation techniques.
- The evaluation of GE indicated on a high-level an achievable min gen of 30% or 35% for the considered OCGTs. Also, a min gen range of 40%-48% was obtained for the considered 1x1 turbine CCGT applications or a 46%-48% range excluding the GT13E2 turbines as indicated by GE.
- The OEM consultations also considered in detail the compliance with several NI GC clauses of interest. This indicated no major obstacles in modifying the proposed min gen criteria.

5. Combined Assessment of Proposed Minimum Generation and Wider Research Conclusions

5.1 Summary of IED/BAT, TSOs and OEMs evaluation

5.1.1 TSOs requirements summary

According to the market research, the TSOs Grid Codes min gen requirements settings can be modified based on the specific needs of the electrical network, particularly to accommodate new connections and the increasing integration of renewable energy sources. However, it is crucial for the TSOs to consider the network's ability to handle fluctuations in generation and demand, ensuring the power system's security and stability. This consideration encompasses maintaining sufficient levels of inertia, which is essential for reliable power system operation.

The analysis of four TSOs, including SONI, suggests that min gen requirements may be modified based on the following observations:

- The historical changes in Finland show that the min gen levels for hydropower, combined cycle gas turbines (CCGTs), motor power plants, and combined heat and power plants were updated in 2013. These updates considered technological advancements that expanded the safe operating range of generation units, making it possible to decrease the min gen threshold to 10%.
- The research of Portugal showed that the TSO adopted the min gen criteria similarly by considering the capabilities of generation-turbine systems, as well as factors such as service quality, reliability, and network security. Consequently, Portugal implemented a min gen requirement of 40%.
- In contrast, the UK have implemented two different min gen levels, namely 65% and 55%. This dual approach allows for increased flexibility in regulating frequency during fluctuations in demand or generation, while also providing a safety margin for the operation of generator-turbines.

Based on the research findings, it is suggested that the min gen requirements can be modified. This is supported by the fact that some TSOs have already updated their min gen requirements to align with the evolving system needs and advancements in turbine capabilities.

There is little evidence to suggest that regulatory and licensing requirements are a driving factor in determining minimum generation.

5.1.2 IED and BAT requirements summary

The TSOs (Grid Code's min gen requirements) may also need to consider the design limitation and capabilities of standard generator OEMs to comply with all the Grid Code requirements, the IED and the impact of other regulations across the entire loading range specified in the Grid Code. The IED evaluation has shown the following:

- IED and its associated BAT requirements, set the maximum allowable gaseous emissions from a generator unit, based on both fuel and combustion plant type in NI. For some plants, there may be additional limits set based on thermal input.
- To operate legally, a generator needs to obtain an appropriate permit from the relevant environmental regulator which is the Northern Ireland Environment Agency (NIEA) in Northern Ireland. This permit would include compliance with emission limit requirements set out in the IED and BAT documents.

- To obtain the permit the NIEA would also assess the overall efficiency (at the rated power) against the BAT requirements. However, this efficiency would not be included within the issued permit.
- The combustion plant operator must remain in compliance with the requirements of their permit in NI.
- The BAT emission limits requirements can be interpreted in two ways depending on the country of application. Each country can interpret the compliance with the BAT emission limits as either applied to the load range above 70%, as is the case in Finland, or to the full load range. The NIEA interprets the BAT emission limits as applied to the entire feasible generator-turbine operating load range specified in the Grid Code.
- There is no limit prescribed within the IED or BAT around the minimum or maximum load on a generator. The min gen is only addressed in the Grid Code.

5.1.3 Generator OEM's summary

This assessment considered the capabilities of three of the top global utility gas turbine OEMs: Siemens Energy, General Electric (GE), and Mitsubishi Power. This considered the minimum generation capabilities of the turbines to comply with the BAT requirements including both the emissions limits requirements and the efficiency limits requirements. It also considered the capabilities of the turbine to comply with the NI GC clauses affected by the proposed change of the min gen requirement. The assessment utilized data gathered during market research phase. The initial project scope considered assessment of a broad range of turbine technologies and sizes. However, due to project time constraints the assessment focused on the utility gas/steam turbines only. It also focused on the 200-500MW power rating range since this range is affected by the proposed modifications to the min gen clauses. Furthermore, the OEMs' minimum emission compliant generation capability is obtained with respect to the full generator-turbine operating load range specified in the Grid Code, as required by the NIEA. The assessment found that:

- The considered turbines can comply with the BAT efficiency requirements at the rated power.
- Siemens turbines can operate with a min gen of 40% for OCGT applications and 45% for CCGT applications, within the emissions compliant load range. The OCGT can also operate with a reduced min gen of 35% using mitigation techniques such as Selective Catalytic Reduction (SCR). However, the economic viability of this technology has not been considered in this assessment. This information was not confirmed by Siemens as it is projects and scenario specific and it would require further detailed studies.
- Mitsubishi turbines can operate at a min gen of 50% without, or possibly as low as 40% with mitigation techniques respectively.
- GE turbines can operate with a min gen of 30% - 35% for OCGTs and for CCGT applications, the min gen range is 40% - 48%.
- The OEMs' emissions compliant min gen levels mostly align with the min gen requirements in the three TSO countries, National Grid in UK, REN in Portugal, and SONI, NI. The only exception is the Finnish grid in Finland where the 10% min gen requirement is significantly lower than the OEMs' emission compliant load levels. The reason for this could be that Finland interprets compliance with the BAT emission limits requirements only for the load range above 70% and based on OEM research the turbines can comply with such requirements. For the 10% to 70% load range, it is possible that other domestic criteria apply. This means that although the 10% min gen requirement considers safety of turbines' operation, it may not consider the BAT emission limit compliance.
- The OEM consultations also considered in detail the compliance with several NI GC clauses of interest. This indicated no major obstacles in modifying the proposed min gen criteria.

5.2 Combined assessment

The analysis carried out indicates that the proposed modification, i.e., removal of the 80MW min gen limit, from the NI Grid Code clauses CC.S 1.1.3.8 and CC.S.1.2.3.3 does not pose significant obstacles. The assessment also indicates that the proposed modification is suitable based on evaluating requirements of four TSOs (including SONI), historical system changes, IED/BAT and Environmental Agencies' requirements (particularly NIEA in the NI system), and the capabilities of the generation-turbines OEMs. Also, the feedback received from generator OEMs suggests that there are no major obstacles in complying with other NI Grid Code clauses that could be affected by the proposed change in min gen requirements.

The assessment has highlighted the importance of considering the following observations/conclusions:

- The assessment has indicated that utility-scale turbines within the power rating range of 200-500MW can effectively operate with
  - min gen criteria of 40% for OCGT applications and 45%-50% for CCGT applications, without the need for any mitigation techniques.
  - min gen criteria of 35% for OCGT applications and 40% for CCGT applications, with the application of the mitigation techniques.
- Increasing the min gen criteria above the proposed settings would reduce the ability of the electrical network to deal with the emerging issue of managing the minimum demand conditions.
- To meet the 40% min gen settings or a more stringent setting, the generator-turbines OEMs may need to apply the mitigation techniques (especially for CCGT plants). Based on Jacobs' experience, implementing such measures may bring some economic challenges for generators.
- The adoption of alternative min gen clause settings may be suggested based on the requirements of the system needs in the electrical network, as well as the assessment of risks, benefits, and other factors such as techno-economic considerations and market impacts.
- The NIEA plays a crucial role in prescribing the emission level constraints, as interpreted from BAT, which affects the min gen capability of generator units in Northern Ireland.

Appendix A. Siemens generator-turbines data

A.1 IED/BAT compliance data

This section presents the obtained Siemens generator-turbine data regarding emissions and efficiency compliance as prescribed in the IED/BAT documents. The information is obtained through the market research studies including the OEMs consultations.

Table A 1 Siemens Simple Cycle gas turbines specifications

Turbine ID	Fuel	Water injection	Power (MW)	Efficiency (%)	CO emissions	NOx emissions[1]
SGT5-2000E	Fuel gas	Without	198 MW	37.6%	≤ 10 ppmvd	≤ 25 ppmvd
	Fuel oil	With	198 MW	37.6%	Not available	≤ 42 ppmvd
SGT5-4000F	Fuel gas	Without	329, 385 MW	41%, 41.5%	≤ 10 ppmvd	≤ 25 ppmvd
	Fuel oil	With	329, 385 MW	41%, 41.5%	Not available	≤ 42 ppmvd
	Fuel oil	Without	329, 385 MW	41%, 41.5%	Not available	≤ 58 ppmvd
SGT5-8000H	Fuel gas	Without	450 MW	41.2%	10 ppmvd	≤ 25 ppmvd[2]
	Fuel oil	With	450 MW	41.2%	10 ppmvd	≤ 42 ppmvd[2]
SGT5-9000HL	Fuel oil/gas	/	593 MW	> 43%	10 ppmvd	≤25 ppmvd[2]
SGT-800	Fuel gas		62 MW	41.1%	Single digit	15 – 25 ppmvd[3]
SGT-750	Fuel gas		39.8 MW	40.3%	Not availbale	<9 ppmvd[4]
SGT-700	Fuel gas		32.8 MW	38.0%	≤10–25 ppmv[5]	≤ 5 – 25ppmv[5]
SGT-600	Fuel gas		24.5 MW	33.6%	≤10 – 80ppmv[5]	≤ 9 ppmvd[5]

(1) NO_x emissions at 15% O_2 dry

(2) NO_x emissions down to 2 ppmvd with SCR

(3) The combustor/burner designs can bring NOx emissions to 9 ppm over a wide load range

(4) The SGT-750 can guarantee 9 ppm NO_x down to a 20% load.

(5) Turn down 50% load

Table A 2 Siemens Combined Cycle gas turbines specifications

Turbine ID	No. of gas turbines	Power (MW)	Efficiency (%)
SGT5-2000E	1	290 MW	55.6%
	2	551 MW	53.3%

SGT5-4000F	1	485, 570 MW	61%, 62%
	2	970, 1140 MW	61%, 62%
SGT5-8000H	1	675 MW	62.4%
	2	1,350 MW	62.4%
SGT5-9000HL	1	880 MW	> 64%
	2	1,760 MW	> 64%
SGT-800	1	89 MW	59.6%
	2	182 MW	60.6%
SGT-750	1	52.1 MW	53.9%
	2	104.8 MW	54.1%
SGT-700	1	49.8 MW	54.5%
	2	100 MW	54.7%
SGT-600	1	36.5 MW	50.7%
	2	74.2 MW	51.6%

Table A 3 Siemens Steam turbine specifications

Turbine ID	Power (MW)	Efficiency (%)
SST-3000	90 - 275 MW	Not available
SST-3000	100 - 500 MW	Not available
SST-5000	120 - 700 MW	64 %
	200 - 500 MW	43 % for subcritical, 46,4 % for supercritical

Table A 4 Emissions acc. BAT (≥ 50MWth; natural gas operation) in DLN effective range of the GT (> 70% GT load)

OCGT requirements	Values	CCGT requirements	Values
NOx (mg/Nm^3) yearly average	15 - 35	NOx (mg/Nm^3) yearly average	10 - 30
NOx (mg/Nm^3) daily average	25 - 50	NOx (mg/Nm^3) daily average	15 - 40
Indicative yearly average CO (mg/Nm^3) - operated ≥ 1500 h/yr	5 - 40	Indicative yearly average CO (mg/Nm^3) - operated ≥ 1500 h/yr	5 - 30

Table A 5 Emissions acc. IFC (≥ 50MWth; natural gas operation) in load range of the GT (> 60% GT load)

OCGT requirements	Values	CCGT requirements	Values
NOx (mg/Nm³) - 95% of all hourly values to meet	30 (poor air quality) - 50 (good air quality)	NOx (mg/Nm³) - 95% of all hourly values to meet	30 (poor air quality) - 50 (good air quality)

Table A 6 Emissions acc. BAT (≥ 50MWth; oil operation)

OCGT requirements	Values	CCGT requirements	Values
NOx (mg/Nm³)	Not mentioned	NOx (mg/Nm³)	Not mentioned

Table A 7 Emissions acc. IFC and IED (≥ 50MWth; oil operation)

OCGT requirements	Values	CCGT requirements	Values
NOx (mg/Nm³) according acc. IFC 95% of all hourly values to meet	152	NOx (mg/Nm³) according acc. IFC 95% of all hourly values to meet	152
NOx (mg/Nm³) according acc. IED 2010	50	NOx (mg/Nm³) according acc. IED 2010	50
CO (mg/Nm³) - operated ≥ 500 h/yr acc. IED 2010	100	CO (mg/Nm³) - operated ≥ 500 h/yr acc. IED 2010	100

Table A 8 Achievable emission limits – natural gas operation between MEL and 100% GT load

Parameters	OCGT		CCGT	
	2000E	4000F	2000E	4000F
MEL (minimum emission compliant load)	40%	40% (partly down to 35%)	45%	45% (With APH maybe lower)
NOx (mg/Nm³) without SCR	40	40	40	40
NOx (mg/Nm³) with SCR cooling of the GT exhaust gas with ambient air or water to reach the operation temperature of the SCR	10	10	10	10
NH3-slip (mg/Nm³)	5	5	5	5
CO (mg/Nm³) - operated ≥ 1500 h/yr	40	40	40	40

Table A 9 Achievable emission limits – oil operation between MEL and 100% GT load

Parameters	OCGT		CCGT	
	2000E	4000F	2000E	4000F

MEL (minimum emission compliant load)	60%	60%	60%	60%
NOx (mg/Nm^3) with oil (emulsion or dry)	50 to 200	50 to 200	50 to 200	50 to 200
NOx (mg/Nm^3) with SCR cooling of the GT exhaust gas with ambient air or water to reach the operation temperature of the SCR	10 to 40	10 to 40	10 to 40	10 to 40
NH3-slip (mg/Nm^3)	5	5	5	5
CO (mg/Nm^3) - operated ≥ 1500 h/yr	40	40	40	40

A.2 Grid Code compliance data

The following are the detailed questions we sent to Siemens with regards to the Grid Code compliance, and the Siemens responses. The questions relate to specific Grid Code clauses as indicated in the questions. The questions are divided based on the technical performance topics.

System frequency and frequency change

- CC5.3.3 in summary states in exceptional circumstances the system frequency could vary causing a considerable rate of change of frequency. Users (power suppliers) must ensure that their plant and apparatus remain synchronised to the NI system for a rate of change of frequency up to and including 1 Hz per second as measured over a rolling 500 milliseconds period within the frequency range mentioned in CC5.3.2 (System Frequency could rise to 52 Hz or fall to 47 Hz). Can the OEM's generators operate within these timeframe parameters even at minimum generation levels as set out in CC.S1.1.3.8?

  Siemens response: Most probably yes while the load definition in CC.S1.1.3.8 is not suitable and not related to the overall definition of Minimum Generation in this document

- CC8.8.6.1 in summary details that all CDGU's shall be capable of staying connected to the system and remaining operable within the frequency ranges and time periods specified in the table provided. Is the ability to stay within these time periods for these frequencies affected by the machine running at minimum generation levels?

  Siemens response: No

- CC8.8.7.3 Frequency sensitivity mode (FSM) in summary states that all generators will be required to be fitted with fast acting proportional frequency control devices (governors) and control devices to provide frequency response under normal operation. Will available speed governors become affected by operating at minimum generation to the point where they cannot satisfy the SONI response requirements for minimum generation?

  Siemens response: No, as long as Minimum Generation is defined above the Inlet Guide Vanes (IGV) load of the GT

- CC8.8.7.3.3 states that in the event of a frequency step change each generator unit shall be capable of activating full and stable active power frequency response in accordance with the performance characteristics stated. These conditions are in relation to max capacity of the unit however can these conditions still be met when the generator is in the condition of minimum generation operation?

Siemens response: Yes

- CC8.8.7.5 With regard to the capability to take part in island operation, In the event of a power surplus, generators are required to be capable of reducing Active Power output from a previous operating point to any new operating point within their Reactive Power capability. In that regard generator units will be capable of reducing Active Power output to Minimum Generation. Can the OEM's units perform this duty in an island operation achieving the minimum generation requirements in place?

  Siemens response: Yes, as long as Minimum Generation is defined above IGV load of the GT

Response to system fault

- CC6.4.2, The basic requirement in all cases is that users' arrangements for protection at the connection point, including types of equipment and protection settings must be compatible with standard practices on the transmission system from time to time, whilst maintaining necessary discrimination and coordination protection. Is meeting this criterion for coordination and discrimination affected by the generator units operating at the minimum generation values set out by SONI?

  Siemens response: The protection settings subject to detail design, for a particular site. The time and current grading plans of the HV-system are typically not dependent from the generator load.

- CC.S1.1.6.2 states that "Unless otherwise agreed, the fault clearance times specified in the connection agreement shall not be greater than (a) 100ms at 275kV and (b) 120ms at 110kV". Could this criterion be met at minimum generation considering reduced fault current values with reduced output power for single and 3 phase faults?

  Siemens response: Considering the HV-circuit breaker opening time is short enough (e.g. 50ms or less for 275kV), the mentioned fault clearance times can be met.

Reactive power supply

- CCS1.1.3.2 States that generating units shall have specified minimum reactive power capability. These are seen below. Is the ability to satisfy these criteria possible with consideration of SONI's condition of minimum generation operation?

  (i) rated power factor (lagging) = 0.8

  (ii) rated power factor (leading) = 0.95

  (iii) short circuit ratio not less than 0.5

  Siemens response: No general response for existing units possible, need to be checked project specific.

- CC.S1.1.3.3 sets out parameters relating to generating units' continuous control of voltage within its reactive power capability limits. The minimum reactive power is defined in the characteristic (graphical representation) provided within that section and the relevant voltage limits are relative to those specified in section CC5.4. Part C of this subsection specifically states that "With regard to Reactive Power below Registered Capacity, when operating at an Active Power output below Registered Capacity, the Generating Unit shall be capable of operating at every possible operating point in the Reactive Power capability of the Generating Unit, at least down to Minimum Generation". Can the OEM's products satisfy these conditions in consideration of SONI's condition of minimum generation operation?

Siemens response: Generally, the synchronous generators can be operated according to its specific reactive capability diagram (provided for the generator terminal voltage).

- The topic CC.S1.1.3.3 provides a characteristic for the connection point at 110kV or 275kV level, for which the GSUT and other site specific elements between the generator and the connection point (e.g. HV-cable, overhead lines) have to be considered.

  Other notable items in subsection CC.S1.1.3.3 which will be relevant in relation to the generators running at minimum generation are below. Can the OEM's products satisfy these conditions in consideration of SONI's condition of minimum generation operation?

  (b)The Generating Unit shall be capable of moving to any operating point within the profiles above inappropriate timescales to target values requested by the TSO

  Siemens response – Confirmed.

- (d) Generating Units shall fulfil the following requirements relating to robustness:
- (i) power oscillations

  Siemens response: remark to (d),(i): in general, covered depending on PSS (stabilizer), min. / max. operating points of the machine to be considered. SE response -Rev1: PSS is provided.

- (ii) Generating units shall be capable of remaining connected to the power system without power reduction as long as voltage and frequency remain within the limits specified in CC5

  Siemens response - Based on minimum generation operation (Minimum Generation is defined above IGV load of the GT) - Confirmed.

- (iii) Generating units shall be capable of remaining connected to the power system during single-phase or three-phase auto –reclosures on meshed network lines, if applicable to which they are connected. The details of that capability shall be subject to coordination and agreements on protection schemes and settings as referred to in CC6.4.4

  Siemens response: remark to (d),(iii): Three phase auto-reclosures have to be excluded at the line to the power plant as per common practice.

Voltage stability

- CC.S1.1.3.3 (e) states that generating units shall fulfil specific requirements relating to voltage stability at varied transmission voltages. In reviewing the voltage and time of operation referenced in the table can voltage (p.u) be achieved at SONI's minimum generation considering voltage output will reduce?

  Siemens response: The permissible voltage range of the generator itself is normally 0.95 p.u. -1.05 p.u. A wider voltage range at the connection point shall be ensured by the OLTC of the GSUT.

- CC.S1.1.3.3 (f) (ii) states "the agreement referred to in CC.S1.1.3.3 (a) (Generating units minimum reactive power capability characteristic) shall cover the specifications and performance of an automatic voltage regulator (AVR) with regard to steady-state and transient voltage control and the specifications and performance of the excitation control system. Are the OEM AVR's still suitable for satisfying these criteria at SONI's minimum generation?

  (ii) the agreement referred to in (a) shall cover the specifications and performance of an automatic voltage regulator (AVR) with regard to steady-state and transient voltage control and the specifications and performance of the excitation control system.

Siemens response – Rev1: The voltage control system of the generator controls the generator terminal voltage within +/-5% of its rated value. The HV grid voltage or reactive power as per given Voltage control instruction for the grid connection point can be suited by the (manual) stepping of the OLTC tapping position of the GSUT.)

- The latter shall include:

  - bandwidth limitation of the output signal to ensure the highest frequency of response cannot excite torsional oscillations on other Generating Units connected to the Power System;

  Siemens response – Rev1: The output signal of the AVR is limited to maximum and minimum output values (usually positive and negative ceiling voltage, calculated project-specifically))

- an underexcitation limiter to prevent the AVR from reducing the Generation Units excitation to a level which would endanger synchronous stability;

  Siemens response – Confirmed

- an overexcitation limiter to ensure that the alternator excitation is not limited to less than the maximum value that can be achieved whilst ensuring that the Generating Unit is operating within its design limits;

  Siemens response – Confirmed

- a stator current limiter;

  Siemens response – Confirmed

  and

- a power system stabiliser function to attenuate power oscillations, this will be assessed by the TSO on a case-by-case basis.

  Siemens response –confirmed

Control arrangements

- CC.S1.1.5.1 Each Generating Unit must be capable, in accordance with CC.S1.1.5.2 and CC.S1.1.5.3, of contributing appropriately to frequency and voltage control by continuous modulation of active power and reactive power supplied to the transmission system. Is this achievable with the generator running at minimum generation levels set out by SONI for the OEM's machines?

  Siemens response: No general response for existing units possible, need to be checked project specific.

- CC.S1.1.5.3 The TSO may specify in the relevant connection agreement that a continuously acting fast response automatic excitation control system is required to control the generator voltage without instability over the entire operating range of the generating unit or power station. Do automatic excitation control systems for generator voltage struggle at levels at minimum generation levels set out by SONI?

  Siemens response: No general response for existing units possible, need to be checked project specific.

Appendix B. Mitsubishi Power generator-turbines data

This section presents the obtained Mitsubishi Power generator-turbine data regarding emissions and efficiency compliance as prescribed in the IED/BAT documents. The information is obtained through the market research studies including the OEMs consultations.

Table B 1 Mitsubishi Simple and Combined Cycle gas turbines specifications

Turbine ID	Power (MW)	Efficiency (%)	CO emissions	NOx emissions*	Turn - down load	1 x gas turbine CCGT		2 x gas turbine CCGT	
						Power (MW)	Efficiency (%)	Power (MW)	Efficiency (%)
H-100	116.45	38.3	9 ppm	9 ppm	50%	171	57.4	346	58.0
M701DA	144.1	34.8	30 ppm	25 ppm	75 %	212.5	51.4	426.6	51.6
M701G	334	39.5	10 ppm	25 ppm	60 %	498	59.3	999.4	59.5
M701F	385	41.9	10 ppm	25 ppm	45 %	566	62.0	1,135	62.2
M701J	478	42.3	9 ppm	25 ppm	50 %	701	62.3		
M701JAC	448	44.0	9 ppm	25 ppm	50 %	650	>64.0		
M701JAC	574	43.4	9 ppm	25 ppm	50 %	840	>64.0		

The following is the Questionnaire sent to Mitsubishi regarding the IED/BAT compliance and the responses from Mitsubishi.

- Can you meet the NOx and CO emission limits specified in the BAT documents with or without applying the mitigation/modification techniques?

  MHI response: Yes.

- Can you meet the NOx and CO emission limits specified in the BAT documents above the minimum generation load level specified in Grid Code documents, with or without applying the mitigation/modification techniques?

  MHI response: Yes, with minimum generation load above 50%.

- Can you meet the NOx and CO emission limits specified in the BAT document across the entire operating load range (the load range for which the plant is designed to operate safely) with or without applying the mitigation/modification techniques?

  MHI response: Yes.

- What is the lowest load level at which you can meet the NOx and CO emission limits specified in the BAT documents?

  MHI response: Approx 50%.

- Have you established methods of reducing minimum load levels on generators to achieve compliance with emission limits at lower load levels, beyond the conventional capability of your plant?

MHI response: Yes, by installing catalysts prior discharging to stack.

- Can you meet the net electrical efficiency specified in the BAT documents?

  MHI response: Yes, as per BAT: with natural gas firing, 36% for open cycle and 53% for combined cycle. Please be aware that unrestricted operation on open cycle units requires <550 gCO_2/kWh: some gas turbines would need blend of natural gas with non-fossil fuel (H_2, bio-gas, ammonia.)

- What is the lowest load the unit can run at and still meet the net electrical efficiency specified in the BAT documents?

  MHI response: 40 ÷ 70% depending on gas turbine type.

- How do you interpret BAT requirements in relation to CCGT generators for load levels lower than rated and lower than 70%?

  MHI response: BAT emission limits apply only above 70% load; below this load, domestic legislation and construction/environmental permit will prevail.

- What techniques do you implement to meet the BAT requirements for lower load levels?

  MHI response: Use of catalysts in the heat recovery steam generators.

- If a Gas Turbine is part of a Combined Cycle Unit, would it have the same emissions as if it were an open cycle unit? Yes. This is not when considering the CCGT as a whole, but rather only giving consideration to the Gas Turbine. Is the minimum generation level of the GT impacted by being part of a CCGT?

  MHI response: Yes, if catalysts are installed in the heat recovery steam generator

Appendix C. General Electric generator-turbines data

This section presents the obtained GE generator-turbine data regarding emissions and efficiency compliance as prescribed in the IED/BAT documents. The information is obtained through the market research studies including the OEMs consultations.

Table C 1 GE Simple and Combined Cycle gas turbines specifications

Turbine ID	Power (MW)	Efficiency (%)	1 x gas turbine CCGT			2 x gas turbine CCGT		
			Power (MW)	Efficiency	Plant turn down load	Power (MW)	Efficiency	Plant turn down load
9HA.01	448	42.9%	680	63.7%	33.0%	1,363	63.8%	15.0%
9HA.02	571	44.0%	838	64.1%	33.0%	1,680	64.3%	15.0%
9F.04	288	38.7%	443	60.2%	48.0%	889	60.4%	22.0%
9E.03	132	34.3%	205	53.1%	45.0%	412	53.5%	22.0%
9E.04	147	36.9%	218	55.0%	46.0%	439	55.3%	22.0%
GT13E2-190	195	38.5%	280	55.3%	28.0%	563	55.6%	14.0%
GT13E2-210	210	38.0%	305	55.1%	40.0%	613	55.5%	19.0%
6B.03	45	33.4%	70	51.9%	41.0%	141	52.4%	20.0%
LMS100 PA+	113.0	43.0%	134.5	51.4%	13.0%	269.7	51.5%	6.0%
LMS100 PB+	106.5	42.6%	127.0	51.0%	13.0%	255	51.4%	6.0%
LM6000 PC	46.6	40.0%	60.3	51.9%	19.0%	121.1	52.2%	19.0%
LM6000 PF+	53.9	40.8%	72.4	55.3%	37.0%	145.6	55.6%	18.0%
LM2500 DLE	22.9	35.7%	33.5	52.4%	34.0%	67.7	52.9%	17.0%
LM2500+ DLE	31.4	38.1%	44.0	54.6%	35.0%	88.8	53.4%	18.0%
LM2500+G4 DLE	34.1	38.7%	48.0	54.6%	35.0%	96.5	54.9%	18.0%
TM2500	34.6	34.9%	49.2	49.7%	35.0%	99.2	50.1%	35.0%