RoCoF
An independent analysis on the ability of Generators to ride through Rate of Change of Frequency values up to 2Hz/s.

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By order of EirGrid

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1 EXECUTIVE SUMMARY

EirGrid asked DNV KEMA to perform a study on behalf of the Transmission System Operators (TSOs), EirGrid and SONI, in Ireland and Northern Ireland to identify limitations for the current energy providers to meet Rate of Change of Frequency (RoCoF) values of up to 2 Hz/s. RoCoF values introduced and analysed in this study are 0.5, 1, 1.5 and 2 Hz/s.

The analyses show that a RoCoF of up to a 1 Hz/s for all generators analysed in this report could achieve compliance, apart from a leading power factor. Though there are signs of instability for 1.5 Hz/s and 2 Hz/s. In general the study shows that a 2 Hz/s RoCoF value is not achievable with the current generation sets, apart from the small OCGT and the salient-pole Hydro machine as exceptions. 1.5 Hz/s can only be achieved by some generators and not for a leading power factor. 1 Hz/s shows theoretical compliance, looking at a 500 ms rolling window, though not for leading power factor. Were a RoCoF value of 1 Hz/s required to be tolerated by the generators, to avoid instability or adverse effects on the generator or its operational performance good advice would be to restrict operational modes (i.e. leading power factor operation) for generators that may be at risk.

In terms of mechanical stress, torque values of the machines do increase with the higher RoCoF values. Calculations show a maximum torque around 140 % of the nominal rated value of the machine for a 0.5 Hz/s RoCoF. The maximum torque for a RoCoF of 1 Hz/s is around 160 %. Generators in general are capable of handling (to some extent) short circuits where torque values may typically vary from 400 % to 600 % of the nominal value. Considering those aspects, the torque associated with the investigated RoCoF values do not introduce an immediate[1] risk to the generator. For example the Ireland grid code specifies fault ride-through criteria regarding voltage dip magnitude. The present generators in Ireland have to be compliant with these requirements. This compliance could result in mechanical stress values of approx. 300 % to 400 % of the nominal rated value, above those estimated for the higher RoCoF values investigated.

The two tables on the next page show the results from the theoretical model used in this study to identify the stability of the synchronous machines. The first table present the analyses results for a rolling 500 ms window. Because a fixed rolling time window results in different absolute frequency drops for differed RoCoF values, additional calculations were preformed for a total frequency drop of 1 Hz. A summary of these results is given in the second table.

[1] It is possible that the wear and tear of the machine might be affected to some extent. In addition, investigation is needed to the eigenvalue of the machine and the frequency of the torque swing induced.

A summary of the analyses results in Ireland and Northern Ireland for the investigated RoCoF values based on a rolling 500ms time window are given below.

Generation Units Result Summary							500 ms window
Generator Set	**Unit Size**	**Inertia Constant H**	**Xd**	**Terminal Voltage**	**Stable**	**during**	**RoCoF**
[name]	[MW]	[Sec.]	[p.u.]	[kV]	[@ 0.5 Hz/s]	[@ 1.0 Hz/s]	[@ 2.0 Hz/s]
CCGT Single-shaft	400	5.5	1.9	20	Y	Y*	N
CCGT Dual-Shaft	260	6	2.3	17	Y	Y*	N
CCGT Dual-Shaft	140	9	2.1	17	Y	Y*	N
Steam Thermal (Reheat)	300	5	1.7	17	Y	Y*	N**
Steam Thermal (Once Through)	250	4.5	2.3	20	Y	Y*	N
Steam Thermal (Fluidized bed peat)	150	8	2.2	11	Y	Y*	N
OCGT	50	1.5	2.9	11	Y	Y*	Y*
Salient-pole Hydro	30	2.7	1.4	11	Y	Y	Y

A summary of the analyses results in Ireland and Northern Ireland for the investigated RoCoF values based on a total frequency drop of 1Hz are given below.

Generation Units Result Summary					1 Hz total frequency drop			
Generator Set	**Unit Size**	**Inertia Constant H**	**Xd**	Terminal Voltage	**Stable**	**during**	**RoCoF**	
[name]	[MW]	[Sec.]	[p.u.]	[kV]	[@ 0.5 Hz/s]	[@ 1.0 Hz/s]	[@ 1.5 Hz/s]	[@ 2.0Hz/s]
CCGT Single-shaft	400	5.5	1.9	20	Y	Y*	Y*	N
CCGT Dual-Shaft	260	6	2.3	17	Y	N	N	N
CCGT Dual-Shaft	140	9	2.1	17	Y	N	N	N
Steam Thermal (Reheat)	300	5	1.7	17	Y	Y*	Y*	N**
Steam Thermal (Once Through)	250	4.5	2.3	20	Y*	Y*	N	N
Steam Thermal (Fluidized bed peat)	150	8	2.2	11	Y*	N	N	N
OCGT	50	1.5	2.9	11	Y*	Y*	Y*	Y*
Salient-pole Hydro	30	2.7	1.4	11	Y	Y	Y	Y

<u>The tables give a general overview of the findings where:</u>

Y is used to indicate stable operation

Y* is used where a pole slip is only observed for a 0.93 leading power factor operation mode;

N is used when a pole slip is also observed for power factors of 1 unity or/and 0.85 lag;

N** is used when no pole slip is observed for power factors of 1 unity or/and 0.85 lag but negative power generation is detected.

The calculations for this study are performed using numerical analysis in a semi simplified mathematical model of a synchronous machine. The chosen generator characteristics used in the model were provided by the TSOs, capturing a large part of the typical asset parameters found in Ireland and Northern Ireland. In the model, the synchronous machine is attached to an infinite bus. First the RoCoF was used to initiate a linear frequency drop of the bus over a 500 ms period. To be able to observe the effect of an equal absolute frequency drop of 1 Hz for different RoCoF values, additional analyses were preformed

Results presented in this document are not an exact outcome but are a first reasonable estimate to give guidance of the main implications for the provision of higher RoCoF values proposed by EirGrid and SONI.

2 INTRODUCTION

The Government targets for Ireland and the ambition for Northern Ireland (NI) are to have 40 % renewable energy penetration by 2020. EirGrid and SONI have put in place a multi-year, multi-stakeholder programme of work, “Delivering a Secure Sustainable System” (DS3), to enable efficient, reliable and secure power system operation. Through the DS3 system services review, the challenges to ensure sufficient and appropriate system services have been identified. In detailed studies and technical analysis the TSOs established the need for additional system services, and also proposed new products to address the emerging challenges associated with achieving the governments’ renewable energy policy objectives and ambitions.

Renewable energy has an impact on the inertia of the electrical network which in turn impacts the potential rate of change of frequency to network events such as short circuits, large step load changes and loss of generation. EirGrid and SONI estimated that having 40 % of renewable energy by 2020 will have a significant impact on the Rate of Change of Frequency (RoCoF) experienced in the network.

EirGrid has asked DNV KEMA, in this context, to identify what the impact for the current generators would be if the present RoCoF capability requirement were to be changed from 0.5 Hz/s to 1 Hz/s, to 1.5 Hz/s, or to 2 Hz/s.

This report gives a general view of the impact on energy generating assets in Ireland and Northern Ireland of increased RoCoF values. It shows in which situations generators will become unstable during a higher RoCoF value as opposed to the present limit stated in the grid code.

RoCoF protection was introduced for anti-islanding for embedded generation. The protection aims to detect severe issues in the electricity grid. The speed of change of the frequency is used for the event of serious issues in the electrical network and to disconnect the generator from the grid in such an event. Anti-islanding prevents small generators being left to supply local loads with the additional loss of correct reference for the protection equipment. Small generators (<50 MW) have RoCoF protection, currently set at 0.5 Hz/s (Ireland) and 0.4 Hz/s (Northern Ireland) in general. Some of these generators are equipped with vector shift protection. Lager generators may not have vector shift or RoCoF protection and in general, opposed to the small embedded generators, should stay connected as long as possible.

To allow for a higher RoCoF value it is important to have an indication if the existing conventional generators connected to the electricity network can cope with the modifications in the grid code proposed.

The speed of frequency changes at high renewable penetration show higher RoCoF values than presently anticipated for, hence, energy generation units could be disconnected from the grid resulting in a brown out or black out if other measures are not taken, and, in a worst case, the assets could be damaged in the event of a pole slip. Making sure that the assets can cope with the faster allowance of frequency rise or drop, together with changing the RoCoF/vector shift protection settings, is therefore one way of improving the Network stability.

Results presented in this document are not an exact outcome but are a first reasonable estimate of the main implications for the provision of higher RoCoF values proposed by EirGrid and SONI. Without detailed investigations on each specific generation asset it is not possible to make a final statement on the compliance of each asset. However, DNV KEMA believes that this report gives clear and useful insight of the implications for the generators examined here of the increased RoCoF values studied.

3 PROJECT APPROACH AND METHODOLOGY

DNV KEMA used their extensive knowledge and expertise to produce a method to identify limitations for the current energy providers regarding the higher RoCoF values proposed for Ireland and Northern Ireland not looking at the protection devices themselves. The project focus was targeted around synchronous generators and their capability. To be able to explain the behaviour of synchronous generators for different RoCoF values, proof was needed in the form of calculations. DNV KEMA designed a semi simplified mathematical calculation model of a synchronous machine using a numerical analysis. With this model the effects on generators can be calculated when changing the RoCoF value.

In the model the machine is attached to an infinite bus. The frequency deviation is initiated using the different RoCoF values creating a linear frequency drop. It was ensured that independent of the RoCoF value, the total drop in frequency was 1 Hz. This means that for a 0.5 Hz/s RoCoF the duration of the frequency drop is 2 seconds as opposed to a 2 Hz/s RoCoF where the duration is 0.5 seconds to reach a 1 Hz drop. The total frequency drop is based on the system boundaries for normal operation. Load shedding in Ireland and Northern Ireland starts at 48.85 Hz. Therefore the TSO will aim to keep the frequency at least above 49 Hz for a loss of the largest in feed.

DNV KEMA also investigated the effects of RoCoF values during a shorter timeframe and results are presented for a 500 ms window in the appendix to this report. In addition a short comparison was carried out for higher RoCoF values combined with a shorter timeframe keeping within a 1 Hz drop. Although out of scope for this study, some inside information on these additional investigations is provided in the conclusions to this report.

Our approach may paint a more pessimistic picture than found in reality as the model used does not include speed governor action or system damping effects. A full PSSE model could be more accurate, for example, and if designed correctly, able to capture the instability phenomena should they have the potential to occur. The numerical analysis used here, though, reveals a clear picture of the ability of generators with the given parameters in this report to ride-through the higher RoCoF values proposed. That said, it should be noted that the RoCoF investigated here is more related to mechanical phenomena as opposed to electrical dynamic effects. The mechanical phenomena occurs much slower in time as opposed to the electrical phenomena. As an important result, the electrical dynamic effects will have already happened in time before the frequency starts dropping. This means that the numerical analysis used in this report is appropriate for analysing RoCoF implications.

Having designed the generic model, representative generator sets for Ireland and Northern Ireland were identified together with the possible operating and technical values required for the model input. Representative generator model details were checked, altered and confirmed by EirGrid and SONI. A summary of the agreed generator details is given here.

Generation Units				
Generator Set	**Unit Size**	**Inertia Constant H**	**Terminal Voltage**	**Xd**
[name]	[MW]	[Sec.]	[kV]	[p.u.]
CCGT Single-shaft	400	5.5	20	1.9
CCGT Dual-Shaft	260	6	17	2.3
CCGT Dual-Shaft	140	9	17	2.1
Steam Thermal (Reheat)	300	5	17	1.7
Steam Thermal (Once Through)	250	4.5	20	2.3
Steam Thermal (Fluidized bed peat)	150	8	11	2.2
OCGT	50	1.5	11	2.9
Salient-pole Hydro	30	2.7	11	1.4

The representative generator list was then used for stability calculations, power swing and accompanied mechanical stress values.

Operational parameters introduced within the mathematical model to simulate the behaviour of each generator set are:

- Power factors: 0.85 lag, 1 unity, 0.93 lead
- Load factors: 80 %, 100 %.

In the approach looking at the protection devices themselves and their implications are left out of scope.

4 RESULTS

This chapter provides the typical outcomes of the studies carried out. The complete overview can be found in the appendix to this report. The total results for each individual set of operational parameters for each individual generation set are listed there. This chapter gives a description and explanation of the typical findings throughout the analyses.

Together with the operational parameters, the following RoCoF values are introduced within the mathematical model to simulate the behaviour of each generator, namely:

- RoCoF: -0.5 Hz/s, -1 Hz/s, -1.5 Hz/s and -2 Hz/s.

The calculations show that changing the RoCoF setting has a large impact on the synchronous machine. Also it showed that there is not one specific parameter that solely determines the capability of the machine. Inertia, number of poles, power factor (cos φ) and load all have an influence on the RoCoF capability. Inertia and poles are fixed parameters characteristics of the machine as opposed to the power factor and load, which can be controlled by the excitation and the governor.

As an example looking at a full 1 Hz drop the CCGT dual shaft generators show -capability issues of handling a 1 Hz/s RoCoF value. Though the single shaft CCGT is capable of coping with the 1 Hz/s RoCoF. Analysing these outcomes identifies that the single shaft CCGT has the capability because of the lower inertia or/and synchronous reactance value. If one of those values in the Dual shaft machines is altered the capability changes.

In general, increasing RoCoF values show the following effects:

- Torque swings
- Pole slip
- Momentary reverse power.

DNV KEMA calculated the technical capability of the agreed synchronous generator characteristics to various RoCoF values. The results are summarised below.

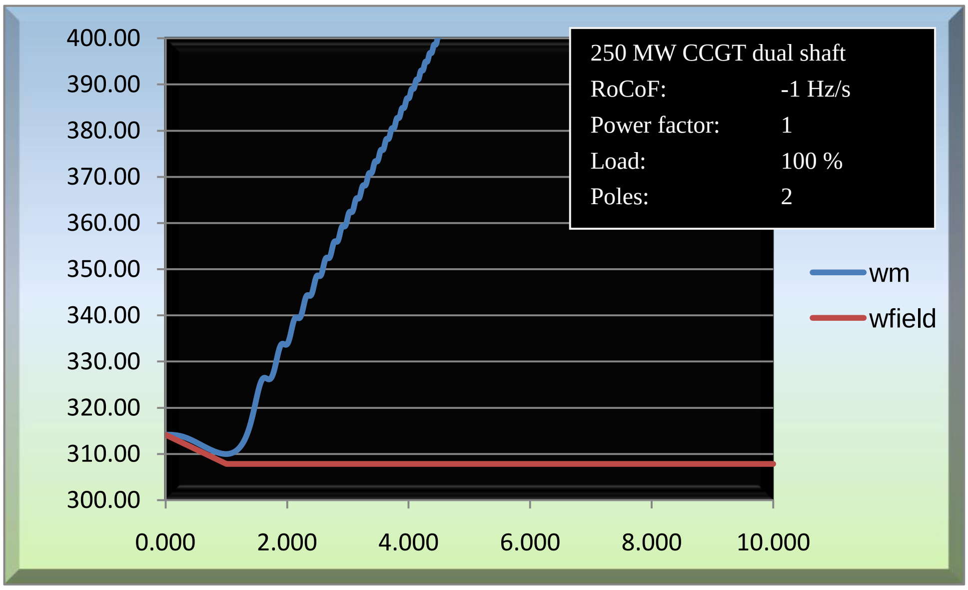
Generation Units Result Summary					1 Hz total frequency drop			
Generator Set	**Unit Size**	**Inertia Constant H**	**Xd**	Terminal Voltage	**Stable during RoCoF**			
[name]	[MW]	[Sec.]	[p.u.]	[kV]	[@ 0.5 Hz/s]	[@ 1.0 Hz/s]	[@ 1.5 Hz/s]	[@ 2.0Hz/s]
CCGT Single-shaft	400	5.5	1.9	20	Y	Y*	Y*	N
CCGT Dual-Shaft	260	6	2.3	17	Y	N	N	N
CCGT Dual-Shaft	140	9	2.1	17	Y	N	N	N
Steam Thermal (Reheat)	300	5	1.7	17	Y	Y*	Y*	N**
Steam Thermal (Once Through)	250	4.5	2.3	20	Y*	Y*	N	N
Steam Thermal (Fluidized bed peat)	150	8	2.2	11	Y*	N	N	N
OCGT	50	1.5	2.9	11	Y*	Y*	Y*	Y*
Salient-pole Hydro	30	2.7	1.4	11	Y	Y	Y	Y

The table gives a general overview of the findings where:
Y is used for stable operation;
Y* is used where a pole slip is only observed for a 0.93 leading power factor operation mode;
N is used when a pole slip is also observed for power factors of 1 unity or/and 0.85 lag;
N** is used when no pole slip is observed for power factors of 1 unity or/and 0.85 lag but negative power generation is detected.
Detailed results for every value can be found in the appendix to this report.

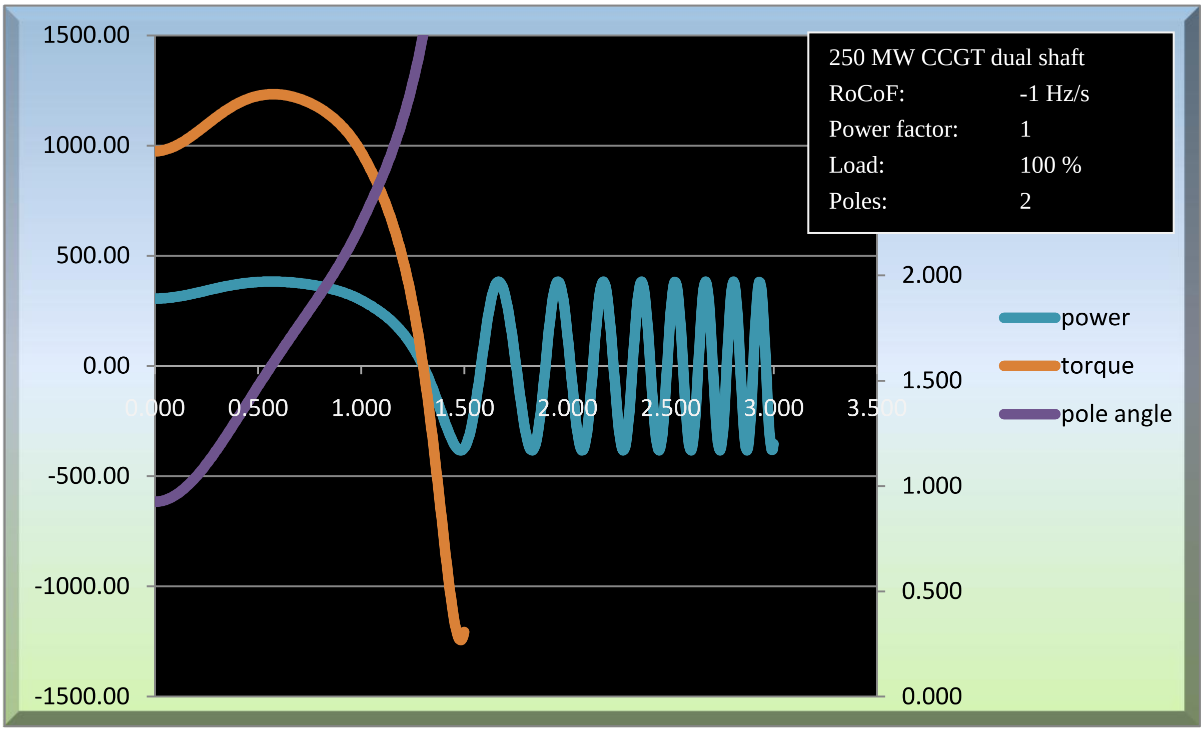
4.1 Instability

When the machine is unable to follow the fast reduction in speed, the rotor loses its opposed force from the electricity grid and will therefore speed up. The fast change of the stator field frequency results here in an inadequate rotor reaction. In other words, the rotor is not able to follow the speed change of the stator field frequency. This reflects back to the amount of attractive force between both stator and rotor fields combined with inertia of the machine. The attractive force between both fields can be controlled by changing the power factor or/and the load of the machine. This explains why different operating parameters could make the unit capable or not capable of tolerating a certain RoCoF value.

In the event that the combination of the attractive force and the inertia is not efficient to keep the rotor field in control, the machine will pole slip. This will most likely severely damage the machine. Our developed model shows the following typical outcome at the event of a pole slip.



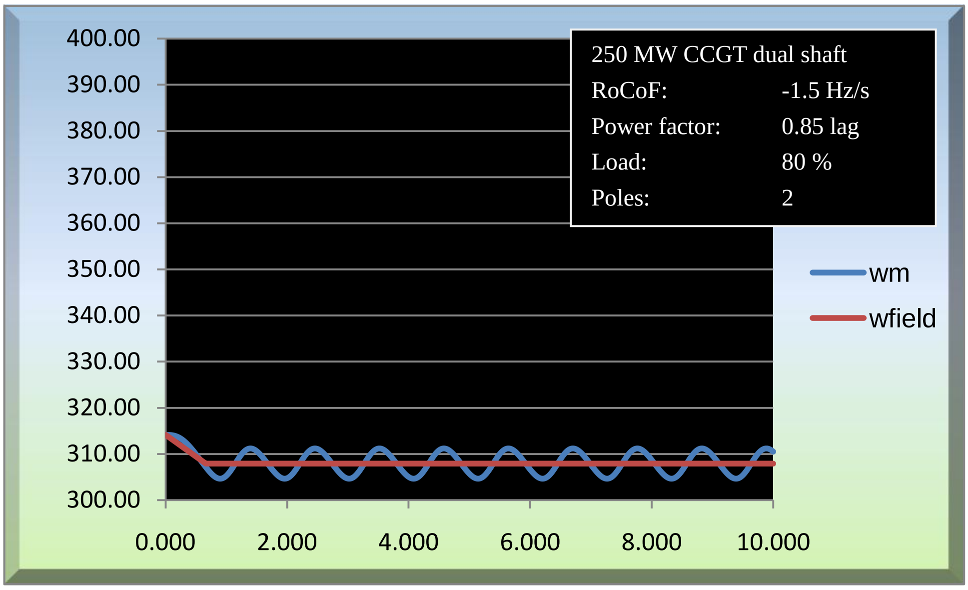
The figure above is for a 2 pole machine. It can be observed that the Stator field (red line) comes down starting at 314 rad/s. The blue line (rotor field) tries to follow but the machine loses it synchronism. This results in a pole slip and the magnetic force of the stator is not able to attract the rotor field anymore. Since power is still applied to the rotor the machine will speed up as there is no opposing force anymore. At that moment the over speed protection will engage but damage may already be done.



The graph above shows the torque, power and pole angle. The pole angle is between the stator field and the rotor field. The machine will lose its synchronism if the angle becomes greater than 90 degrees or ½π rad. This graph enables observation of the stability in more detail. Looking at the pole angle (purple line) synchronism is lost after approx. 520 ms. The torque shows at that period a peak and then drops significantly. The generator output power curve (blue line) also drops and is oscillating under and above the zero line. The latter indicates that the synchronous machine on average does not produce power anymore, hence the rotor is not able to induce its power into the stator. Instead the power is used to speeds up the rotor.

4.2 Reverse power

At the event of generating reverse power the machine does not necessarily pole slip but generates for short moments in time negative power. In other words it consumes power in short periods of time. When a generator is consuming active power it operates like a motor. The next graph shows that the rotor keeps in check[2] with the reduced stator (electrical) field frequency.



At the same time the synchronous machine is acting as a motor in short periods of time, shown in the following graph.

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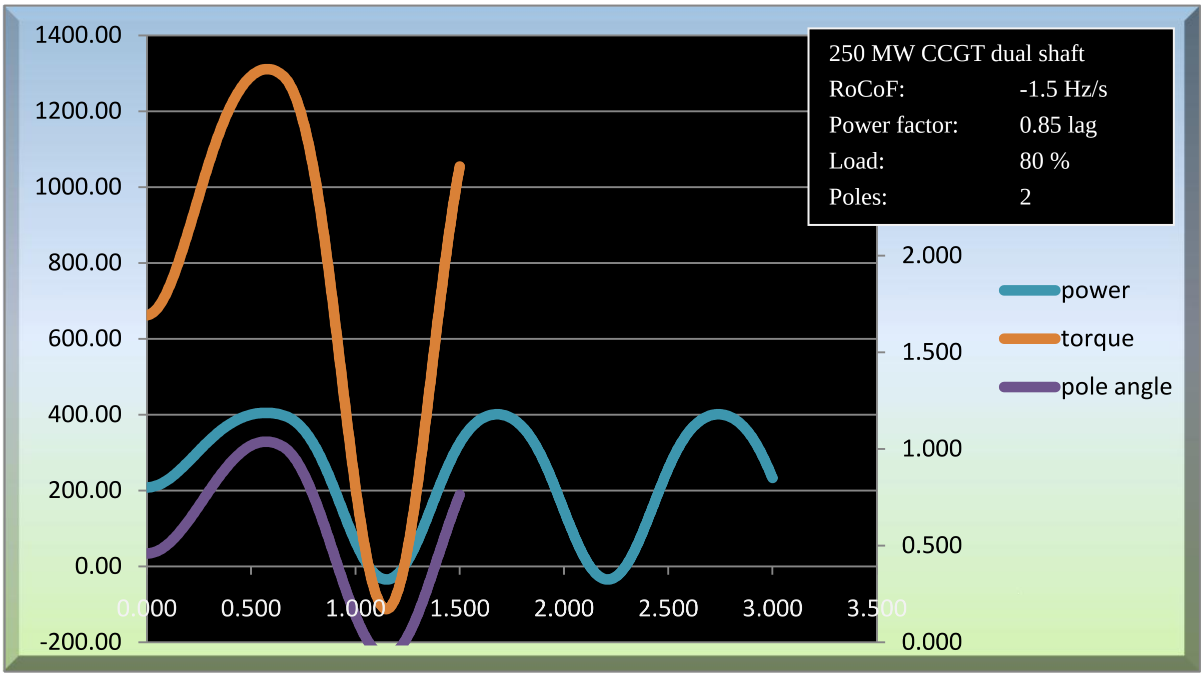
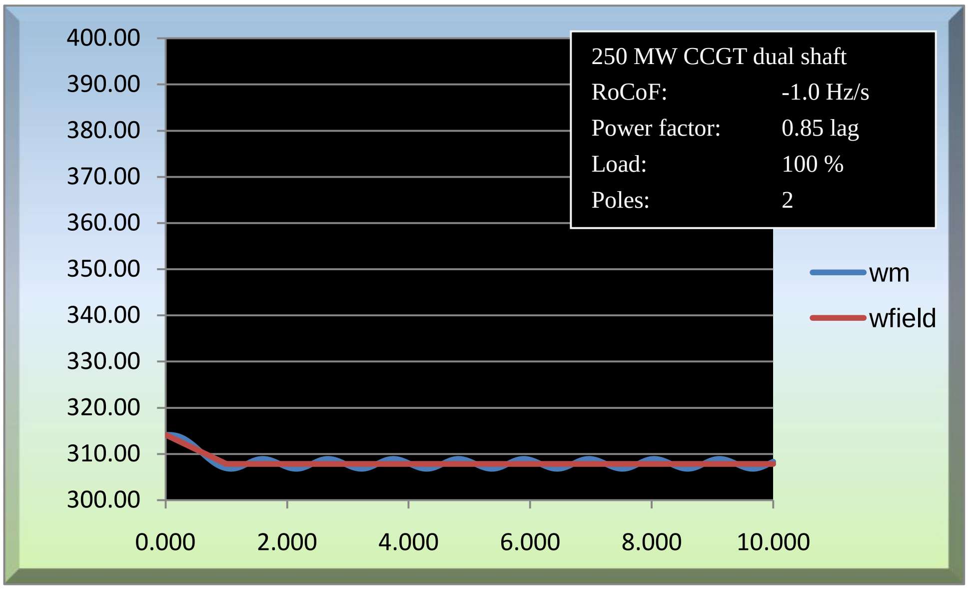
[2] Because the model is simplified, there is no damping in the oscillation around the electrical field speed. In reality this will flatten-out to a constant value.



Following the frequency change the accompanied torque swings, due to the inertia and current field behaviour, could be such that the power output of the generator can be momentarily reversed (blue line). The generator is protected against Motor operation by the reverse power protection. If triggered it will shutdown the unit. The directional active overpower protection is triggered depending on the net amount of power generation. A normal (32P) setting on the protection relays is a threshold of 5 % of nominal apparent power (Sn) with a delay of a few seconds. To know if a certain unit will stay connected when reverse power is observed, a detailed bespoke simulation is necessary including all machine and protections specifics. On the graph shown here (above) it is unlikely that the directional active overpower protection will disconnect the unit from the grid.

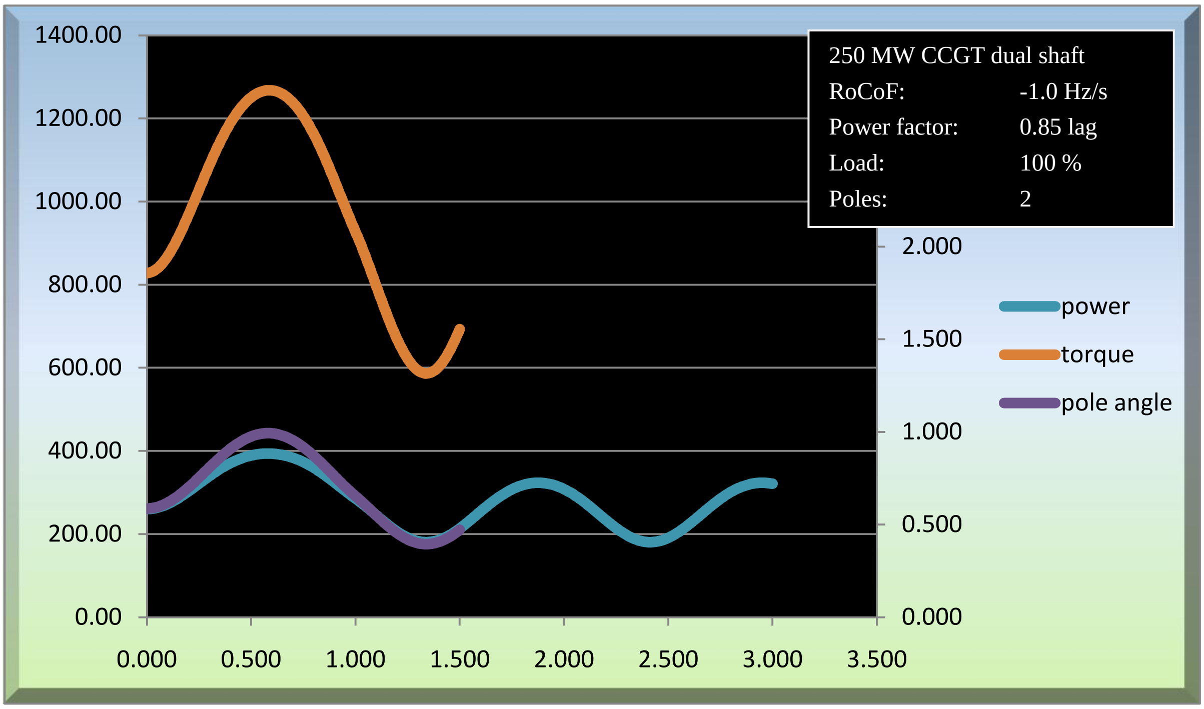
4.3 Stable operation

When the machine shows stable operation, our model typically gives the following graphs.



The above graph displays the stator frequency drop in rad/s (red line). The rotor field (blue line) wants at first to stay at the same speed and after approx. 300 ms the stator frequency is followed. The rotor frequency keeps dropping a bit while the stator frequency is stabilized. Soon after though, the rotor frequency speeds up a little and keeps following the new stator frequency[3].

[3] In the graph a little ripple is shown up till 10 seconds with the same amplitude. This is because of the model used as no damping. In reality this will flatten-out to a constant value.

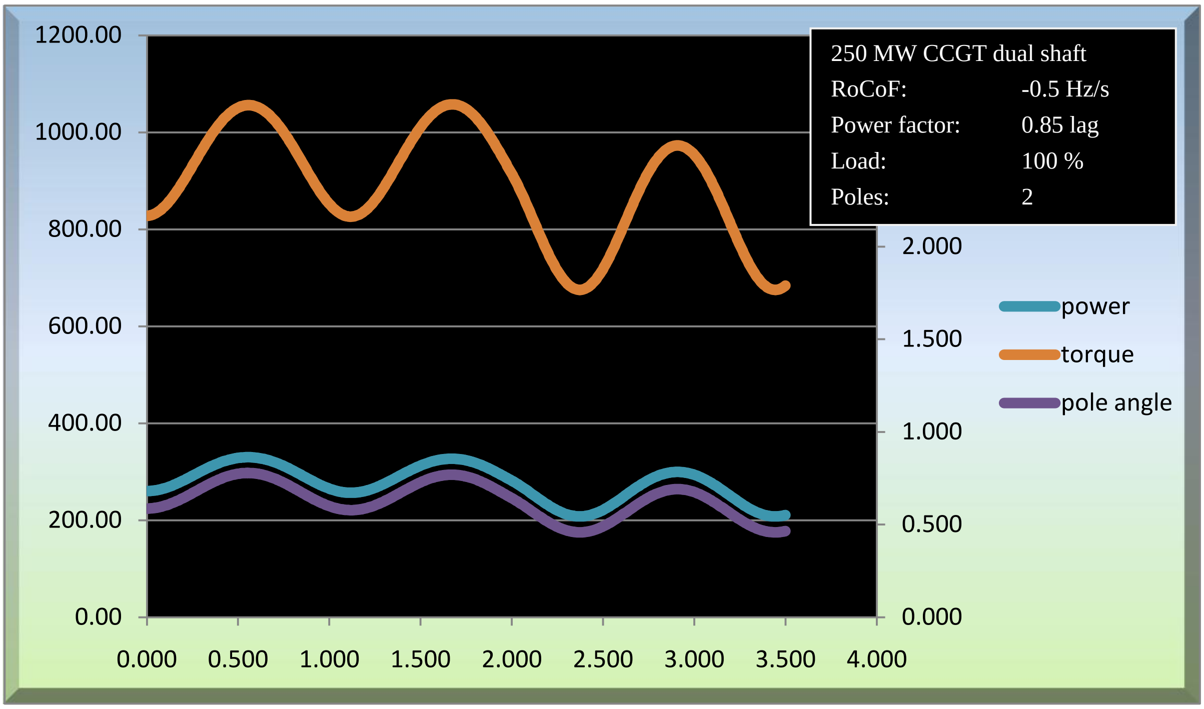


In the graph above the torque, power and pole angle are illustrated. The pole angle stays well within 90 degrees or ½π rad. Now the torque can be observed showing no negative value. Note that this results in a constant positive power flow through time and not as illustrated, this is a result of the semi simplified model used.

4.4 Stress on the Synchronous Machine

The torque in all example graphs of chapter 4.1, 4.2 and 4.3 show an increase. The initial torque value, at t = 0 s, is the stable value (not necessary the nominal value of the machine) when no change is made in frequency, load or power factor. As soon the frequency is dropped the angle between the electrical stator field and rotor increases resulting in a greater force between the two magnetic fields, hence more power is momentarily demanded from the machine. The higher the RoCoF, under the same load conditions, the higher the torque increase. Observe the difference in the graph of chapter 4.3 where the torque is displayed for a 1.0 Hz/s RoCoF and the graph in this chapter showing the torque for a -0.5 Hz/s RoCoF.

The generator inertia causes a time delay. This time delay results in a torque swing accompanied by a decrease and increase in rotor speed against the Stator field. It is important to look at the frequency of the torque swing. If this frequency comes close to the eigenvalue of the machine the machine could become unstable due to resonance frequencies.



The -0.5 Hz/s RoCoF shows a maximum of 128 % of the nominal torque value of this synchronous machine as opposed to a 153 % value with -1.0 Hz/s RoCoF. Considering the current Fault Ride-Through requirements in Ireland and Northern Ireland these torque values due to RoCoF are closer to normal operational torque values than torques experienced under short circuit conditions.

Generators remaining synchronised during a fault disturbance which is causing a voltage dip of 95 % (5 % retained) at the HV terminals of the generator transformer delivers significantly more stress. Calculations show that an increase of 300 to 500 % of the nominal torque value of the machine could occur.

Therefore the increase of 153 % in torque of the nominal value will not cause immediate failure of the synchronous machines currently compliant with the Ireland and Northern Ireland grid code. Considerations however may need to be made regarding lifetime reduction/ maintenance intervals. Allowing multiple RoCoF events each year could effect lifetime. Lifetime assessment with regards to allowable RoCoF events are outside the scope of this project.

5 CONCLUSION

The analyses results can be found in the appendix. For the 500 ms rolling time window no unstable operation is found at a RoCoF of 1 Hz/s, apart from a leading power factor operating condition. As a result it seems likely that all generators analysed in this document should be capable of tolerating such an event without obvious negative effects.

During the study it became clear that this becomes different for a longer time window looking at a 1 Hz frequency drop and the higher RoCoF values of 1.5 Hz/s and 2 Hz/s where unstable operation was detected.

In terms of mechanical stress during stable operation, no values that could lead to immediate catastrophic failure were found as result of increased RoCoF values. Therefore DNV KEMA concludes that when a machine is healthy and shows stable operation, the proposed RoCoF values do not pose an immediate threat. Other requirements other than RoCoF in the grid code can pose greater burdens on the synchronous machines. Though without detailed investigations on each specific generation asset it is not possible to make a final statement on the higher RoCoF compliance.

To estimate the stability implications DNV KEMA employed a numerical analysis using a semi simplified mathematical model of a synchronous machine. This approach may paint a more pessimistic picture since it does not include any network damping contributions that occur in reality.

Notwithstanding this, the calculation results determined that the forces during high RoCoF would exceed the maximum steady state torque experienced. The highest value found for a 1 Hz/s RoCoF was 176 %. On average the torque values for a 1 Hz/s RoCoF are around 160 %. However this is considerably less than the estimated 300 % to 400 % torque experienced for voltage dips due to network short circuits on generators as mandated in the Ireland Grid Code and supported by existing experiences to date. To properly estimate the forces during higher RoCoF events detailed analysis maybe required. Though given the stated capability of existing generators to ride through undamaged forces of 300 % to 400 %, immediate failure is not to be expected. However, further investigation is needed to analyse the effect on wear and tear and the accompanied maintenance schedules that may need adjusting due to an increased frequency of higher RoCoF events.

It is important to note that when the duration of the RoCoF event is shortened, higher RoCoF values could be possible. For example, the 260 MW CCGT Dual-shaft machine remains stable for a 250ms RoCoF event of -2.2 Hz/s under the operation conditions of 100 % load and a power factor of 1 unity.

The use of a fully developed dynamic simulation (e.g. PSSE or DigSilent applications) should be more accurate and if designed correctly able to more appropriately predict and estimate the instability phenomena including the damping implications. Within the scope of this project such an exercise was not feasible. However the simplified model used identified a clear general picture of where a generator is likely to become unstable.

Further investigation is required to allow for appropriate protection settings and devices when higher RoCoF values are accepted in the electricity grid, since this is not a straight-forward matter.

6 APPENDIX

6.1 Results

Summary results for the 0.5, 1 and 2 Hz/s RoCoF over a rolling window of 500 ms

Generation Units Result Summary							500 ms window
Generator Set	**Unit Size**	**Inertia Constant H**	**Xd**	**Terminal Voltage**	**Stable**	**during**	**RoCoF**
[name]	[MW]	[Sec.]	[p.u.]	[kV]	[@ .5 Hz/s]	[@ 1 Hz/s]	[@ 2 Hz/s]
CCGT Single-shaft	400	5.5	1.9	20	Y	Y*	N
CCGT Dual-Shaft	260	6	2.3	17	Y	Y*	N
CCGT Dual-Shaft	140	9	2.1	17	Y	Y*	N
Steam Thermal (Reheat)	300	5	1.7	17	Y	Y*	N**
Steam Thermal (Once Through)	250	4.5	2.3	20	Y	Y*	N
Steam Thermal (Fluidized bed peat)	150	8	2.2	11	Y	Y*	N
OCGT	50	1.5	2.9	11	Y	Y*	Y*
Salient-pole Hydro	30	2.7	1.4	11	Y	Y	Y

Summary results for the 0.5, 1, 1.5 and 2 Hz/s RoCoF for a total of 1 Hz frequency drop

Generation Units Result Summary								1 Hz total frequency drop
Generator Set	**Unit Size**	**Inertia Constant H**	**Xd**	Terminal Voltage	**Stable**	**during**	**RoCoF**	
[name]	[MW]	[Sec.]	[p.u.]	[kV]	[@ .5 Hz/s]	[@ 1 Hz/s]	[@ 1.5 Hz/s]	[@ 2 Hz/s]
CCGT Single-shaft	400	5.5	1.9	20	Y	Y*	Y*	N
CCGT Dual-Shaft	260	6	2.3	17	Y	N	N	N
CCGT Dual-Shaft	140	9	2.1	17	Y	N	N	N
Steam Thermal (Reheat)	300	5	1.7	17	Y	Y*	Y*	N**
Steam Thermal (Once Through)	250	4.5	2.3	20	Y*	Y*	N	N
Steam Thermal (Fluidized bed peat)	150	8	2.2	11	Y*	N	N	N
OCGT	50	1.5	2.9	11	Y*	Y*	Y*	Y*
Salient-pole Hydro	30	2.7	1.4	11	Y	Y	Y	Y

The tables give a general overview of the findings where:
Y is used to indicate stable operation
Y* is used where a pole slip is only observed for a 0.93 leading power factor operation mode;
N is used when a pole slip is also observed for power factors of 1 unity or/and 0.85 lag;
N** is used when no pole slip is observed for power factors of 1 unity or/and 0.85 lag but negative power generation is detected.

6.1.1 Results 0.5, 1 and 2 Hz/s over a rolling window of 500 ms

Generation Units Result Summary							500 ms window
Generator Set	**Unit Size**	**Inertia Constant H**	**Xd**	**Terminal Voltage**	**Stable**	**during**	**RoCoF**
[name]	[MW]	[Sec.]	[p.u.]	[kV]	[@ .5 Hz/s]	[@ 1 Hz/s]	[@ 2 Hz/s]
CCGT Single-shaft	400	5.5	1.9	20	Y	Y*	N
CCGT Dual-Shaft	260	6	2.3	17	Y	Y*	N
CCGT Dual-Shaft	140	9	2.1	17	Y	Y*	N
Steam Thermal (Reheat)	300	5	1.7	17	Y	Y*	N**
Steam Thermal (Once Through)	250	4.5	2.3	20	Y	Y*	N
Steam Thermal (Fluidized bed peat)	150	8	2.2	11	Y	Y*	N
OCGT	50	1.5	2.9	11	Y	Y*	Y*
Salient-pole Hydro	30	2.7	1.4	11	Y	Y	Y

CCGT Single-shaft	400 MW					
ID	**cosφ**		**load**	**RoCoF**	**Stable**	MaxTorque
	[-]		[%]	[Hz/s]		[%]
A	0.85	lag	80	-0.5	Y	106
B	0.85	lag	80	-1	Y	130
C	0.85	lag	80	-2	N**	175
D	0.85	lag	100	-0.5	Y	125
E	0.85	lag	100	-1	Y	150
F	0.85	lag	100	-2	N**	190
G	1		80	-0.5	Y	119
H	1		80	-1	Y	140
I	1		80	-2	N	162
J	1		100	-0.5	Y	141
K	1		100	-1	Y	157
L	1		100	-2	N	162
M	0.93	lead	80	-0.5	Y	110
N	0.93	lead	80	-1	Y	125
O	0.93	lead	80	-2	N	129
P	0.93	lead	100	-0.5	Y	126
Q	0.93	lead	100	-1	N	128
R	0.93	lead	100	-2	N	129

CCGT Dual-Shaft 260 MW

ID	cosφ		load	RoCoF	Stable	MaxTorque
	[-]		[%]	[Hz/s]		[%]
A	0.85	lag	80	-0.5	Y	108
B	0.85	lag	80	-1	Y	134
C	0.85	lag	80	-2	N**	175
D	0.85	lag	100	-0.5	Y	127
E	0.85	lag	100	-1	y	152
F	0.85	lag	100	-2	N**	184
G	1		80	-0.5	Y	119
H	1		80	-1	Y	140
I	1		80	-2	N	150
J	1		100	-0.5	Y	140
K	1		100	-1	Y	149
L	1		100	-2	N	149
M	0.93	lead	80	-0.5	Y	109
N	0.93	lead	80	-1	Y	120
O	0.93	lead	80	-2	N	120
P	0.93	lead	100	-0.5	Y	119
Q	0.93	lead	100	-1	N	119
R	0.93	lead	100	-2	N	121

CCGT Dual-Shaft 140 MW

ID	cosφ		load	RoCoF	Stable	MaxTorque
	[-]		[%]	[Hz/s]		[%]
A	0.85	lag	80	-0.5	Y	119
B	0.85	lag	80	-1	Y	153
C	0.85	lag	80	-2	N**	192
D	0.85	lag	100	-0.5	Y	138
E	0.85	lag	100	-1	y	169
F	0.85	lag	100	-2	N**	192
G	1		80	-0.5	Y	128
H	1		80	-1	Y	151
I	1		80	-2	N	155
J	1		100	-0.5	Y	146
K	1		100	-1	Y	154
L	1		100	-2	N	155
M	0.93	lead	80	-0.5	Y	115

N	0.93	lead	80	-1	Y	123
O	0.93	lead	80	-2	N	124
P	0.93	lead	100	-0.5	Y	123
Q	0.93	lead	100	-1	N	123
R	0.93	lead	100	-2	N	124

Steam Thermal (Reheat) 300 MW

ID	**cosφ**		**load**	**RoCoF**	**Stable**	MaxTorque
	[-]		[%]	[Hz/s]		[%]
A	0.85	lag	80	-0.5	Y	103
B	0.85	lag	80	-1	Y	126
C	0.85	lag	80	-2	N**	169
D	0.85	lag	100	-0.5	Y	123
E	0.85	lag	100	-1	y	146
F	0.85	lag	100	-2	Y	187
G	1		80	-0.5	Y	117
H	1		80	-1	Y	138
I	1		80	-2	N**	169
J	1		100	-0.5	Y	140
K	1		100	-1	Y	158
L	1		100	-2	Y	171
M	0.93	lead	80	-0.5	Y	109
N	0.93	lead	80	-1	Y	126
O	0.93	lead	80	-2	N**	136
P	0.93	lead	100	-0.5	Y	128
Q	0.93	lead	100	-1	N	135
R	0.93	lead	100	-2	N	135

Steam Thermal (Once Through) 250 MW

ID	**cosφ**		**load**	**RoCoF**	**Stable**	MaxTorque
	[-]		[%]	[Hz/s]		[%]
A	0.85	lag	80	-0.5	Y	101
B	0.85	lag	80	-1	Y	121
C	0.85	lag	80	-2	N**	159
D	0.85	lag	100	-0.5	Y	121
E	0.85	lag	100	-1	y	141
F	0.85	lag	100	-2	Y	174

G	1		80	-0.5	Y	114
H	1		80	-1	Y	132
I	1		80	-2	N**	150
J	1		100	-0.5	Y	136
K	1		100	-1	Y	148
L	1		100	-2	N	149
M	0.93	lead	80	-0.5	Y	106
N	0.93	lead	80	-1	Y	118
O	0.93	lead	80	-2	N	120
P	0.93	lead	100	-0.5	Y	119
Q	0.93	lead	100	-1	N	119
R	0.93	lead	100	-2	N	121

Steam Thermal (Fluidized bed peat) 150 MW

ID	cosφ		load	RoCoF	Stable	MaxTorque
	[-]		[%]	[Hz/s]		[%]
A	0.85	lag	80	-0.5	Y	115
B	0.85	lag	80	-1	Y	147
C	0.85	lag	80	-2	N	187
D	0.85	lag	100	-0.5	Y	134
E	0.85	lag	100	-1	y	164
F	0.85	lag	100	-2	N	188
G	1		80	-0.5	Y	125
H	1		80	-1	Y	147
I	1		80	-2	N	152
J	1		100	-0.5	Y	144
K	1		100	-1	Y	151
L	1		100	-2	N	152
M	0.93	lead	80	-0.5	Y	113
N	0.93	lead	80	-1	Y	121
O	0.93	lead	80	-2	N	122
P	0.93	lead	100	-0.5	Y	121
Q	0.93	lead	100	-1	N	121
R	0.93	lead	100	-2	N	122

OCGT 50 MW

ID	cosφ [-]		load [%]	RoCoF [Hz/s]	Stable	MaxTorque [%]
A	0.85	lag	80	-0.5	Y	87
B	0.85	lag	80	-1	Y	94
C	0.85	lag	80	-2	Y	108
D	0.85	lag	100	-0.5	Y	107
E	0.85	lag	100	-1	y	114
F	0.85	lag	100	-2	Y	128
G	1		80	-0.5	Y	101
H	1		80	-1	Y	108
I	1		80	-2	Y	121
J	1		100	-0.5	Y	125
K	1		100	-1	Y	131
L	1		100	-2	Y	140
M	0.93	lead	80	-0.5	Y	94
N	0.93	lead	80	-1	Y	101
O	0.93	lead	80	-2	Y	112
P	0.93	lead	100	-0.5	Y	113
Q	0.93	lead	100	-1	N	115
R	0.93	lead	100	-2	N	115

Salient-pole Hydro 30 MW

ID	cosφ [-]		load [%]	RoCoF [Hz/s]	Stable	MaxTorque [%]
A	0.85	lag	80	-0.5	Y	88
B	0.85	lag	80	-1	Y	95
C	0.85	lag	80	-2	Y	110
D	0.85	lag	100	-0.5	Y	108
E	0.85	lag	100	-1	y	115
F	0.85	lag	100	-2	Y	130
G	1		80	-0.5	Y	101
H	1		80	-1	Y	107
I	1		80	-2	Y	121
J	1		100	-0.5	Y	124
K	1		100	-1	Y	130
L	1		100	-2	Y	143
M	0.93	lead	80	-0.5	Y	93

N	0.93	lead	80	-1	Y	99
O	0.93	lead	80	-2	Y	110
P	0.93	lead	100	-0.5	Y	115
Q	0.93	lead	100	-1	Y	125
R	0.93	lead	100	-2	Y	130

6.1.2 Results 0.5, 1 and 2 Hz/s with a total frequency drop of 1 Hz

Generation Units Result Summary									1 Hz total frequency drop
Generator Set	Unit Size	Inertia Constant H	Xd	Terminal Voltage	Stable	during	RoCoF		
[name]	[MW]	[Sec.]	[p.u.]	[kV]	[@ .5 Hz/s]	[@ 1 Hz/s]	[@ 1.5 Hz/s]	[@ 2 Hz/s]	
CCGT Single-shaft	400	5.5	1.9	20	Y	Y	Y*	N	
CCGT Dual-Shaft	260	6	2.3	17	Y	N	N	N	
CCGT Dual-Shaft	140	9	2.1	17	Y	N	N	N	
Steam Thermal (Reheat)	300	5	1.7	17	Y	Y*	Y*	N**	
Steam Thermal (Once Through)	250	4.5	2.3	20	Y*	Y*	N	N	
Steam Thermal (Fluidized bed peat)	150	8	2.2	11	Y*	N	N	N	
OCGT	50	1.5	2.9	11	Y*	Y*	Y*	Y*	
Salient-pole Hydro	30	2.7	1.4	11	Y	Y	Y	Y	

CCGT Single-shaft	400 MW					
ID	cosφ		load	RoCoF	Stable	MaxTorque
	[-]		[%]	[Hz/s]		[%]
A	0.85	lag	80	-0.5	Y	106
B	0.85	lag	80	-1	Y	130
C	0.85	lag	80	-2	N**	175
D	0.85	lag	100	-0.5	Y	125
E	0.85	lag	100	-1	Y	150
F	0.85	lag	100	-2	N**	190
G	1		80	-0.5	Y	119
H	1		80	-1	Y	142
I	1		80	-2	N	162
J	1		100	-0.5	Y	142
K	1		100	-1	Y	161
L	1		100	-2	N	162
M	0.93	lead	80	-0.5	Y	112
N	0.93	lead	80	-1	Y	129
O	0.93	lead	80	-2	N	129
P	0.93	lead	100	-0.5	Y	128
Q	0.93	lead	100	-1	N	128
R	0.93	lead	100	-2	N	129

CCGT Dual-Shaft						260 MW
ID	**cosφ**		**load**	**RoCoF**	**Stable**	MaxTorque
	[-]		[%]	[Hz/s]		[%]
A	0.85	lag	80	-0.5	Y	108
B	0.85	lag	80	-1	Y	134
C	0.85	lag	80	-2	N**	175
D	0.85	lag	100	-0.5	Y	128
E	0.85	lag	100	-1	Y	153
F	0.85	lag	100	-2	N**	184
G	1		80	-0.5	Y	121
H	1		80	-1	Y	144
I	1		80	-2	N	150
J	1		100	-0.5	Y	143
K	1		100	-1	N	149
L	1		100	-2	N	149
M	0.93	lead	80	-0.5	Y	113
N	0.93	lead	80	-1	N	120
O	0.93	lead	80	-2	N	120
P	0.93	lead	100	-0.5	N	119
Q	0.93	lead	100	-1	N	119
R	0.93	lead	100	-2	N	121

CCGT Dual-Shaft						140 MW
ID	**cosφ**		**load**	**RoCoF**	**Stable**	MaxTorque
	[-]		[%]	[Hz/s]		[%]
A	0.85	lag	80	-0.5	Y	121
B	0.85	lag	80	-1	Y	159
C	0.85	lag	80	-2	N**	192
D	0.85	lag	100	-0.5	Y	141
E	0.85	lag	100	-1	Y	176
F	0.85	lag	100	-2	N**	192
G	1		80	-0.5	Y	134
H	1		80	-1	Y	155
I	1		80	-2	N	155
J	1		100	-0.5	Y	153
K	1		100	-1	N	154
L	1		100	-2	N	155

M	0.93	lead	80	-0.5	Y	122
N	0.93	lead	80	-1	N	123
O	0.93	lead	80	-2	N	124
P	0.93	lead	100	-0.5	N	123
Q	0.93	lead	100	-1	N	123
R	0.93	lead	100	-2	N	124

Steam Thermal (Reheat) 300 MW

ID	cosφ		load	RoCoF	Stable	MaxTorque
	[-]		[%]	[Hz/s]		[%]
A	0.85	lag	80	-0.5	Y	103
B	0.85	lag	80	-1	Y	126
C	0.85	lag	80	-2	N**	169
D	0.85	lag	100	-0.5	Y	123
E	0.85	lag	100	-1	Y	146
F	0.85	lag	100	-2	N**	187
G	1		80	-0.5	Y	117
H	1		80	-1	Y	139
I	1		80	-2	N**	169
J	1		100	-0.5	Y	140
K	1		100	-1	Y	160
L	1		100	-2	Y	171
M	0.93	lead	80	-0.5	Y	110
N	0.93	lead	80	-1	Y	129
O	0.93	lead	80	-2	N**	136
P	0.93	lead	100	-0.5	Y	130
Q	0.93	lead	100	-1	N	135
R	0.93	lead	100	-2	N	135

Steam Thermal (Once Through) 250 MW

ID	cosφ		load	RoCoF	Stable	MaxTorque
	[-]		[%]	[Hz/s]		[%]
A	0.85	lag	80	-0.5	Y	101
B	0.85	lag	80	-1	Y	121
C	0.85	lag	80	-2	N**	159
D	0.85	lag	100	-0.5	Y	121
E	0.85	lag	100	-1	Y	141

F	0.85	lag	100	-2	Y	174
G	1		80	-0.5	Y	115
H	1		80	-1	Y	133
I	1		80	-2	N**	150
J	1		100	-0.5	Y	137
K	1		100	-1	Y	150
L	1		100	-2	N	149
M	0.93	lead	80	-0.5	Y	107
N	0.93	lead	80	-1	Y	121
O	0.93	lead	80	-2	N	120
P	0.93	lead	100	-0.5	N	119
Q	0.93	lead	100	-1	N	119
R	0.93	lead	100	-2	N	121

Steam Thermal (Fluidized bed peat)						150 MW
ID	**cosφ**		**load**	**RoCoF**	**Stable**	MaxTorque
	[-]		[%]	[Hz/s]		[%]
A	0.85	lag	80	-0.5	Y	117
B	0.85	lag	80	-1	Y	151
C	0.85	lag	80	-2	N**	187
D	0.85	lag	100	-0.5	Y	136
E	0.85	lag	100	-1	Y	169
F	0.85	lag	100	-2	N**	188
G	1		80	-0.5	Y	130
H	1		80	-1	N**	153
I	1		80	-2	N	152
J	1		100	-0.5	Y	149
K	1		100	-1	N	151
L	1		100	-2	N	152
M	0.93	lead	80	-0.5	Y	119
N	0.93	lead	80	-1	N	121
O	0.93	lead	80	-2	N	122
P	0.93	lead	100	-0.5	N	121
Q	0.93	lead	100	-1	N	121
R	0.93	lead	100	-2	N	122

OCGT						50 MW
ID	**cosφ**		**load**	**RoCoF**	**Stable**	MaxTorque
	[-]		[%]	[Hz/s]		[%]
A	0.85	lag	80	-0.5	Y	87
B	0.85	lag	80	-1	Y	94
C	0.85	lag	80	-2	Y	108
D	0.85	lag	100	-0.5	Y	107
E	0.85	lag	100	-1	Y	114
F	0.85	lag	100	-2	Y	128
G	1		80	-0.5	Y	101
H	1		80	-1	Y	108
I	1		80	-2	Y	121
J	1		100	-0.5	Y	125
K	1		100	-1	Y	131
L	1		100	-2	Y	140
M	0.93	lead	80	-0.5	Y	94
N	0.93	lead	80	-1	Y	101
O	0.93	lead	80	-2	Y	112
P	0.93	lead	100	-0.5	N	113
Q	0.93	lead	100	-1	N	115
R	0.93	lead	100	-2	N	115

Salient-pole Hydro						30 MW
ID	**cosφ**		**load**	**RoCoF**	**Stable**	MaxTorque
	[-]		[%]	[Hz/s]		[%]
A	0.85	lag	80	-0.5	Y	92
B	0.85	lag	80	-1	Y	104
C	0.85	lag	80	-2	Y	110
D	0.85	lag	100	-0.5	Y	112
E	0.85	lag	100	-1	Y	124
F	0.85	lag	100	-2	Y	130
G	1		80	-0.5	Y	105
H	1		80	-1	Y	115
I	1		80	-2	Y	121
J	1		100	-0.5	Y	128
K	1		100	-1	Y	138
L	1		100	-2	Y	143
M	0.93	lead	80	-0.5	Y	97

N	0.93	lead	80	-1	Y	105
O	0.93	lead	80	-2	Y	110
P	0.93	lead	100	-0.5	Y	118
Q	0.93	lead	100	-1	Y	125
R	0.93	lead	100	-2	Y	130

6.1.3 Results 0.5, 1 and 1.5 Hz/s with a total frequency drop of 1 Hz

Generation Units Result Summary									1 Hz total frequency drop
Generator Set	**Unit Size**	**Inertia Constant H**	**Xd**	Terminal Voltage	**Stable**	**during**	**RoCoF**		
[name]	[MW]	[Sec.]	[p.u.]	[kV]	[@ .5 Hz/s]	[@ 1 Hz/s]	[@ 1.5 Hz/s]	[@ 2 Hz/s]	
CCGT Single-shaft	400	5.5	1.9	20	Y	Y	Y*	N	
CCGT Dual-Shaft	260	6	2.3	17	Y	N	N	N	
CCGT Dual-Shaft	140	9	2.1	17	Y	N	N	N	
Steam Thermal (Reheat)	300	5	1.7	17	Y	Y*	Y*	N**	
Steam Thermal (Once Through)	250	4.5	2.3	20	Y*	Y*	N	N	
Steam Thermal (Fluidized bed peat)	150	8	2.2	11	Y*	N	N	N	
OCGT	50	1.5	2.9	11	Y*	Y*	Y*	Y*	
Salient-pole Hydro	30	2.7	1.4	11	Y	Y	Y	Y	

CCGT Single-shaft	400 MW					
ID	**cosφ**		**load**	**RoCoF**	**Stable**	MaxTorque
	[-]		[%]	[Hz/s]		[%]
A	0.85	lag	80	-0.5	Y	106
B	0.85	lag	80	-1	Y	130
C	0.85	lag	80	-1.5	Y	154
D	0.85	lag	100	-0.5	Y	125
E	0.85	lag	100	-1	Y	150
F	0.85	lag	100	-1.5	Y	172
G	1		80	-0.5	Y	119
H	1		80	-1	Y	140
I	1		80	-1.5	Y	160
J	1		100	-0.5	Y	141
K	1		100	-1	Y	157
L	1		100	-1.5	Y	162
M	0.93	lead	80	-0.5	Y	110
N	0.93	lead	80	-1	Y	125
O	0.93	lead	80	-1.5	N**	129
P	0.93	lead	100	-0.5	Y	126
Q	0.93	lead	100	-1	N	128
R	0.93	lead	100	-1.5	N	128

CCGT Dual-Shaft 260 MW

ID	cosφ [-]		load [%]	RoCoF [Hz/s]	Stable	MaxTorque [%]
A	0.85	lag	80	-0.5	Y	108
B	0.85	lag	80	-1	Y	134
C	0.85	lag	80	-1.5	N**	158
D	0.85	lag	100	-0.5	Y	128
E	0.85	lag	100	-1	Y	153
F	0.85	lag	100	-1.5	Y	175
G	1		80	-0.5	Y	121
H	1		80	-1	Y	144
I	1		80	-1.5	N**	150
J	1		100	-0.5	Y	143
K	1		100	-1	N	149
L	1		100	-1.5	N	149
M	0.93	lead	80	-0.5	Y	113
N	0.93	lead	80	-1	N	120
O	0.93	lead	80	-1.5	N	120
P	0.93	lead	100	-0.5	N	119
Q	0.93	lead	100	-1	N	119
R	0.93	lead	100	-1.5	N	121

CCGT Dual-Shaft 140 MW

ID	cosφ [-]		load [%]	RoCoF [Hz/s]	Stable	MaxTorque [%]
A	0.85	lag	80	-0.5	Y	121
B	0.85	lag	80	-1	Y	159
C	0.85	lag	80	-1.5	N**	186
D	0.85	lag	100	-0.5	Y	141
E	0.85	lag	100	-1	Y	176
F	0.85	lag	100	-1.5	N**	192
G	1		80	-0.5	Y	134
H	1		80	-1	Y	155
I	1		80	-1.5	N	155
J	1		100	-0.5	Y	153
K	1		100	-1	N	154
L	1		100	-1.5	N	154

M	0.93	lead	80	-0.5	Y	122
N	0.93	lead	80	-1	N	123
O	0.93	lead	80	-1.5	N	124
P	0.93	lead	100	-0.5	N	123
Q	0.93	lead	100	-1	N	123
R	0.93	lead	100	-1.5	N	123

Steam Thermal (Reheat) 300 MW

ID	cosφ		load	RoCoF	Stable	MaxTorque
	[-]		[%]	[Hz/s]		[%]
A	0.85	lag	80	-0.5	Y	103
B	0.85	lag	80	-1	Y	126
C	0.85	lag	80	-1.5	Y	148
D	0.85	lag	100	-0.5	Y	123
E	0.85	lag	100	-1	Y	146
F	0.85	lag	100	-1.5	Y	167
G	1		80	-0.5	Y	117
H	1		80	-1	Y	139
I	1		80	-1.5	Y	158
J	1		100	-0.5	Y	140
K	1		100	-1	Y	160
L	1		100	-1.5	Y	171
M	0.93	lead	80	-0.5	Y	110
N	0.93	lead	80	-1	Y	129
O	0.93	lead	80	-1.5	N**	136
P	0.93	lead	100	-0.5	Y	130
Q	0.93	lead	100	-1	N	135
R	0.93	lead	100	-1.5	N	135

Steam Thermal (Once Through) 250 MW

ID	cosφ		load	RoCoF	Stable	MaxTorque
	[-]		[%]	[Hz/s]		[%]
A	0.85	lag	80	-0.5	Y	101
B	0.85	lag	80	-1	Y	121
C	0.85	lag	80	-1.5	Y	141
D	0.85	lag	100	-0.5	Y	121
E	0.85	lag	100	-1	Y	141

F	0.85	lag	100	-1.5	Y	159
G	1		80	-0.5	Y	115
H	1		80	-1	Y	133
I	1		80	-1.5	Y	148
J	1		100	-0.5	Y	137
K	1		100	-1	Y	150
L	1		100	-1.5	N	149
M	0.93	lead	80	-0.5	Y	107
N	0.93	lead	80	-1	Y	121
O	0.93	lead	80	-1.5	N	120
P	0.93	lead	100	-0.5	N	119
Q	0.93	lead	100	-1	N	119
R	0.93	lead	100	-1.5	N	121

Steam Thermal (Fluidized bed peat)						150 MW
ID	**cosφ**		**load**	**RoCoF**	**Stable**	MaxTorque
	[-]		[%]	[Hz/s]		[%]
A	0.85	lag	80	-0.5	Y	117
B	0.85	lag	80	-1	Y	151
C	0.85	lag	80	-1.5	N**	179
D	0.85	lag	100	-0.5	Y	136
E	0.85	lag	100	-1	Y	169
F	0.85	lag	100	-1.5	N**	187
G	1		80	-0.5	Y	130
H	1		80	-1	N**	153
I	1		80	-1.5	N**	152
J	1		100	-0.5	Y	149
K	1		100	-1	N	151
L	1		100	-1.5	N	152
M	0.93	lead	80	-0.5	Y	119
N	0.93	lead	80	-1	N	121
O	0.93	lead	80	-1.5	N	122
P	0.93	lead	100	-0.5	N	121
Q	0.93	lead	100	-1	N	121
R	0.93	lead	100	-1.5	N	121

OCGT						50 MW
ID	cosφ		load	RoCoF	Stable	MaxTorque
	[-]		[%]	[Hz/s]		[%]
A	0.85	lag	80	-0.5	Y	87
B	0.85	lag	80	-1	Y	94
C	0.85	lag	80	-1.5	Y	101
D	0.85	lag	100	-0.5	Y	107
E	0.85	lag	100	-1	Y	114
F	0.85	lag	100	-1.5	Y	121
G	1		80	-0.5	Y	101
H	1		80	-1	Y	108
I	1		80	-1.5	Y	115
J	1		100	-0.5	Y	125
K	1		100	-1	Y	131
L	1		100	-1.5	Y	136
M	0.93	lead	80	-0.5	Y	94
N	0.93	lead	80	-1	Y	101
O	0.93	lead	80	-1.5	Y	107
P	0.93	lead	100	-0.5	N	113
Q	0.93	lead	100	-1	N	115
R	0.93	lead	100	-1.5	N	115

Salient-pole Hydro						30 MW
ID	cosφ		load	RoCoF	Stable	MaxTorque
	[-]		[%]	[Hz/s]		[%]
A	0.85	lag	80	-0.5	Y	92
B	0.85	lag	80	-1	Y	104
C	0.85	lag	80	-1.5	Y	109
D	0.85	lag	100	-0.5	Y	112
E	0.85	lag	100	-1	Y	124
F	0.85	lag	100	-1.5	Y	128
G	1		80	-0.5	Y	105
H	1		80	-1	Y	115
I	1		80	-1.5	Y	119
J	1		100	-0.5	Y	128
K	1		100	-1	Y	138
L	1		100	-1.5	Y	142
M	0.93	lead	80	-0.5	Y	97

N	0.93	lead	80	-1	Y	105
O	0.93	lead	80	-1.5	Y	109
P	0.93	lead	100	-0.5	Y	118
Q	0.93	lead	100	-1	Y	125
R	0.93	lead	100	-1.5	Y	129