RoCoF

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

Willem Uijlings

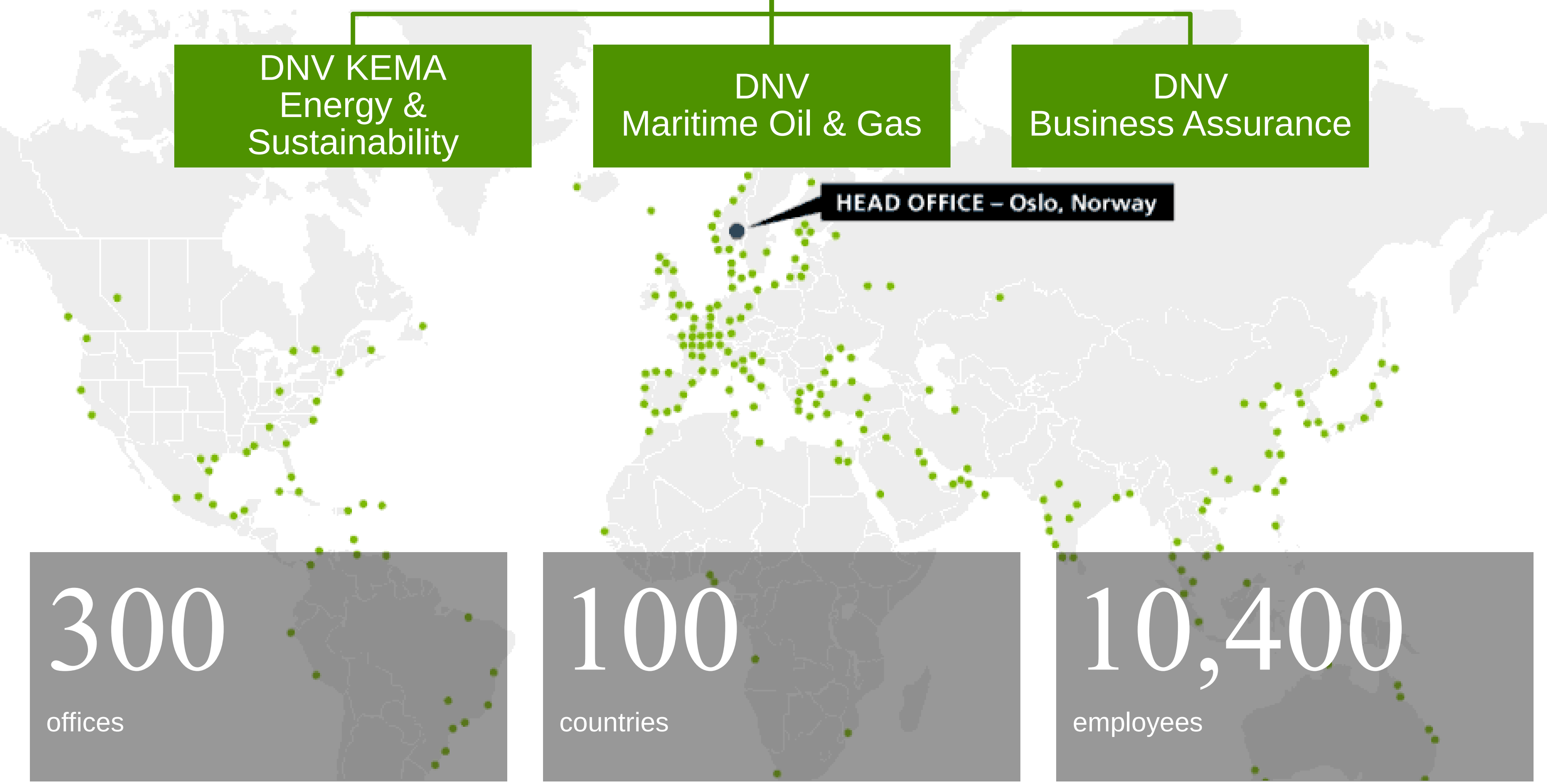
Agenda

1. DNV KEMA
2. Introduction why RoCoF, why calculation/ approach
3. Inertia & Frequency drop
4. Pole Angle & Torque
5. Instability
6. Power Swing
7. Project Results
8. Context DNV KEMA report & Recommendations

The DNV Group

DNV Group

- DNV KEMA Energy & Sustainability
- DNV Maritime Oil & Gas
- DNV Business Assurance



300 offices

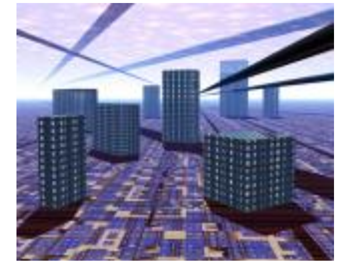
100 countries

10,400 employees

DNV KEMA Energy & Sustainability

- DNV KEMA Energy & Sustainability offers innovative solutions to customers across the energy value chain, ensuring reliable, efficient and sustainable energy supply, now and in the future.
- 2,300+ experts across all continents
- KEMA and DNV combined: a heritage of nearly 150 years
- Headquartered in Arnhem, the Netherlands
- Offices and agents in over 30 countries around the globe

One Company Serving the Needs of the Energy Market Place



Policy & Strategy → Production → Trading → Transport & Distribution → Use

- Business and technical consultancy, expert advice, operational services
- Testing, inspections, certification, verification
- Risk, performance and quality management
- Research & innovation

We understand the business consequence of a technical decision and the technical consequences of a business decision

Announcement December 2012:

DNV and GL join forces to make history

Combining two major players

DNV

- Founded 1864
- Høvik, Norway
- 10,400 employees

Dedicated competences in:

- Tankers
- Offshore Classification
- Power & Transmission
- System certification

DNV GL Group

- Shared ambition for quality and innovation
- Head office in Høvik
- 17,100 employees

A leading company in:

- Classification
- Oil & Gas
- Energy
- Business Assurance

GL

- Founded 1867
- Hamburg
- 6,700 employees

Dedicated competences in:

- Container ships
- Energy efficiency
- Marine warranty
- Renewables

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Introduction

Studies identified an increased Rate of Change of Frequency (RoCoF) with the increase of renewable energy penetration (40 % in 2020)

- Government targets for Ireland and the ambition for Northern Ireland
- “Delivering a Secure Sustainable System” (DS3)
- Conventional energy generation decreasing (synchronous inertia)
- Renewable energy generation increasing (non or virtual inertia)
- European markets and regulations
  - National policies for anti-islanding (RoCoF and vector shift protection)
  - Entso e (24 January 2012 & 26 June 2012)
- To generate more insight and explain the effects of allowing an increase in RoCoF values, DNV KEMA study progressed into a calculation model

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Inertia & Frequency drop

Higher inertia is good for the stability of the electricity grid. On the other hand, a higher inertia could potentially reduce the ability to follow speedy frequency changes

- Synchronous machines rotor and field
- Weight of the synchronous machine turbine combination contribute to inertia
- Inertia contribute to maintain the steady state rotation speed

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Pole Angle & Torque

The angle of the Rotor and Stator fields will have an effect on the attractive forces between them and thus the Torque.

- Nominal Torque value
  - Definition
  - Reference
- Nominal maximum technical Torque value
- Power Factor influence
- Calculated Torque with reference value
- Current generator compliance
  - IEC 60034-3, 3 phase short circuit => torque 600-800 %
  - Voltage dip due to system faults could => 300-400 % (Grid impedance and location)

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Instability

A (non salient pole) synchronous machine produces its maximum torque when the angle between the Rotor and Stator rotating magnetic fields are at 90 degrees (when the stator winding resistance is ignored)

- Stable operation
  - Rotor stays synchronous with stator field
- Instable operation
  - Rotor stays synchronous with stator field but momentary reverse power is observed
  - Loss of synchronism, pole slip and speeding up of the rotor is observed

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Power Swing

Power swings are observed caused by a combination of inertia and torque

- Torque swings
  - Resonance frequency
- Momentary reverse power
  - Bi-directional forces
- Frequency of events
  - Maintenance
- Protection settings

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Project Results

Results indicate that a 1 Hz/s frequency drop does not cause instability of the generators studied in the model used for a 500 ms window.

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

Project Results

Detailed results from the simplified mathematical model used.

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

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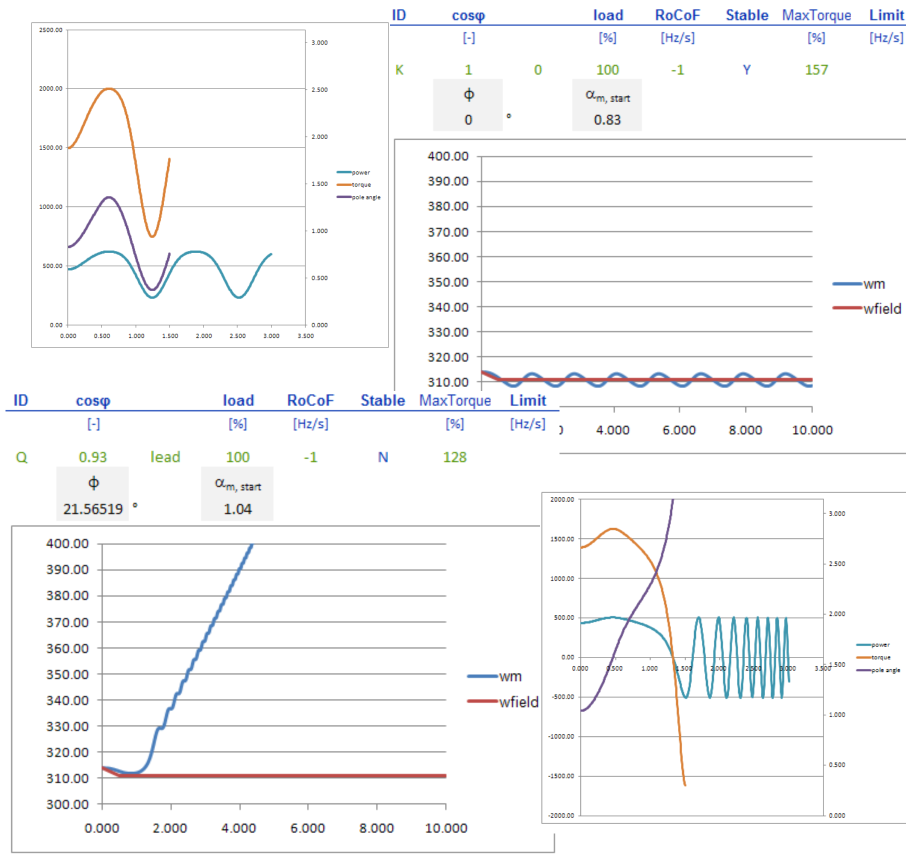
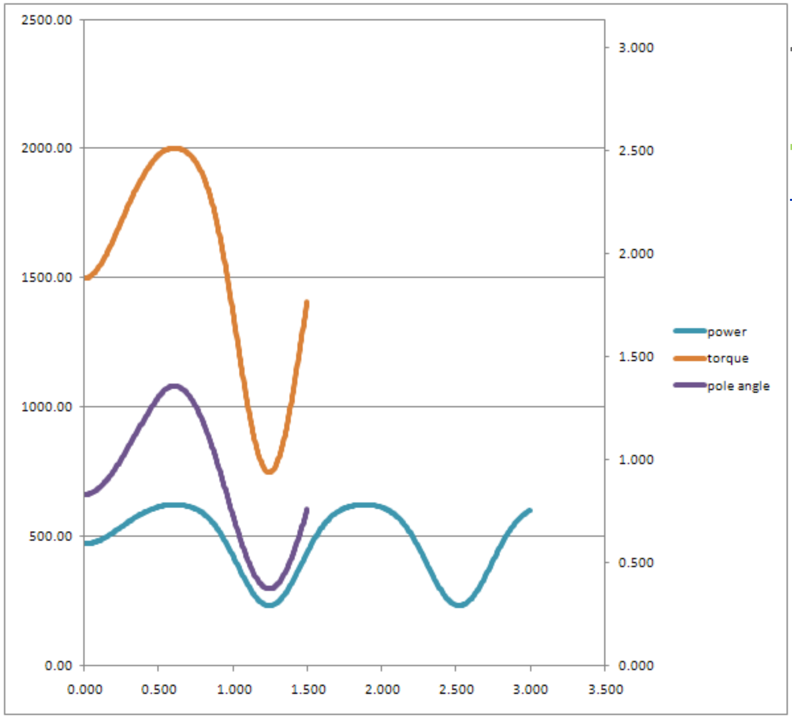


Project Results

Deta... ...atical model used.

CCGT S



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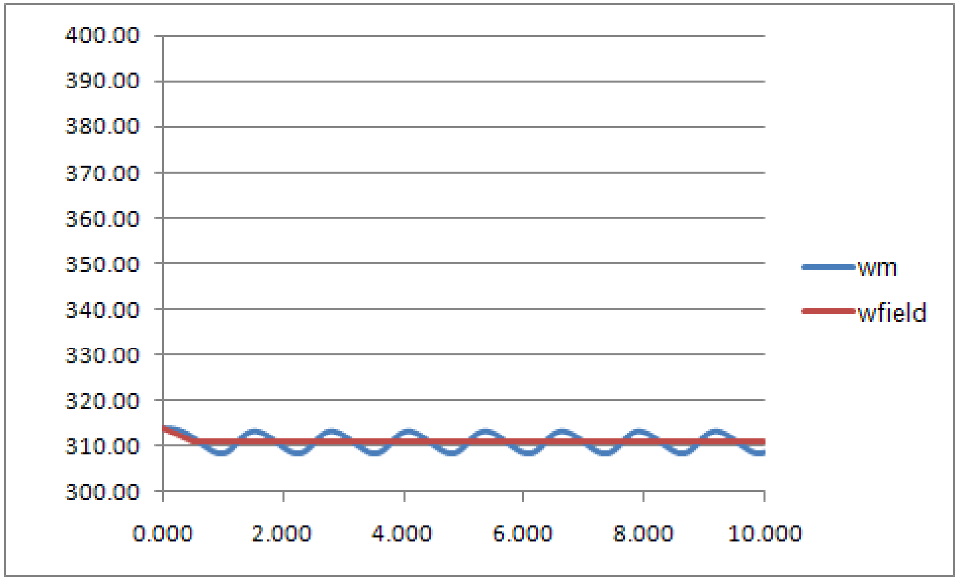
ID	cosφ		load	RoCoF	Stable	MaxTorque	Limit
	[-]		[%]	[Hz/s]		[%]	[Hz/s]
K	1	0	100	-1	Y	157	

φ		$\alpha_{m,\ start}$
0	°	0.83

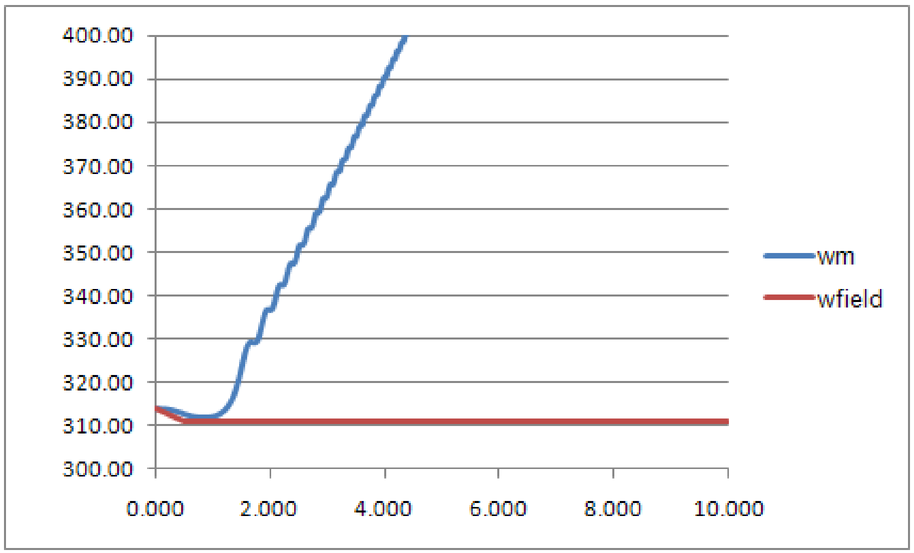


Project Results

Detailed results from the simplified mathematical model used.

ID	cosφ		load	RoCoF	Stable	MaxTorque	Limit
	[-]		[%]	[Hz/s]		[%]	[Hz/s]
Q	0.93	lead	100	-1	N	128	

ϕ	$\alpha_{m,\,start}$
21.56519 °	1.04



Q	0.93	lead	100	-1	N	128
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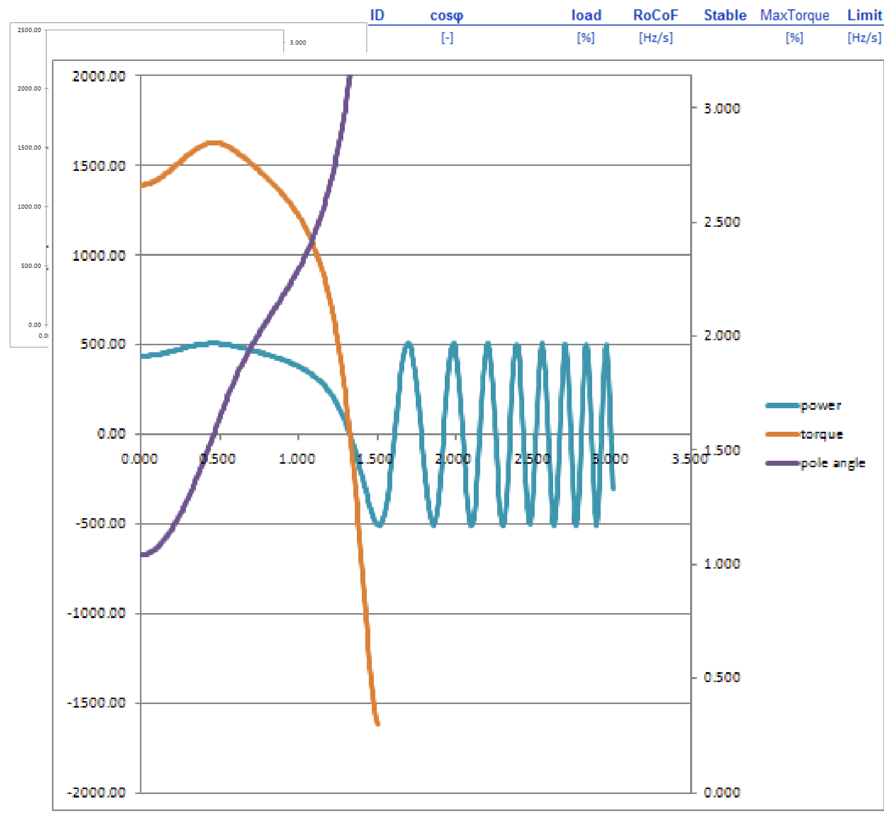

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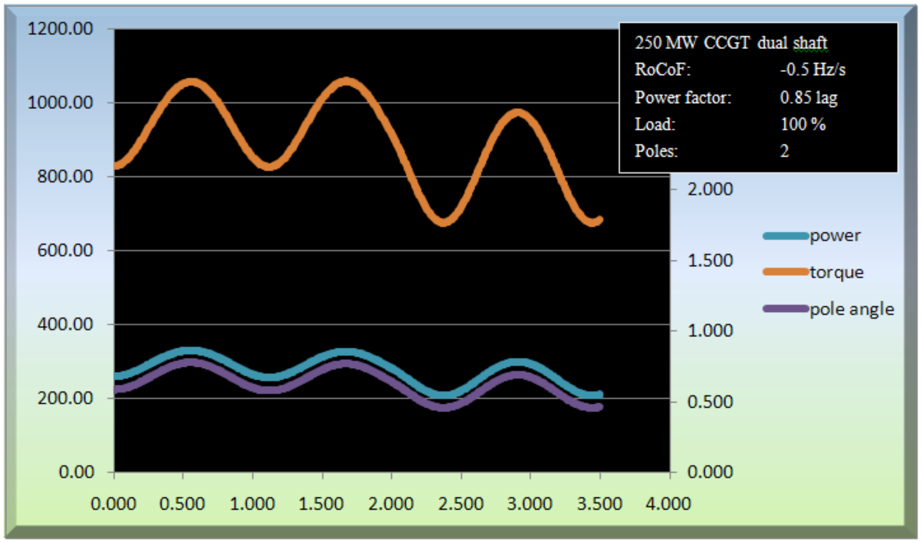
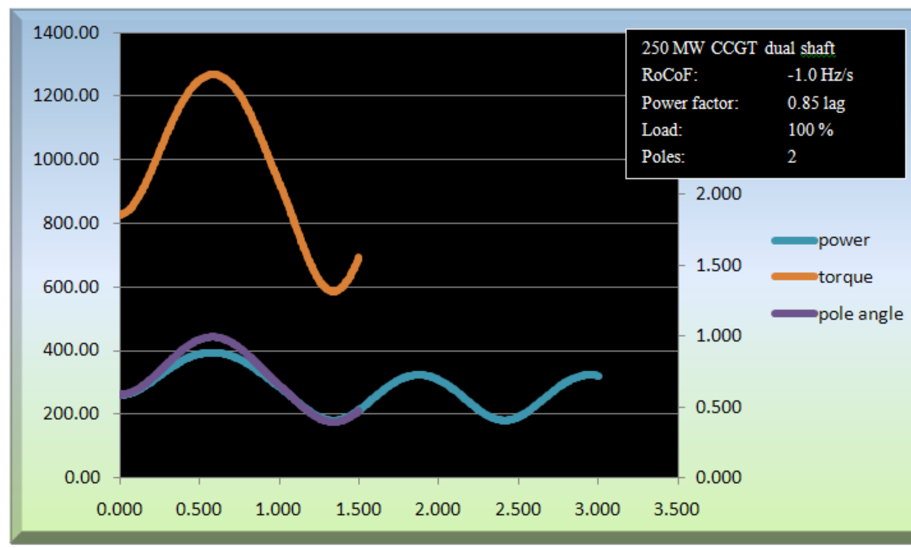


- 250 Mwe CCGT dual shaft at pf 0.85 lag and 100 % load



- RoCoF -0.5 Hz/s results in a torque load of 128 %
- RoCoF -1.0 Hz/s results in a torque load of 153 %

Project Results

Analyses of the results from the study.

- Higher torque values
- Current ride-through criteria results in 300 % to 400 % torque load
- Operation modes
  - Load
  - Power factor
- Lifetime
- RoCoF duration
- Higher RoCoF values during shorter time frames
- Negative Power
- Torque swings and it's frequency

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Context DNV KEMA report & Recommendations

Results presented are a first reasonable estimate to give guidance of the main implications for the provision of higher RoCoF values in Ireland and Northern Ireland.

- Implications 1 Hz/s RoCoF over a 500 ms rolling window
  - Specify operation modes
  - Check current compliance standards regarding possible additional studies
- Without detailed investigations on each specific generation asset it is not possible to make a final statement on the compliance.
- PSS equipment (Power system stabilisers)
- Friction between turbine and engine (bi-directional forces)
- Material stress in shoe of largest LP turbine blades (bi-directional forces)
- Protection interpretation large RoCoF -> Grid disturbance => emergency stop
- Protection modification keeping sufficient discrimination process
- Study does not conclude a final statement though DNV KEMA believes that the analyses provide a good calculated estimate of the stability of the synchronous machine.

Thank you for your attention

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