The Voice of the Networks

Energy Networks Association

Loss of Mains Protection Settings for all Small Generators

Stakeholder Workshop

15 June 2018, London

Agenda

Welcome and Introductions	Mike Kay 10:30
Background and Work so far	Graham Stein 10:30-11:00
Loss of Mains setting change	Mike Kay 11:00-11:30
Risk assessment for the setting change	Adam Dyśko 11:30-12:00
Retrospective setting change cost & benefit	Graham Stein 12:00-12:30
Lunch	12:30-13:15
Implementation and next steps	Mike Kay Graham Stein
Close	Mike Kay

Purpose of workshop

- Provide an update on Loss of Mains protection setting changes
- Provide an update on potential further changes to the Distribution Code, ER G59 and ER G83
  - Loss of Mains protection settings
- Explain why changes are being considered and how they might be implemented
- Inform affected parties how they can contribute to the implementation plan

Background

Graham Stein
Network Operability Manager
Electricity System Operator
National Grid

graham.stein@nationalgrid.com

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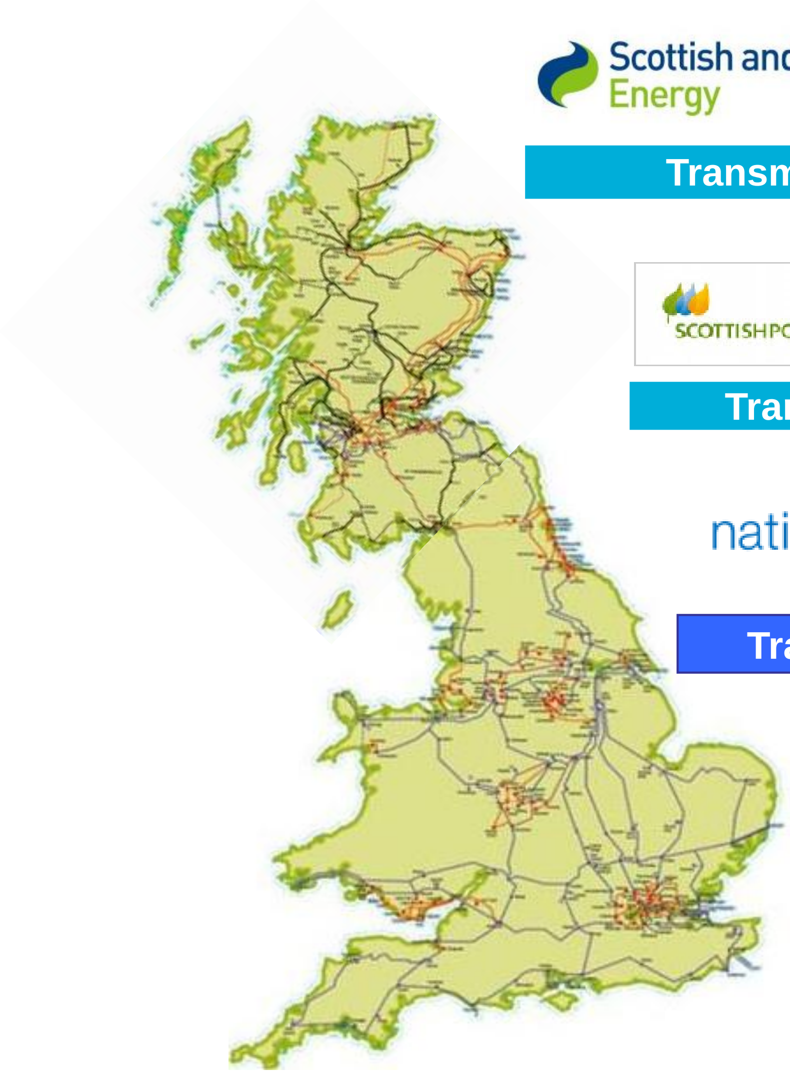
Electricity Transmission



Scottish and Southern Energy

Transmission Owner

SCOTTISHPOWER

Transmission Owner

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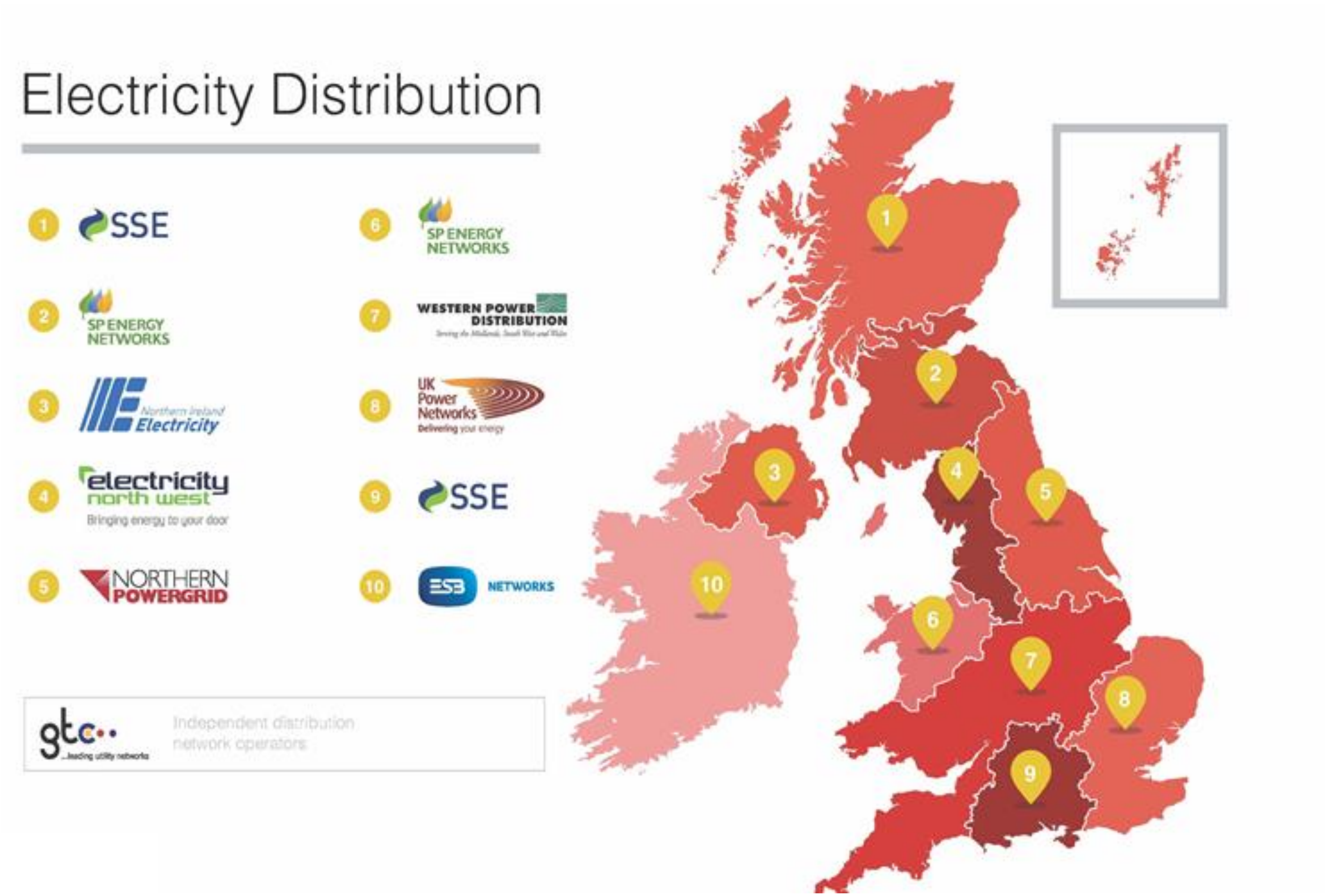
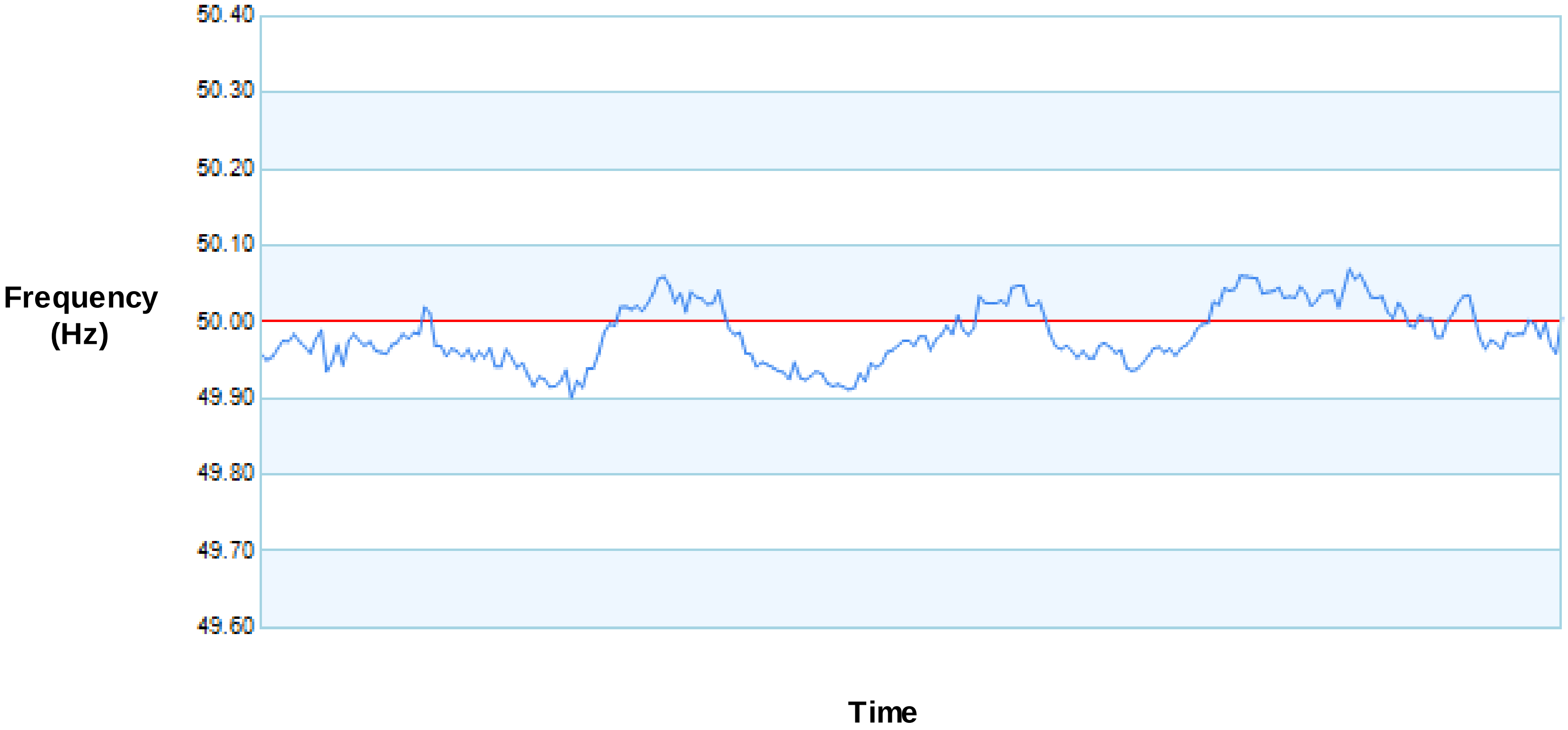
Transmission Owner

National Grid is System Operator for whole of GB and offshore

Distribution Network



Frequency



http://www2.nationalgrid.com/uk/industry-information/electricity-transmission-operational-data/

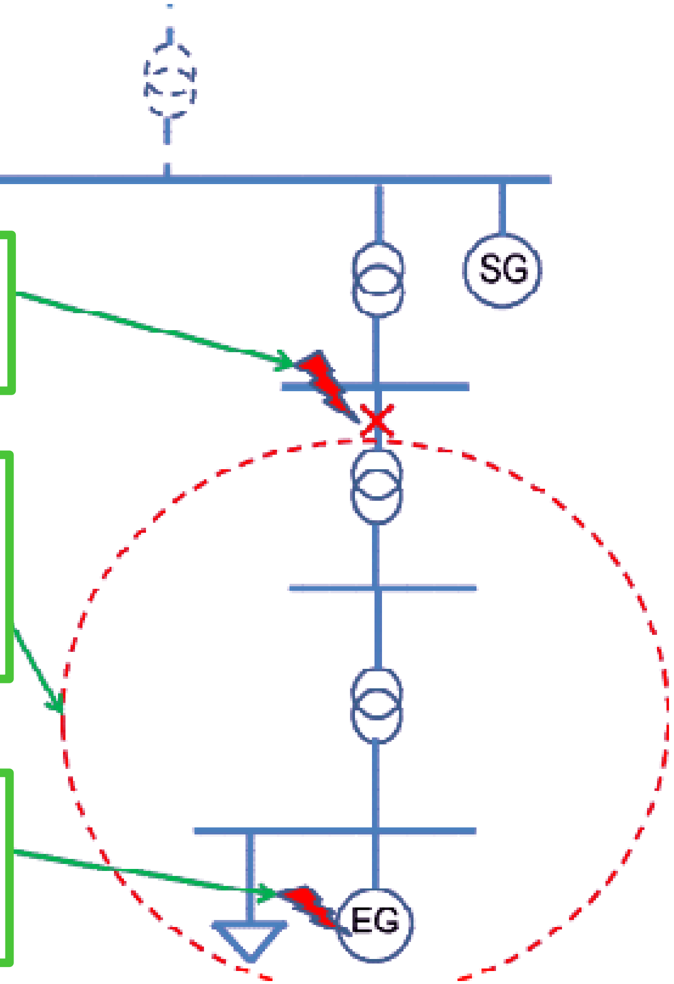
Loss of Mains Protection (RoCoF based)

RoCoF relay Operation

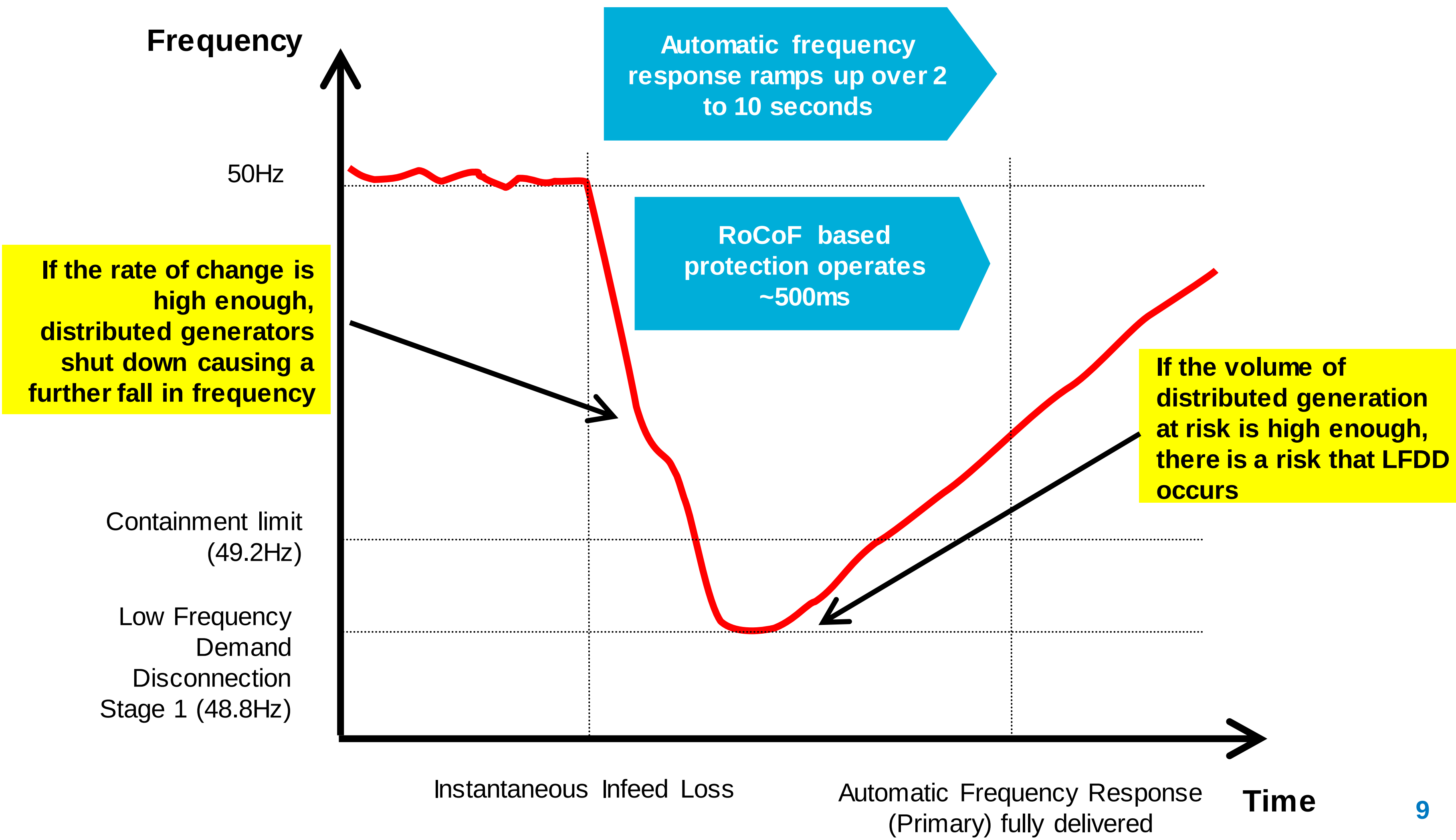
1. An event on either the transmission or the distribution network can force the breaker to open and create an AC island isolated from the main AC system

2. The frequency of the AC island can't be maintained by SO, and it is dependent on the balance of the generation and the demand within the island. It is very likely that the frequency of the AC island will deviate rapidly from 50Hz.

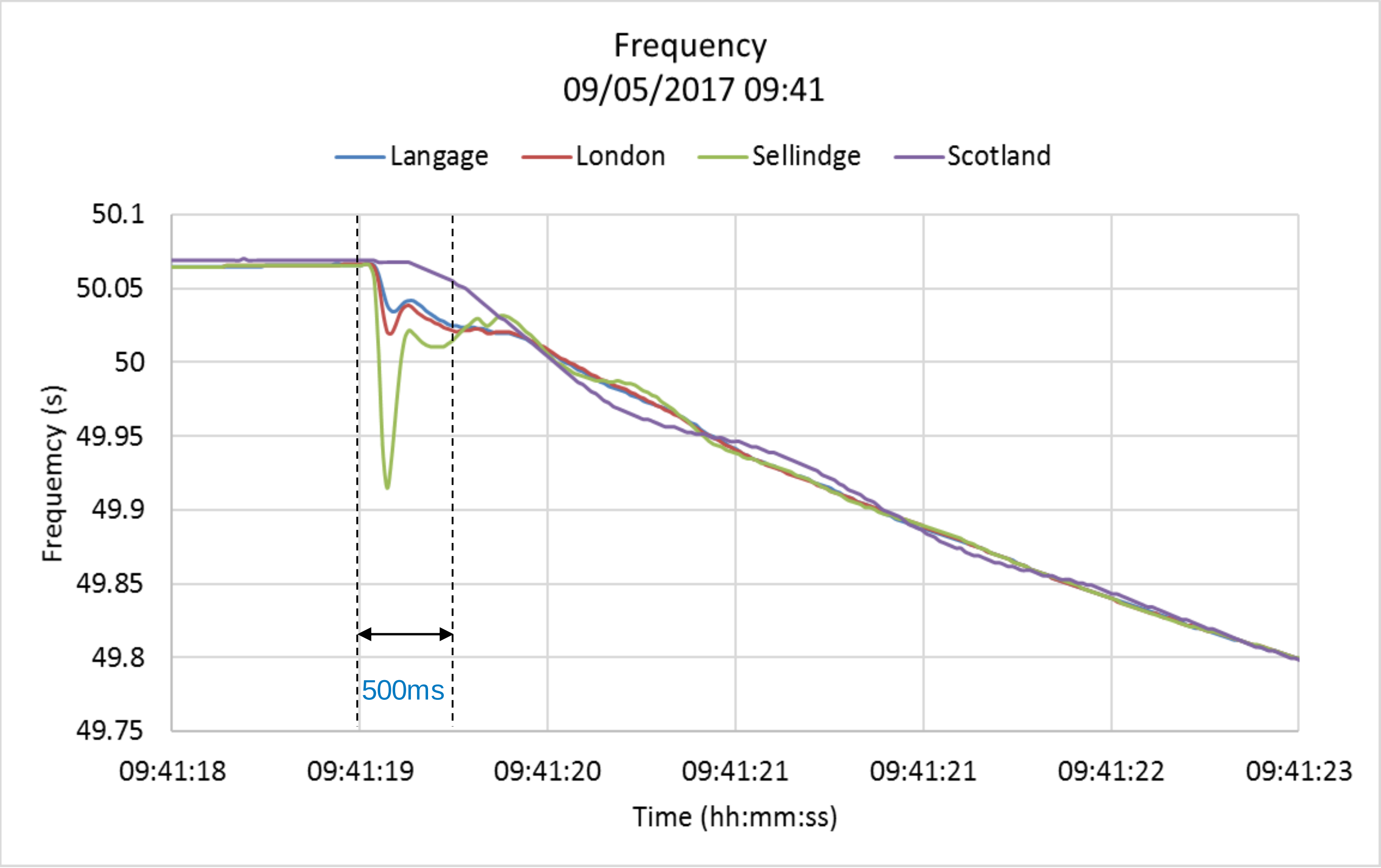
3. Caused by the rapid rate of change of frequency, the embedded generation RoCoF protection relay triggers and therefore the AC island is forced to black out



Background

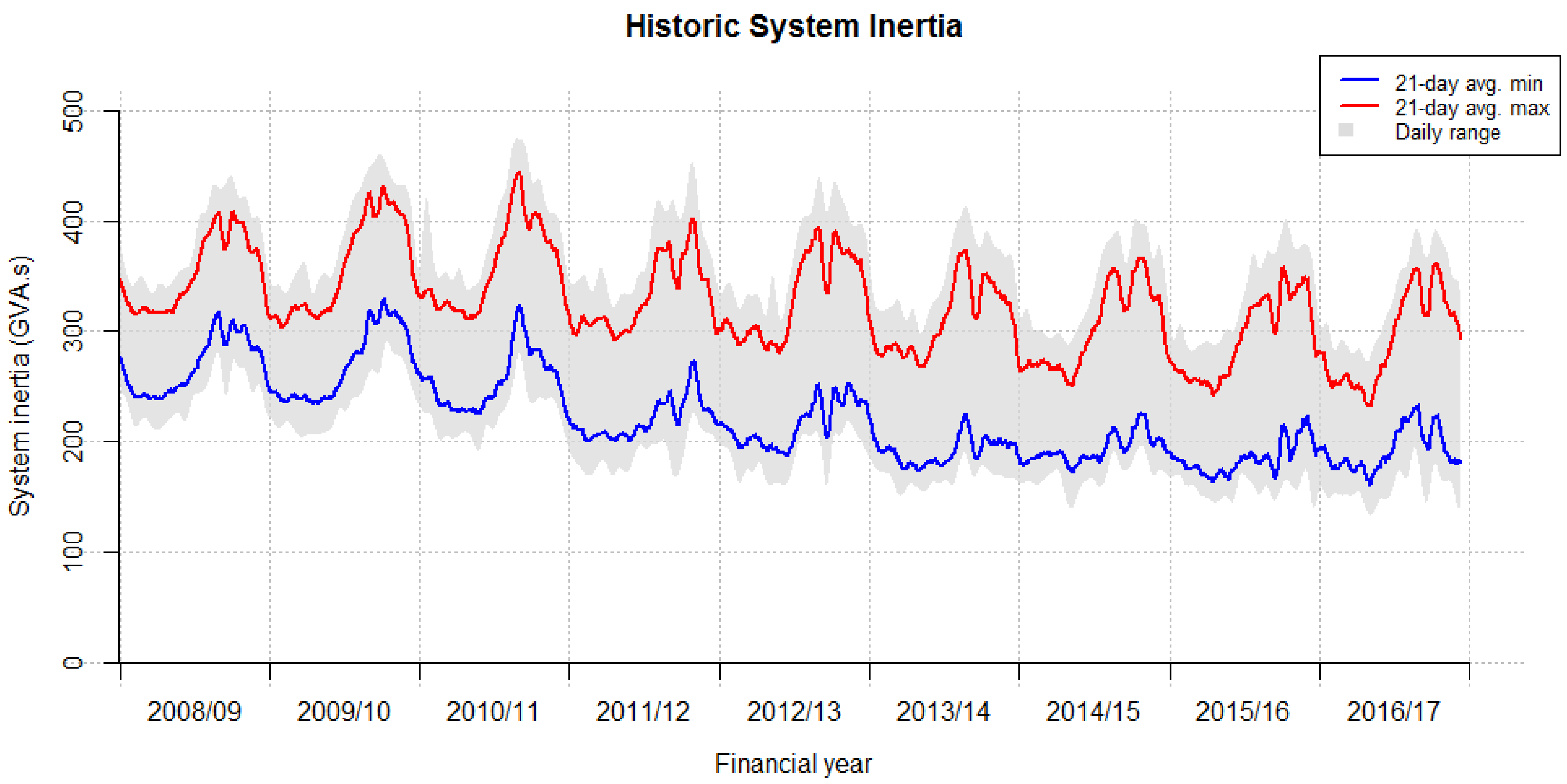

Frequency
Automatic frequency response ramps up over 2 to 10 seconds
50Hz
RoCoF based protection operates ~500ms
If the rate of change is high enough, distributed generators shut down causing a further fall in frequency
If the volume of distributed generation at risk is high enough, there is a risk that LFDD occurs
Containment limit (49.2Hz)
Low Frequency Demand Disconnection Stage 1 (48.8Hz)
Instantaneous Infeed Loss
Automatic Frequency Response (Primary) fully delivered
Time

Background



Frequency
09/05/2017 09:41
Langage
London
Sellindge
Scotland
50.1
50.05
50
49.95
49.9
49.85
49.8
49.75
Frequemcy (s)
500ms
09:41:18
09:41:19
09:41:20
09:41:21
09:41:21
09:41:22
09:41:23
Time (hh:mm:ss)

Evolution of system inertia



Summary of the RoCoF Risk

- The maximum rate of change risk occurs when demand is low and there is a large instantaneous infeed or offtake risk to manage
- The maximum rate of change is rising because
  - Synchronous generation is being displaced by non-synchronous plant – interconnectors, wind, photo-voltaic etc
  - There will be larger infeed losses in the future

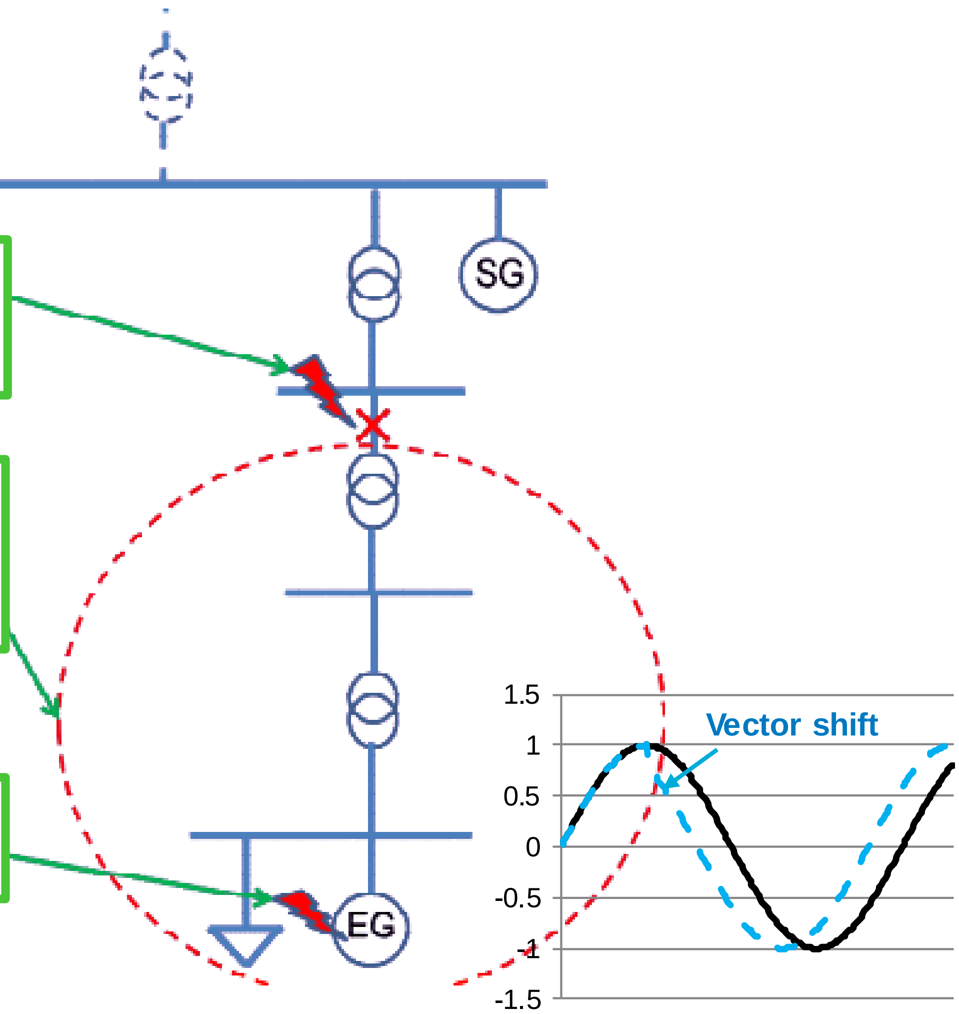
Loss of Mains Protection (Vector Shift based)

Vector Shift Operation

1. An event on either the transmission or the distribution network can force the breaker to open and create an AC island isolated from the main AC system

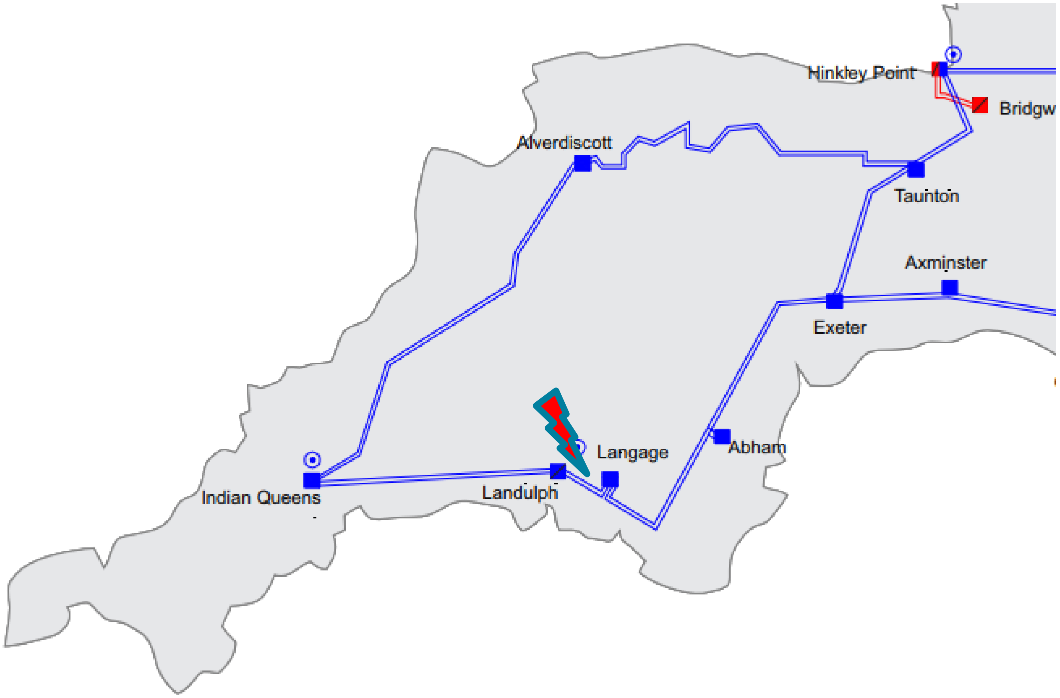
2. When the main AC system is removed and the generator could experiences a relatively large change in load (in either direction) then there will be a near instantaneous change in the phase shift

3. The embedded generation Vector Shift protection relay triggers and therefore the AC island is forced to black out



EG tripping for transmission fault

- VS protection could trip inappropriately over a wide area for transmission faults
- 22/5/2016 11:15; following the transmission fault at Langage – Landulph 400kV circuit, 380MW demand increase was observed



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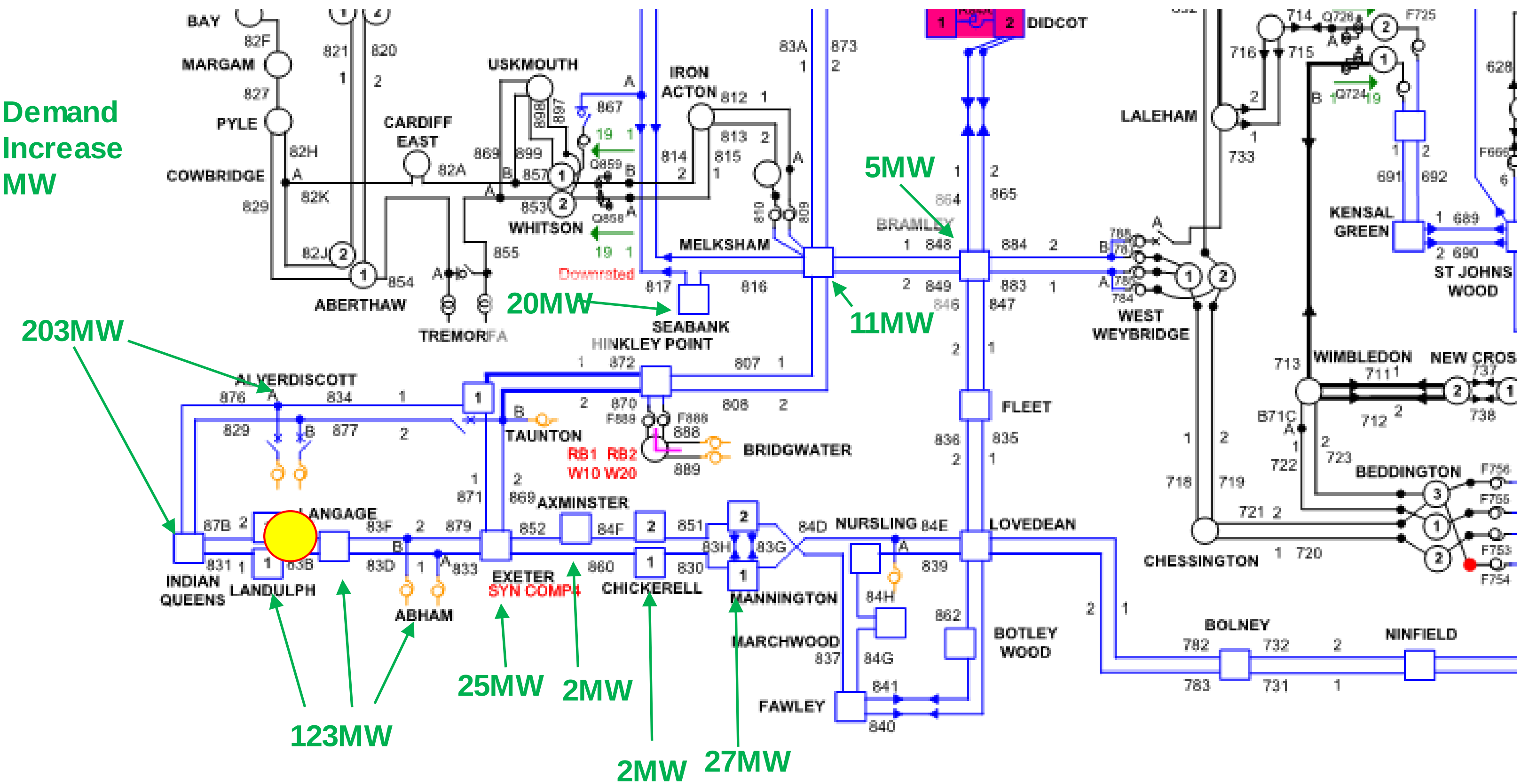
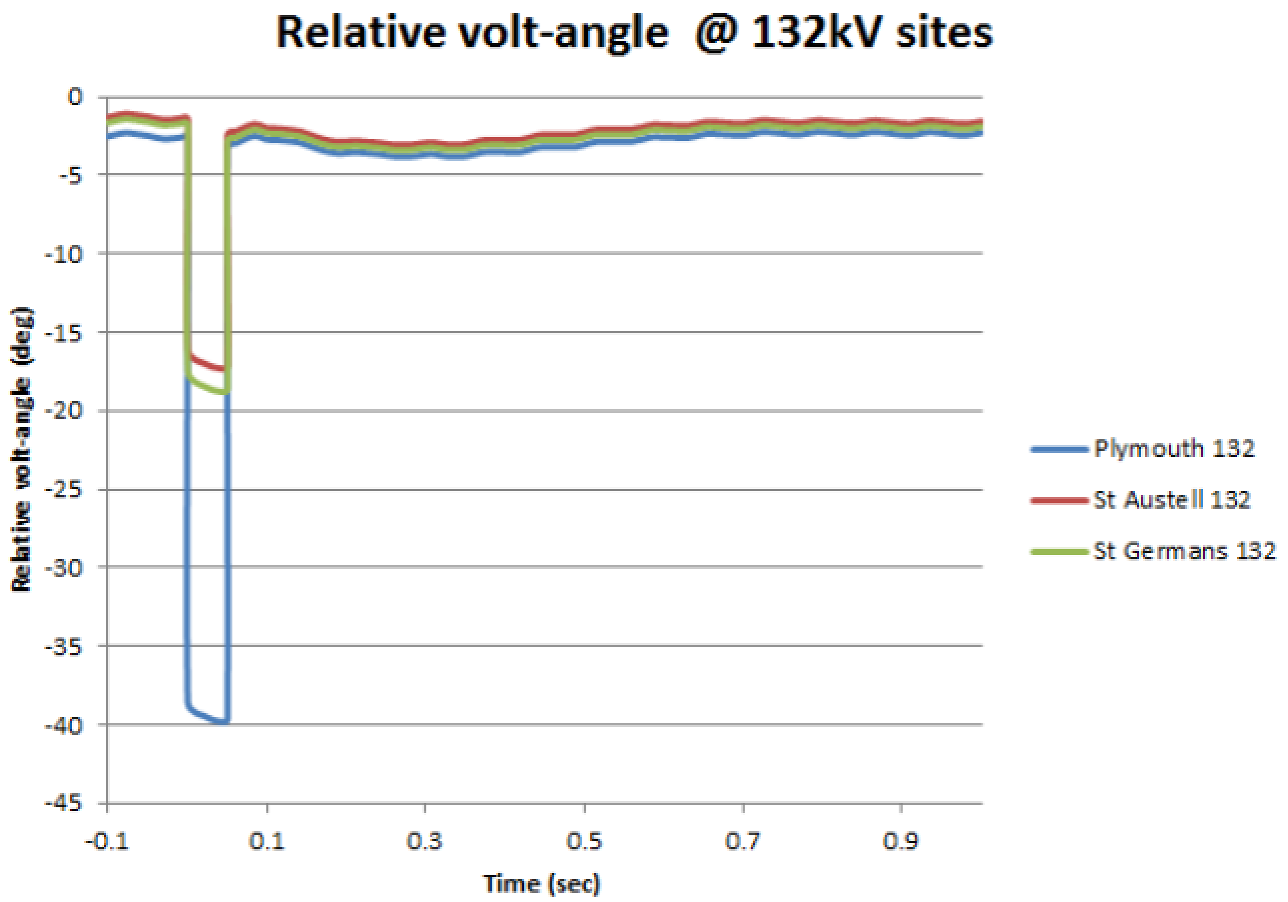
EG tripping for transmission fault

Date	Fault		Demand Increase Seen
22 May 2016 11:15	Langage – Landulph 400kV circuit	Lightning OHL	380 MW



Simulated VS during the 22/5/2016 fault



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Other VS risk system events

Date/ Time	Fault	T Demand Increase	National Solar Output
17/3/2016 12:27	Grain Bus Coupler 4	469MW	61%
20 /3/2016 16:13	Grain- Kingsnorth 400kV circuit	200MW	17%
22/5/2016 11:15	Langage – Landulph 400kV circuit	380 MW	52%
07/6/2016 17:04	Cowley-Leighton Buzzard-Sundon 400kV circuit	145MW	28%
21/5/2017 18:20	Littlebrook 400kV Reserve Bar	200 MW	39%
08/6/2017 16:47	COTT – EASO – RYHA CCT energised from EASO4 only	241MW	22%
10/7/2017 14:19	Bramford – Sizewell 4 400kV circuit	300 MW	37%
17/7/2017 15:26	Kensal Green Reserve Bar	580MW DG Loss less 160MW demand loss	50%

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Technical Solutions

- Options for Managing the Risk
  - Limiting the largest loss limits the rate of change
  - Increasing inertia by synchronising additional plant reduces the rate of change
    - displaces non synchronous generation
  - Limiting the Rate of Change using automatic action (not currently feasible)
  - Changing or Removing RoCoF based protection
  - Changing or Removing VS based protection
  - Different LoMs approach
- Each option comes at a cost

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Changing LoM Settings

Current context of LoM change

- Progressive introduction of EU Network Codes
  - Requirement for Generators
    - Applies to new generation only
    - Has fault ride through and RoCoF withstand requirements – DC0079 proposals are consistent with these
  - System Operations Guidelines
    - Still in implementation discussions
    - Applies to all generation irrespective of age
    - Currently not believed to have any impact in GB
- Work in both Grid and Distribution Codes as to how this all applies to storage – but these protection issues apply equally to storage as to any other form of generation

Changing the Distribution Code

- The distribution licences require:
  - The licensee shall periodically review (including upon the request of the Authority) the Distribution Code and its implementation
  - The review shall involve an evaluation of whether any revision or revisions to the Distribution Code would better facilitate the achievement of the Distribution Code objectives and, where the impact is likely to be material, this shall include an assessment of the quantifiable impact of any such revision on greenhouse gas emissions
- Distribution Code Objectives
  - *To permit the development, maintenance and operation of an efficient, coordinated and economical system for the distribution of electricity;*
  - *To facilitate competition in the generation and supply of electricity*
  - *Efficiently discharge the obligations imposed upon DNOs by the Distribution Licence and comply with the Regulation [ie EU third energy package] and any relevant legally binding decision of the European Commission and/or Agency for the Co-operation of Energy Regulators.*
  - *Promote efficiency in the implementation and administration of the Distribution Code.*

Changing the Distribution Code

- Following any such review, the licensee shall send to the Authority
  - a report on the outcome of such review
  - any proposed revisions to the Distribution Code
  - any written representations or objections from authorised electricity operators liable to be materially affected
- This process is facilitated via the Distribution Code Review Panel (DCRP) and its associated working groups – in this case DC0079
- Currently any proposed change to the Distribution Code (or its daughter documents such as G59) needs to be approved by Ofgem (ie the Authority)

DCRP/GCRP Workgroup completed

- GC0035 Workgroup
  - Workgroup Terms of Reference for delivery to the GCRP and DCRP in July 2013
    - Review the behaviour of the Total System when subject to Frequency Changes
    - Take account of international practice and European Code development
    - Research details of RoCoF based protection settings for embedded generation at stations above 5MW
    - Investigate and quantify the risks of desensitising RoCoF based protections on embedded generators of 5MW and greater rated capacity
    - Develop a workplan for the next stage

DCRP/GCRP Workgroup completed

- GC0035 Workgroup
  - Recommended the new RoCoF setting for DG >5MW
    - Up to 0.5Hzs^{-1} and to 1Hzs^{-1} with 0.5s definite time delay
    - Base-lined against current recommended settings
    - Encompassing 'larger' distributed generation (between 5MVA and 50MVA)
    - Building on previous LoM and NVD work
    - Risk assessment completed by the University of Strathclyde
  - Proposals approved on 24 July 2014 and has been implemented; to date, setting changes on 5GW of generation has been completed

DC0079 summary

- Summary of LoM protection changes recommended:
- August 2014
  - RoCoF to be set at 1.0 Hzs^{-1}, 0.5s definite time for all >5MW generation (0.5Hzs^{-1}, 0.5s allowed for synchronous)
  - VS unchanged
- Feb 2018
  - RoCoF to be set at 1.0Hzs^{-1}, 0.5s definite time for new non-type-tested generation <5MW
  - VS banned for all new non-type-tested generation

DC007summary continued

- July 2018
  - RoCoF to be set at 1.0Hzs^{-1}, 0.5s definite time for new type-tested generation <5MW
  - VS banned for all new type-tested generation
- Proposal is now:
  - to retrospectively apply the 1.0 Hzs^{-1}, 0.5s definite time, no VS, to ALL **G59** generation
  - No need to change G83 type tested generation
  - Change the O/F setting to single stage 52.0 Hz where possible
  - The ability remains to agree different settings with the DNO in exceptional circumstances

Proposed settings for <5MW generation

RoCoF settings for Power Stations <5MW Registered Capacity		
Date of Commissioning		
Generating Plant Commissioned before 01/02/18	Settings permitted until [01/01/22]	Not to be less than K2 x 0.125 Hz/s[#] and not to be greater than 1.0Hz/s[¶#], time delay 0.5s
	Setting permitted on or after [01/01/22]	1.0Hz/s[¶#], time delay 0.5s
Generating Plant commissioned on or after 01/07/18		1.0Hz/s[¶#], time delay 0.5s

Proposed settings for ≥ 5MW generation

RoCoF[§] settings for Power Stations ≥5MW Registered Capacity			
Date of Commissioning	Small Power Stations		Medium Power Stations
	Asynchronous	Synchronous	
Generating Plant Commissioned before 01/08/164 Settings permitted until 01/08/16	1.0Hz/s[¶#], time delay 0.5sNot to be less than K2 x 0.125 Hz/s[#] and not to be greater than 1.0Hz/s[¶#], time delay 0.5s	0.5Hz/s[¶# Ω], time delay 0.5sNot to be less than K2 x 0.125 Hz/s[#] and not to be greater than 0.5Hz/s[¶# Ω], time delay 0.5s	Intertripping Expected
Generating Plant commissioned between 01/08/14 and 31/07/16 inclusive	1.0Hz/s[¶#], time delay 0.5s	0.5Hz/s[¶# Ω], time delay 0.5s	Intertripping expected
Generating Plant commissioned on or after 01/08/16	1.0Hz/s[¶#], time delay 0.5s	1.0Hz/s[¶#], time delay 0.5s	Intertripping expected

RoCoF settings for Power Stations ≥5MW Registered Capacity	
Small Power Stations	Medium Power Stations
1.0Hz/s, time delay 0.5s	Intertripping Expected

Vector Shift

Historic Vector Shift Settings		
Date of Commissioning	Small Power Stations	Medium Power Stations
Settings permitted for **Generating Plant** commissioned before 01/02/18 and allowable up to [31/12/21]. VS is not allowed from [01/01/22]	K1 x 6 degrees	Intertripping Expected
Settings permitted for **Generating Plant** commissioned on or after 01/02/18	Vector Shift not allowed as LoM in these Power Stations	Intertripping Expected

Analysing impact on existing generation through systematic risk assessment

Adam Dyśko
University of Strathclyde
Glasgow

a.dysko@strath.ac.uk

University of Strathclyde Engineering

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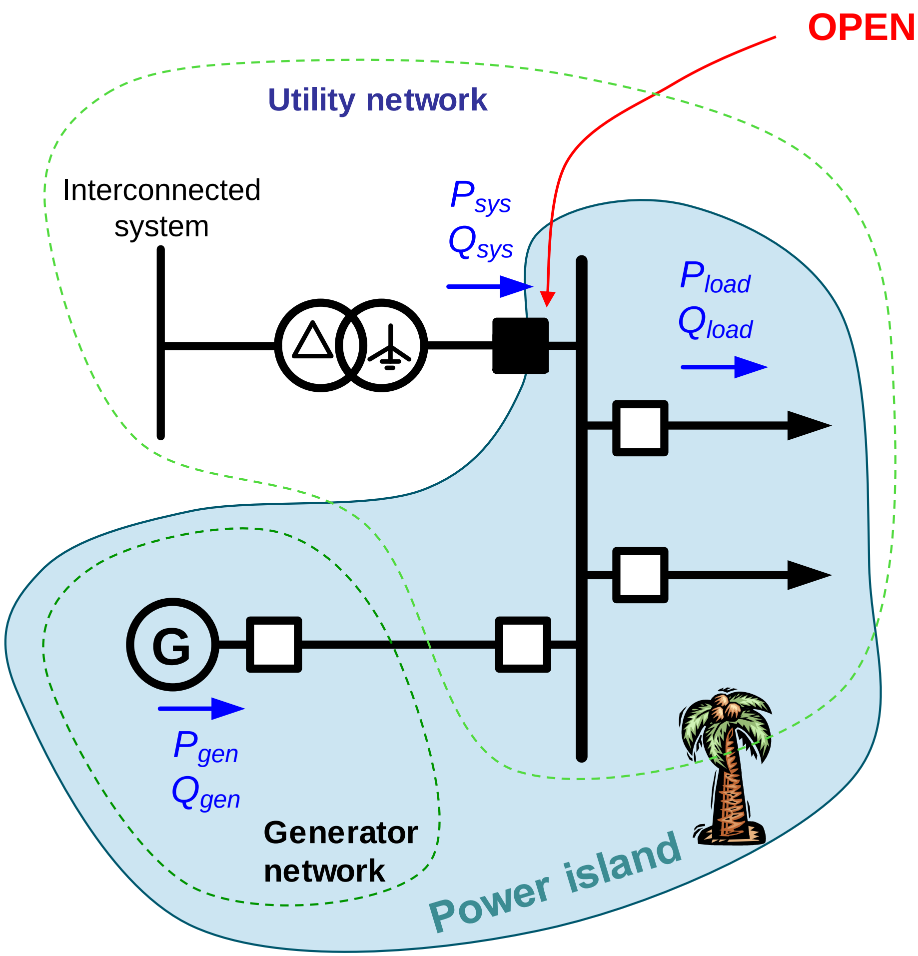
Risk assessment of the setting change

- Why is LoM risk assessment important?
- LoM risk assessement methodology
  - DG register analysis
  - Generation modelling and NDZ assessment
  - Probability tree based risk assessment
- Risk assessment outcome
  - Risk of RoCoF settings adjustment
  - Risk of disabling Vector Shift
  - Small scale PV inverter stability

Loss-of-Mains – LoM

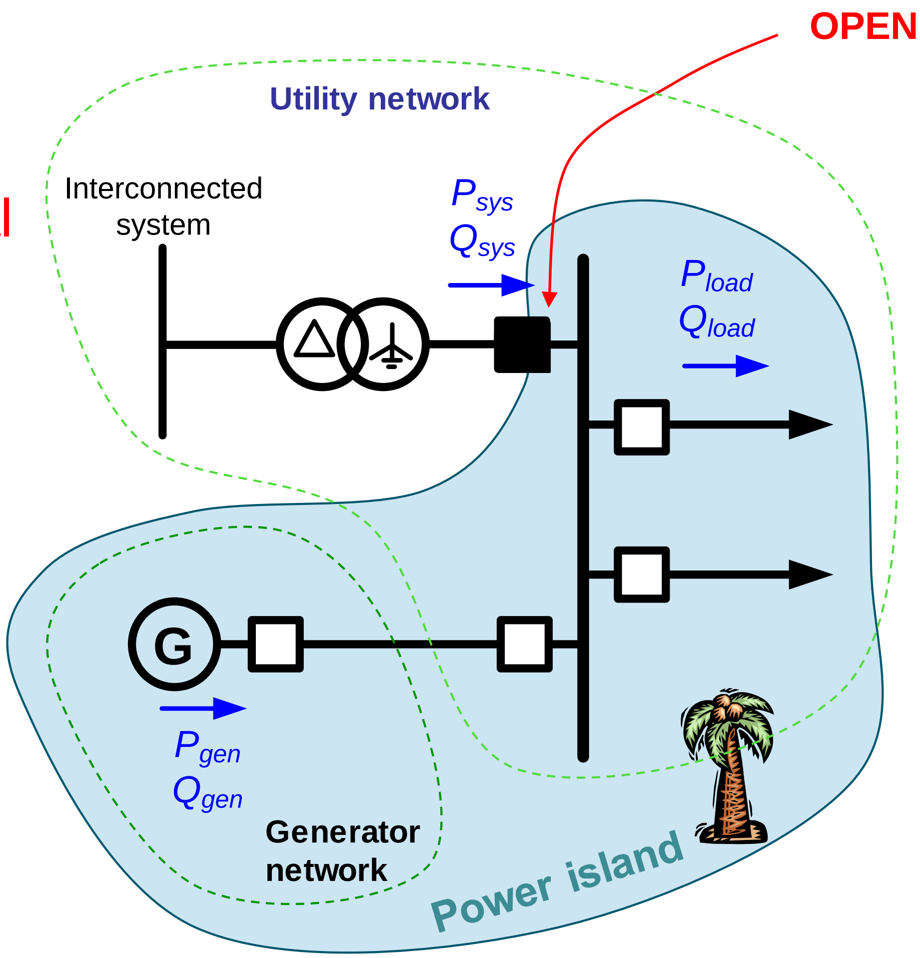
- Loss of Mains (or islanding) occurs when part of the public utility network (incorporating generation) loses connection with the rest of the system

- If LoM is not detected, then the generator could remain connected, causing a safety hazard within the network.



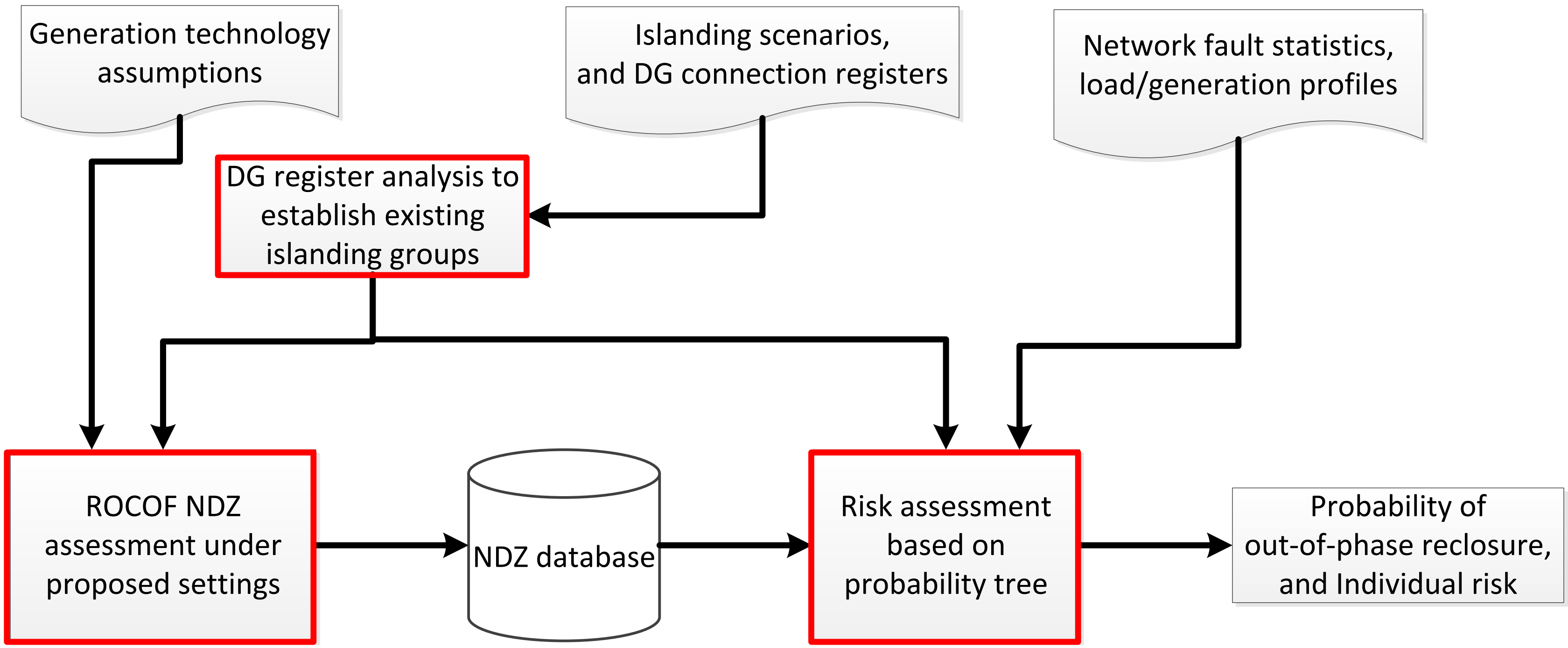
Loss-of-Mains – LoM

- Risks of operating in islanded mode
  - System can become unearthed
  - Faults in islanded mode may remain undetected (personal safety)
  - System can be live when utility personnel believe it is not energised
  - Unsynchronised reclose can occur (damage to generator)
- ⇒ Islanding is not permitted in most countries.



Risk assessment methodology*

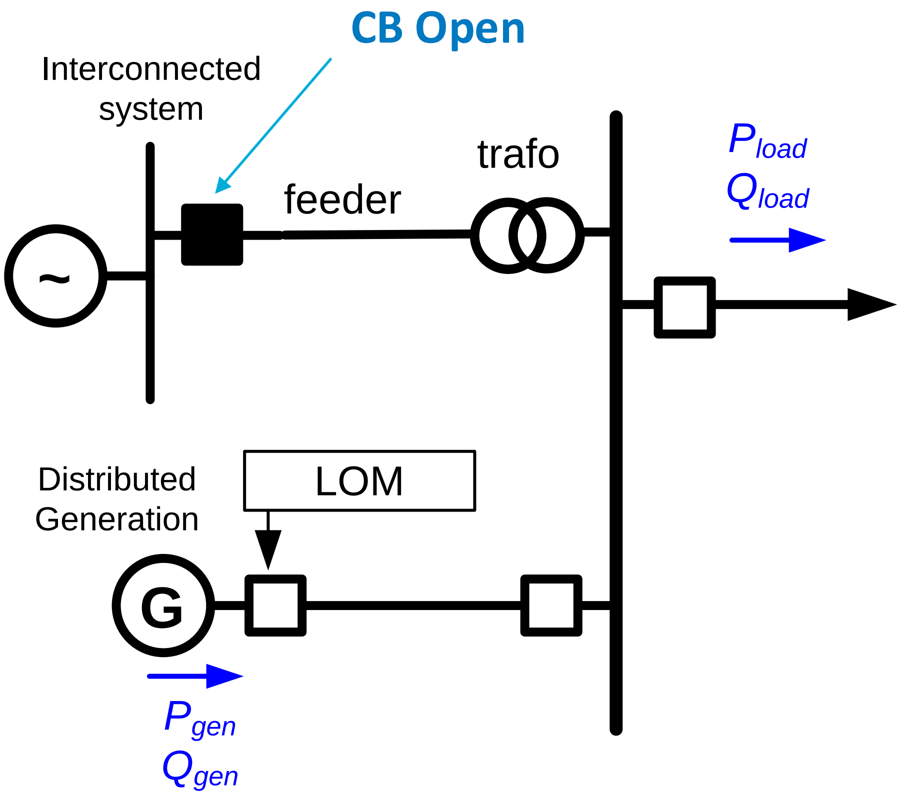
- Establishing dominant islanding generation groupings (mixes)
- Simulation based NDZ assessment
- Probability tree based risk calculation



* Similar methodology was used in early NVD risk assessment study (2008-09) for G59/2, for the earlier stages of DC0079, and also in the recent revision of the LoM settings in Northern Ireland.

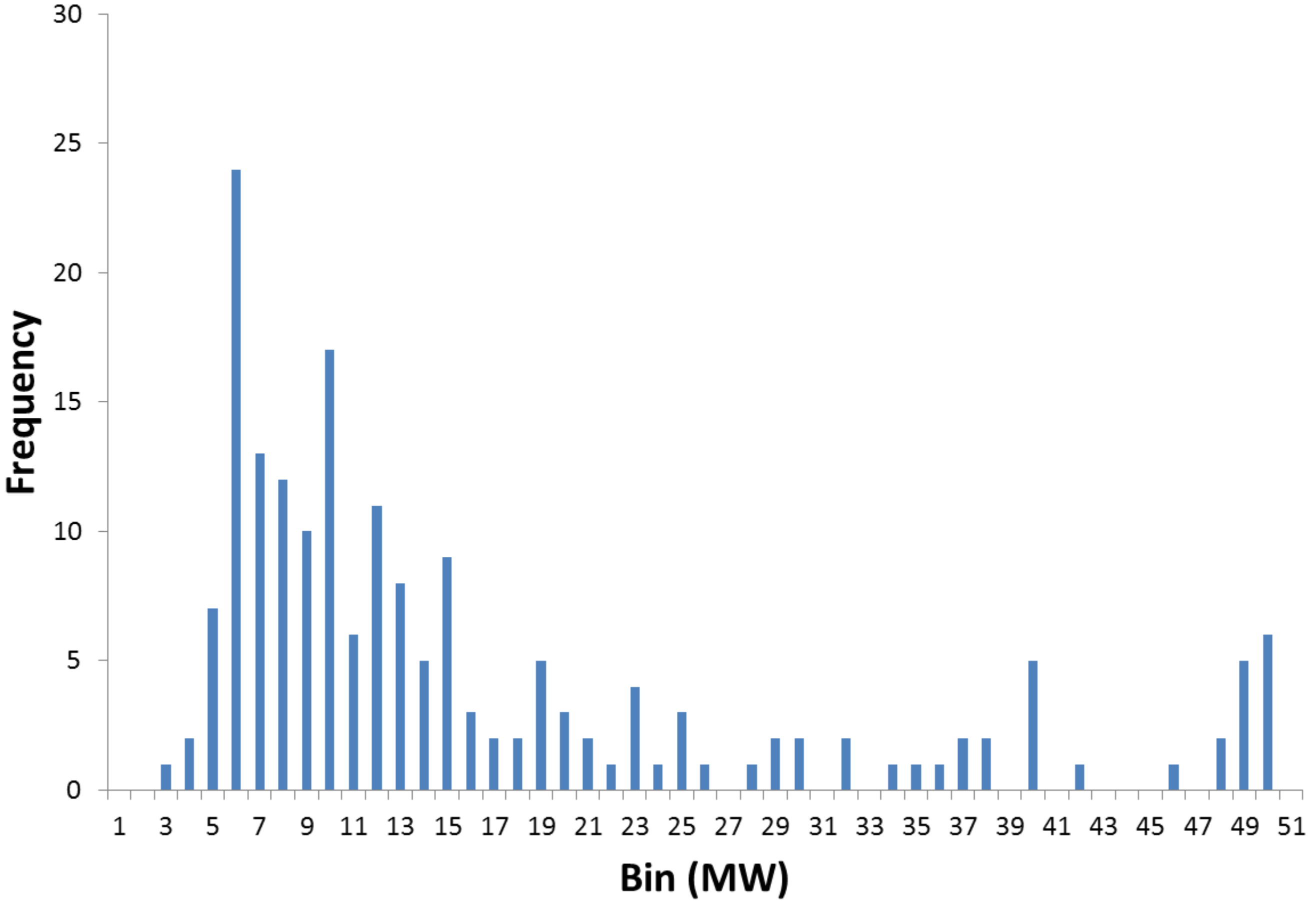
Islanding scenarios

- Phase 1 – DG capacity ≥ 5MW
  - Scenario 1:
    Loss of supply to Primary Substation
- Phase 2 – DG capacity < 5MW
  - Scenario 1:
    Loss of supply to Primary Substation
  - Scenario 2:
    Loss of individual HV feeder



Generation type and size distribution

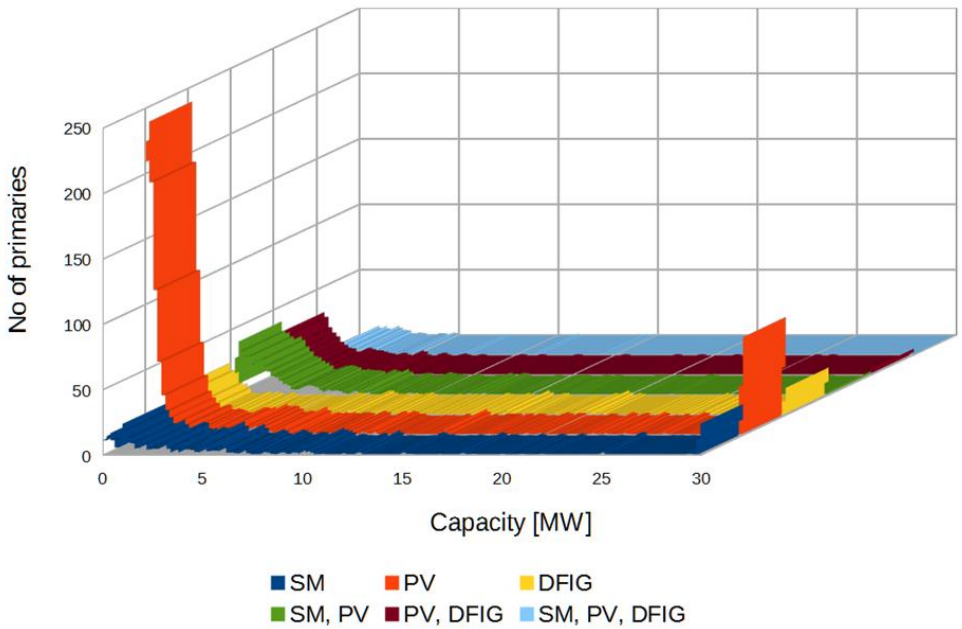
Phase 1: ≥ 5MW, Synchronous generation only, 183 sites



Generation type and size distribution

Group	Substations	Percentage
SM	346	14.4
PV	1049	43.6
DFIG	178	7.4
IM	23	1.0
PMSG	3	0.1
SM, PV	424	17.6
SM, DFIG	47	2.0
SM, IM	3	0.1
SM, PMSG	0	0.0
PV, DFIG	215	8.9
PV, IM	20	0.8
PV, PMSG	1	0.0
DFIG, IM	9	0.4
DFIG, PMSG	9	0.4
IM, PMSG	0	0.0
SM, PV, DFIG	58	2.4
SM, PV, IM	8	0.3
SM, PV, PMSG	0	0.0
SM, DFIG, IM	1	0.0
SM, DFIG, PMSG	0	0.0
SM, IM, PMSG	0	0.0
PV, DFIG, IM	12	0.5
PV. DFIG, PMSG	1	0.0
PV, IM, PMSG	0	0.0
DFIG, IM, PMSG	0	0.0
SM, PV, DFIG, IM	1	0.0
SM, PV, DFIG, PMSG	0	0.0
SM, PV, IM, PMSG	0	0.0
SM, DFIG, IM, PMSG	0	0.0
PV, DFIG, IM, PMSG	0	0.0
Total	2408	100.0

Phase 2: <5MW,
Scenario 1 – loss of supply to Primary Substation

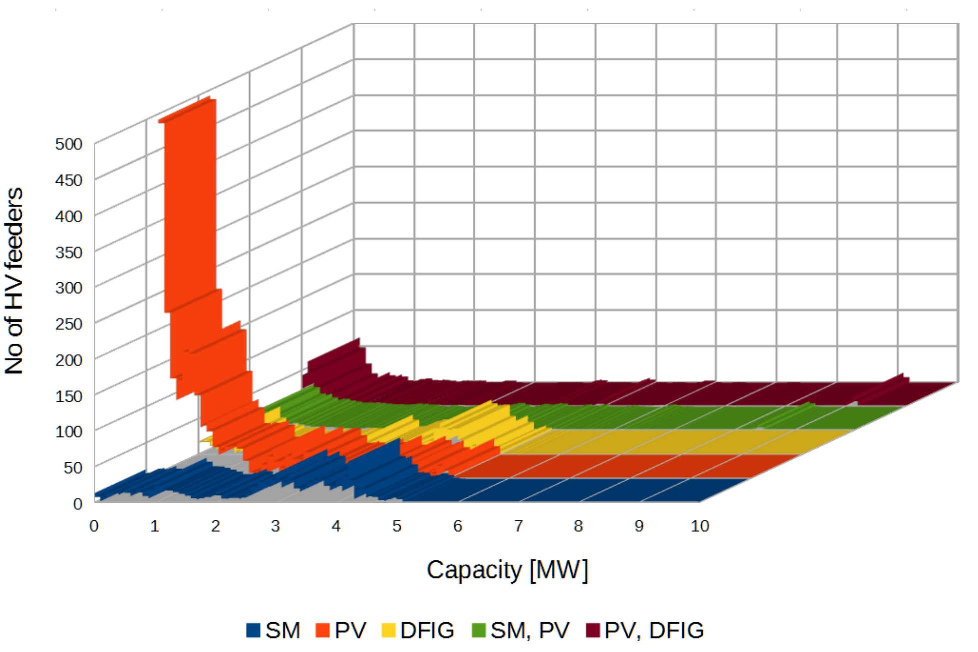


- Capacity distribution of dominant groups

Generation type and size distribution

Group	HV feeders	Percentage
SM	844	6.1
PV	11789	84.7
DFIG	520	3.7
IM	36	0.3
PMSG	1	0.0
SM, PV	260	1.9
SM, DFIG	111	0.8
SM, IM	10	0.1
SM, PMSG	0	0.0
PV, DFIG	246	1.8
PV, IM	13	0.1
PV, PMSG	1	0.0
DFIG, IM	14	0.1
DFIG, PMSG	1	0.0
IM, PMSG	0	0.0
SM, PV, DFIG	47	0.3
SM, PV, IM	9	0.1
SM, PV, PMSG	0	0.0
SM, DFIG, IM	1	0.0
SM, DFIG, PMSG	0	0.0
SM, IM, PMSG	0	0.0
PV, DFIG, IM	13	0.1
PV, DFIG, PMSG	0	0.0
PV, IM, PMSG	0	0.0
DFIG, IM, PMSG	0	0.0
SM, PV, DFIG, IM	0	0.0
SM, PV, DFIG, PMSG	0	0.0
SM, PV, IM, PMSG	0	0.0
SM, DFIG, IM, PMSG	0	0.0
PV, DFIG, IM, PMSG	0	0.0
Total	13916	100.0

Phase 2: <5MW,
Scenario 2 – loss of individual HV feeder



- Capacity distribution of dominant groups

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Assumed generation groupings (mixes)

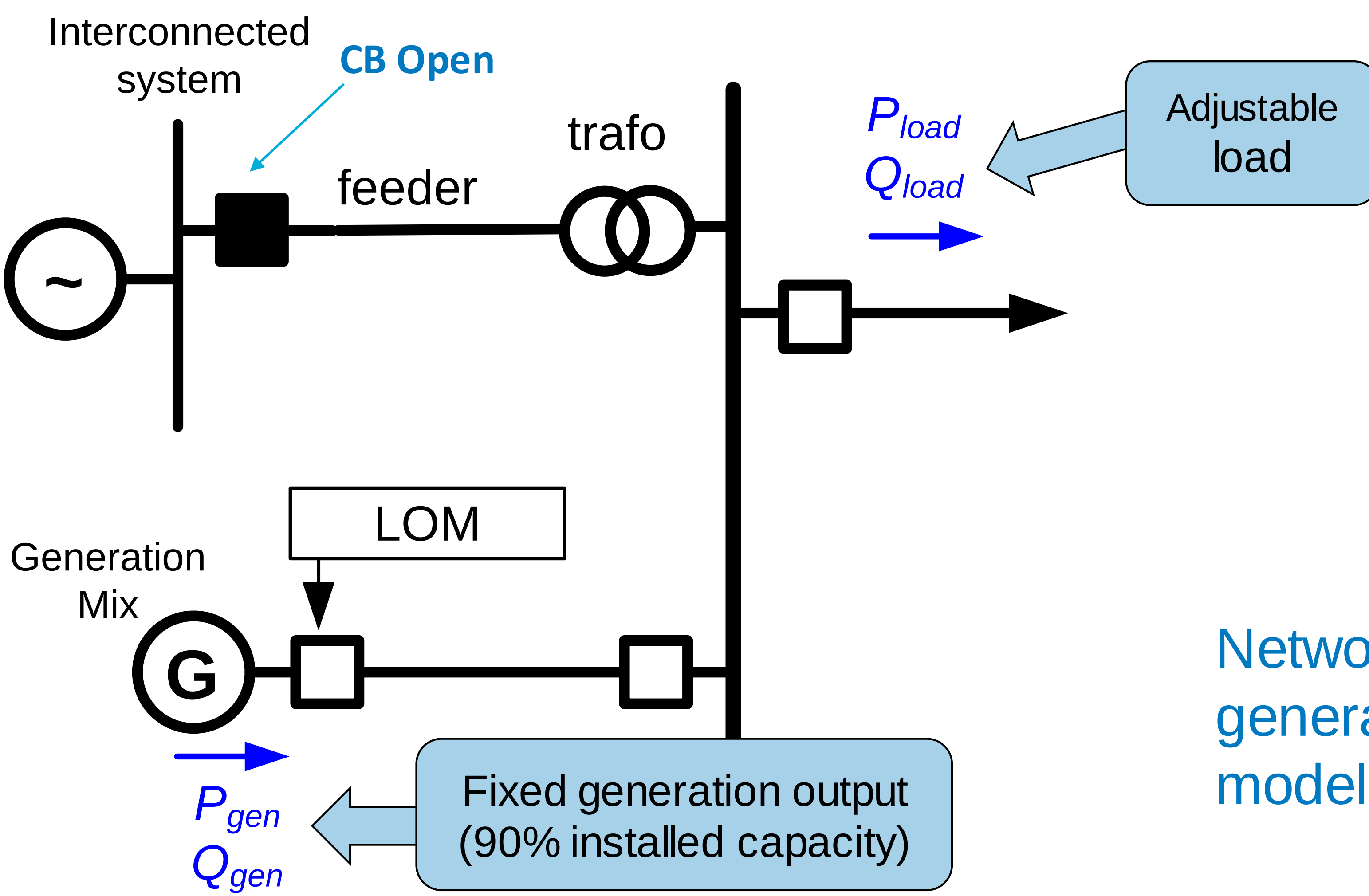
Phase 2: <5MW

Grouping Type	Generation Mix
Single	1 (100% SG)
	2 (100% PV)
	3 (100% DFIG)
Groups of 2	4 (75% SG + 25% PV)
	5 (50% SG + 50% PV)
	6 (25% SG + 75% PV)
	7 (75% PV + 25% DFIG)
	8 (50% PV + 50% DFIG)
	9 (25% PV + 75% DFIG)
Groups of 3	10 (70% SG + 15% PV + 15% DFIG)
	11 (15% SG + 70% PV + 15% DFIG)
	12 (15% SG + 15% PV + 70% DFIG)

Based on available DG connection registers covering: WPD, ENW, NPG, UKPN and SPD.

Non-detection zone (NDZ) assessment

Experimental setup



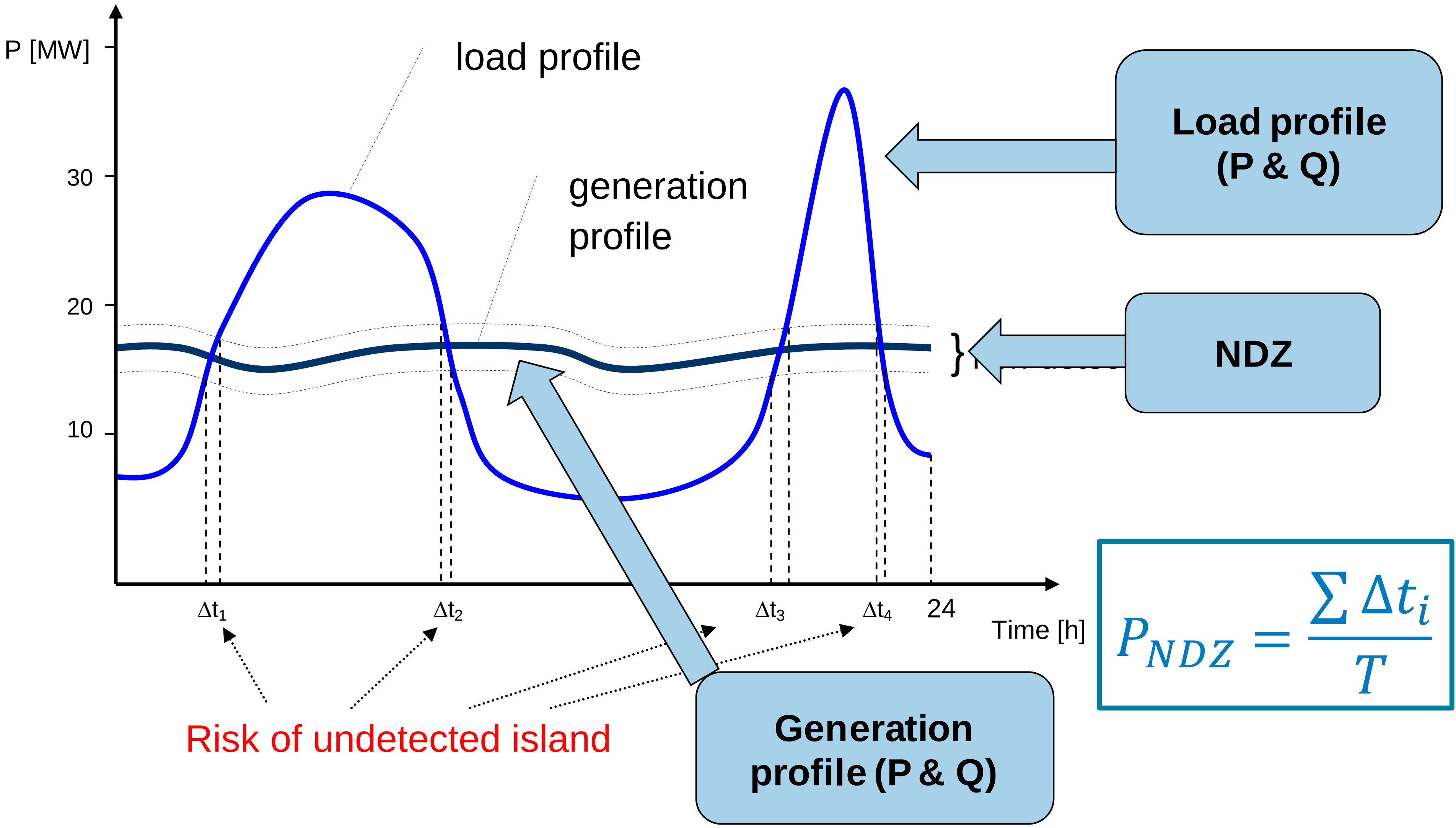
Network and generation modelling

Example RoCoF NDZ results

Phase 2: Generation Mix 1 (SM 100%)

Setting Option	NDZ_{PI} [%]	NDZ_{PE} [%]	NDZ_{QI} [%]	NDZ_{QE} [%]
1 (0.13Hz/s – 0s)	1.03	0.53	2.12	1.42
2 (0.2Hz/s – 0s)	1.03	0.78	2.45	1.92
3 (0.5Hz/s – 0.5s)	3.05	1.58	7.36	14.56
4 (1Hz/s – 0.5s)	5.85	3.56	14.09	35.20
G59 protection only				
UF/OF	6.92	3.14	12.16	23.67
UV/OV	>50%	>50%	>50%	>50%

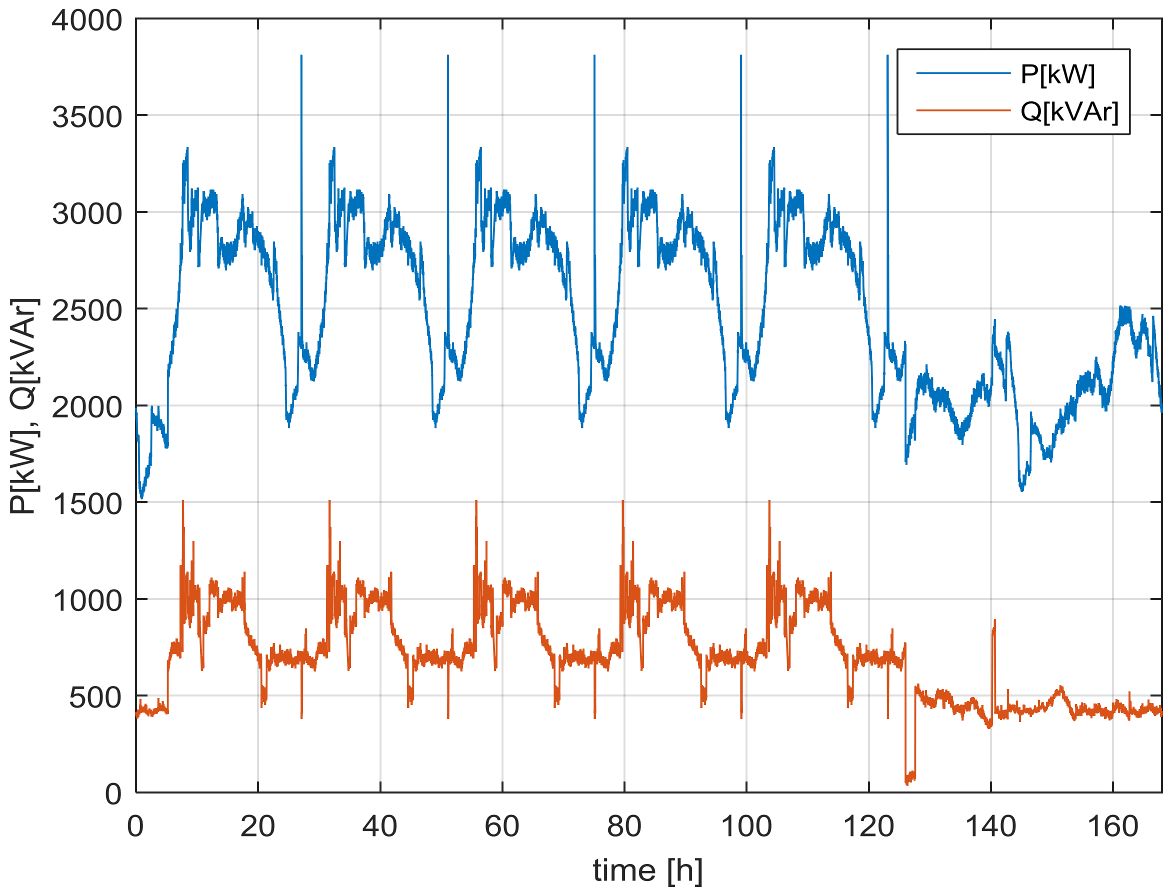
Probability of Load/Generation matching



$$P_{NDZ} = \frac{\sum \Delta t_i}{T}$$

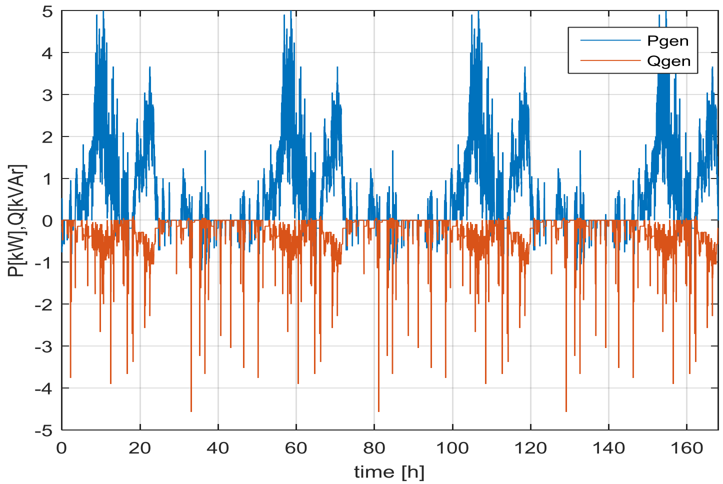
Example load profile data

- Primary substation load profile (ENW)
- Rural area (April 2013)
- 1 week duration
- 1s resolution

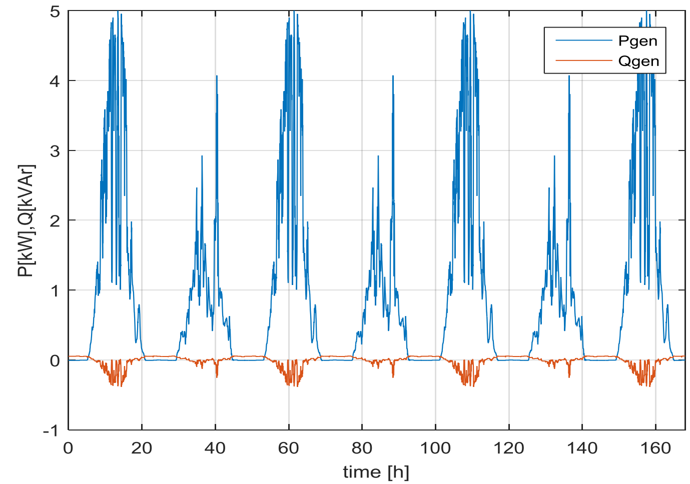


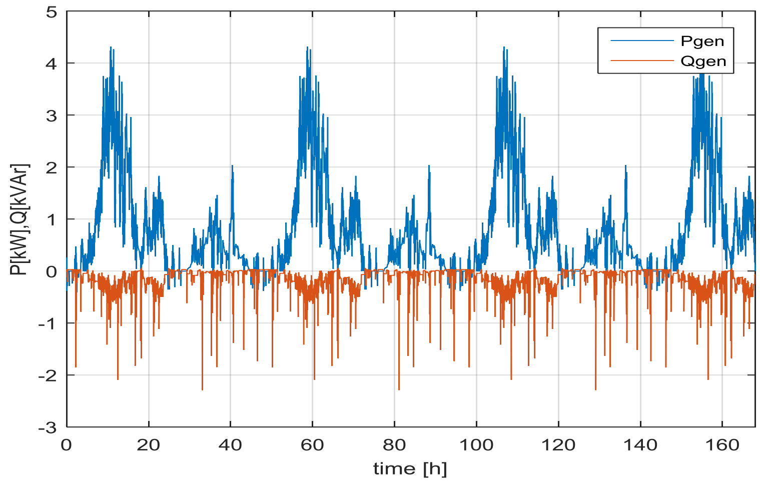
Examples of generation profile data

Mix 3 (Wind)

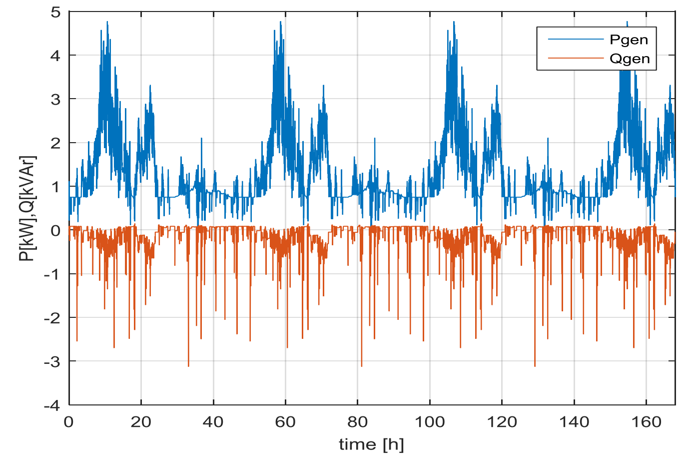


Mix 2 (PV)



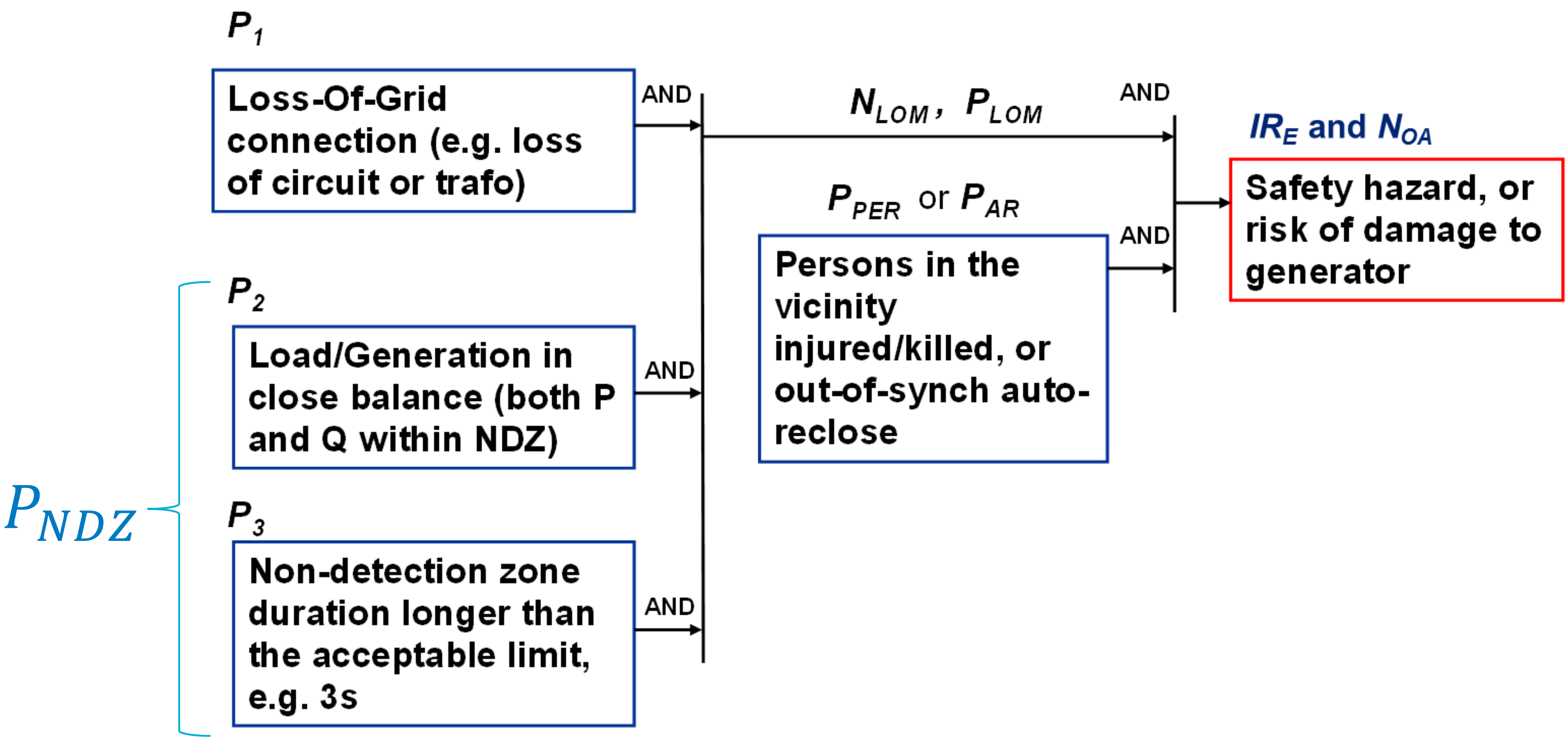


Mix 8 (50% PV + 50%Wind)



Mix 12 (15% SG+15% PV+70%Wind)

Risk Probability Tree



RoCoF settings adjustment
Risk assessment outcome

- **Phase 1: ≥5MW**

Setting Option	RoCoF [Hz/s]	Time Delay [s]	Dead Band applied	N_{LOM}	P_{LOM}	IR_E	N_{OA}
1	0.5	0	No	1.64E-01	1.04E-07	1.04E-09	1.31E-01
2	0.5	0.5	No	1.78E-01	1.13E-07	1.13E-09	1.42E-01
3	1	0	No	3.35E-01	2.13E-07	2.13E-09	2.68E-01
4	**1**	**0.5**	**No**	**3.73E-01**	**2.37E-07**	**2.37E-09**	**2.98E-01**
5	0.5	0	Yes	2.07E-01	1.31E-07	1.31E-09	1.65E-01
6	0.5	0.5	Yes	2.89E-01	1.83E-07	1.83E-09	2.31E-01
7	1	0	Yes	3.25E-01	2.06E-07	2.06E-09	2.60E-01
8	1	0.5	Yes	4.13E-01	2.62E-07	2.62E-09	3.31E-01
9	0.12	0	No	1.44E-02	9.14E-09	9.14E-11	1.15E-02
10	**0.13**	**0**	**No**	**1.92E-02**	**1.22E-08**	**1.22E-10**	**1.53E-02**
11	0.2	0	No	4.17E-02	2.65E-08	2.65E-10	3.34E-02

Risk values for P_{LOM}, IR_E and N_{OA} based on the worst scenario load profile

RoCoF settings adjustment
Risk assessment outcome

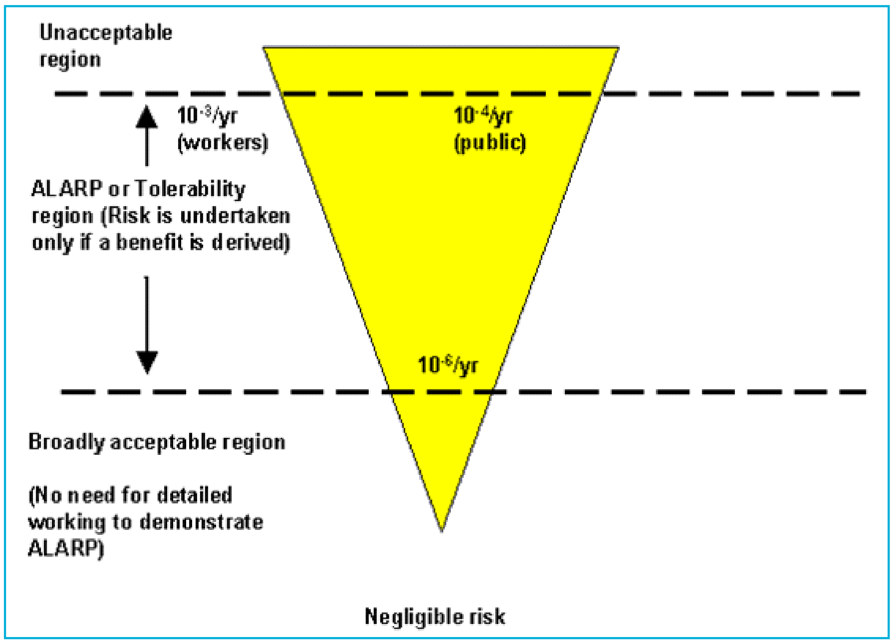
- **Phase 2: <5MW**

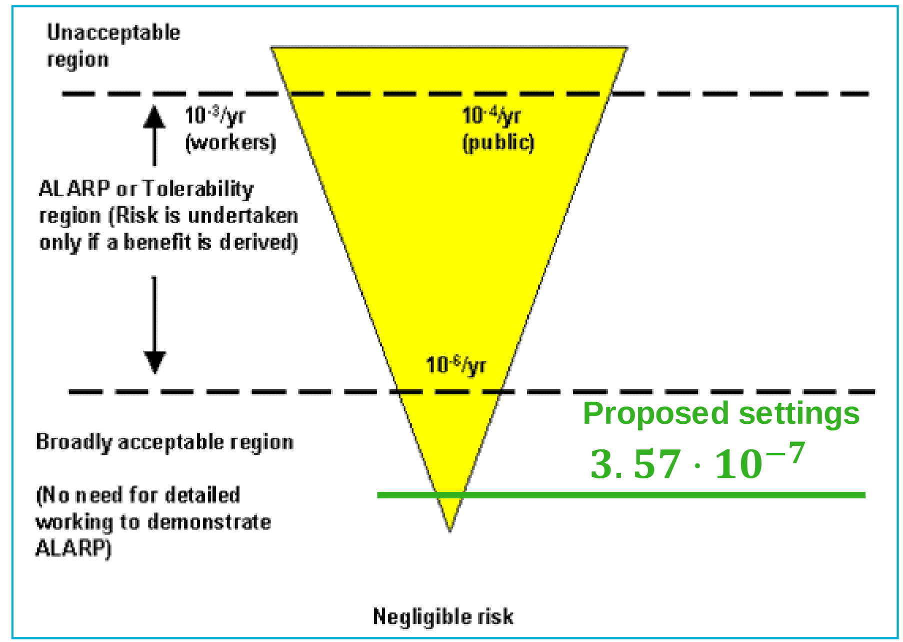
Setting Option	RoCoF [Hz/s]	Time Delay [s]	N_{LOM}	P_{LOM}	IR_E	N_{OA}
1	**0.13**	**0**	**1.66E-01**	**8.06E-08**	**8.06E-10**	**1.33E-01**
2	0.2	0	3.29E-01	1.95E-07	1.95E-09	2.64E-01
3	0.5	0.5	2.96E+01	1.87E-05	1.87E-07	2.37E+01
4	**1.0**	**0.5**	**5.66E+01**	**3.57E-05**	**3.57E-07**	**4.53E+01**

Risk values for P_{LOM}, IR_E and N_{OA} obtained through averaging of all load profiles

RoCoF settings adjustment Personal Risk

- Phase 1: ≥5MW
- Phase 2: <5MW





Proposed settings $2.37 \cdot 10^{-9}$

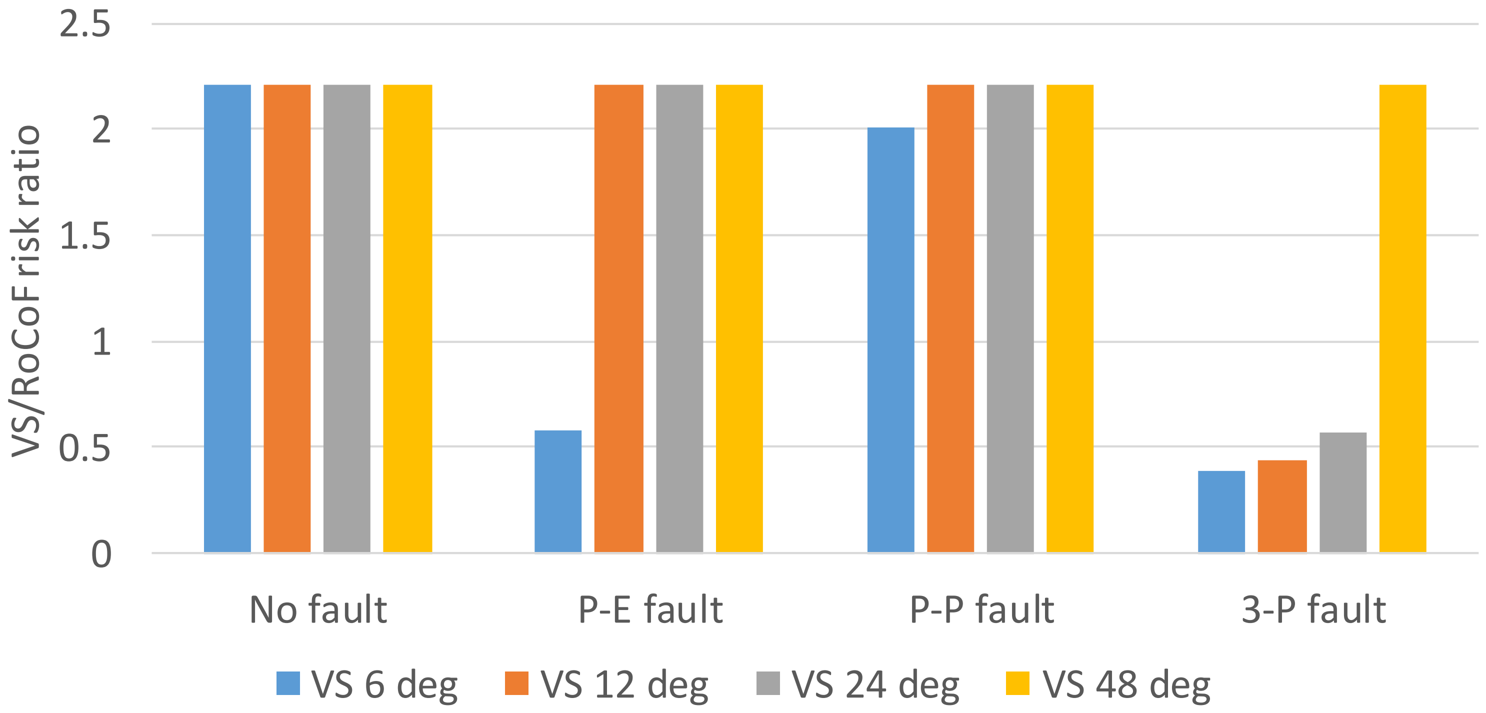
Current settings $1.22 \cdot 10^{-10}$

Current settings $8.06 \cdot 10^{-10}$

All personal risk values in broadly acceptable region

Risk assessment of VS protection

VS vs RoCoF (1 Hz/s – 500 ms delay) relative risk (based on SG and DFIG technologies)



- For settings above 6 deg VS is worse than RoCoF except for the case with a 3-phase fault.
- **Changing VS to RoCoF is preferable**.

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Can RoCoF protection be disabled ?

NDZ: Generation Mix 1 (100% SG)

LoM Setting Option	NDZ_{PI} Import [%]	NDZ_{PE} Export [%]	NDZ_{QI} Import [%]	NDZ_{QE} Export [%]
RoCoF				
0.13 Hz/s	1.03	0.53	2.12	1.42
0.2 Hz/s	1.03	0.78	2.45	1.92
0.5 Hz/s, 0.5 s	3.05	1.58	7.36	14.56
1 Hz/s, 0.5 s	**5.85**	3.56	14.09	35.20
VS: 12^{O}(1phe fault)	>50	>50	>50	>50
OF, UF, OV, UV				
UF/OF	**6.92**	**3.14**	**12.16**	**23.67**
UV/OV	>50	>50	>50	>50
NDZ increase ->	**1.07**	0	0	0

- Increase of risk expected compared to RoCoF (1 Hz/s, 0.5 s) – albeit small.

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Can RoCoF protection be disabled ?

NDZ: Generation Mix 2 (100% IC)

LoM Setting Option	NDZ_{PI} Import [%]	NDZ_{PE} Export [%]	NDZ_{QI} Import [%]	NDZ_{QE} Export [%]
RoCoF				
0.13 Hz/s	0	0	0	0
0.2 Hz/s	0	0	0	0
0.5 Hz/s, 0.5 s	>50	>50	>50	>50
1 Hz/s, 0.5 s	>50	>50	>50	>50
OF, UF, OV, UV				
UF/OF	**0.65**	**0.87**	**0.28**	**0.43**
UV/OV	16.49	17.13	8.32	4.35
NDZ increase ->	0	0	0	0

- No increase of risk expected compared to RoCoF (1 Hz/s, 0.5 s).

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Can RoCoF protection be disabled ?

NDZ: Generation Mix 3 (100% DFIG)

LoM Setting Option	NDZ_{PI} Import [%]	NDZ_{PE} Export [%]	NDZ_{QI} Import [%]	NDZ_{QE} Export [%]
RoCoF				
0.13 Hz/s	0	0	0	0
0.2 Hz/s	0	0	0	0
0.5 Hz/s, 0.5 s	0.83	1.44	4.68	2.29
1 Hz/s, 0.5 s	**1.98**	**2.38**	**7.20**	**5.04**
VS: 12^{O}(1phe fault)	>50	31.041	>50	>50
OF, UF, OV, UV				
UF/OF	**3.97**	**2.69**	**8.69**	**9.98**
UV/OV	8.18	12.02	>50	17.92
NDZ increase ->	**1.99**	**0.31**	**1.49**	**4.94**

- Increase of risk expected compared to RoCoF (1 Hz/s, 0.5 s).

Can RoCoF protection be disabled ?

NDZ: Generation Mix 4 (75% SG + 25% PV)

LoM Setting Option	NDZ_{PI} Import [%]	NDZ_{PE} Export [%]	NDZ_{QI} Import [%]	NDZ_{QE} Export [%]
RoCoF				
0.13 Hz/s	0.92	0.32	1.27	1.73
0.2 Hz/s	0.92	0.32	1.99	1.9
0.5 Hz/s, 0.5 s	4.86	3.19	12.17	24.38
1 Hz/s, 0.5 s	6.78	5.32	15.96	>50%
OF, UF, OV, UV				
UF/OF	**5.37**	**2.49**	**8.65**	**17.45**
UV/OV	>50%	>50%	>50%	>50%
NDZ increase ->	0	0	0	0

- No increase of risk expected compared to RoCoF (1 Hz/s, 0.5 s).

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Can RoCoF protection be disabled ?

NDZ: Generation Mix 5 (50% SG + 50% PV)

LoM Setting Option	*NDZ_{PI}* Import [%]	*NDZ_{PE}* Export [%]	*NDZ_{QI}* Import [%]	*NDZ_{QE}* Export [%]
RoCoF				
0.13 Hz/s	0	0	0	0
0.2 Hz/s	0	0	0	0
0.5 Hz/s, 0.5 s	4.55	4.30	12.75	45.61
1 Hz/s, 0.5 s	6.34	4.79	16.03	>50%
OF, UF, OV, UV				
UF/OF	**3.85**	**1.66**	**5.26**	**11.23**
UV/OV	>50%	>50%	>50%	>50%
NDZ increase ->	0	0	0	0

- No increase of risk expected compared to RoCoF (1 Hz/s, 0.5 s).

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Can RoCoF protection be disabled ?

NDZ: Generation Mix 6 (25% SG + 75% PV)

LoM Setting Option	NDZ_{PI} Import [%]	NDZ_{PE} Export [%]	NDZ_{QI} Import [%]	NDZ_{QE} Export [%]
RoCoF				
0.13 Hz/s	0	0	0	0
0.2 Hz/s	0	0	0	0
0.5 Hz/s, 0.5 s	4.77	18.79	15.13	17.37
1 Hz/s, 0.5 s	5.58	18.76	15.13	21.57
OF, UF, OV, UV				
UF/OF	**2.43**	**1.10**	**2.31**	**6.33**
UV/OV	>50%	>50%	>50%	>50%
NDZ increase ->	0	0	0	0

- No increase of risk expected compared to RoCoF (1 Hz/s, 0.5 s).

Can RoCoF protection be disabled ?

NDZ: Generation Mix 7 (75% PV + 25% DFIG)

LoM Setting Option	NDZ_{PI} Import [%]	NDZ_{PE} Export [%]	NDZ_{QI} Import [%]	NDZ_{QE} Export [%]
RoCoF				
0.13 Hz/s	0	0	0	0
0.2 Hz/s	0	0	0	0
0.5 Hz/s, 0.5 s	>50%	>50%	>50%	46.54
1 Hz/s, 0.5 s	>50%	>50%	>50%	46.54
OF, UF, OV, UV				
UF/OF	**2.21**	**0.47**	**1.06**	**2.59**
UV/OV	40.22	14.13	>50%	4.38
NDZ increase ->	0	0	0	0

- No increase of risk expected compared to RoCoF (1 Hz/s, 0.5 s).

Can RoCoF protection be disabled ?

NDZ: Generation Mix 8 (50% PV + 50% DFIG)

LoM Setting Option	NDZ_{PI} Import [%]	NDZ_{PE} Export [%]	NDZ_{QI} Import [%]	NDZ_{QE} Export [%]
RoCoF				
0.13 Hz/s	0	0	0	0
0.2 Hz/s	0	0	0	0
0.5 Hz/s, 0.5 s	>50%	>50%	>50%	>50%
1 Hz/s, 0.5 s	>50%	>50%	>50%	>50%
OF, UF, OV, UV				
UF/OF	>50%	**1.08**	**2.69**	**4.83**
UV/OV	**20.08**	21.23	>50%	>50%
NDZ increase ->	0	0	0	0

- No increase of risk expected compared to RoCoF (1 Hz/s, 0.5 s).

Can RoCoF protection be disabled ?

NDZ: Generation Mix 9 (25% PV + 75% DFIG)

LoM Setting Option	NDZ_{PI} Import [%]	NDZ_{PE} Export [%]	NDZ_{QI} Import [%]	NDZ_{QE} Export [%]
RoCoF				
0.13 Hz/s	0	0	0	0
0.2 Hz/s	0	0	0	0
0.5 Hz/s, 0.5 s	>50%	>50%	>50%	>50%
1 Hz/s, 0.5 s	>50%	>50%	>50%	>50%
OF, UF, OV, UV				
UF/OF	>50%	**1.77**	**5.41**	**7.02**
UV/OV	**6.11**	18.71	39.21	12.33
NDZ increase ->	0	0	0	0

- No increase of risk expected compared to RoCoF (1 Hz/s, 0.5 s).

Can RoCoF protection be disabled ?

NDZ: Generation Mix 10 (70% SG + 15% PV + 15% DFIG)

LoM Setting Option	NDZ_{PI} Import [%]	NDZ_{PE} Export [%]	NDZ_{QI} Import [%]	NDZ_{QE} Export [%]
RoCoF				
0.13 Hz/s	0.34	0.41	1.57	1.39
0.2 Hz/s	0.60	0.41	2.01	2.16
0.5 Hz/s, 0.5 s	>50%	2.18	9.69	>50%
1 Hz/s, 0.5 s	>50%	>50%	14.87	>50%
OF, UF, OV, UV				
UF/OF	**5.23**	**2.45**	**10.14**	**19.24**
UV/OV	>50%	>50%	>50%	>50%
NDZ increase ->	0	0	0	0

- No increase of risk expected compared to RoCoF (1 Hz/s, 0.5 s).

Can RoCoF protection be disabled ?

NDZ: Generation Mix 11 (15% SG + 70% PV + 15% DFIG)

LoM Setting Option	NDZ_{PI} Import [%]	NDZ_{PE} Export [%]	NDZ_{QI} Import [%]	NDZ_{QE} Export [%]
RoCoF				
0.13 Hz/s	0	0	0	0
0.2 Hz/s	0	0	0	0
0.5 Hz/s, 0.5 s	>50%	>50%	>50%	>50%
1 Hz/s, 0.5 s	>50%	>50%	>50%	>50%
OF, UF, OV, UV				
UF/OF	**2.60**	**0.93**	**2.77**	**6.44**
UV/OV	>50%	>50%	>50%	>50%
NDZ increase ->	0	0	0	0

- No increase of risk expected compared to RoCoF (1 Hz/s, 0.5 s).

Can RoCoF protection be disabled ?

NDZ: Generation Mix 12 (15% PV + 15% PV + 70% DFIG)

LoM Setting Option	NDZ_{PI} Import [%]	NDZ_{PE} Export [%]	NDZ_{QI} Import [%]	NDZ_{QE} Export [%]
RoCoF				
0.13 Hz/s	0	0	0	0
0.2 Hz/s	0	0	0	0
0.5 Hz/s, 0.5 s	>50%	>50%	7.52	>50%
1 Hz/s, 0.5 s	>50%	>50%	10.63	>50%
OF, UF, OV, UV				
UF/OF	**3.80**	**2.29**	**8.93**	**12.78**
UV/OV	>50%	33.75	>50%	12.78
NDZ increase ->	0	0	0	0

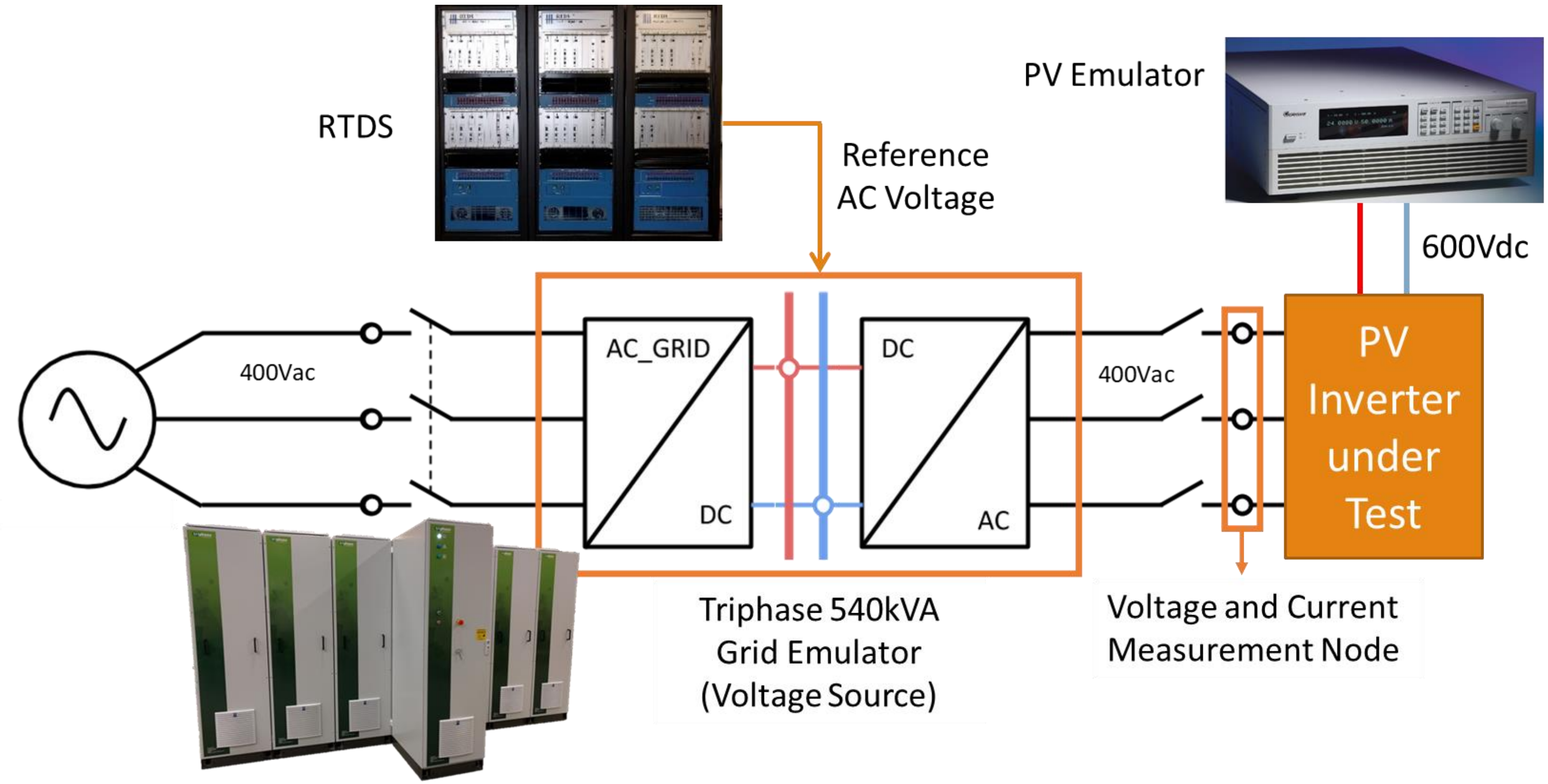
- No increase of risk expected compared to RoCoF (1 Hz/s, 0.5 s).

Can RoCoF protection be disabled ?

- After analysing NDZ values for the three prevailing technologies (SG, DIFG and IC, also including their mixes) it can be concluded that an increase of risk could be expected when disabling RoCoF protection for SG and DIFIG generation only, i.e. risk compared to the recommended RoCoF setting of 1 Hz/s, 0.5 s delay.
- Therefore, for generating technologies other than SG and DIFIG, in cases where LoM protection cannot easily be changed to RoCoF setting of 1 Hz/s, 0.5 s delay, the LoM protection can be disabled (providing frequency and voltage protection are in place).
- In some situations disabling RoCoF could perhaps also be permitted on SG generation as the NDZ difference is small. This is particularly the case when there is an existing or anticipated presence of inverter connected generation in the vicinity.

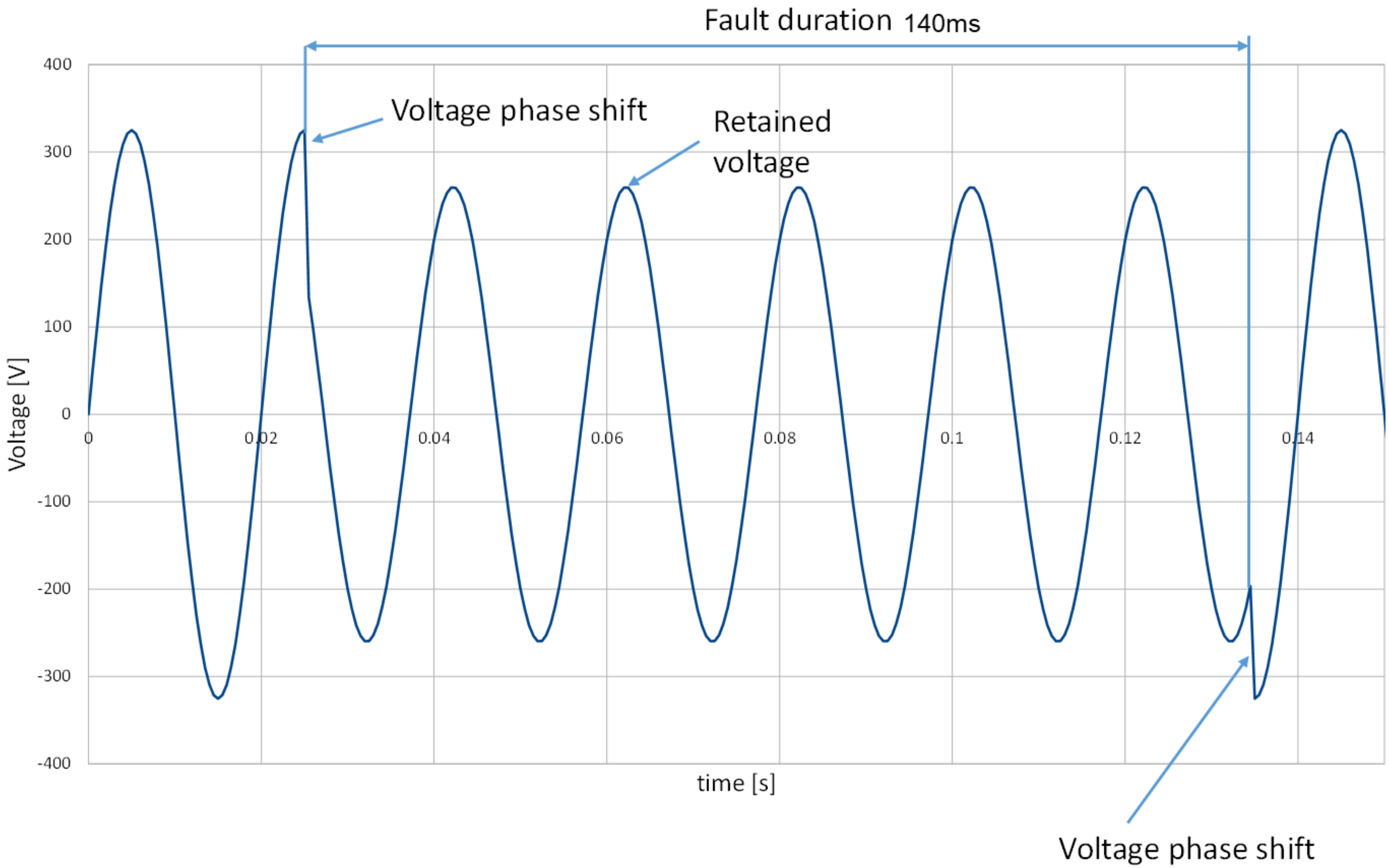
LV PV inverter testing – VS events

- Five single phase and two 3-phase inverters tested
- Voltage phasor phase shifts up to 60° applied
- Voltage step change down to 0% retained voltage applied
- Two different loading levels

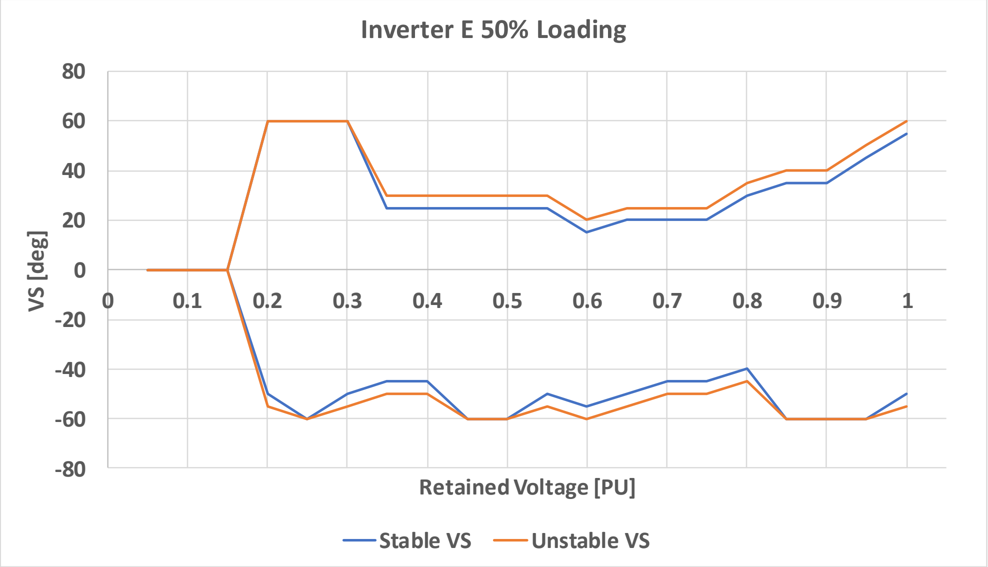


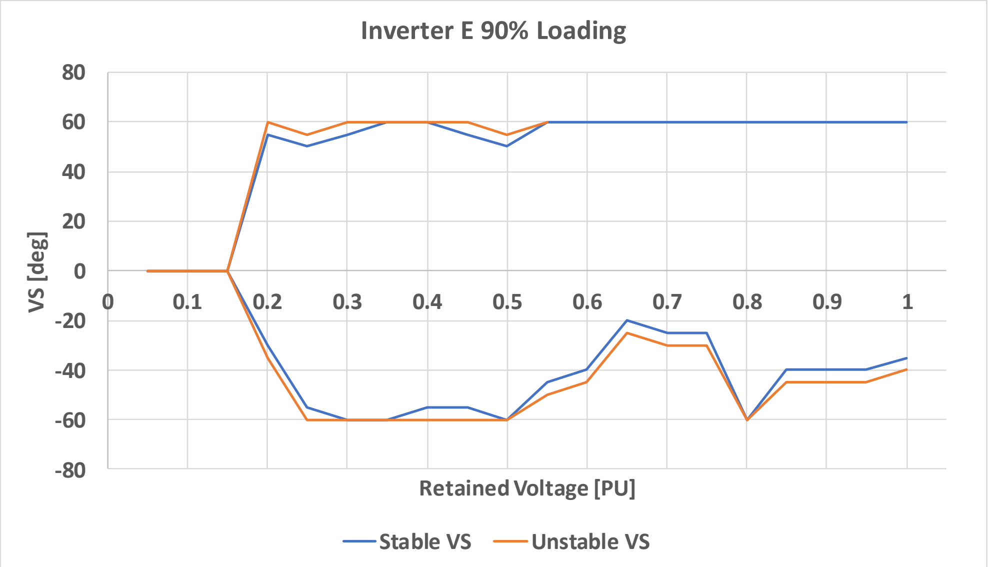
LV PV inverter testing – VS events

- Synthesized waveform



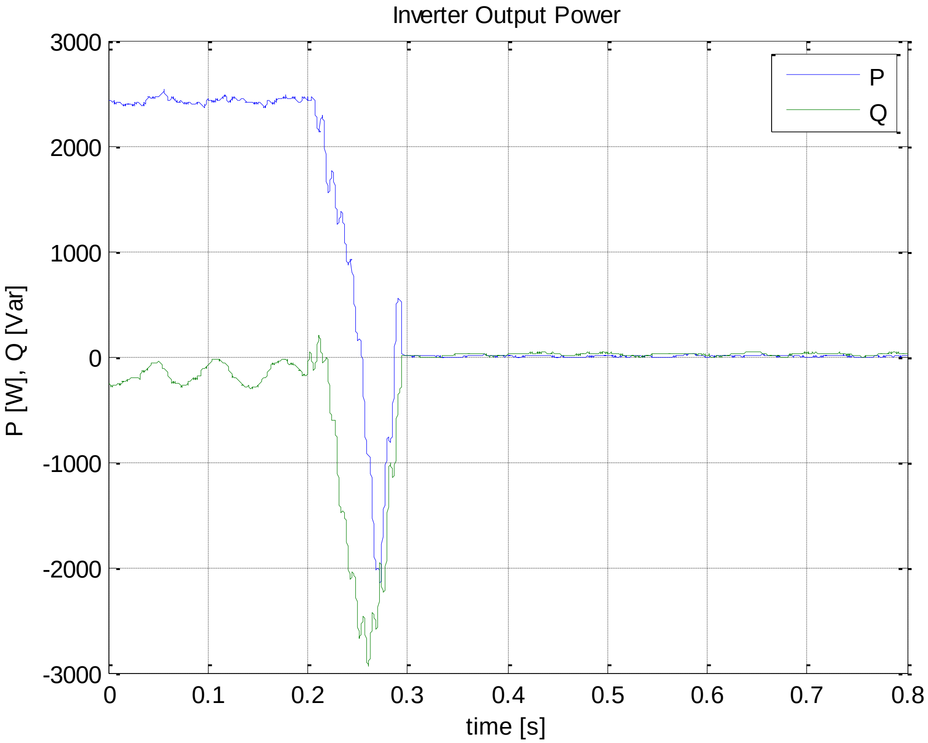
Example inverter performance



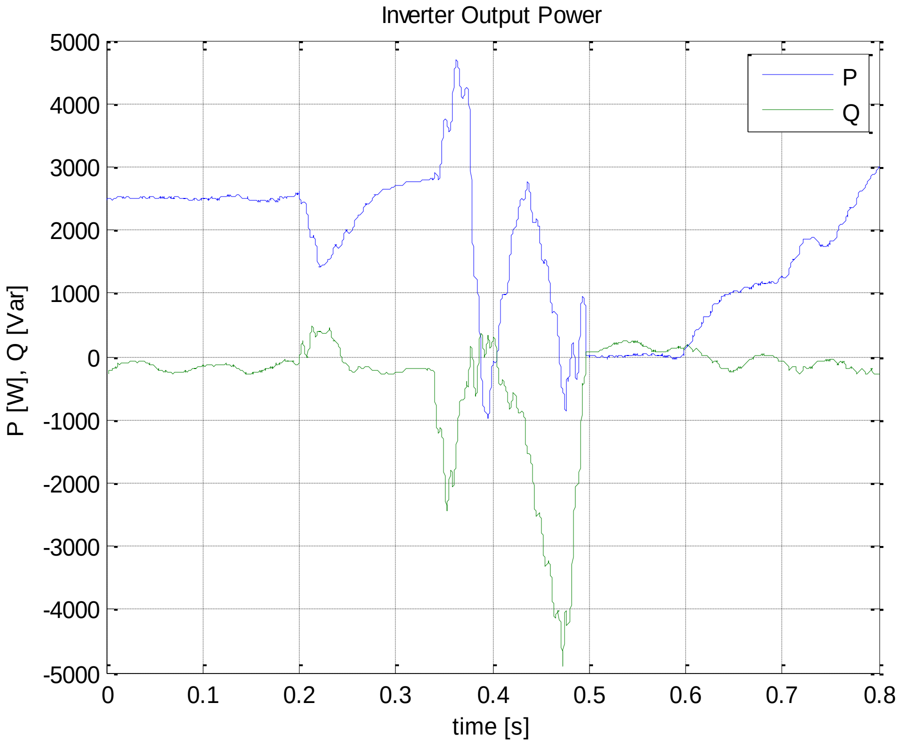


Example inverter performance

- Unstable case



- Stable case



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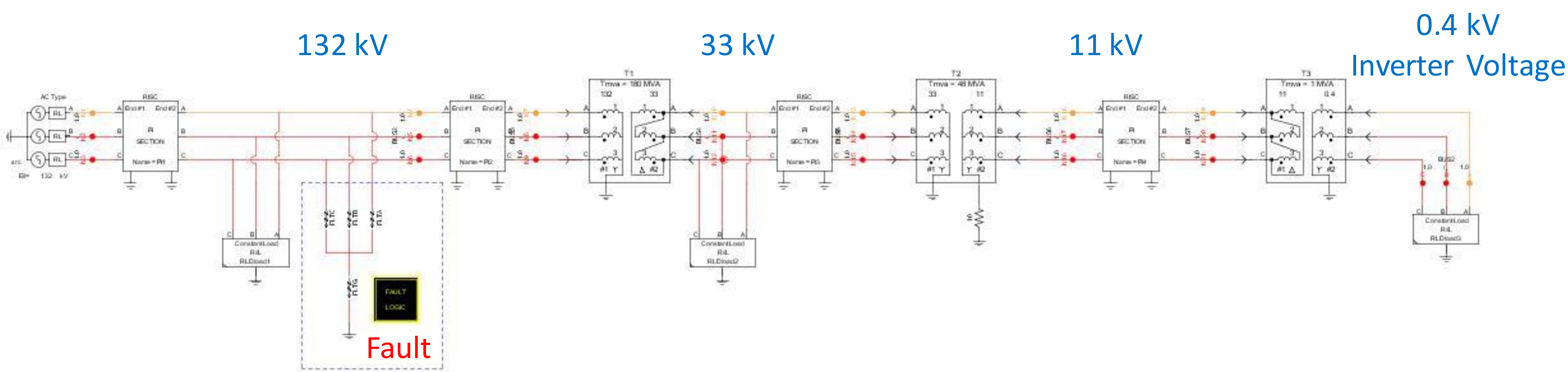
Unsymmetrical Transmission Fault Testing

- 132kV / 33kV / 11kV / 400 V system is modelled in RTDS/RSCAD.
- A fault (P-E, P-P or P-P-E) is applied at 132 kV level (solid and 1Ω resistive) for 0.14s.
- The LV signals is used as the Triphase output reference.



LV PV inverter testing – key findings

- The inverters exhibited a wide range of behaviour under voltage magnitude and VS testing.
- Generally, inverters remain connected with higher retained voltages.
- The output power is heavily influenced by the retained voltage, but some inverters stop exporting real power for the duration of the event followed by a fast recovery.
- Three out of seven inverters remained connected for tests between 0-100% retained voltage and up to $\pm 60^{\circ}$ VS.
- All inverters remained connected during G83 recommended 50° VS type testing.
- One three-phase inverter remained connected during unsymmetrical faults, while the other tripped.

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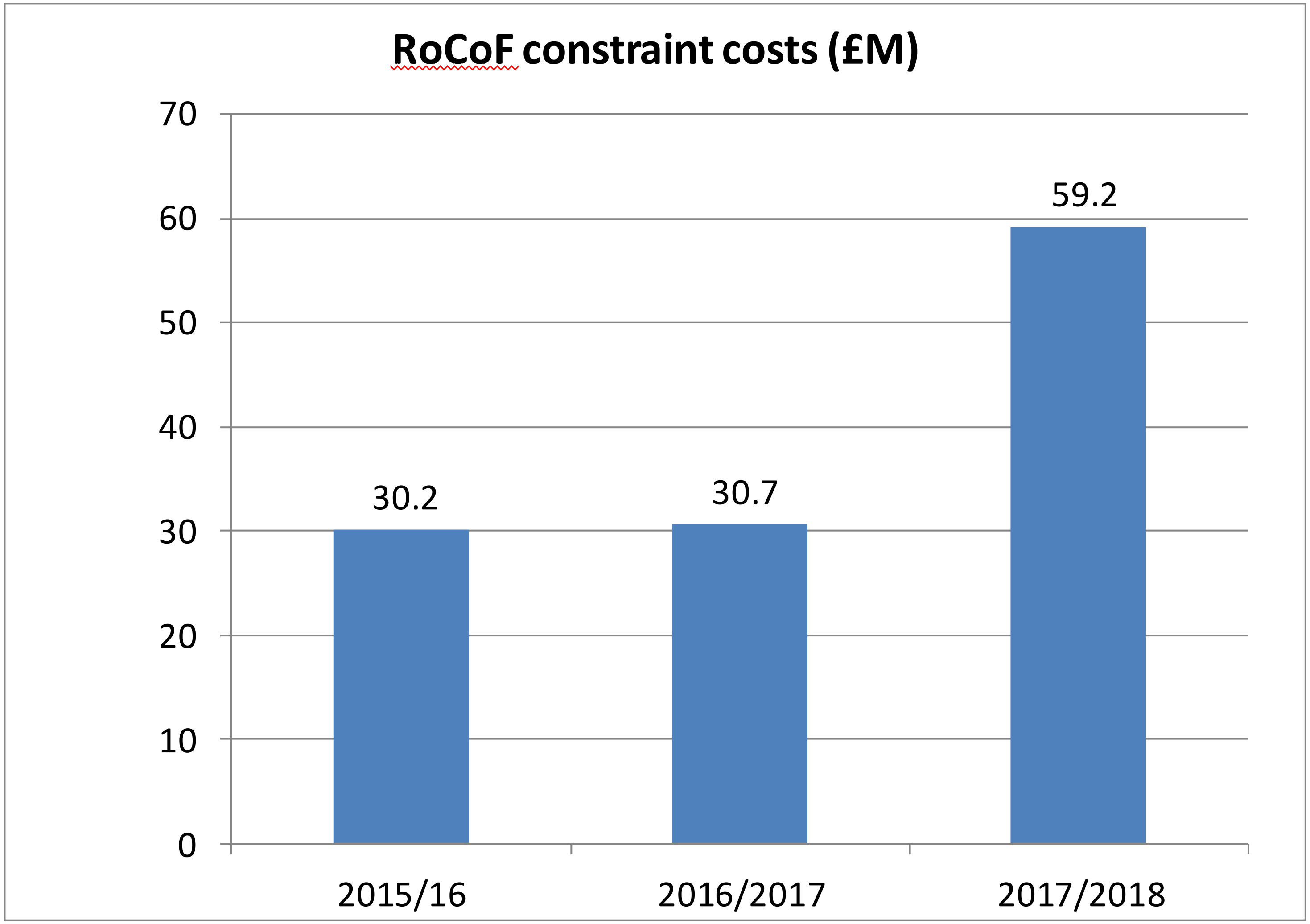
Summary

- Personal risks related to the proposed change of settings of the RoCoF based LoM protection are all within the broadly acceptable region (i.e. $<10^{-6}$)
- NDZ evaluation of VS protection demonstrated very poor sensitivity for settings above 6°, meaning that most generation fitted with VS in effect has no LoM.
- Based on NDZ values for RoCoF protection, in cases where RoCoF with recommended settings cannot be easily applied, it is acceptable to disable LoM protection except for SG and DFIG.
- Single-phase PV inverters remain stable under VS events up to 50°. Some three-phase inverters may disconnect under imbalanced transmission system faults.

DC0079 retrospective change cost benefit analysis

Past RoCoF Constraint Costs



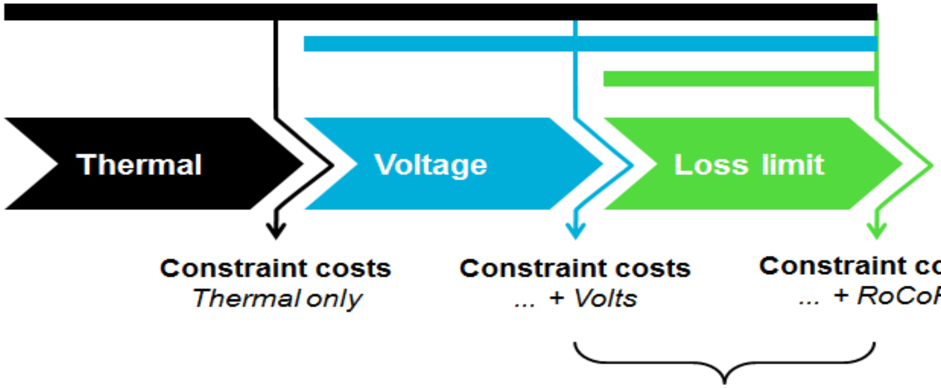
Forecasting Model

- BID3 Economic Model
  - Pan-European Market Model
  - Used for the Network Options Assessment
- Typically used for assessing network reinforcement options
- New developments are allowing us to start to investigate other operability constraints
  - Real-time voltage ‘rules’
    - Area unit constraints on synchronous generators
  - Large loss risk limit
    - Loss risk size constraint given RoCoF limit of 0.125 Hz/s

Calculating RoCoF Constraint Cost

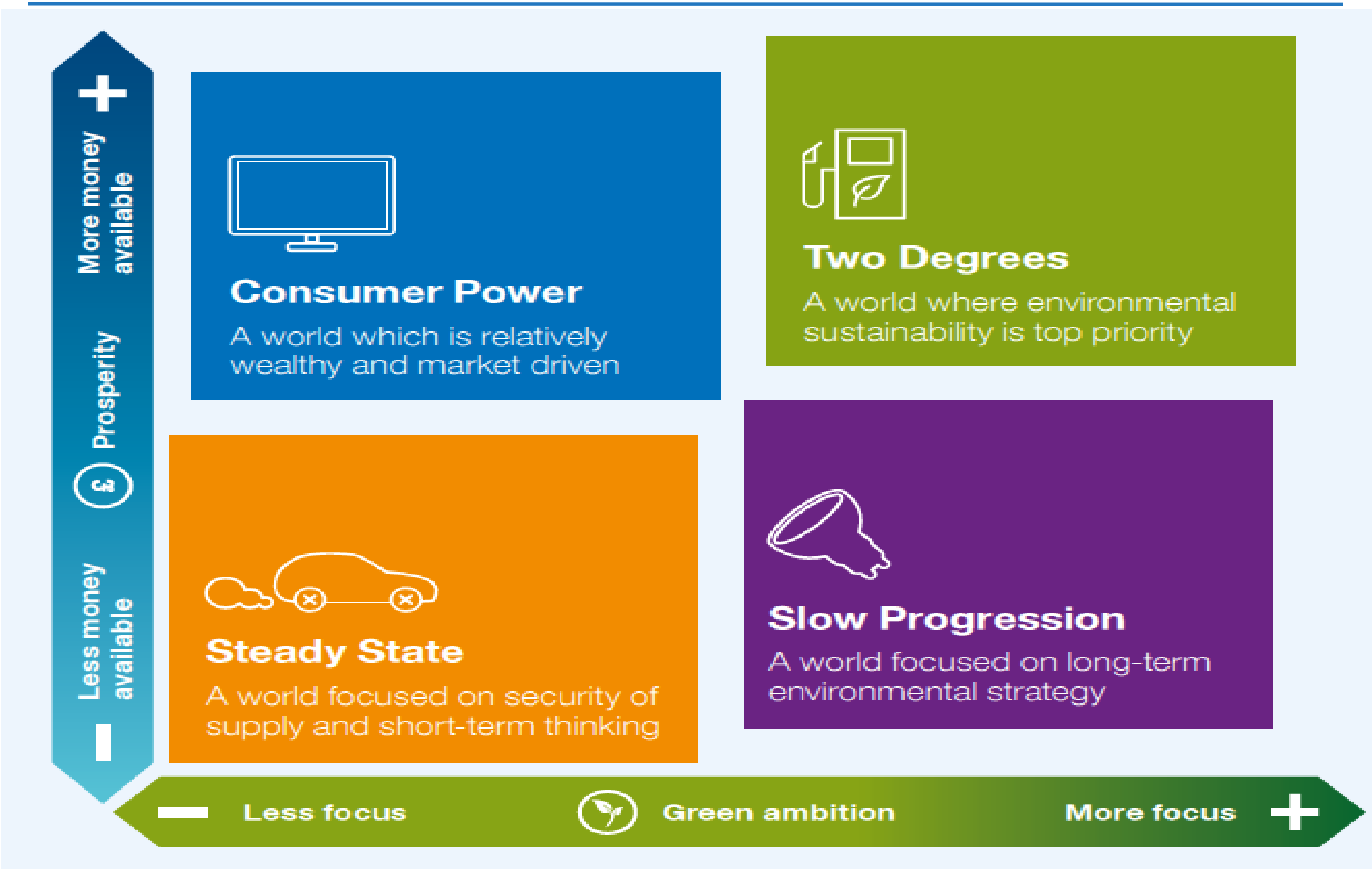
- The BID3 first run with only thermal and voltage constraints activated.
- It was then re-run with additional RoCoF constraints activated.
- The cost of the RoCoF constraint is the difference between the total constraints costs of the two runs.

The model re-optimises all constraints when a new constraint is added.



The difference between these two constraint cost totals is the cost of the ‘RoCoF Constraint’

FES scenarios

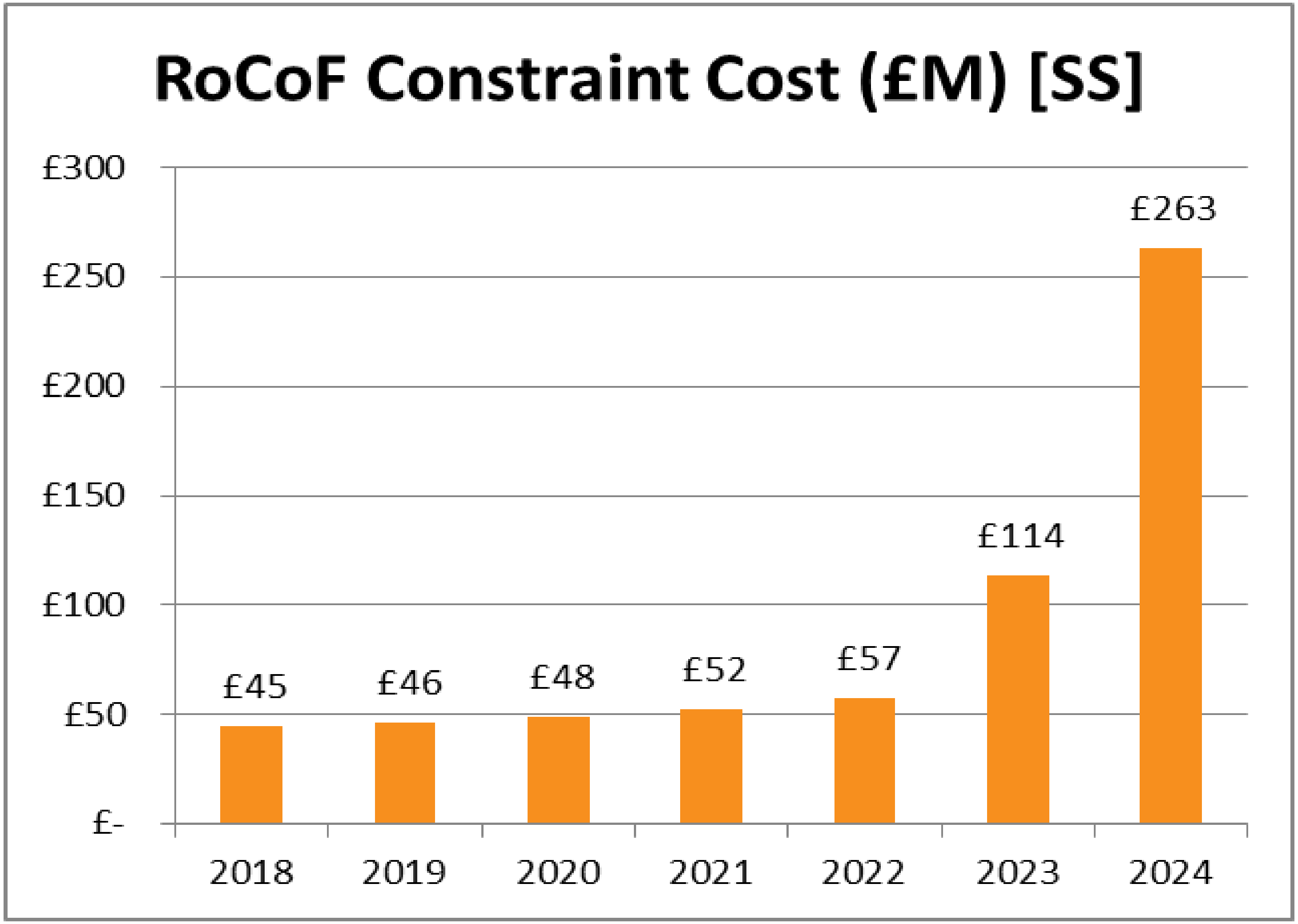


Steady state

Steady State

In **Steady State** business as usual prevails and the focus is on ensuring security of supply at a low cost for consumers. This is the least affluent of the scenarios and the least green. There is little money or appetite for investing in long-term low carbon technologies, therefore innovation slows.

RoCoF cost forecast under Steady State



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Implementation Cost Assumption

Nature Of Work	Cost per site (£)
Site Visit	200
Re-programme / reset /disable existing relay	200
Remove Vector shift (synchronous plant except DFIG)	200
Replace VS relay or single function RoCoF Relay	7700

Note that these costs assume an efficient integrated programme - ie site visits and labour organized to support an efficient programme

Implementation Cost

	Nature Of Work	Low Estimate		WG Estimate		High Estimate	
		Number of Sites	Cost (£)	Number of Sites	Cost(£)	Number of Sites	Cost(£)
1	Synch - reset RoCoF	355	71,074	477	95,379	260	52,070
2	Synch replace RoCoF	19	144,019	477	3,672,080	2,343	18,042,324
3	Synch reset VS to RoCoF	1,049	209,849	977	195,469	878	175,564
4	Synch replace VS with RoCoF	117	897,685	977	7,525,549	7,900	60,832,857
5	Asynch reset RoCoF	2,585	516,930	2,927	585,401	559	111,730
6	Asynch remove RoCoF	136	27,207	2,927	585,401	5,028	1,005,568
7	Asynch reset VS to RoCoF	41,176	8,235,255	20,625	4,124,951	3,304	660,876
8	Asynch remove VS	4,575	915,028	20,625	4,124,951	29,739	5,947,886

Plant Category	No of Sites	Expected Cost £m	Low estimate £m	High estimate £m
P_g >5MW	677	2.2	0.5	4.2
1MW$\leq P_g$ < 5MW	1445	4.6	1	8.9
P_g <1MW	47890	24.1	19.5	83.8
Total	50012	30.9	21	96.9

CBA Assumption

- Implementation will be over three years starting from 2018
- Social discount rate 3.5% from UK Government Green Book.
- Benefits will start accruing at the end of the project.

NPV analysis for central implementation cost of £31M

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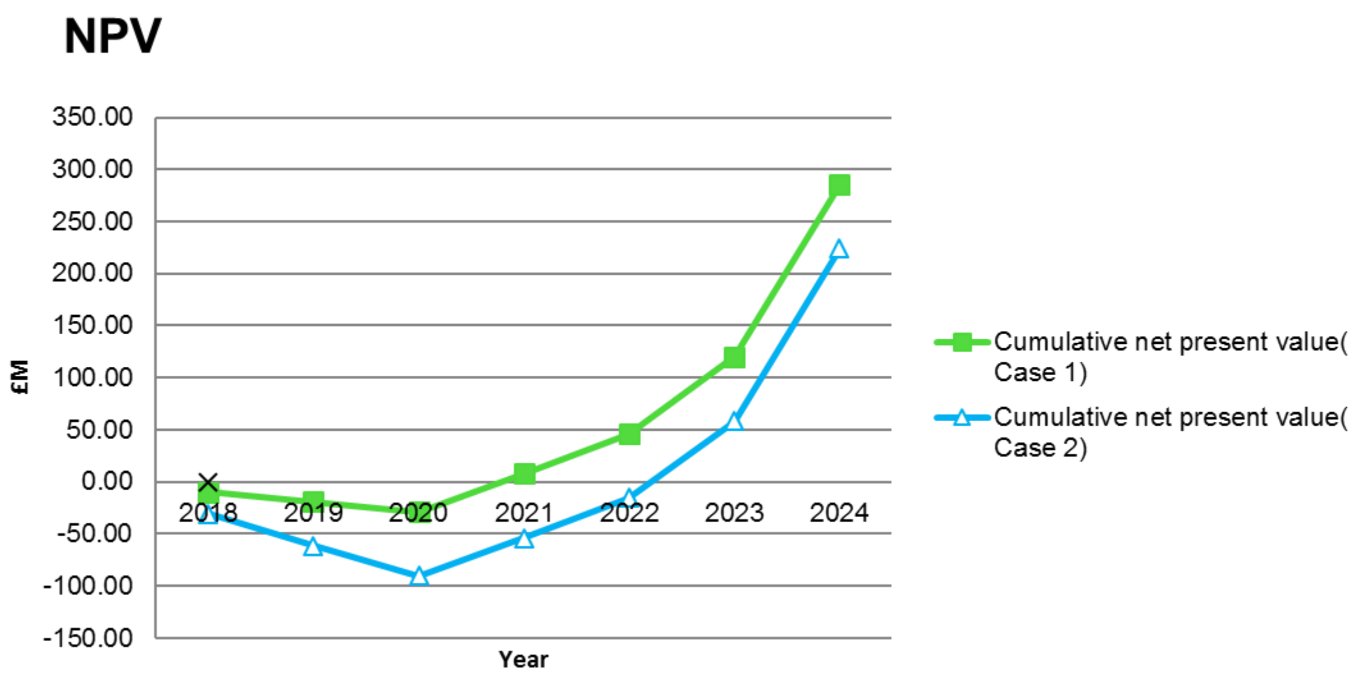
Year	2018	2019	2020	2021	2022	2023	2024
Remediation Cost	10.30	10.30	10.30				
OPEX (base) (constraints)	44.70	46.50	48.50	52.20	57.00	113.60	263.30
Opex (case 1) (constraints)	44.70	46.50	48.50	7.83	8.55	17.04	39.50
Savings (base - case 1)	0.00	0.00	0.00	44.37	48.45	96.56	223.81
PV OPEX(Discounted Savings)	0.00	0.00	0.00	38.67	40.79	78.55	175.91
Remediation(Discounted Cost)	9.95	9.62	9.29	0.00	0.00	0.00	0.00
Present Value of Savings - Costs (annual)	**-9.95**	**-9.62**	**-9.29**	**38.67**	**40.79**	**78.55**	**175.91**
Cumulative net present value(Case 1)	**-9.95**	**-19.57**	**-28.86**	**9.81**	**50.60**	**129.15**	**305.06**
Savings (Discounted total)	333.92						
Costs (Discounted total)	28.86						
Net Present Value (total)	**305.06**						
Benefit: Cost ratio	**11.57**						

NPV analysis for central implementation cost of £96M

Year	2018	2019	2020	2021	2022	2023	2024
Remediation Cost	32.23	32.23	32.23				
OPEX (base) (constraints)	44.70	46.50	48.50	52.20	57.00	113.60	263.30
Opex (case 2) (constraints)	44.70	46.50	48.50	7.83	8.55	17.04	39.50
Savings (base - case 2)	0.00	0.00	0.00	44.37	48.45	96.56	223.81
PV OPEX(Discounted Savings)	0.00	0.00	0.00	38.67	40.79	78.55	175.91
Remediation(Discounted Cost)	31.14	30.09	29.07	0.00	0.00	0.00	0.00
Present Value of Savings - Costs (annual)	**-31.14**	**-30.09**	**-29.07**	**38.67**	**40.79**	**78.55**	**175.91**
Cumulative net present value(High Estim	**-31.14**	**-61.23**	**-90.31**	**-51.64**	**-10.85**	**67.71**	**243.61**
Savings (Discounted total)	333.92						
Costs (Discounted total)	90.31						
Net Present Value (total)	**243.61**						
Benefit: Cost ratio	**3.70**						

nationalgrid

Result Summary and Conclusion



	Investment Cost(£M)	Discounted benefits (£M)	Discounted Cost (£M)	Net Present Value (£M)
Case 1	30.9	314.28	28.86	285.42
Case 2	96.9	314.28	90.49	223.78

The Voice of the Networks

Energy Networks Association

How to implement

Issues

What are our known challenges?	What do we know that helps us?
• Large number of network users need to comply • Stakeholders with little need or desire to interact with licensees or regulators • Unprecedented retrospective programme • More information required to define success criteria (ie when you can stop) • Large number of network licensees involved in a rapidly changing environment • Urgency	• Lessons learnt from >5MW change • Volume of challenge is under control • Technical solution agreed • Clear regulatory ask • Ireland experience

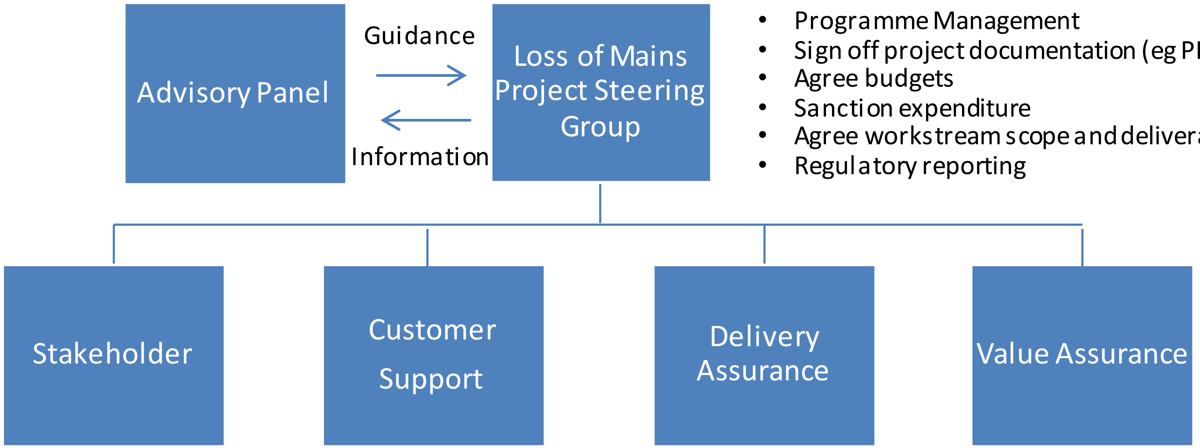
Proposed Approach

Key Issues to Address	Proposal
• Large number of network users need to comply • Stakeholders with little need or desire to interact with licensees or regulators	• Proactive engagement – go out and find who needs to comply • Provide the support required to do the work for customers that can't or don't want to do it themselves • Give affected stakeholders opportunity to shape programme
• Unprecedented Programme	• Set up governance necessary to allow decisions to be made as issues arise • Agree success criteria at start of programme

Proposal: Programme

- Multi-workstream programme with Steering Committee Responsible for delivery
- Stakeholders playing major role on the Steering Committee
  - Stakeholders delivering the change
- Core delivery through a Customer Support workstream tasked with facilitating compliance
- Assurance provided by two workstreams to ensure work is done and delivers the desired outcome

Structure: Responsibilities



- Programme Management
- Sign off project documentation (eg PID)
- Agree budgets
- Sanction expenditure
- Agree workstream scope and deliverables
- Regulatory reporting

- Develop engagement plan
- Develop engagement tools and platforms
- Ensure engagement plan is delivered

- Develop and deliver customer support model
- Deliver DNO responsibilities (eg network guidance)
- Procure and manage third party engineering support
- Customer engagement

- Provide assurance of Distribution Code compliance including
  - Appropriate witness testing
  - Planning Code documentation

- Define Programme success criteria
- Define and deliver monitoring requirements
- Quantify and track benefits
- Develop transition plan

Proposal: Customer Support

- Customer Support Workstream responsibilities
  - Identify and prioritise customers that need to comply
  - Make contact and identify those that want help to do so
  - Provide help for those that want it including
    - Assessing any network implications
    - Potentiall
    - Potentially making physical changes on site (ie protection setting or equipment changes)
  - Broader customer engagement in line with engagement plan
  - Manage risks and liabilities and statutory compliance

Organisational Responsibilities

What	Who	Link to Programme
Compliance with Distribution Code	Affected network Users	Represented at • Steering Group, • Customer Support Workstream • Delivery Assurance Workstream
Assurance of Compliance with Distribution Code	DNOs	Leading • Customer Support Workstream • Delivery Assurance Workstream
Assurance of Value	National Grid Electricity System Operator	Leading the Value Assurance Workstream

VS change accelerated programme

- National Grid in collaboration with three DNOs initiated an accelerated VS change programme to mitigate the risk for summer 2018
- Programme implemented under Balancing Service framework

	VS change 2018	DC0079
Duration	Within a month before June	Multi-Years
Target EG	800MW, 72 sites in specific area	More than 15GW and 50,000 sites nationally
Total cost	£250k	£31M
Benefit	Realized within year	Realized once the whole programme complete
Governance	Tactical exercise between licensees	Steering committee with stakeholder input

Key consultation questions

- Do you support the proposal to remove vector shift protection technique?
- Do you support the proposed change in RoCoF settings to $1Hzs^{-1}$ with a delay of 500ms for distributed generators below 5MW?
- Do you agree that RoCoF protection should be disabled, in cases where settings cannot be changed, for all non-synchronous plant except for DFIG?
- Do you support the proposal that all DFIG machines should use RoCoF protection technique set at $1Hzs^{-1}$ with a 500ms time delay as loss of mains?

Key consultation questions

- Do you agree that all synchronous generation >5MW, should have a RoCoF setting of $1Hzs^{-1}$ with a delay of 500ms retrospectively applied?
- Do you agree that the same approach for asynchronous generation <5MW should be applied to that >5MW in that if the existing protection cannot be reset to RoCoF of $1Hzs^{-1}$ with a delay of 500ms, then it should just be disconnected/removed?
- Do you agree with the workgroup's proposal for type-tested plant?
- Do you agree that where practicable on existing relays, the overfrequency setting should be changed to the current requirements (and left as-set if the relay cannot accommodate it)?

Key consultation questions

- Do you agree with the workgroup's CBA analysis for the retrospective protection change?
- Do you agree with the proposed change implementation approach?
- What do you believe are the most important considerations in implementing the change?
- How can we ensure that all generation owners are aware of the consultation and given a chance to respond?

Discussion and Next Steps

- Questions:
  - What can we learn from the past programme of protection setting changes?
  - Who should be interested?
  - How do we make sure they have their say?

Getting Involved

- Options
  - Contact the workgroup, either individually or through the Technical Secretary
  - Contact a Distribution Code Review Panel member at an appropriate time
  - Respond to consultation
  - Further engagement events

Getting Involved

- Contacts from today:

Mike Kay	mkay@iee.org
Graham Stein	Graham.Stein@nationalgrid.com
Adam Dyśko	a.dysko@strath.ac.uk
Xiaoyao Zhou	Xiaoyao.zhou@nationalgrid.com