Risk Assessment of Loss of Mains Protection – Phase II

21 May 2015

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Outline

- WP1 – Hardware testing based characterisation of DG – PNDC
- WP2 – Simulation based characterisation of DG
- WP3 – Risk assessment calculation
  - Further DG connection register analysis (WPD, ENW and UKPN)
  - Establishing dominant connection groups

WP2 – Simulation based characterisation of DG

- Most popular generation mixes have been considered.
- SM, PV, SM-PV, PV-DFIG, SM-PV-DFIG

LOM Settings

ROCOF

Setting Option	ROCOF [Hz/s]	Time Delay [s]
1	0.13	0
2	0.2	0
3	0.5	0.5
4	1.0	0.5

ENA G-59 / Issue 3

Voltage- Dependent		$V_{\Phi-\Phi}$ [%]	Time Delay [s]
Under Voltage	Stage 1	-13	2.5
	Stage 2	-20	0.5
Over Voltage	Stage 1	+10	1.0
	Stage 2	+13	0.5
Frequency Dependent		**Frequency [Hz]**	**Time Delay [s]**
Under Frequency	Stage 1	47.5	20
	Stage 2	47	0.5
Over Frequency	Stage 1	51.5	90
	Stage 2	52	0.5

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Load Modelling

Active & Reactive Power

$$P(s) = P_0 \cdot \left(\frac{V}{V_0}\right)^{n_p} \cdot \frac{1 + T_{p1}s}{1 + T_{p2}s}$$

$$Q(s) = P_0 \cdot \left(\frac{V}{V_0}\right)^{n_q} \cdot \frac{1 + T_{q1}s}{1 + T_{q2}s}$$

Where:

$\boldsymbol{V_0}$ **:** Initial Positive Sequence Voltage

$\boldsymbol{V}$ **:** Positive Sequence Voltage

$\boldsymbol{P_0, Q_0}$**:** Initial active and reactive power at the initial voltage $\boldsymbol{V_0}$

$\boldsymbol{n_p, n_q}$**:** Exponents controlling the nature of the load for P and Q

$\boldsymbol{T_{p1}, T_{p2}, T_{q1}, T_{q2}}$ **,:** Time constants controlling P and Q

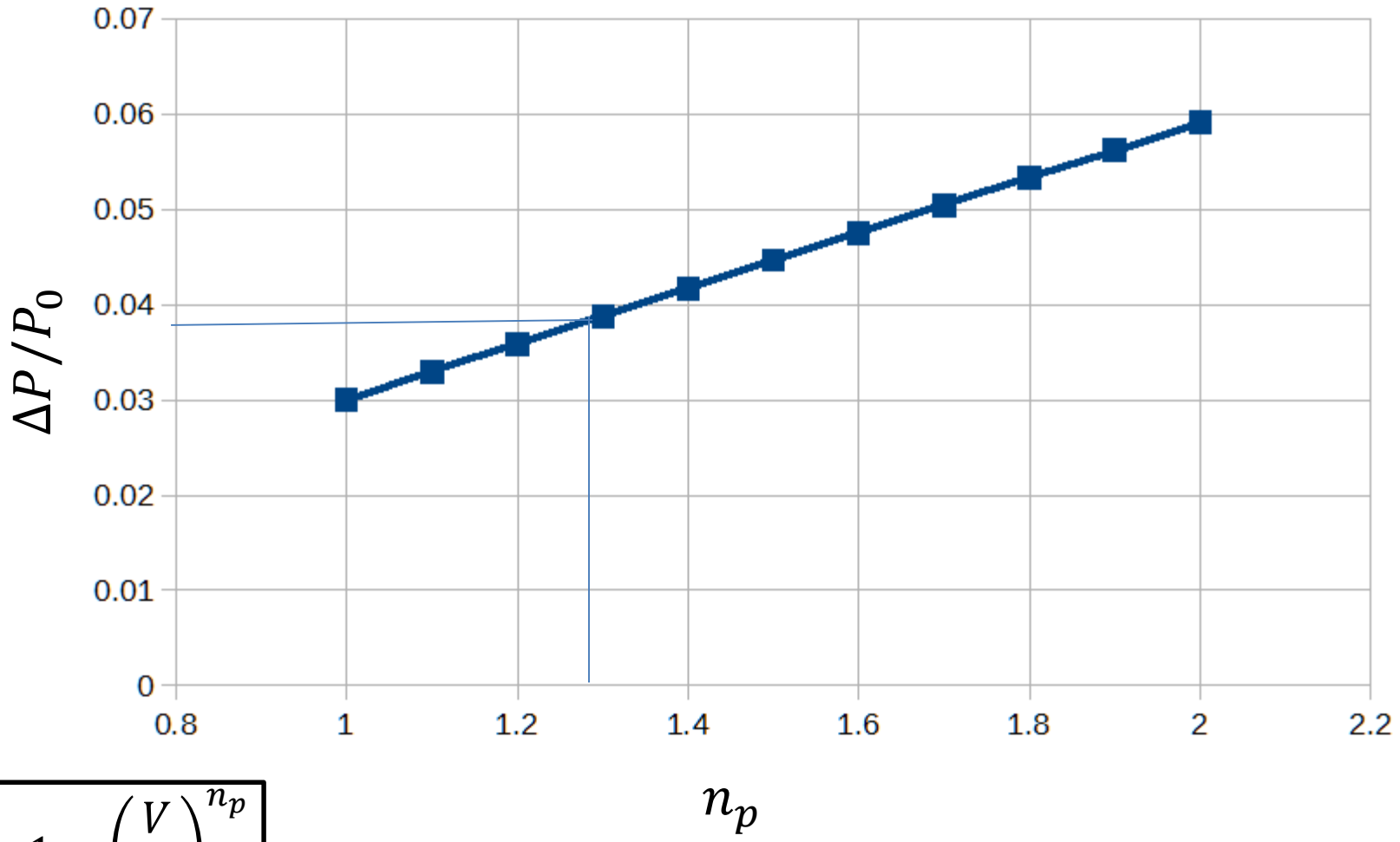
n=1.3 was used in simulations

nationalgrid
THE POWER OF ACTION

Demand Control Effectiveness

- First queried during Exercise Phoenix (2006/7)
- Limited tests carried out by EDF Energy and Central Networks in Summer and Autumn 2008
- Tests were on 3 types of demand
  - Domestic, commercial & large industrial
- 3% voltage reduction gave average of 3.4% demand reduction (5% historically expected)
- Minimum 2.6%, maximum 5.1% demand reduction
- Reduction was sustained but difficult to identify amongst normal demand variation
- Customer supplies may be interrupted earlier than previously anticipated

Load response at 3% voltage reduction



$$\frac{\Delta P}{P_0} = 1 - \left(\frac{V}{V_0}\right)^{n_p}$$

Non Detection Zone

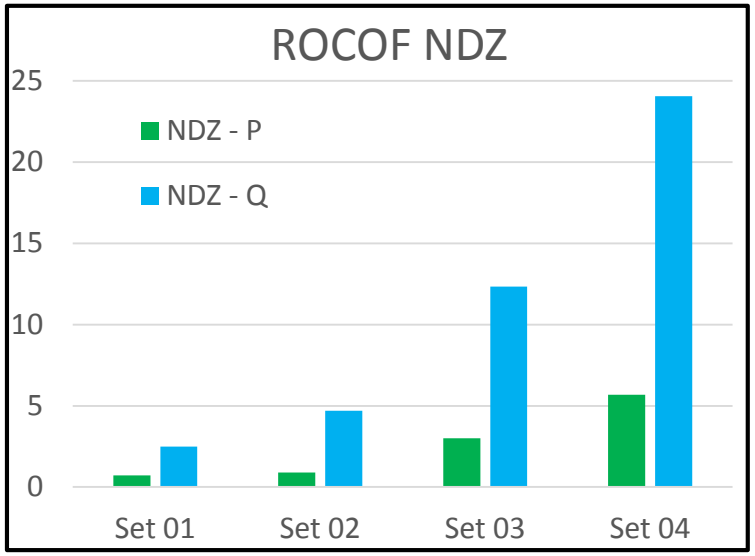
SG

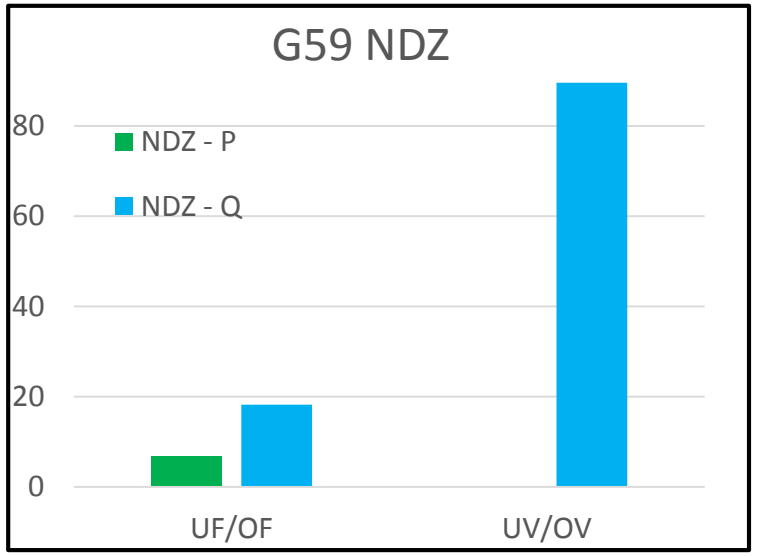
Constant Z		
Setting Option	NDZ-P [%]	NDZ-Q [%]
1	0.86	2.24
2	0.96	2.65
3	3.06	10.8
4	5.86	21.58

Dynamic		
Setting Option	NDZ-P [%]	NDZ-Q [%]
1	0.72	2.48
2	0.9	4.7
3	3	12.34
4	5.69	24.05

Frequency Based	
NDZ-P [%]	NDZ-Q [%]
6.86	18.25

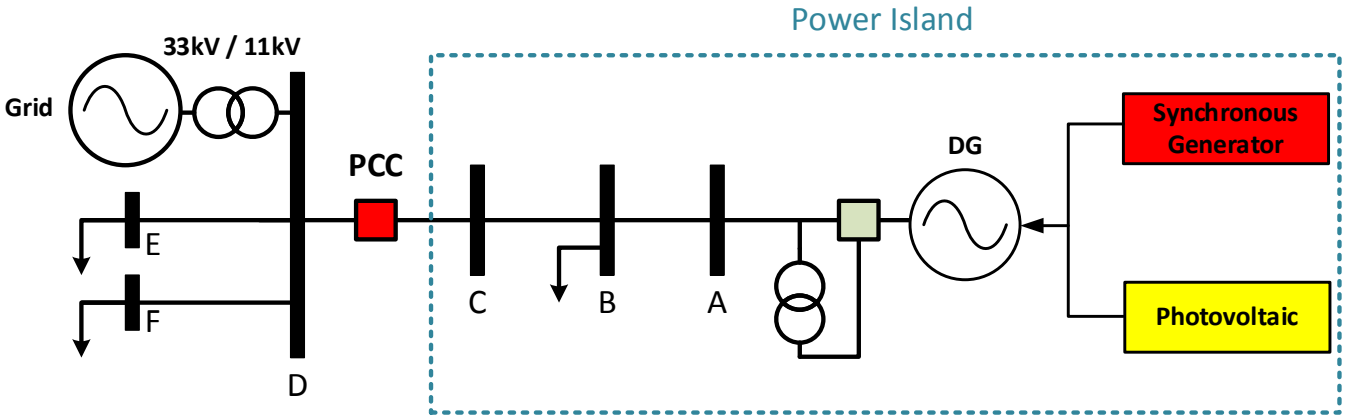
Voltage Based	
NDZ-P [%]	NDZ-Q [%]
--	87.6





Generation Mix Stability Studies

Synchronous Generator & Photovoltaic Panels



2 MVA Total Installed Capacity		
Case	SG [%]	PV [%]
1	75	25
2	50	50
3	25	75

Unstable →

Non Detection Zone

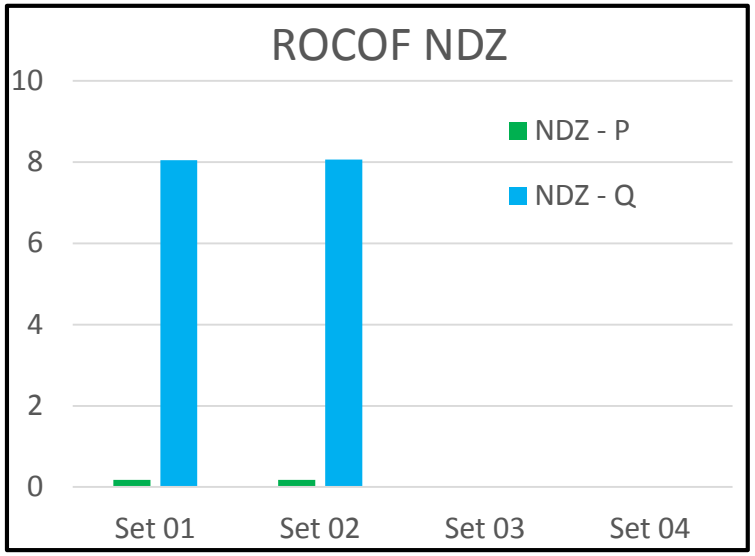
SG – PV
75% - 25%

Constant Z		
Setting Option	**NDZ-P [%]**	**NDZ-Q [%]**
1	1	0.89
2	1.4	1.45
3	3.6	20.5
4	5.9	24.28

Dynamic		
Setting Option	**NDZ-P [%]**	**NDZ-Q [%]**
1	0.175	8.05
2	0.179	8.06
3	X	X
4	X	X

Frequency Based	
NDZ-P [%]	**NDZ-Q [%]**
87.39	5.96

Voltage Based	
NDZ-P [%]	**NDZ-Q [%]**
>100	>100



Non Detection Zone

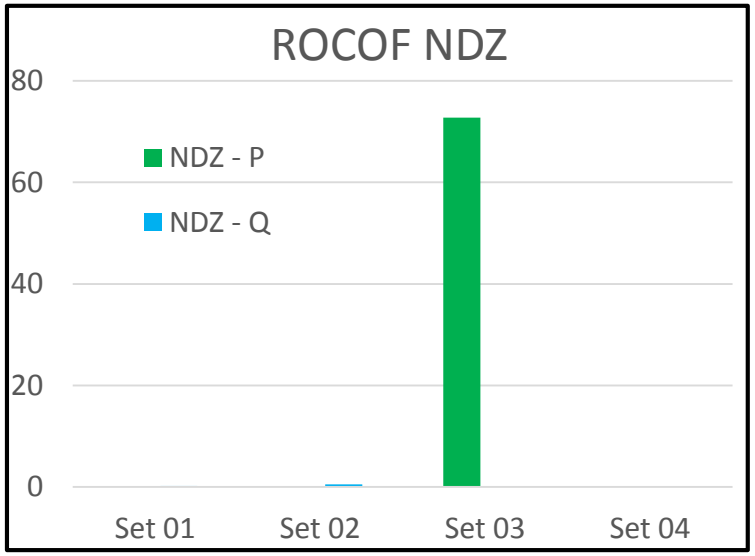
SG – PV
50% - 50%

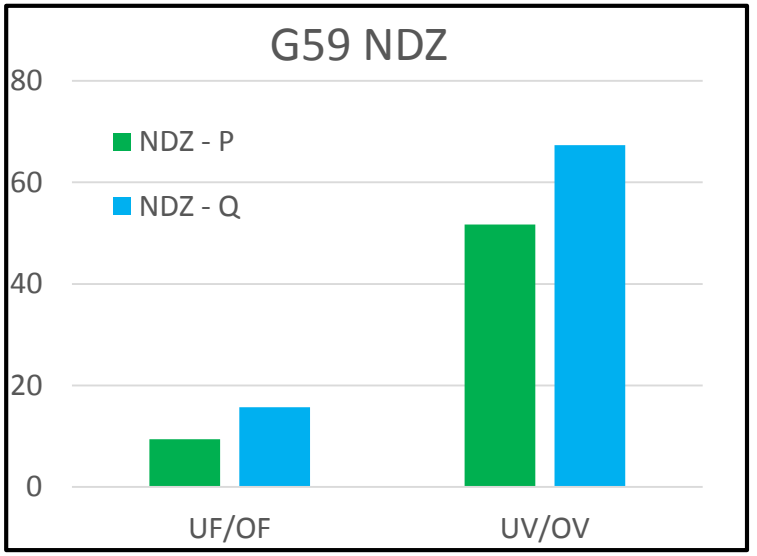
Constant Z		
Setting Option	**NDZ-P [%]**	**NDZ-Q [%]**
1	0.4	0.3
2	0.42	0.4
3	2.9	14.38
4	4.56	20

Dynamic		
Setting Option	**NDZ-P [%]**	**NDZ-Q [%]**
1	0.14	0.24
2	0.15	0.5
3	72.78	X
4	X	X

Frequency Based	
NDZ-P [%]	**NDZ-Q [%]**
9.41	15.71

Voltage Based	
NDZ-P [%]	**NDZ-Q [%]**
51.68	67.32

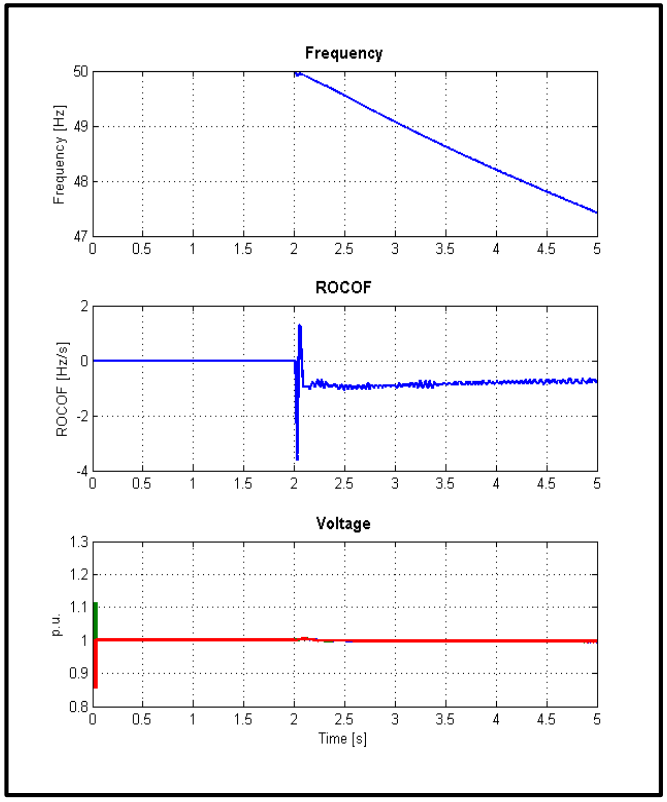




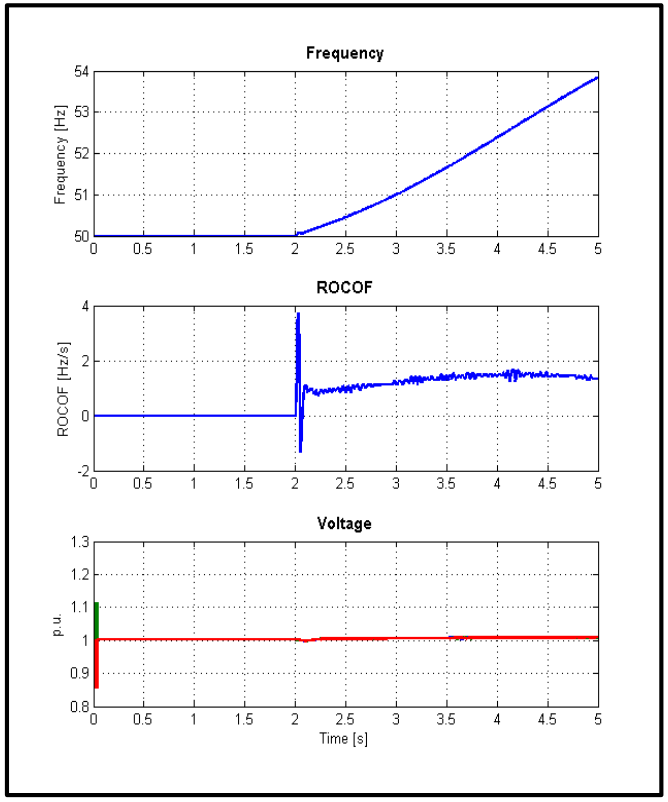
Synchronous Generator

Overload vs Underload
-Active Power-

5 % Over-loading



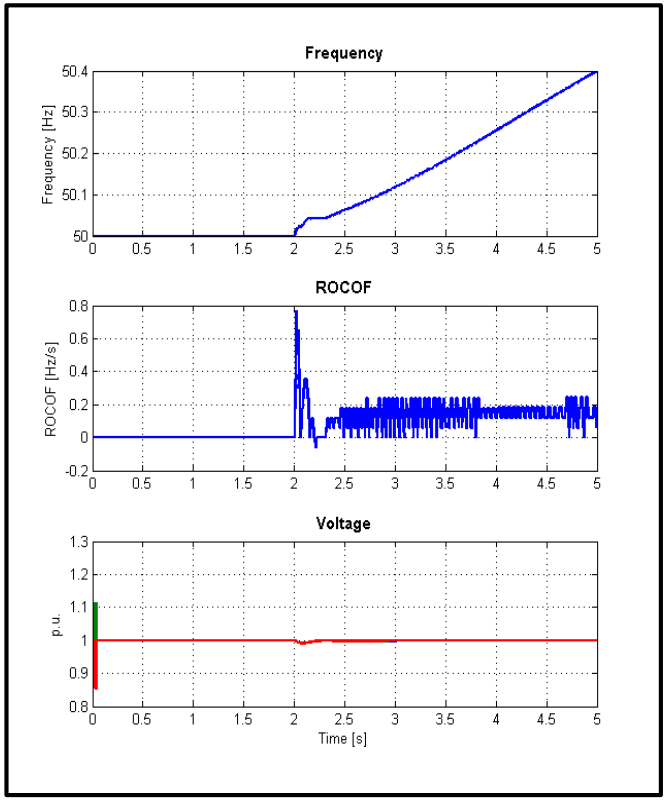
5 % Under-loading



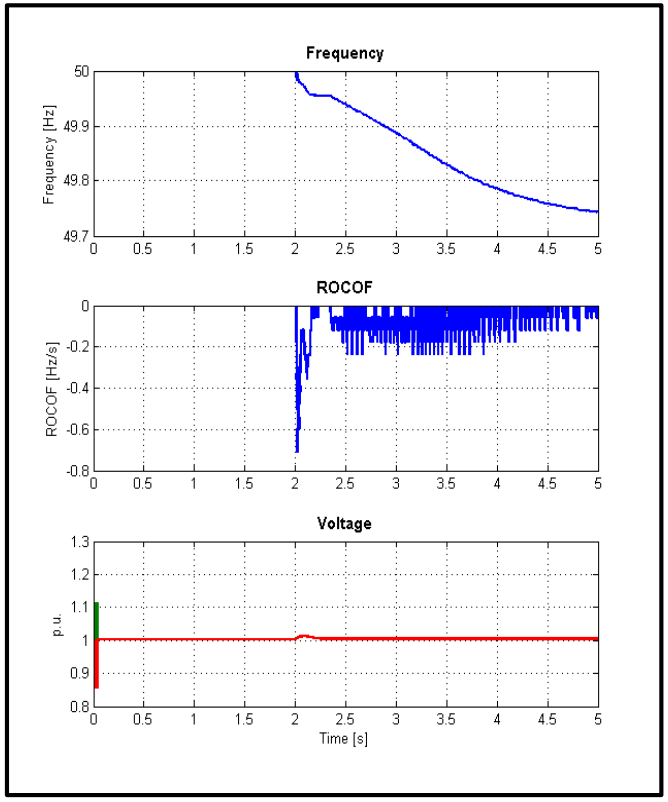
Synchronous Generator

Overload vs Underload
-Reactive Power-

5 % Over-loading

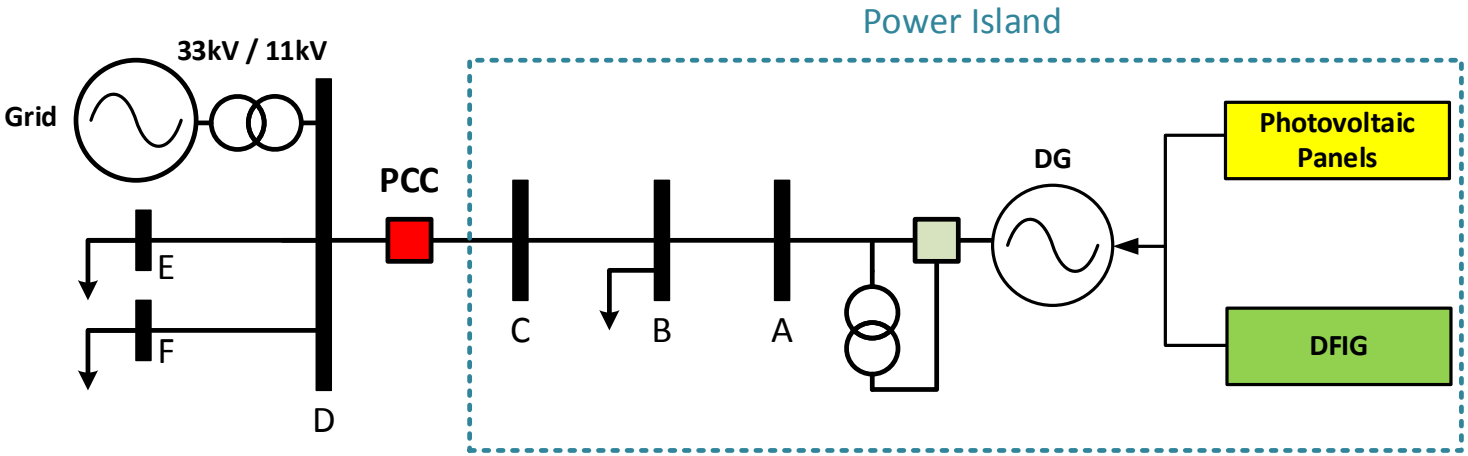


5 % Under-loading



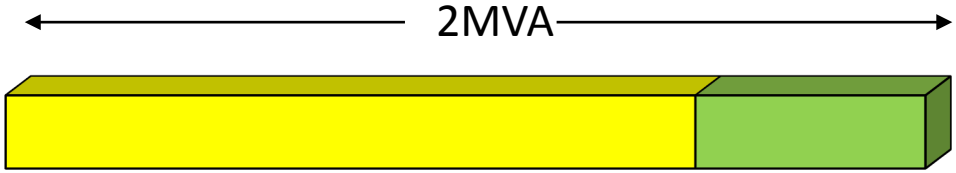
Generation Mix Stability Studies

PV & DFIG



2 MVA Total Installed Capacity		
Case	PV Panels [%]	DFIG [%]
1	75	25
2	50	50
3	25	75

PV-DFIG Case 1



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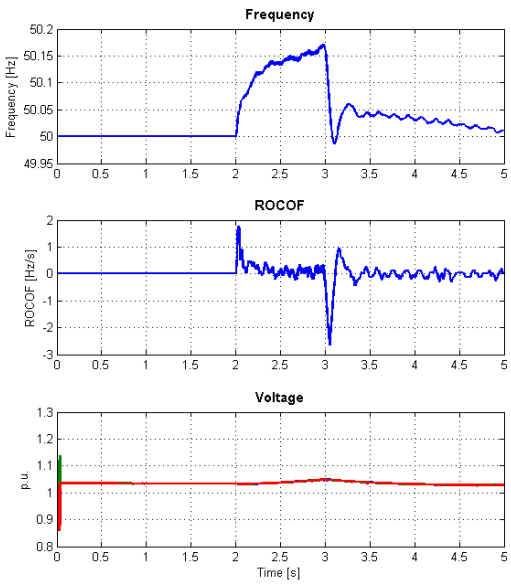
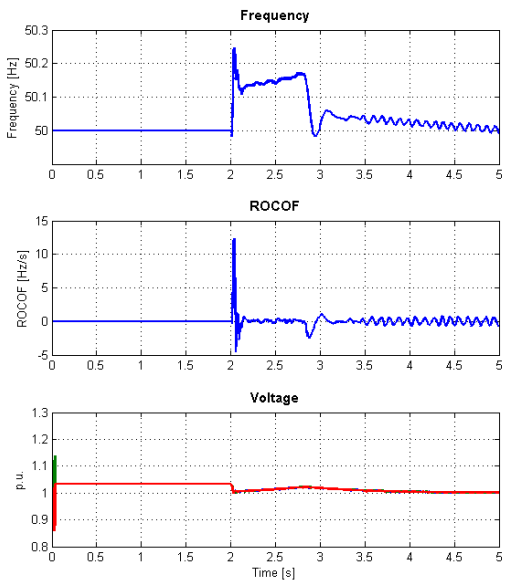
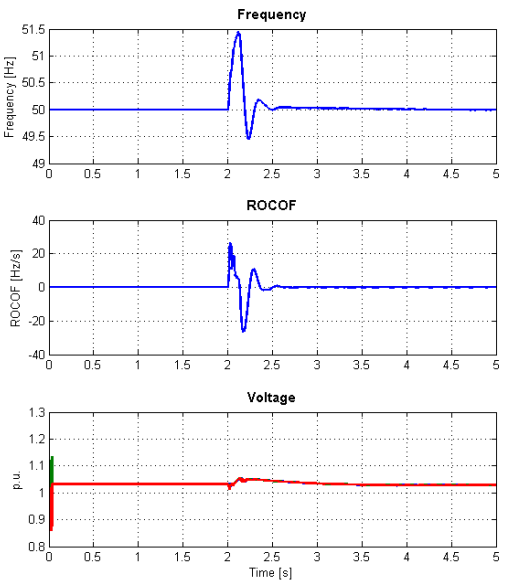
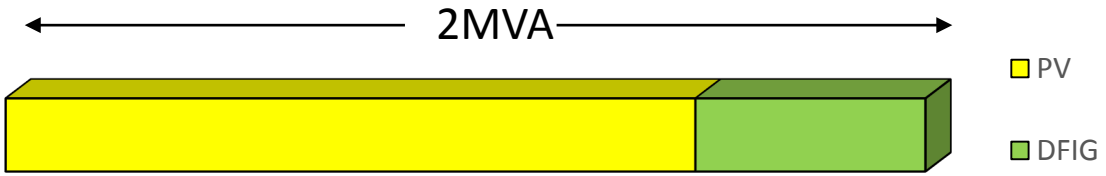
Active Power Imbalance: 0% Reactive Power Imbalance: 0%	Active Power Imbalance: 5% Reactive Power Imbalance: 0%	Active Power Imbalance: 0% Reactive Power Imbalance: 5%
		

100 % Constant Z Load

PV-DFIG Case 1



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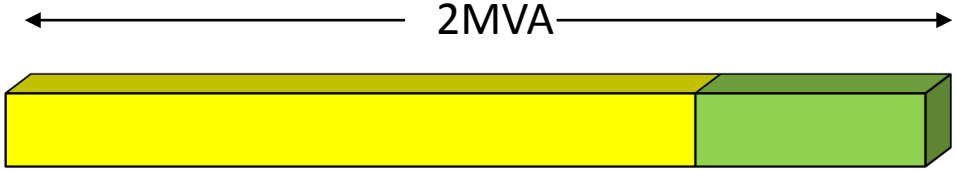
Active Power Imbalance: 0% Reactive Power Imbalance: 0%	
ROCOF Setting	**Trip**
1	1
2	1
3	0
4	0
Voltage Protection	**Trip**
Under Voltage	0
Over Voltage	0
Frequency Protection	**Trip**
Under Frequency	0
Over Frequency	0

Active Power Imbalance: 5% Reactive Power Imbalance: 0%	
ROCOF Setting	**Trip**
1	1
2	1
3	0
4	0
Voltage Protection	**Trip**
Under Voltage	0
Over Voltage	0
Frequency Protection	**Trip**
Under Frequency	0
Over Frequency	0

Active Power Imbalance: 0% Reactive Power Imbalance: 5%	
ROCOF Setting	**Trip**
1	1
2	1
3	0
4	0
Voltage Protection	**Trip**
Under Voltage	0
Over Voltage	0
Frequency Protection	**Trip**
Under Frequency	0
Over Frequency	0

100 % Constant Z Load

PV-DFIG Case 1



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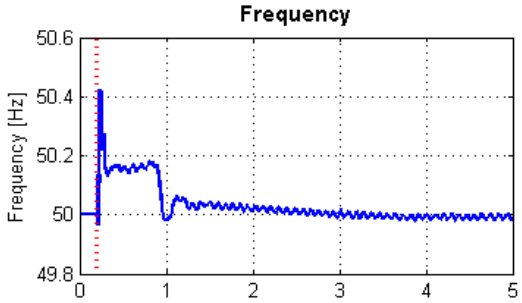
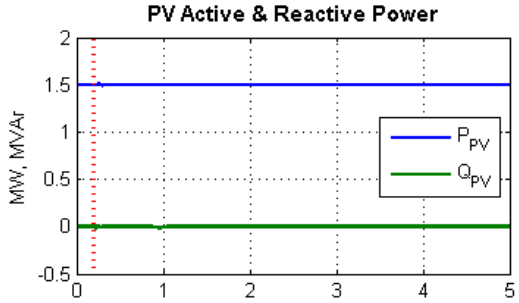
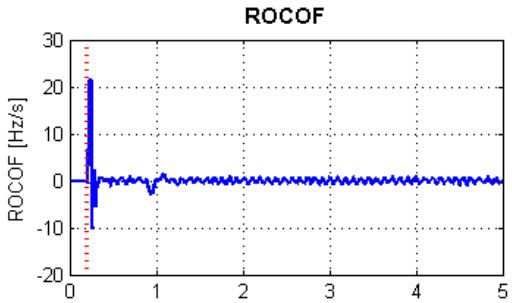
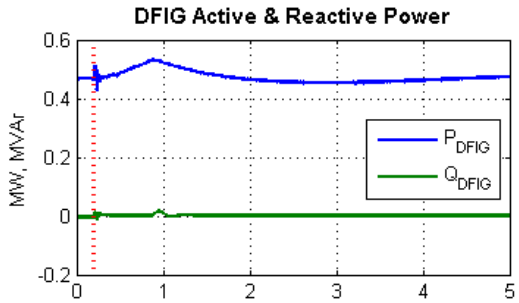
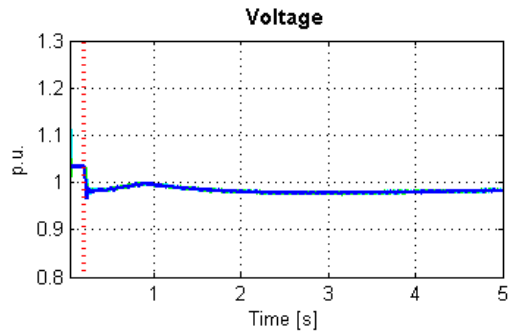
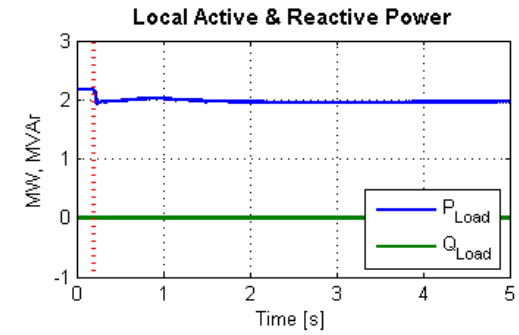










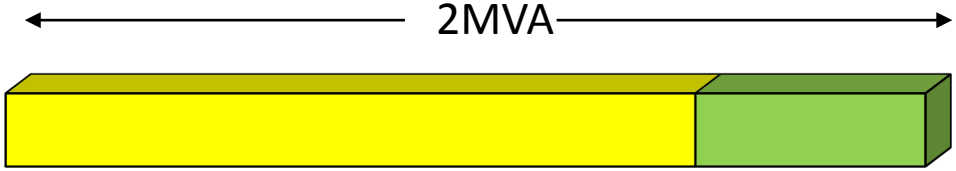


G59 / Issue 3 Settings	
Voltage Protection	**Trip**
Under Voltage	0
Over Voltage	0
Frequency Protection	**Trip**
Under Frequency	0
Over Frequency	0

10 % Active Power Imbalance

100 % Constant Z Load

PV-DFIG Case 1



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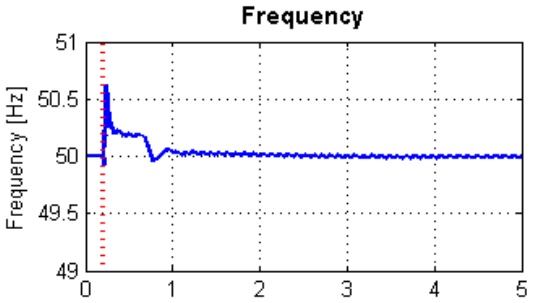
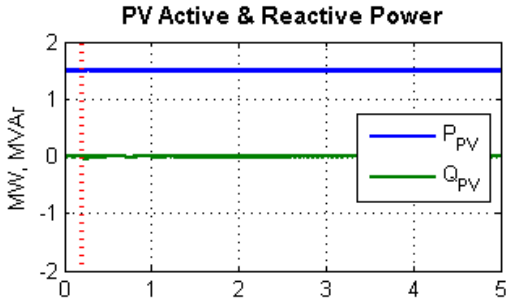
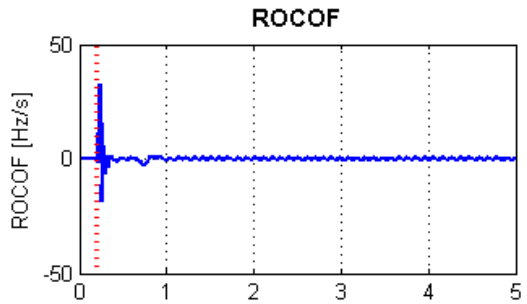
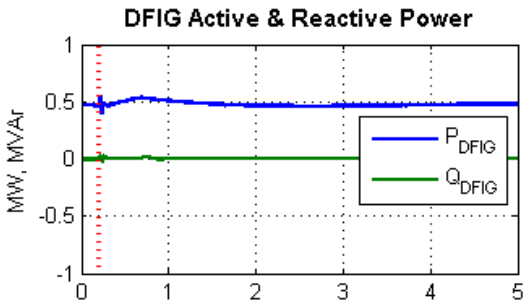
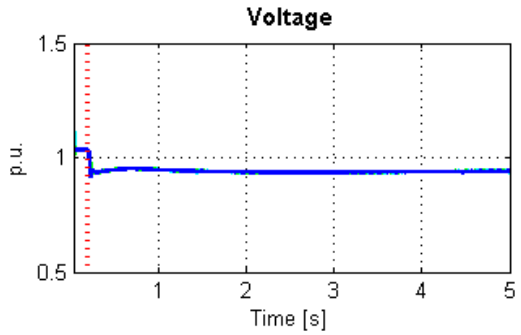
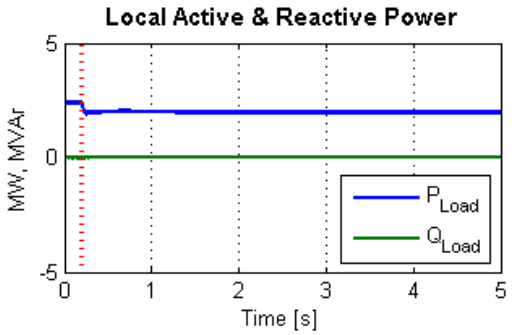










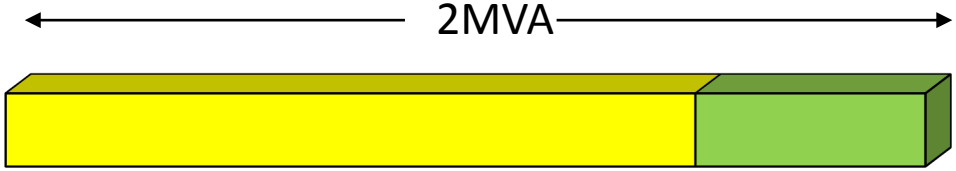


G59 / Issue 3 Settings	
Voltage Protection	**Trip**
Under Voltage	0
Over Voltage	0
Frequency Protection	**Trip**
Under Frequency	0
Over Frequency	0

20 % Active Power Imbalance

100 % Constant Z Load

PV-DFIG Case 1



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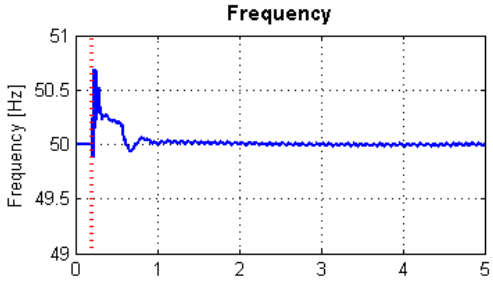
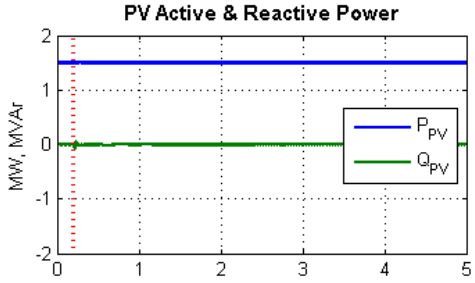
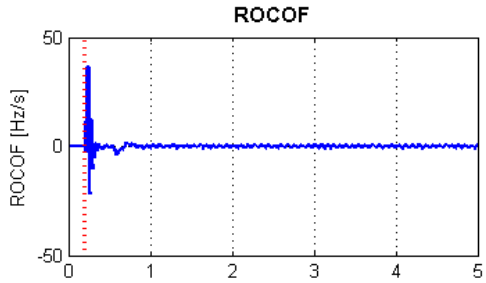
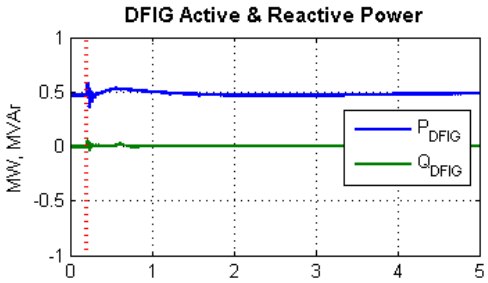
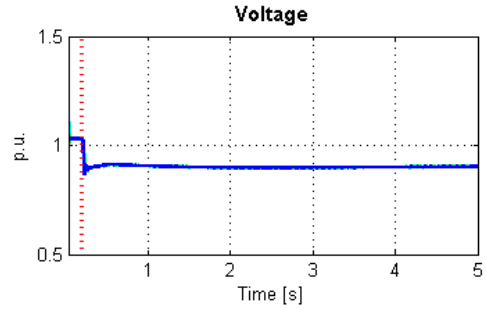
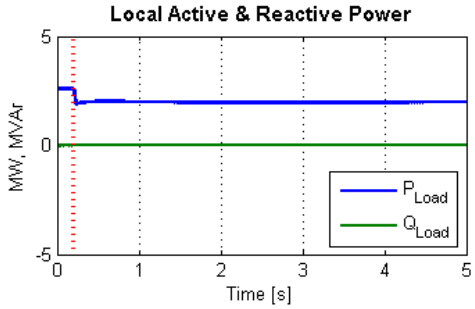










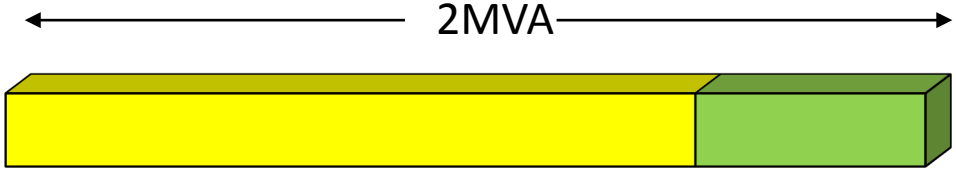


G59 / Issue 3 Settings	
Voltage Protection	**Trip**
Under Voltage	0
Over Voltage	0
Frequency Protection	**Trip**
Under Frequency	0
Over Frequency	0

30 % Active Power Imbalance

100 % Constant Z Load

PV-DFIG Case 1



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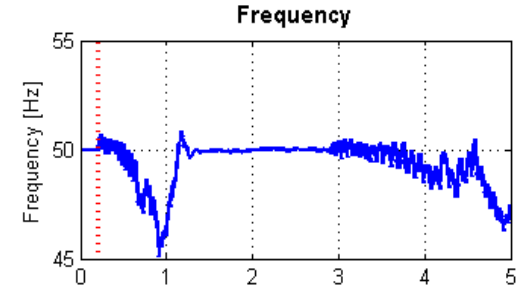
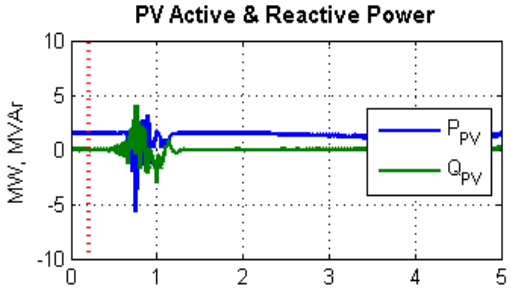
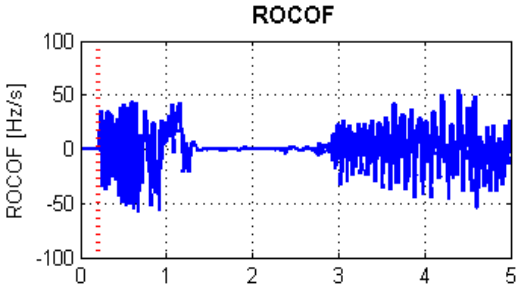
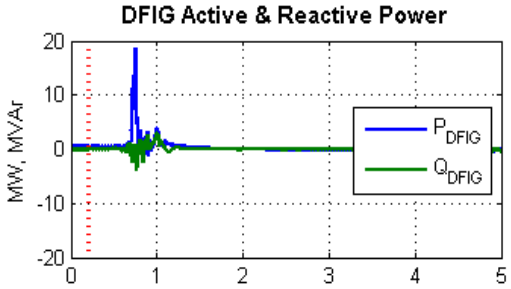
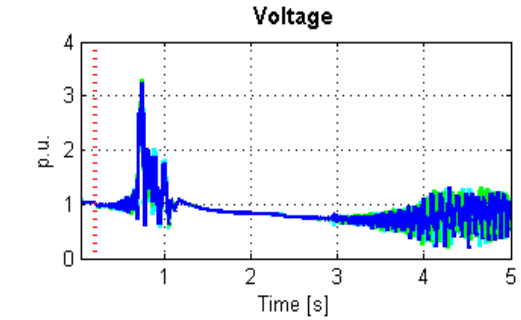
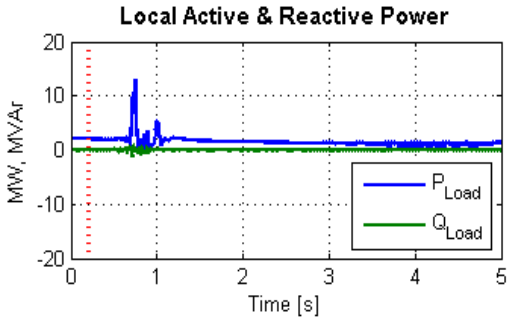










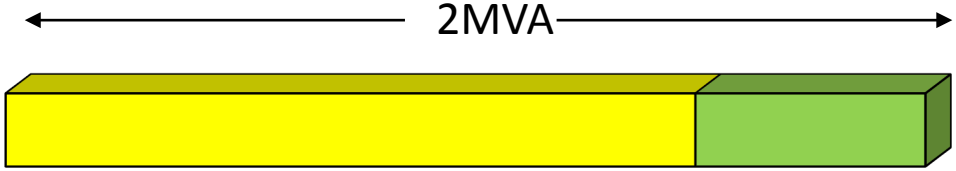


G59 / Issue 3 Settings	
Voltage Protection	**Trip**
Under Voltage	1
Over Voltage	0
Frequency Protection	**Trip**
Under Frequency	0
Over Frequency	0

10 % Active Power Imbalance

50 % Constant Z Load
50 % Constant P Load

PV-DFIG Case 1



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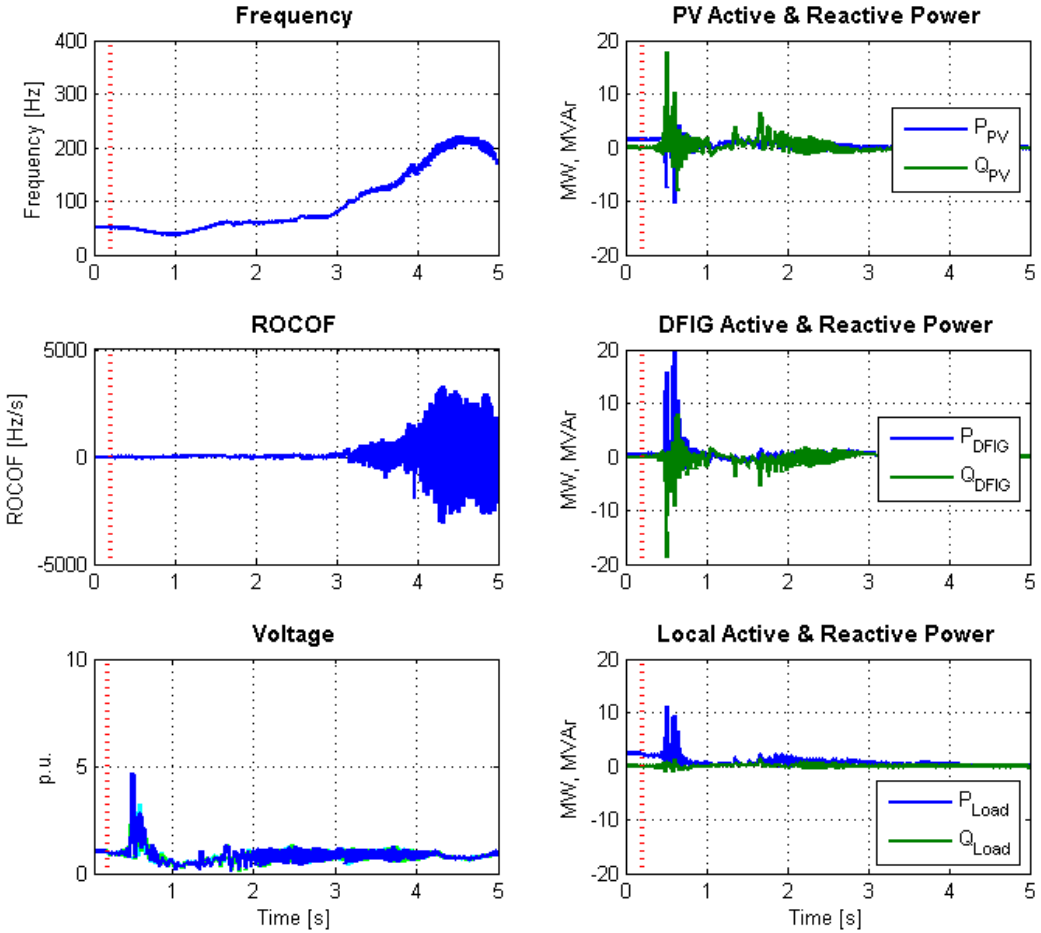
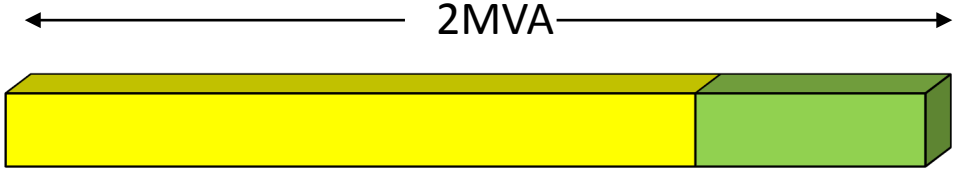


G59 / Issue 3 Settings	
Voltage Protection	**Trip**
Under Voltage	1
Over Voltage	0
Frequency Protection	**Trip**
Under Frequency	0
Over Frequency	1

20 % Active Power Imbalance

50 % Constant Z Load
50 % Constant P Load

PV-DFIG Case 1



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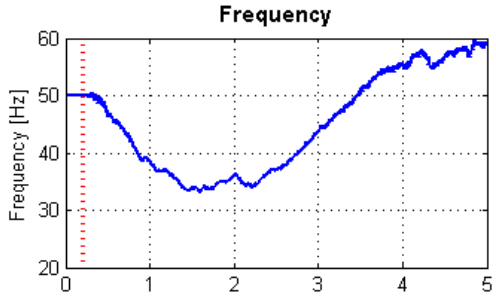
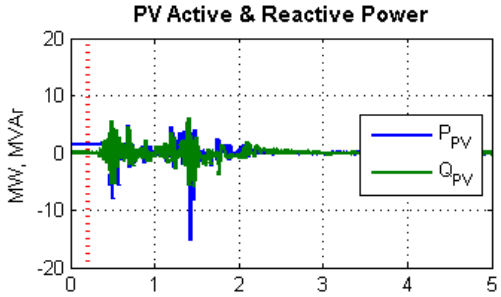
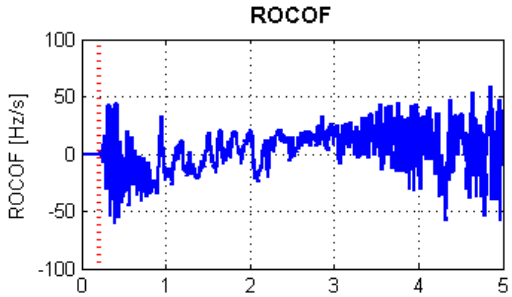
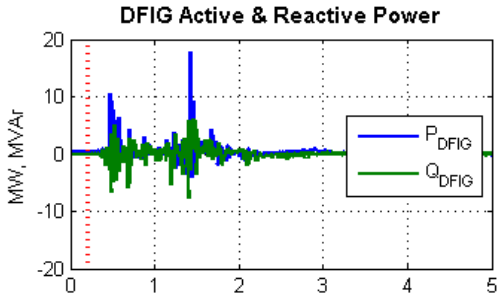
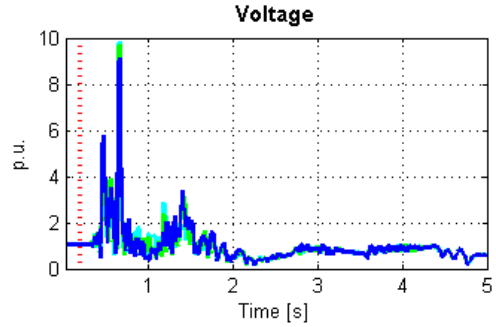
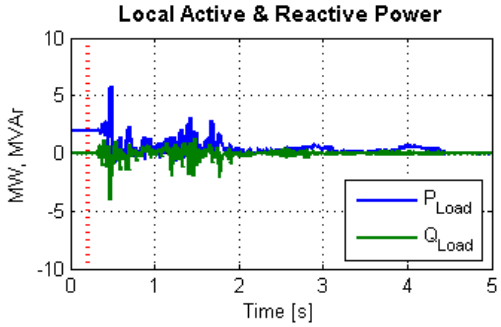










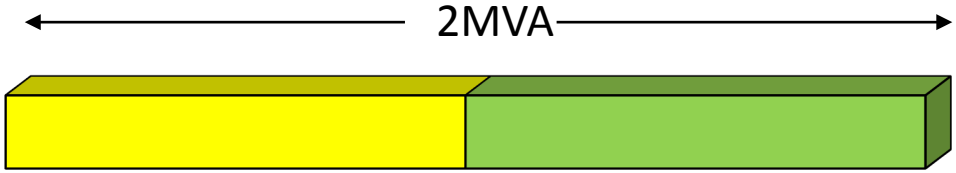


G59 / Issue 3 Settings	
Voltage Protection	**Trip**
Under Voltage	1
Over Voltage	0
Frequency Protection	**Trip**
Under Frequency	1
Over Frequency	1

0 % Active Power Imbalance

100 % Constant P Load

PV-DFIG Case 2



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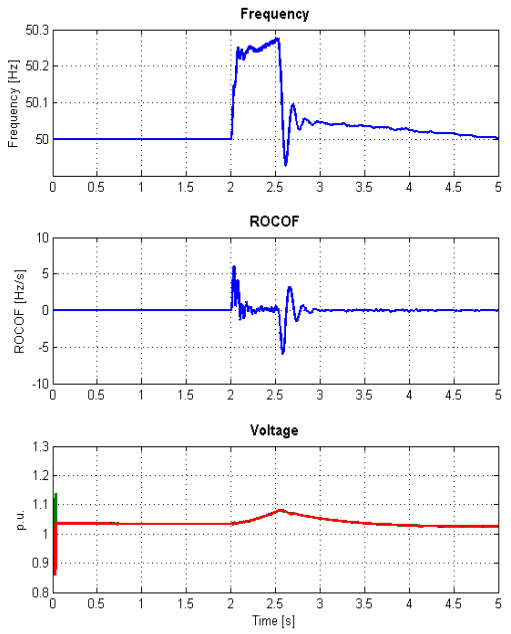
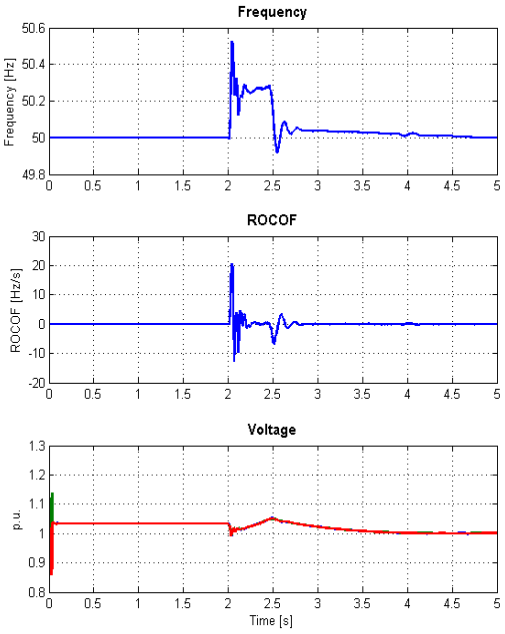
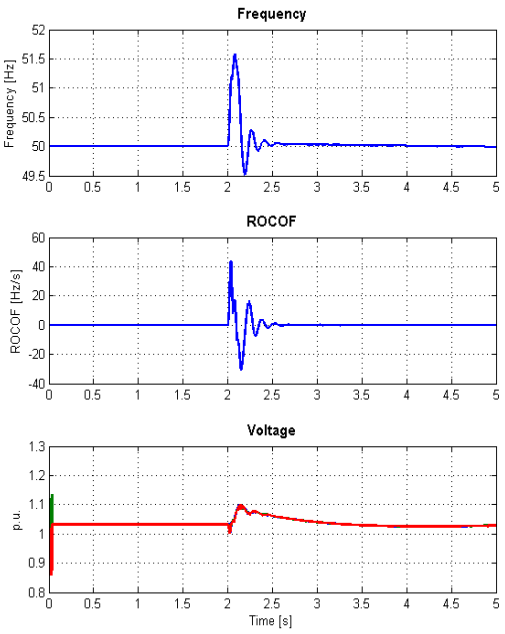
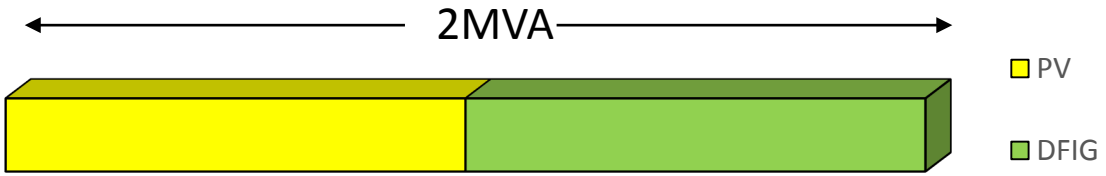
Active Power Imbalance: 0% Reactive Power Imbalance: 0%	Active Power Imbalance: 5% Reactive Power Imbalance: 0%	Active Power Imbalance: 0% Reactive Power Imbalance: 5%
		

100 % Constant Z Load

PV-DFIG Case 2



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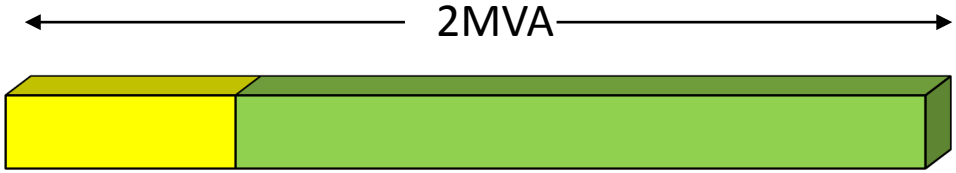
Active Power Imbalance: 0% Reactive Power Imbalance: 0%		Active Power Imbalance: 5% Reactive Power Imbalance: 0%		Active Power Imbalance: 0% Reactive Power Imbalance: 5%	
ROCOF Setting	**Trip**	**ROCOF Setting**	**Trip**	**ROCOF Setting**	**Trip**
1	1	1	1	1	1
2	1	2	1	2	1
3	0	3	0	3	0
4	0	4	0	4	0
Voltage Protection	**Trip**	**Voltage Protection**	**Trip**	**Voltage Protection**	**Trip**
Under Voltage	0	Under Voltage	0	Under Voltage	0
Over Voltage	0	Over Voltage	0	Over Voltage	0
Frequency Protection	**Trip**	**Frequency Protection**	**Trip**	**Frequency Protection**	**Trip**
Under Frequency	0	Under Frequency	0	Under Frequency	0
Over Frequency	0	Over Frequency	0	Over Frequency	0

100 % Constant Z Load

PV-DFIG Case 3



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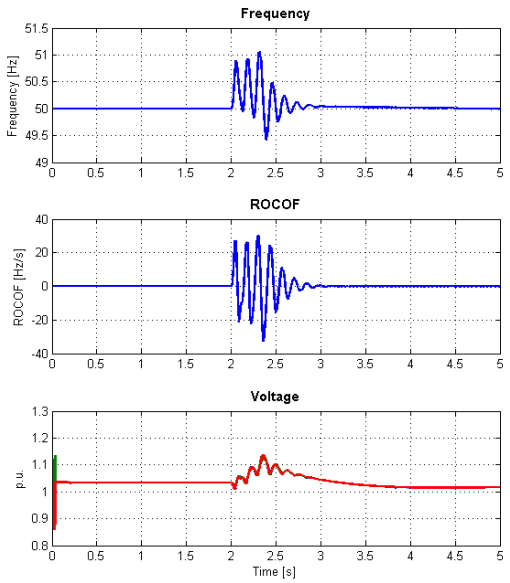
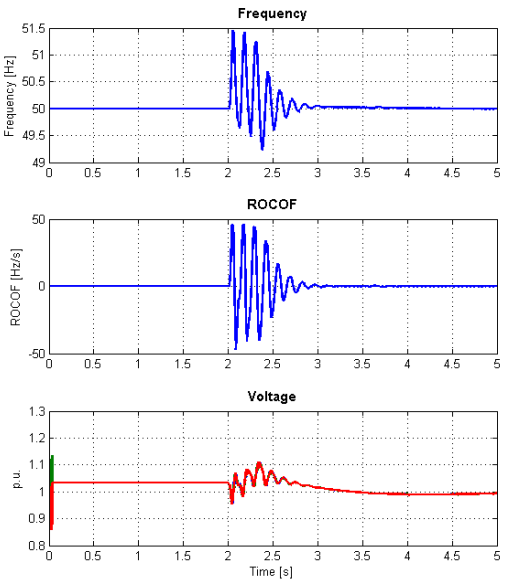
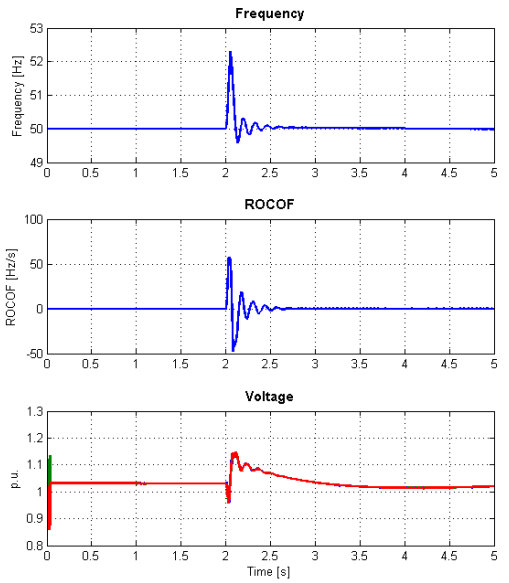
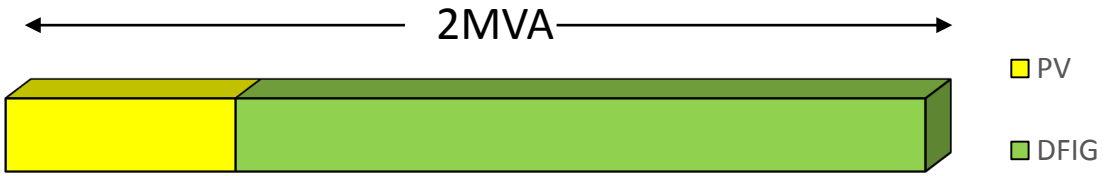
Active Power Imbalance: 0% Reactive Power Imbalance: 0%	Active Power Imbalance: 5% Reactive Power Imbalance: 0%	Active Power Imbalance: 0% Reactive Power Imbalance: 5%
		

100 % Constant Z Load

PV-DFIG Case 3



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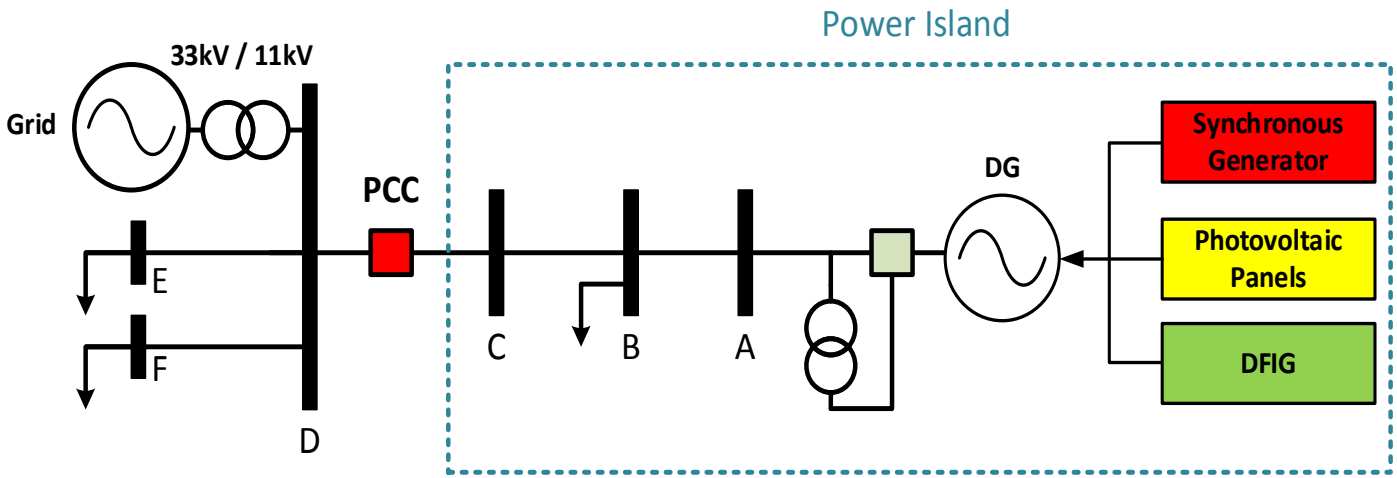
Active Power Imbalance: 0% Reactive Power Imbalance: 0%		Active Power Imbalance: 5% Reactive Power Imbalance: 0%		Active Power Imbalance: 0% Reactive Power Imbalance: 5%	
ROCOF Setting	**Trip**	**ROCOF Setting**	**Trip**	**ROCOF Setting**	**Trip**
1	1	1	1	1	1
2	1	2	1	2	1
3	0	3	0	3	0
4	0	4	0	4	0
Voltage Protection	**Trip**	**Voltage Protection**	**Trip**	**Voltage Protection**	**Trip**
Under Voltage	0	Under Voltage	0	Under Voltage	0
Over Voltage	0	Over Voltage	0	Over Voltage	0
Frequency Protection	**Trip**	**Frequency Protection**	**Trip**	**Frequency Protection**	**Trip**
Under Frequency	0	Under Frequency	0	Under Frequency	0
Over Frequency	0	Over Frequency	0	OverFrequency	0

100 % Constant Z Load

Generation Mix Stability Studies

SG - PV - DFIG



2 MVA Total Installed Capacity			
Case	SG [%]	PV [%]	DFIG [%]
1	70	15	15
2	15	70	15
3	15	15	70

Unstable →

SG-PV-DFIG Case 1

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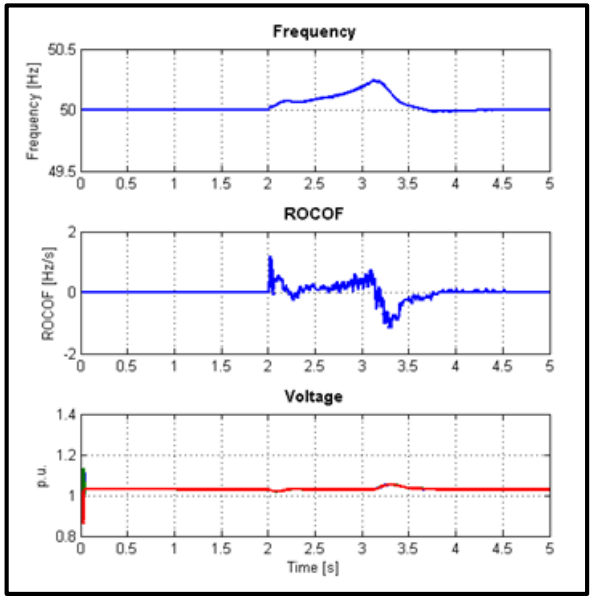
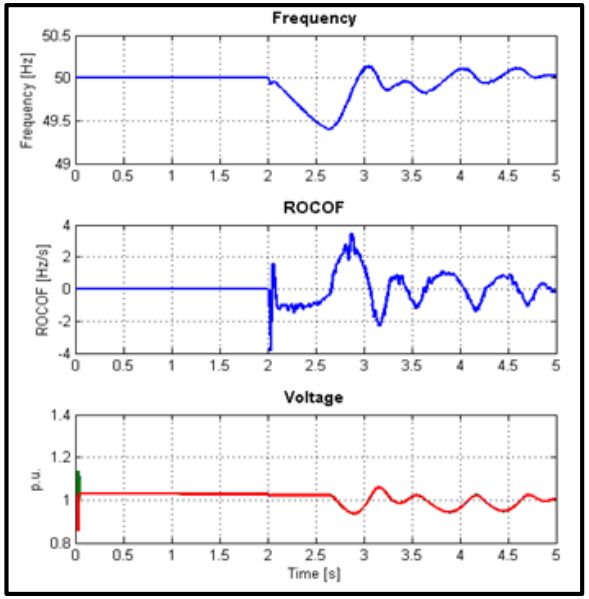
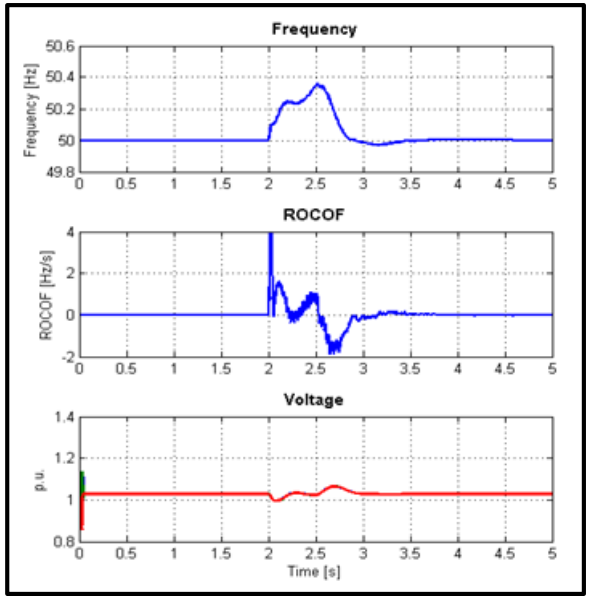
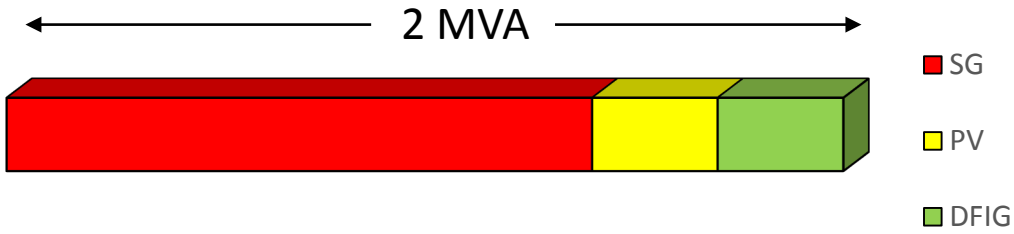
Active Power Imbalance: 0% Reactive Power Imbalance: 0%	Active Power Imbalance: 5% Reactive Power Imbalance: 0%	Active Power Imbalance: 0% Reactive Power Imbalance: 5%
		

100 % Constant Z Load

SG-PV-DFIG Case 1



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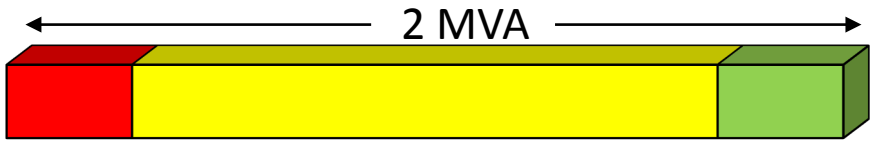
Active Power Imbalance: 0% Reactive Power Imbalance: 0%	
ROCOF Setting	**Trip**
1	1
2	1
3	0
4	0
Voltage Protection	**Trip**
Under Voltage	0
Over Voltage	0
Frequency Protection	**Trip**
Under Frequency	0
Over Frequency	0

Active Power Imbalance: 5% Reactive Power Imbalance: 0%	
ROCOF Setting	**Trip**
1	1
2	1
3	0
4	0
Voltage Protection	**Trip**
Under Voltage	0
Over Voltage	0
Frequency Protection	**Trip**
Under Frequency	0
Over Frequency	0

Active Power Imbalance: 0% Reactive Power Imbalance: 5%	
ROCOF Setting	**Trip**
1	1
2	1
3	0
4	0
Voltage Protection	**Trip**
Under Voltage	0
Over Voltage	0
Frequency Protection	**Trip**
Under Frequency	0
Over Frequency	0

100 % Constant Z Load

SG-PV-DFIG Case 2



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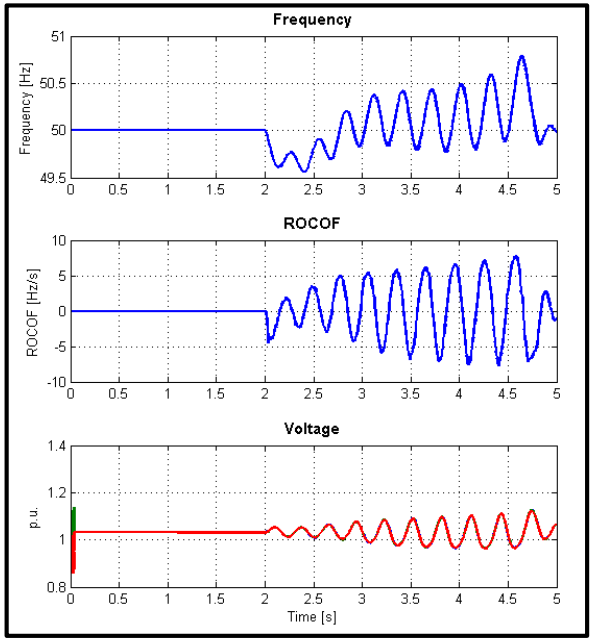
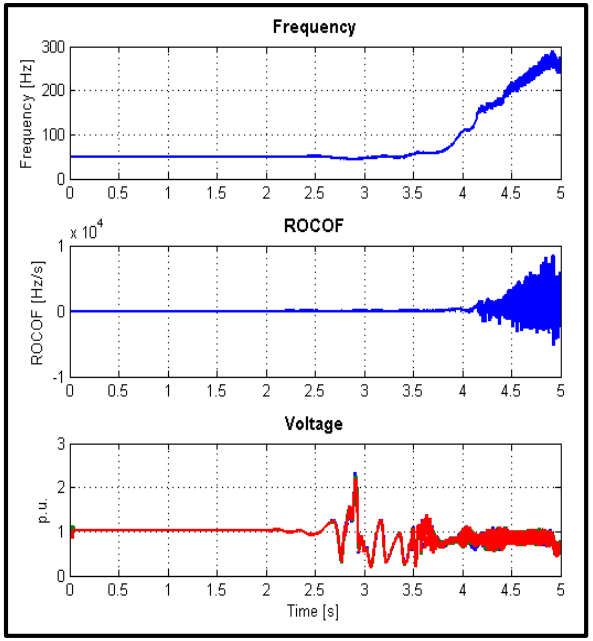
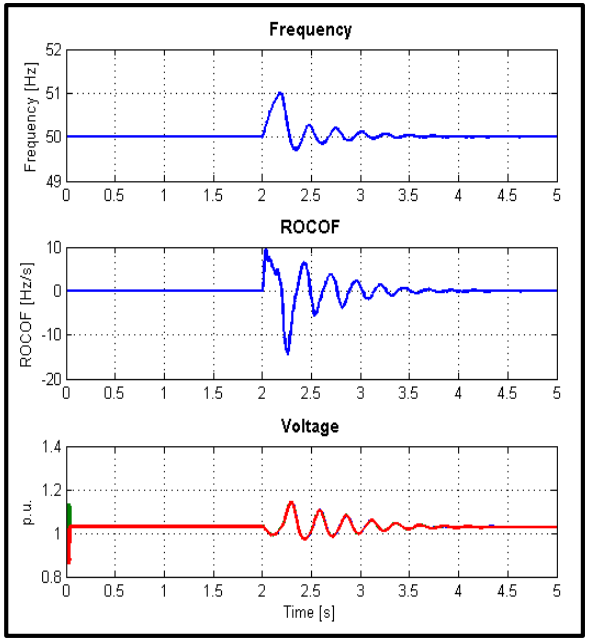
Active Power Imbalance: 0% Reactive Power Imbalance: 0%	Active Power Imbalance: 5% Reactive Power Imbalance: 0%	Active Power Imbalance: 0% Reactive Power Imbalance: 5%

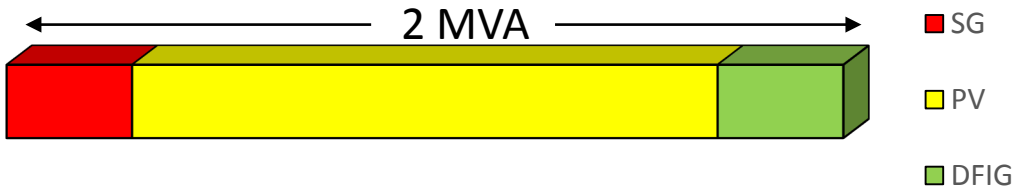






100 % Constant Z Load

SG-PV-DFIG Case 2



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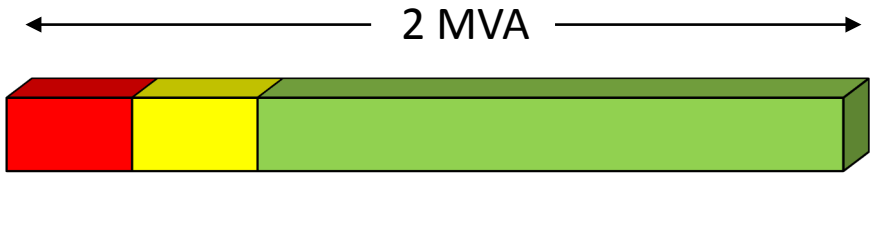
Active Power Imbalance: 0% Reactive Power Imbalance: 0%	
ROCOF Setting	**Trip**
1	1
2	1
3	0
4	0
Voltage Protection	**Trip**
Under Voltage	0
Over Voltage	0
Frequency Protection	**Trip**
Under Frequency	0
Over Frequency	0

Active Power Imbalance: 5% Reactive Power Imbalance: 0%	
ROCOF Setting	**Trip**
1	1
2	1
3	0
4	0
Voltage Protection	**Trip**
Under Voltage	0
Over Voltage	1
Frequency Protection	**Trip**
Under Frequency	0
Over Frequency	1

Active Power Imbalance: 0% Reactive Power Imbalance: 5%	
ROCOF Setting	**Trip**
1	1
2	1
3	0
4	0
Voltage Protection	**Trip**
Under Voltage	0
Over Voltage	0
Frequency Protection	**Trip**
Under Frequency	0
Over Frequency	0

100 % Constant Z Load

SG-PV-DFIG Case 3



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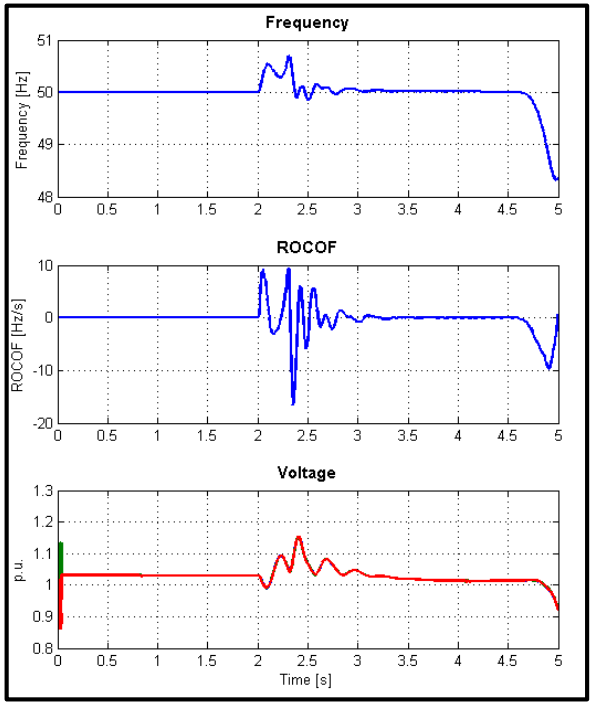
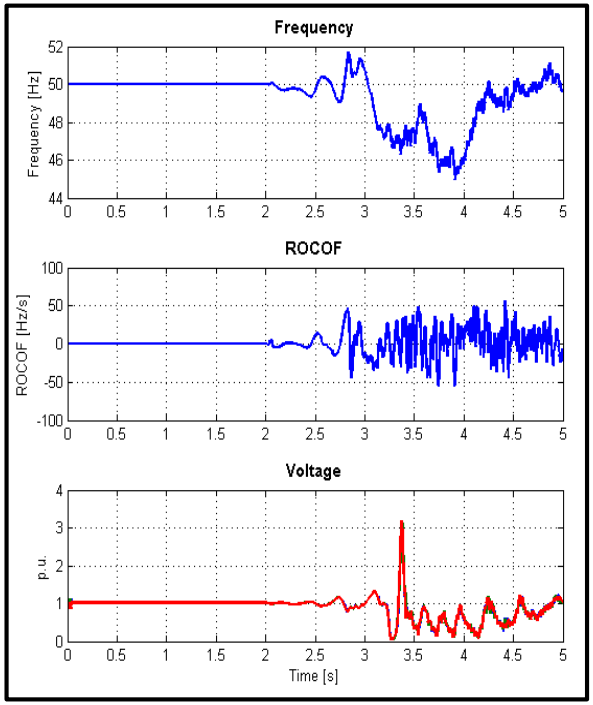
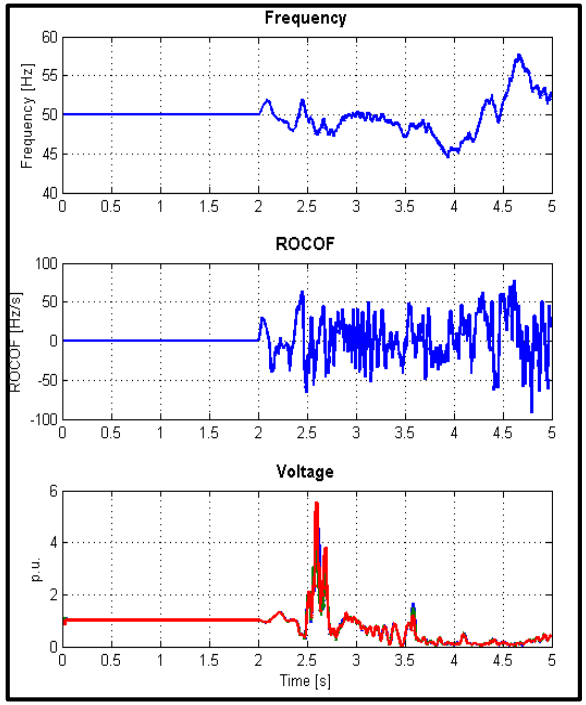
Active Power Imbalance: 0% Reactive Power Imbalance: 0%	Active Power Imbalance: 5% Reactive Power Imbalance: 0%	Active Power Imbalance: 0% Reactive Power Imbalance: 5%

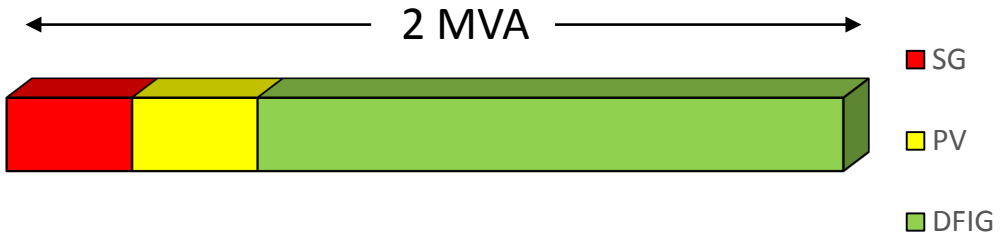






100 % Constant Z Load

SG-PV-DFIG Case 3



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Active Power Imbalance: 0% Reactive Power Imbalance: 0%	
ROCOF Setting	**Trip**
1	1
2	1
3	0
4	0
Voltage Protection	**Trip**
Under Voltage	0
Over Voltage	0
Frequency Protection	**Trip**
Under Frequency	0
Over Frequency	0

Active Power Imbalance: 5% Reactive Power Imbalance: 0%	
ROCOF Setting	**Trip**
1	0
2	0
3	0
4	0
Voltage Protection	**Trip**
Under Voltage	1
Over Voltage	0
Frequency Protection	**Trip**
Under Frequency	0
Over Frequency	0

Active Power Imbalance: 0% Reactive Power Imbalance: 5%	
ROCOF Setting	**Trip**
1	1
2	1
3	0
4	0
Voltage Protection	**Trip**
Under Voltage	1
Over Voltage	0
Frequency Protection	**Trip**
Under Frequency	0
Over Frequency	0

100 % Constant Z Load

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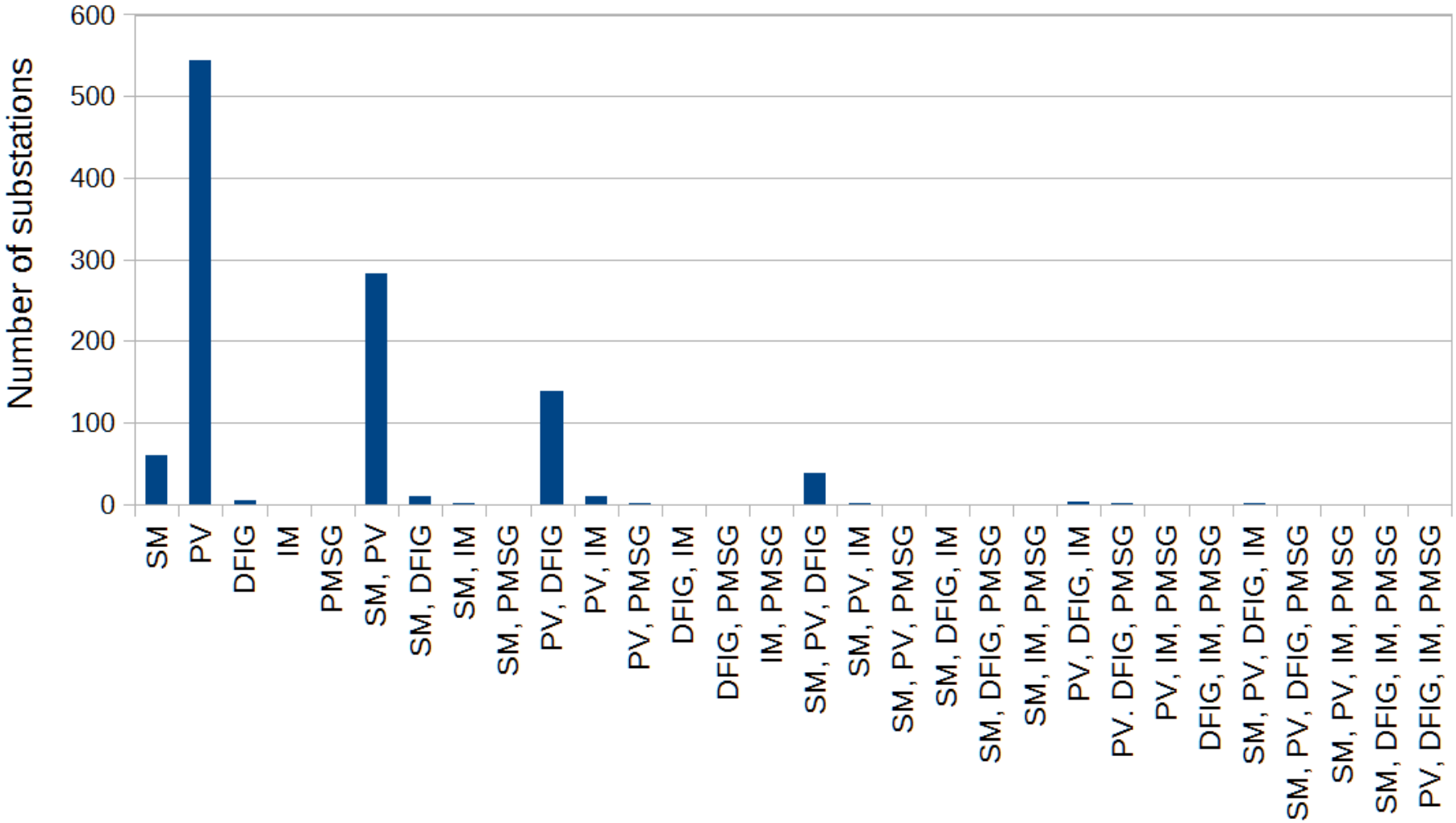
DG register analysis (WPD, ENW and UKPN – Needs Updating)

WP3 – Risk assessment calculation

- Technologies with cumulative contribution of 10% or less were removed from the mix.
- The remaining generation was scaled up to the full capacity installed at the primary substation
- Data from WPD, ENW and UKPN has been included. UKPN needs updated.

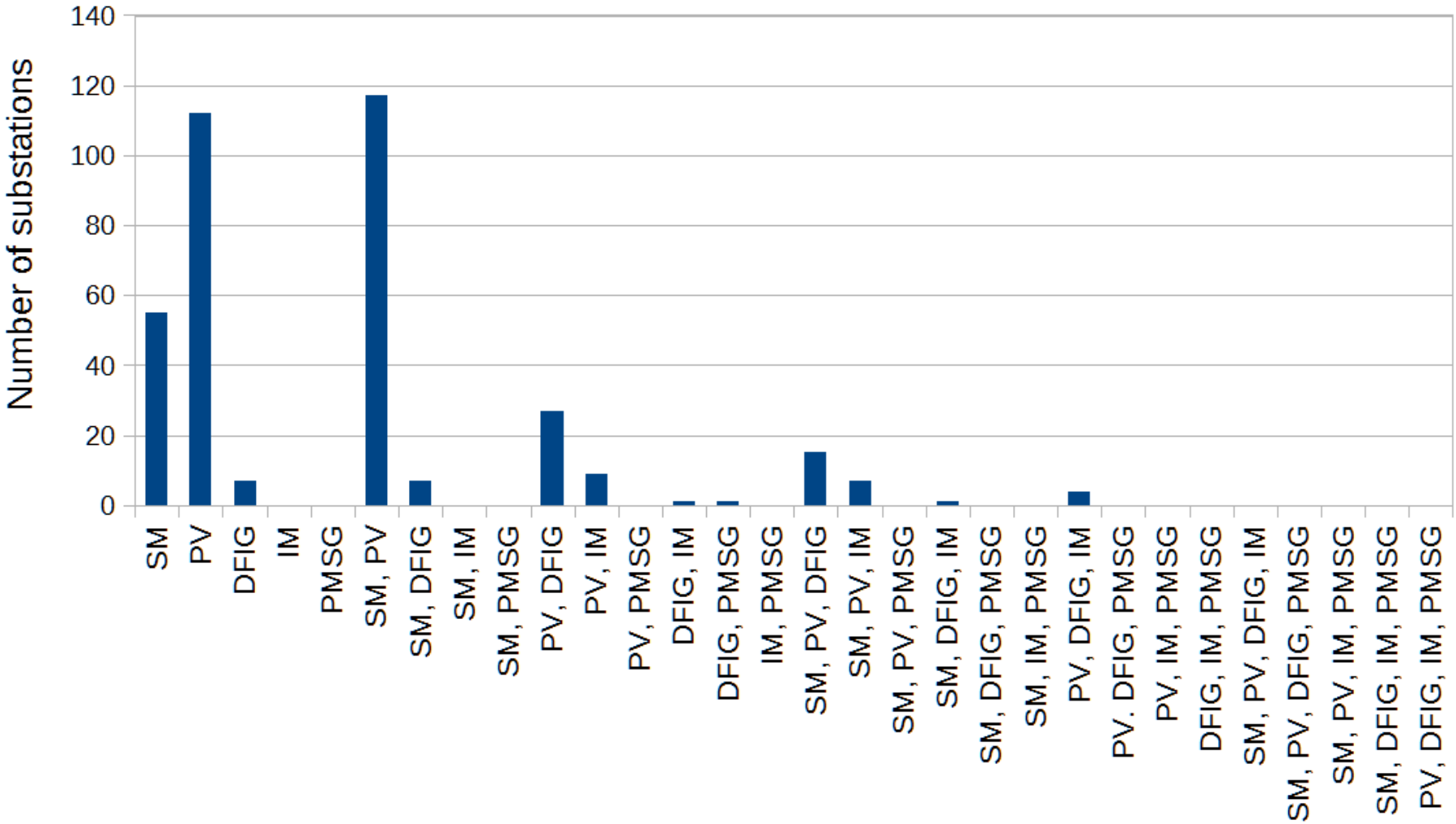
WP3 – Risk assessment calculation

- Establishing dominant groups (WPD).



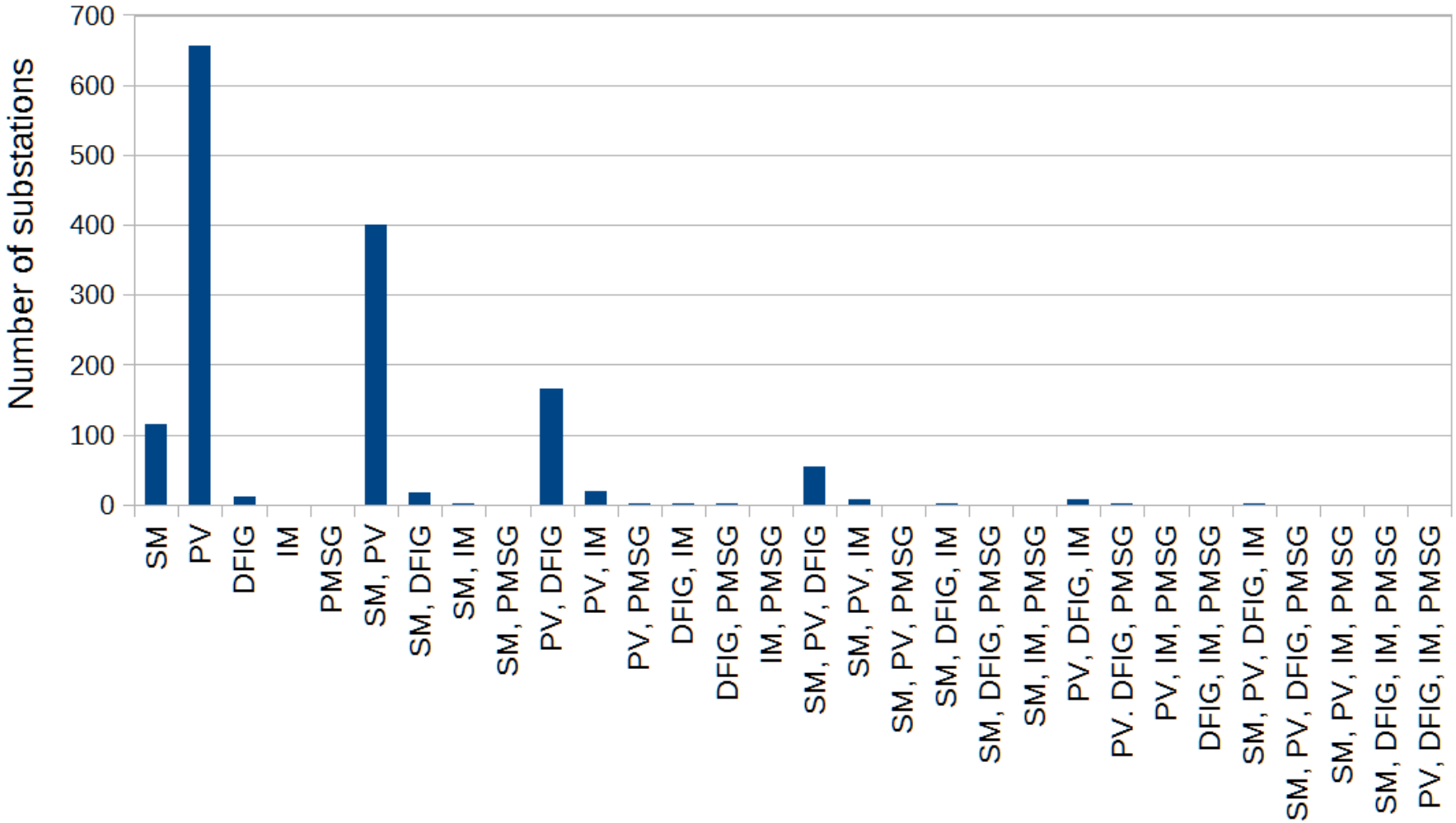
WP3 – Risk assessment calculation

- Establishing dominant groups (ENW).



WP3 – Risk assessment calculation

- Establishing dominant groups (WPD, ENW).



WP3 – Risk assessment calculation

Group	Substations	Percentage
SM	60	5.5
PV	544	49.5
DFIG	5	0.5
IM	0	0.0
PMSG	0	0.0
SM, PV	283	25.8
SM, DFIG	10	0.9
SM, IM	1	0.1
SM, PMSG	0	0.0
PV, DFIG	139	12.7
PV, IM	10	0.9
PV, PMSG	1	0.1
DFIG, IM	0	0.0
DFIG, PMSG	0	0.0
IM, PMSG	0	0.0
SM, PV, DFIG	39	3.6
SM, PV, IM	1	0.1
SM, PV, PMSG	0	0.0
SM, DFIG, IM	0	0.0
SM, DFIG, PMSG	0	0.0
SM, IM, PMSG	0	0.0
PV, DFIG, IM	3	0.3
PV. DFIG, PMSG	1	0.1
PV, IM, PMSG	0	0.0
DFIG, IM, PMSG	0	0.0
SM, PV, DFIG, IM	1	0.1
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	1098	100.0

- Establishing dominant groups (WPD).
- Groups of primary substations with more than 3% of the total population were only considered for risk assessment analysis.

WP3 – Risk assessment calculation

Group	Substations	Percentage
SM	55	15.2
PV	112	30.9
DFIG	7	1.9
IM	0	0.0
PMSG	0	0.0
SM, PV	117	32.2
SM, DFIG	7	1.9
SM, IM	0	0.0
SM, PMSG	0	0.0
PV, DFIG	27	7.4
PV, IM	9	2.5
PV, PMSG	0	0.0
DFIG, IM	1	0.3
DFIG, PMSG	1	0.3
IM, PMSG	0	0.0
SM, PV, DFIG	15	4.1
SM, PV, IM	7	1.9
SM, PV, PMSG	0	0.0
SM, DFIG, IM	1	0.3
SM, DFIG, PMSG	0	0.0
SM, IM, PMSG	0	0.0
PV, DFIG, IM	4	1.1
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	363	100.0

- Establishing dominant groups (ENW).
- Groups of primary substations with more than 3% of the total population were only considered for risk assessment analysis.

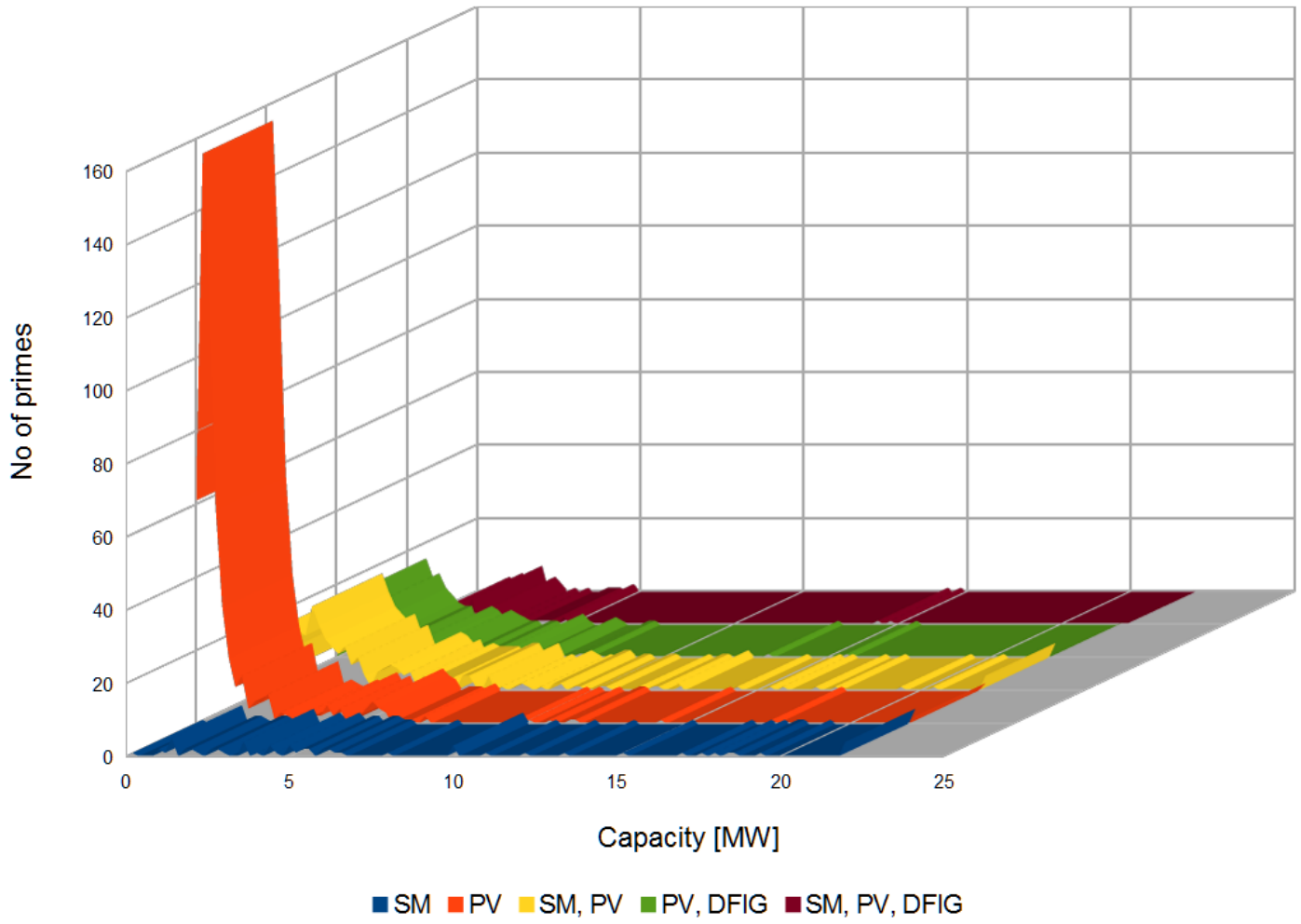
WP3 – Risk assessment calculation

Group	Substations	Percentage
SM	115	7.9
PV	656	44.9
DFIG	12	0.8
IM	0	0.0
PMSG	0	0.0
SM, PV	400	27.4
SM, DFIG	17	1.2
SM, IM	1	0.1
SM, PMSG	0	0.0
PV, DFIG	166	11.4
PV, IM	19	1.3
PV, PMSG	1	0.1
DFIG, IM	1	0.1
DFIG, PMSG	1	0.1
IM, PMSG	0	0.0
SM, PV, DFIG	54	3.7
SM, PV, IM	8	0.5
SM, PV, PMSG	0	0.0
SM, DFIG, IM	1	0.1
SM, DFIG, PMSG	0	0.0
SM, IM, PMSG	0	0.0
PV, DFIG, IM	7	0.5
PV. DFIG, PMSG	1	0.1
PV, IM, PMSG	0	0.0
DFIG, IM, PMSG	0	0.0
SM, PV, DFIG, IM	1	0.1
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	64	100.0

- Establishing dominant groups (WPD and ENW).
- Groups of primary substations with more than 3% of the total population were only considered for risk assessment analysis.

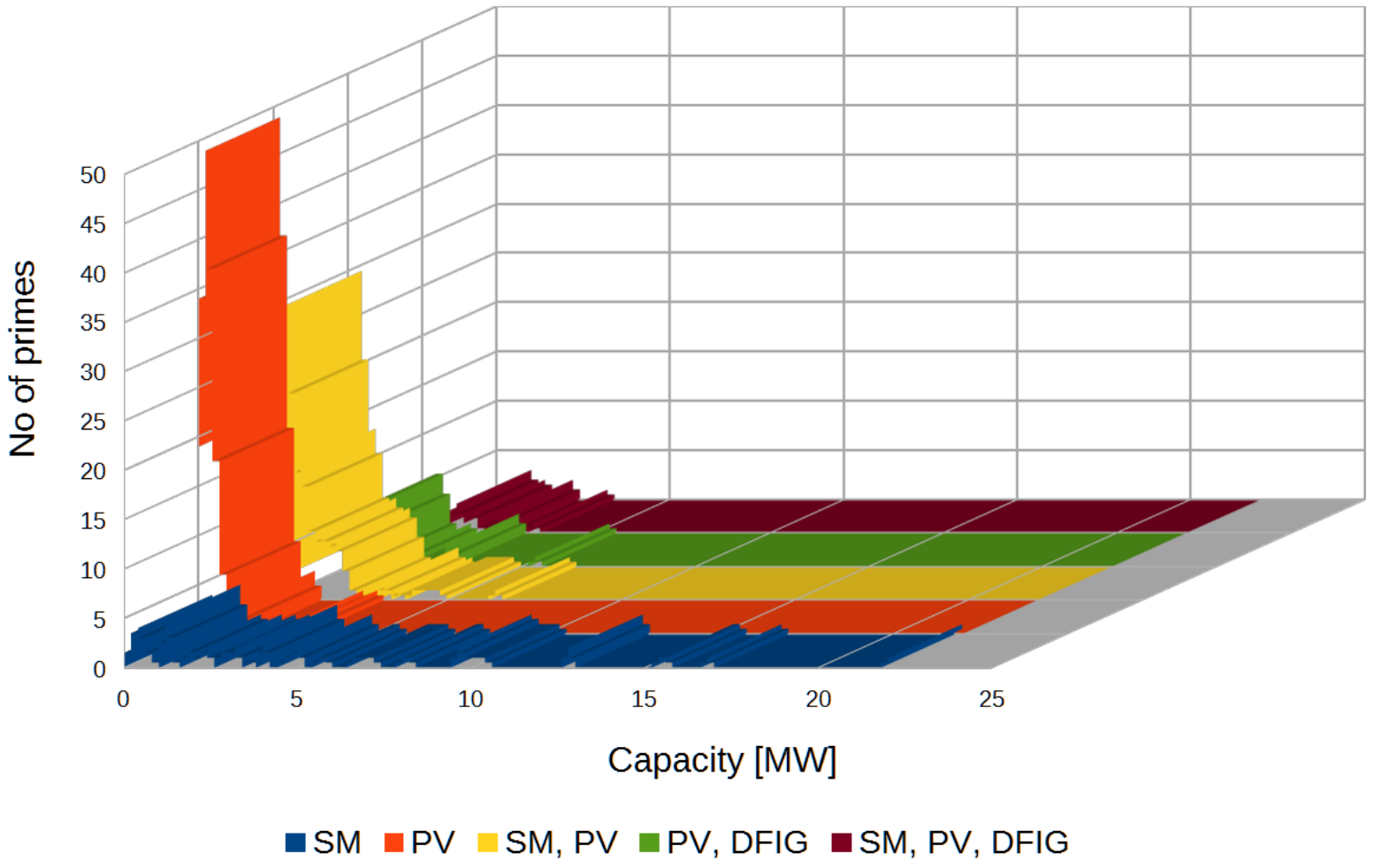
WP3 – Risk assessment calculation

- Distribution of dominant groups - WPD.



WP3 – Risk assessment calculation

- Distribution of dominant groups - ENW.



WP3 – Risk assessment calculation

- Distribution of dominant groups – WPD, ENW.