# Risk Assessment of Loss of Mains Protection – Phase II

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# Outline

- WP1 – Hardware testing based characterisation of DG – PNDC

- WP3 – Risk assessment calculation
  - DG connection register analysis (WPD)
  - Establishing dominant connection groups
  - Mixing generation profiles
  - Methodology

- WP2 – Simulation based characterisation of DG

# WP1 – Hardware testing based characterisation of DG – PNDC

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## Test Setup

- PV emulator supplying single phase 3kW Fronius inverter.
  - Desired power output set (power levels depend on test).
  - PV emulator outputs DC voltage and current within set limits using MPPT curve.
- Fluke power quality analyser measurements at:
  - Inverter output.
  - PCC (convention set as export to grid).
- Single phase load bank used as local load (1kW steps).


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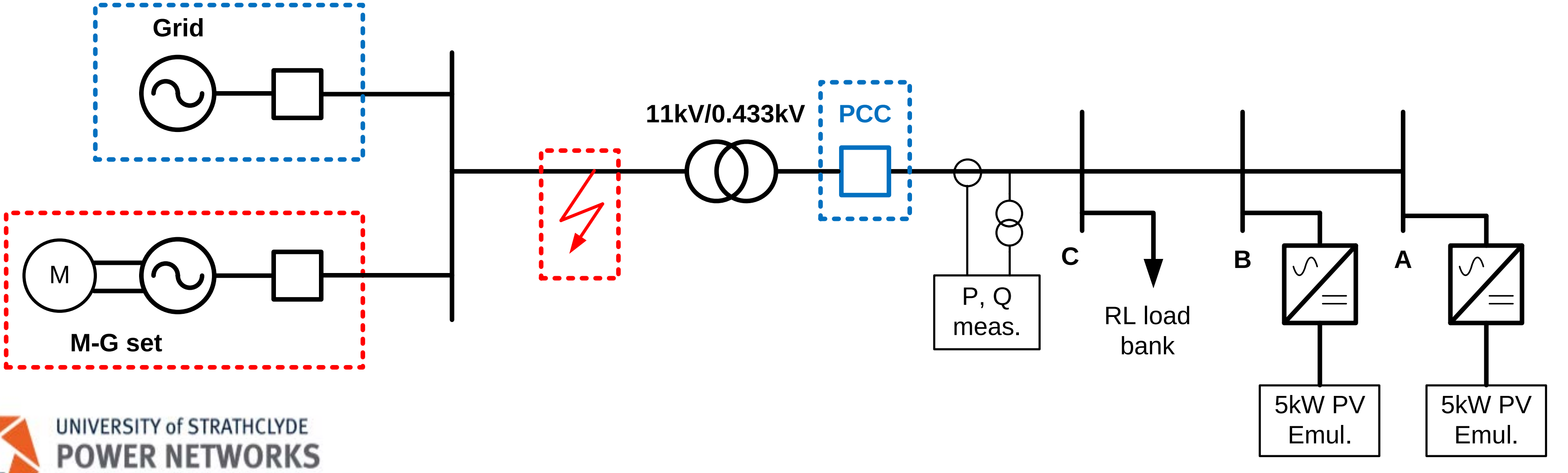
# WP1 – Hardware testing based characterisation of DG – PNDC

## Tests conducted

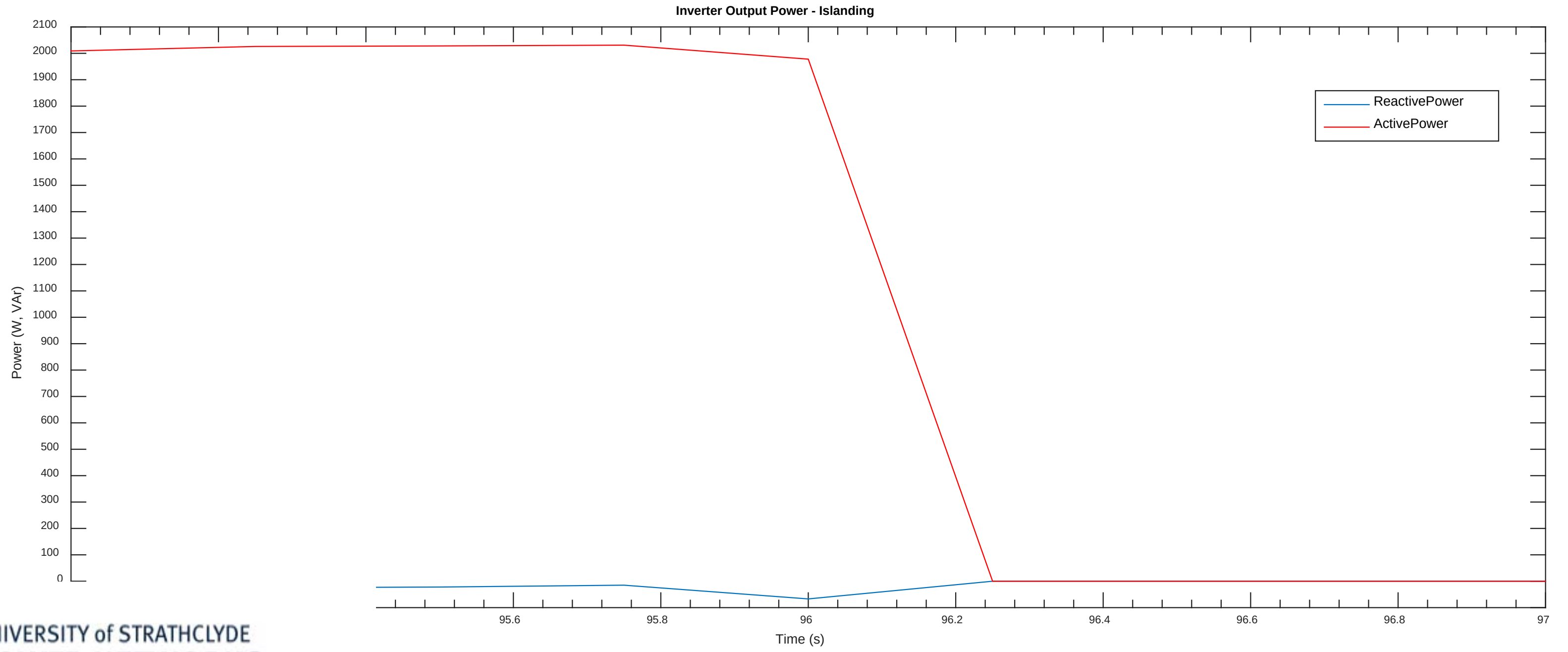
- Islanding: 2kW load while inverter output is adjusted to minimise PCC power flow. The public grid is used in this case.
- Frequency ramps: ramp down then ramp up between 49.5-48.5Hz at a +/-0.5Hz/s rate. The MG set is used in this case.
- HV fault: 60Ω single phase earth fault applied on the upstream 11kV network. The MG set is used in this case.



# WP1 – Hardware testing based characterisation of DG – PNDC

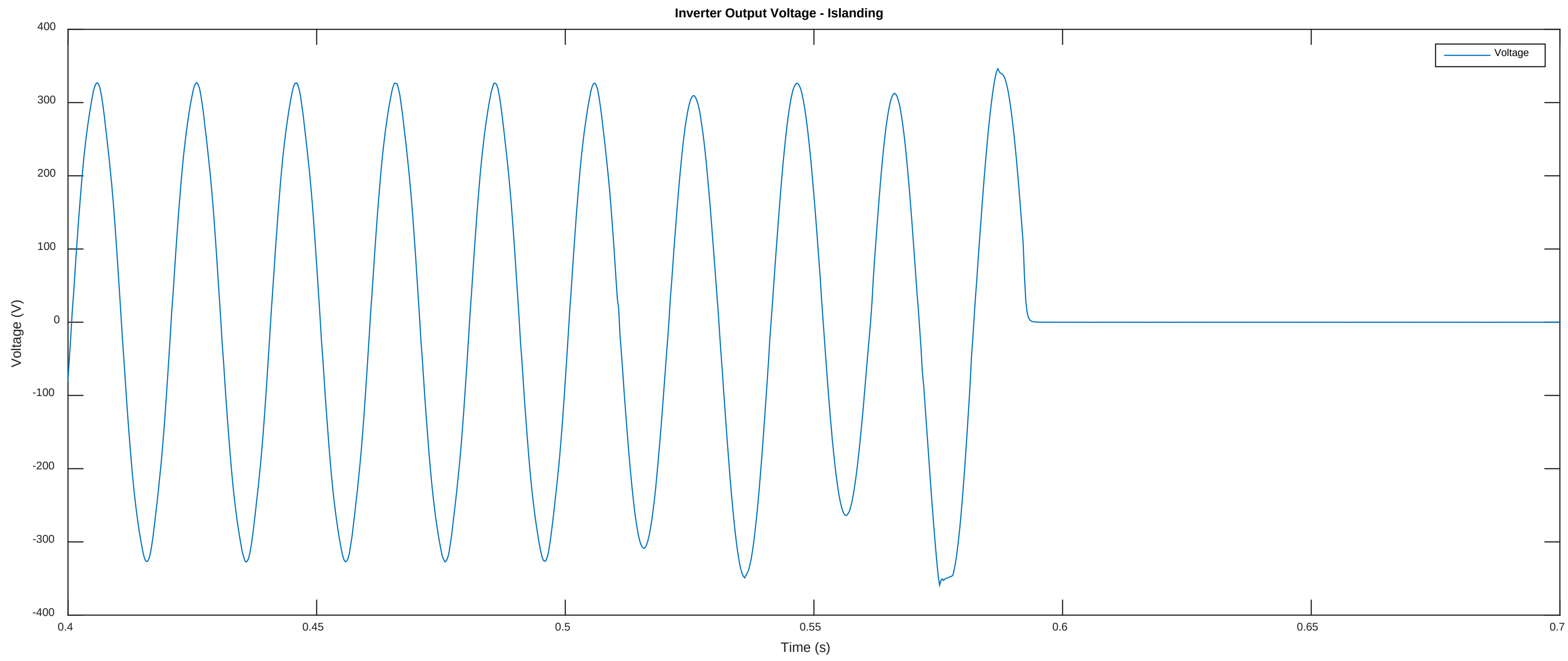
## Islanding results – Inverter Power

- At the point of islanding:
  - Measured inverter output around 2.03kW and -20VAr.
  - Measured PCC export around +/-2W and 140VAr.
- Inverter trips within 4 cycles.



# WP1 – Hardware testing based characterisation of DG – PNDC

## Islanding results – Inverter Voltage

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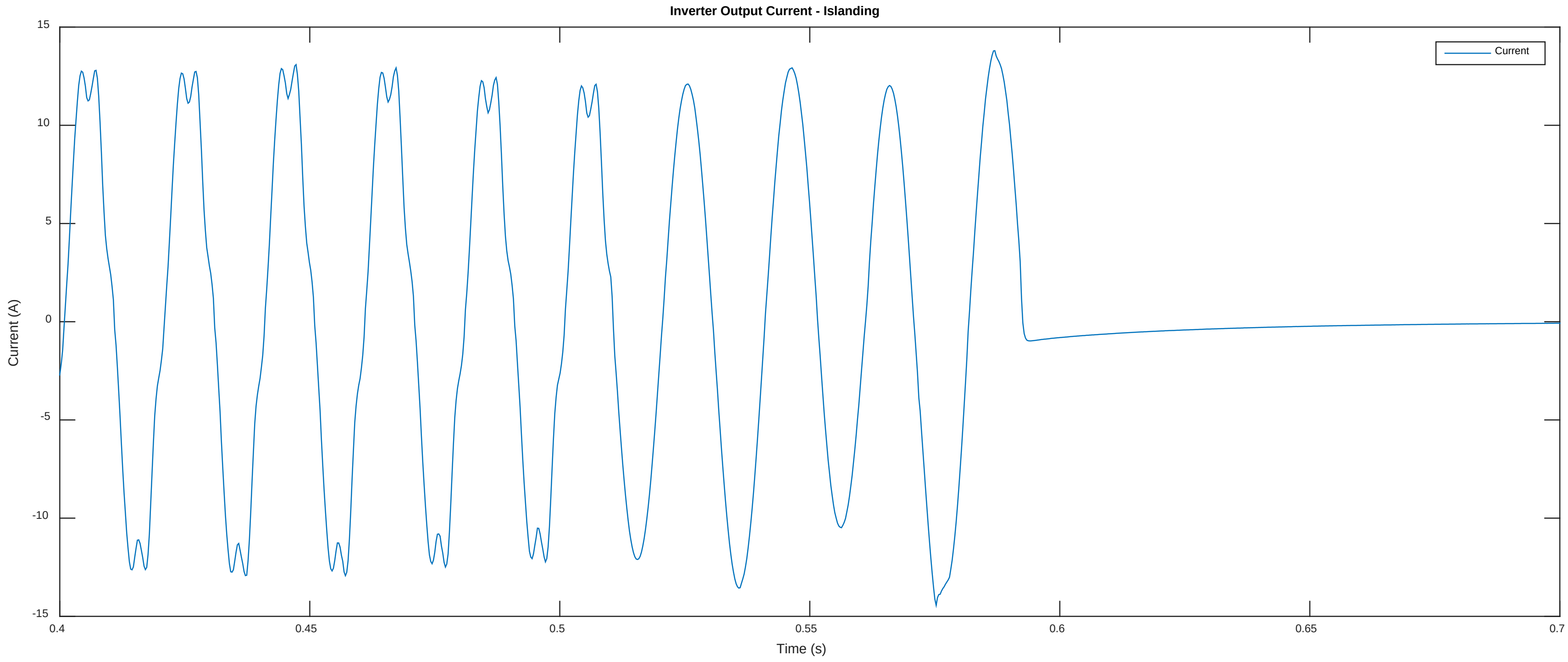
# WP1 – Hardware testing based characterisation of DG – PNDC

## Islanding results – Inverter Current

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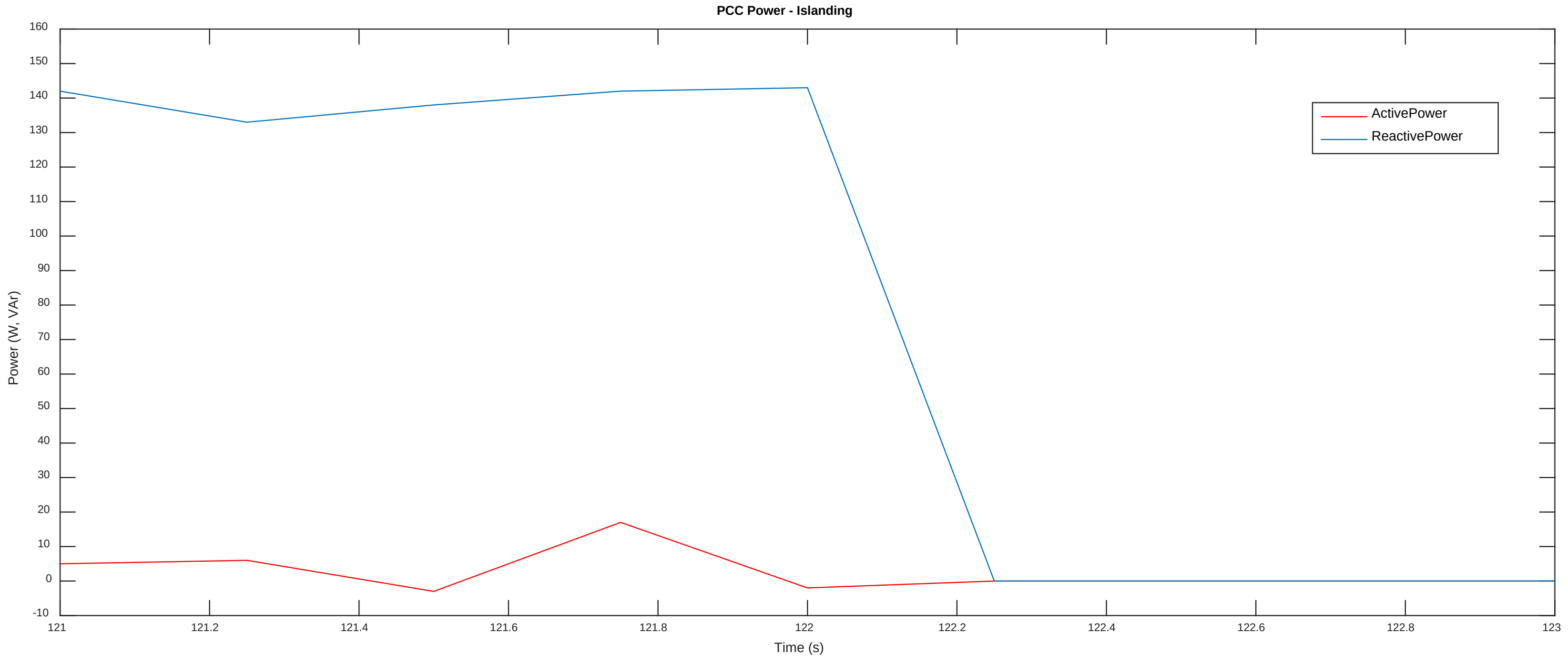
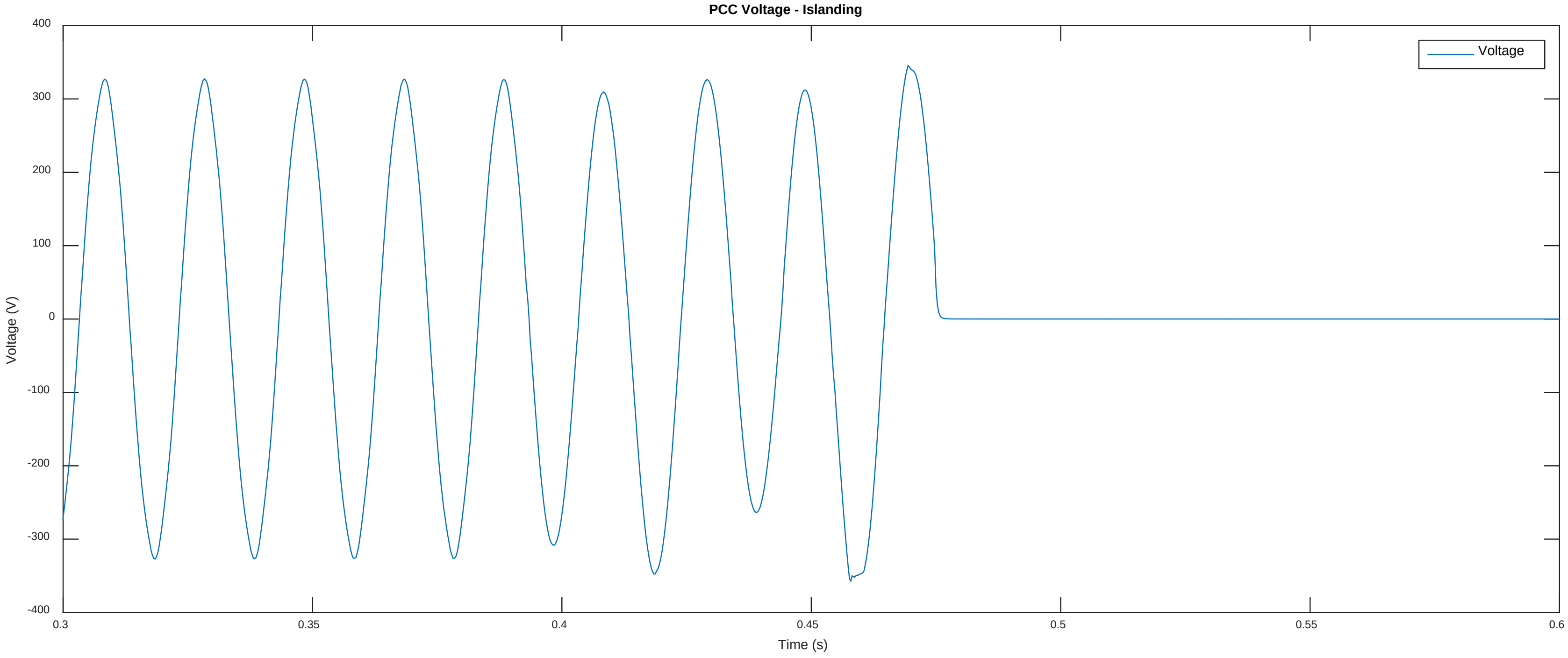
# WP1 – Hardware testing based characterisation of DG – PNDC

## Islanding results – PCC Power



# WP1 – Hardware testing based characterisation of DG – PNDC

## Islanding results – PCC Voltage

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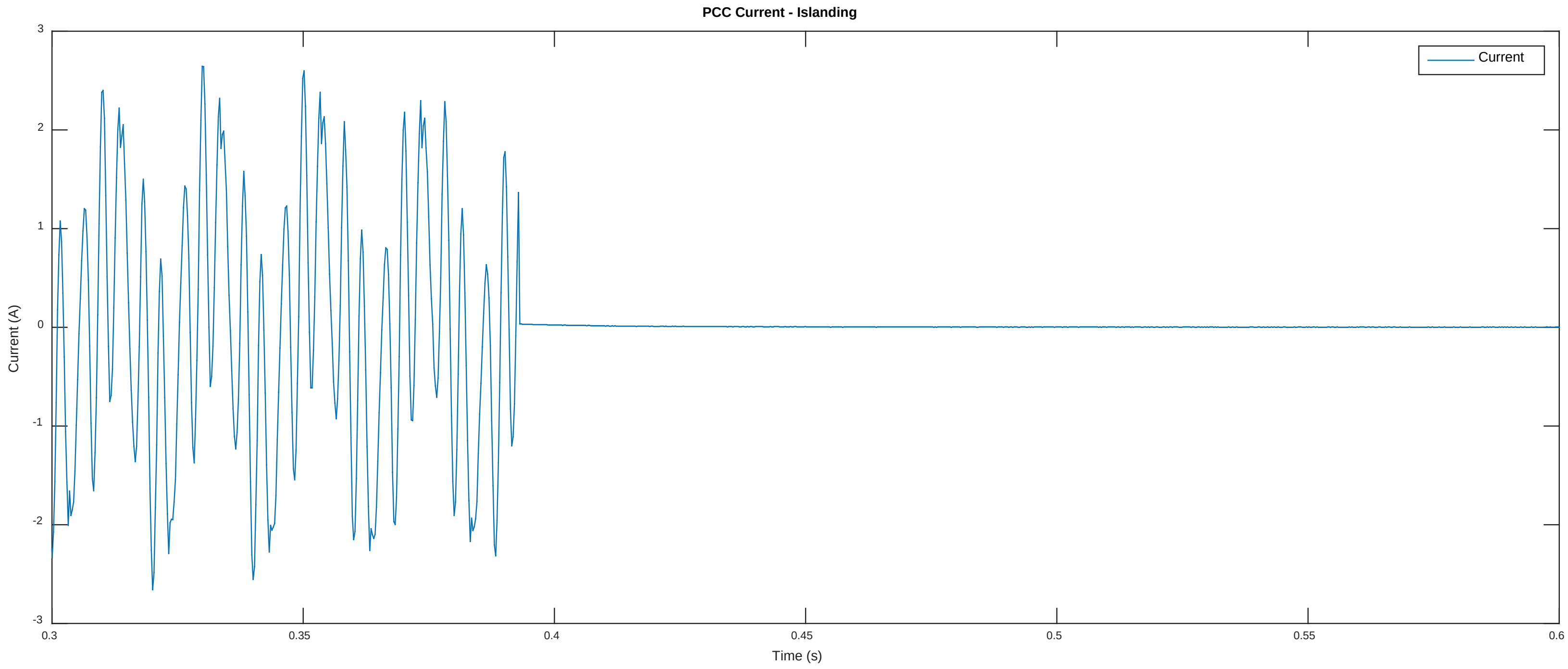
# WP1 – Hardware testing based characterisation of DG – PNDC

## Islanding results – PCC Current



# WP1 – Hardware testing based characterisation of DG – PNDC

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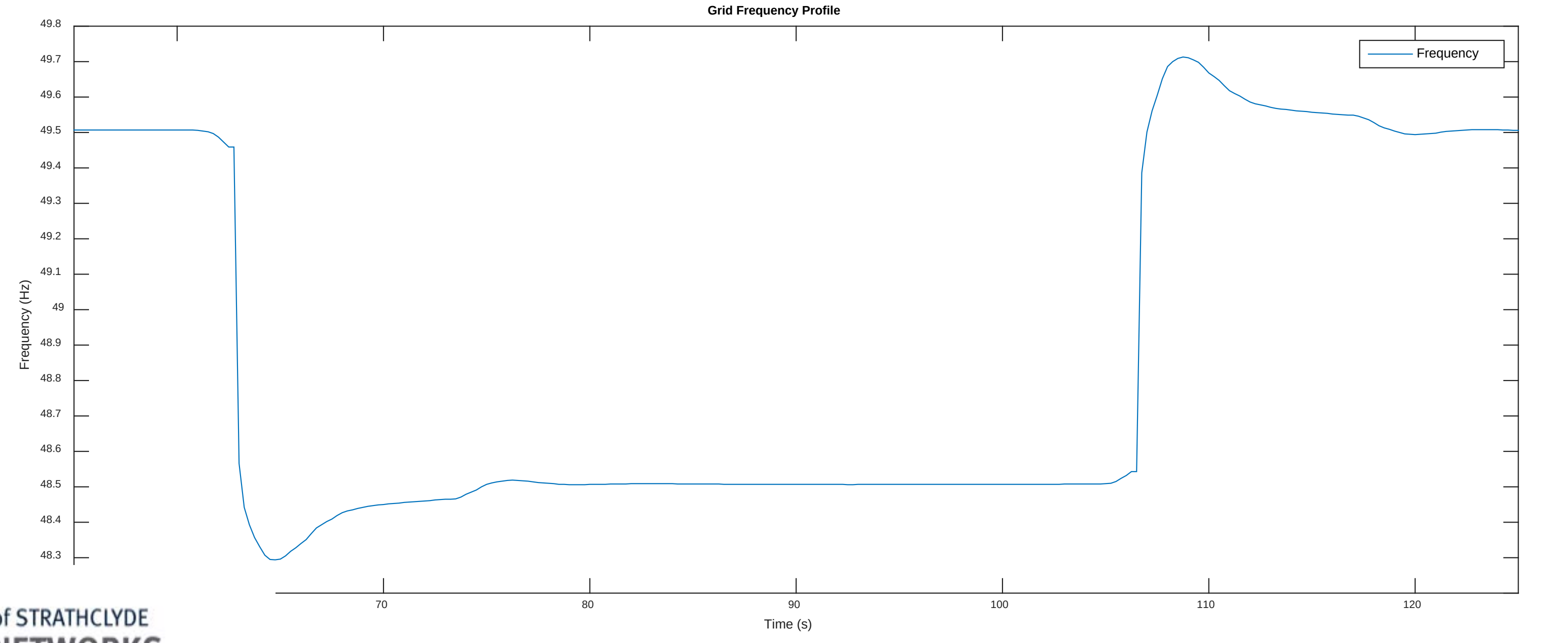
## Frequency ramp results – Frequency profile

- MG set speed controlled tightly using RTDS:
  - Ramp up and down rate of +/-0.5Hz/s within 49.5Hz – 48.5Hz band.
  - Band selected to avoid HV network protection or inverter tripping caused by MG set speed control overshoot.
- Inverter remains stable during and after ramps.

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# WP1 – Hardware testing based characterisation of DG – PNDC

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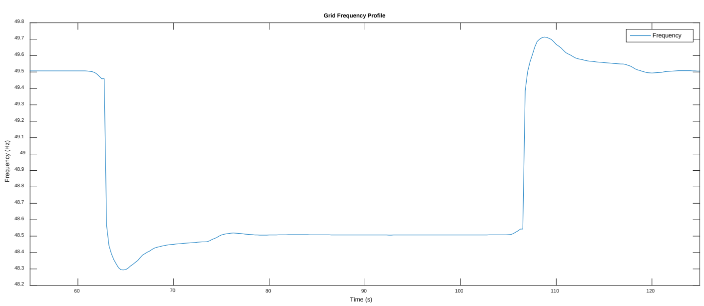


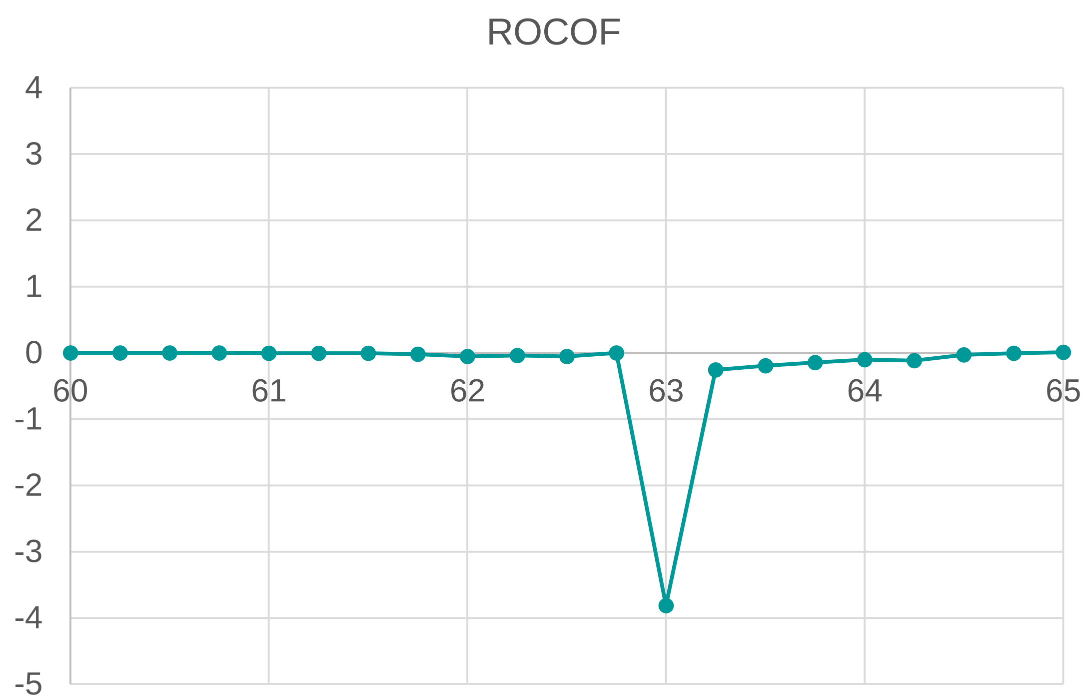

# WP1 – Hardware testing based characterisation of DG – PNDC

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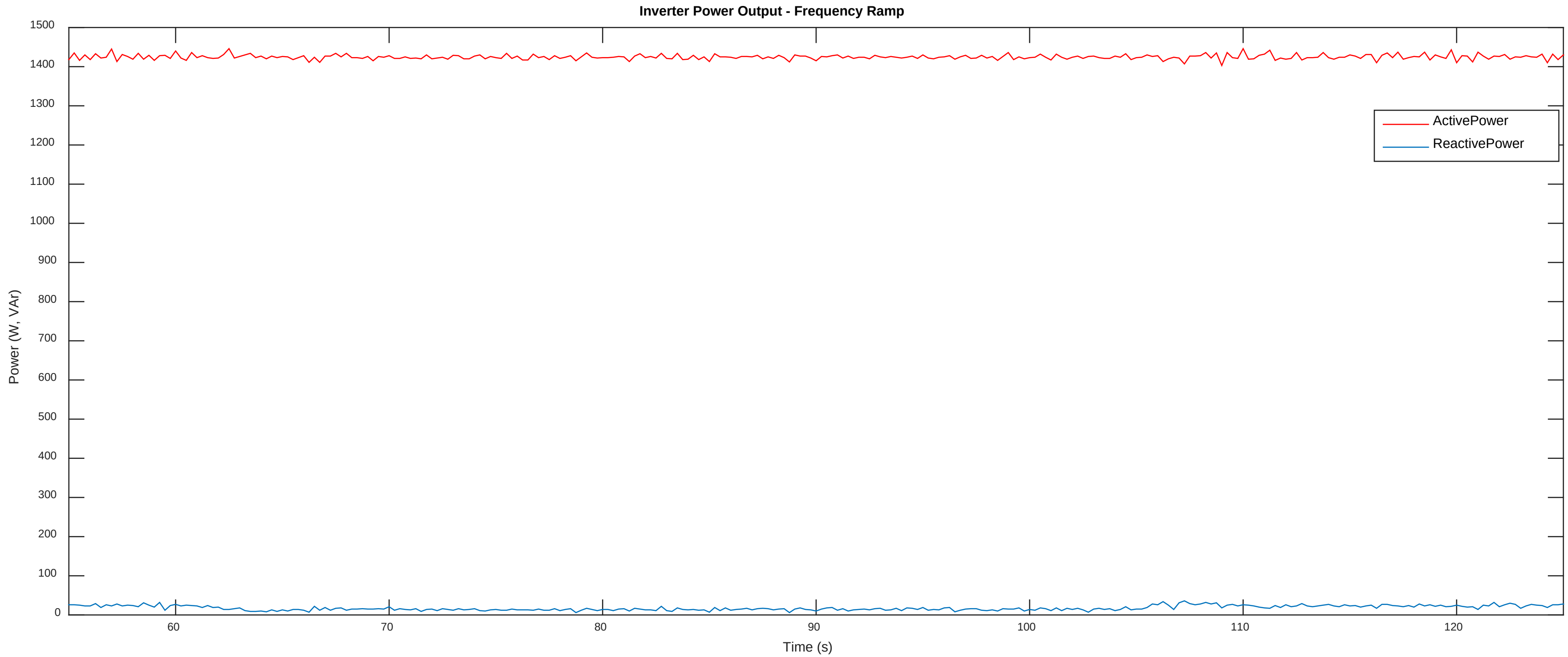
## Frequency ramp results – Inverter Power

- Load bank set to 2kW.
- Inverter output set to around1.4kW.
- Measured inverter output reactive power of around 20VAr.

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# WP1 – Hardware testing based characterisation of DG – PNDC

## Next steps

- In the process of ordering further inverters for further testing:
  - 5kW SMA SunnyBoy.
  - 5kW ABB (PowerOne).
  - 5kW Kaco.
  - 10kW SMA TriPower (three phase).
- Testing will include up to 2 single phase inverters simultaneously.
- Installation of new inverters and testing planned for second half of April.
- Build working group feedback into upcoming testing.

# DG register analysis (WPD)

# WP3 – Risk assessment calculation

- Technology mapping (based on WPD data).

| Primary substation | Generator type | Connected export capacity [kW] | Accepted not yet connected export capacity [kW] | Total export capacity [kW] |
|---|---|---|---|---|
| Abington 33/11kv | Photovoltaic | 79.38 | 0 | 79.38 |
| Acreage Lane 33/11kv | Hydro | 3.56 | 0 | 3.56 |
| Acreage Lane 33/11kv | Landfill Gas Sewage Gas Biogas (not CHP) | 11700 | 0 | 11700 |
| Acreage Lane 33/11kv | Other Generation | 1200 | 0 | 1200 |
| Acreage Lane 33/11kv | Photovoltaic | 503.21 | 0 | 503.21 |
| Alford 33/11kv | Photovoltaic | 260.389 | 0 | 260.389 |
| Allenton 33/11kv | Micro CHP (Domestic) | 0.215 | 0 | 0.215 |
| Allenton 33/11kv | Photovoltaic | 883.01 | 0 | 883.01 |
| Alliance & Leicester 33/11kv | Biomass & Energy Crops (not CHP) | 1850 | 0 | 1850 |
| Alliance & Leicester 33/11kv | Landfill Gas Sewage Gas Biogas (not CHP) | 2590 | 0 | 2590 |
| Alliance & Leicester 33/11kv | Other Generation | 1000 | 0 | 1000 |
| Alliance & Leicester 33/11kv | Photovoltaic | 225.564 | 0 | 225.564 |
| Ambergate 33/11kv | Onshore Wind | 91 | 225 | 316 |
| Ambergate 33/11kv | Photovoltaic | 131.36 | 0 | 131.36 |
| Anderson Lane 33/11kv | Photovoltaic | 597.94 | 0 | 597.94 |
| Annesley (Kirkby) 11kv S Stn | Onshore Wind | 11 | 500 | 511 |

# WP3 – Risk assessment calculation

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- Technology mapping (based on WPD data).
  - All types of connections were mapped onto 5 main generating technologies

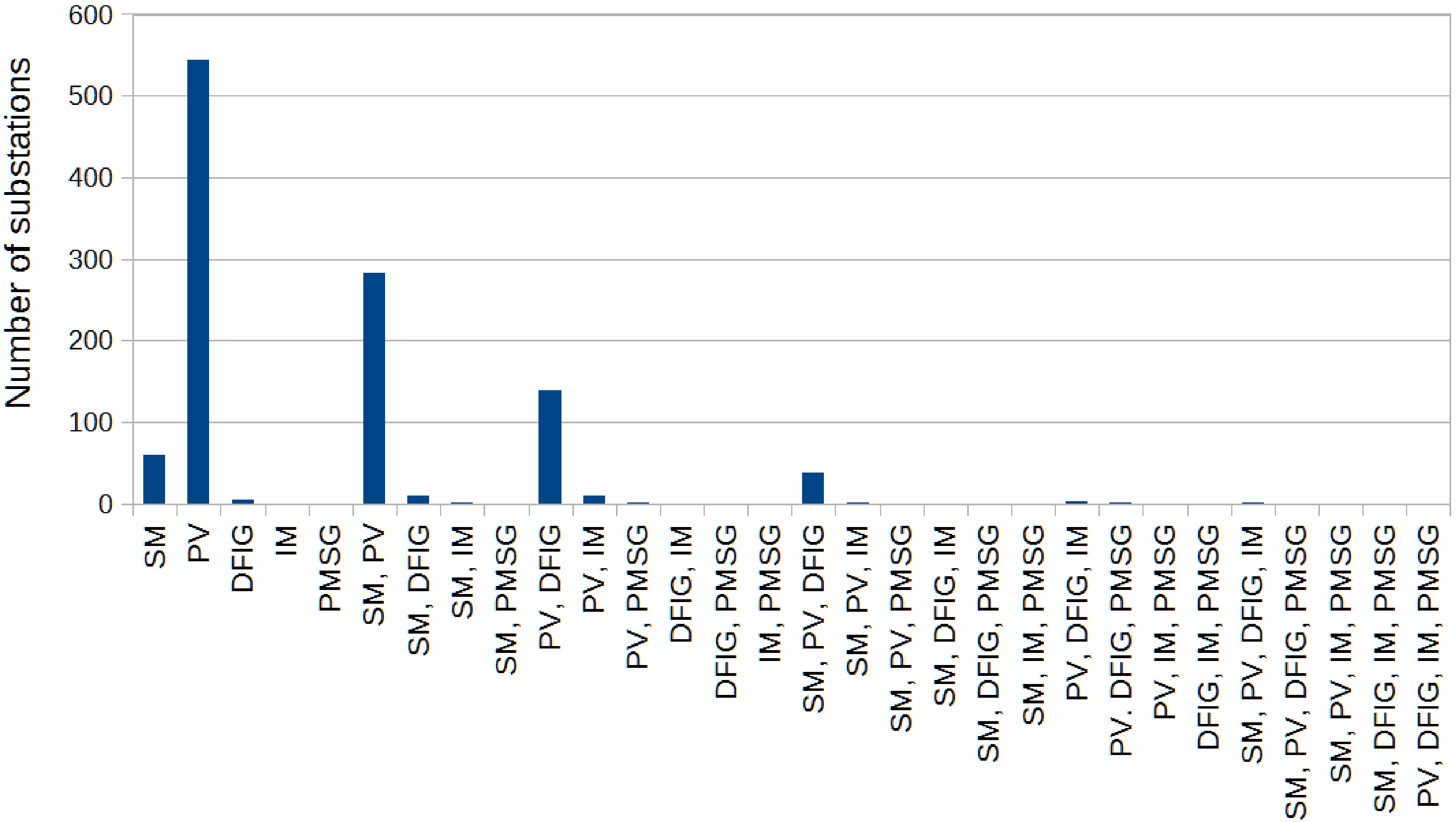
| | |
|---|---|
| Biomass & Energy Crops (not CHP) | SM |
| Hydro | IM |
| Landfill Gas Sewage Gas Biogas (not CHP) | SM |
| Large CHP (>=50mw) | SM |
| Medium CHP (>5MW <50MW) | SM |
| Micro CHP (Domestic) | SM |
| Mini CHP (<1MW) | SM |
| Offshore Wind | PMSG |
| Onshore Wind | DFIG |
| Other Generation | SM |
| Photovoltaic | PV |
| Small CHP (>1MW <5MW) | SM |
| Waste Incineration (not CHP) | SM |

# 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

# WP3 – Risk assessment calculation

- Establishing dominant groups.



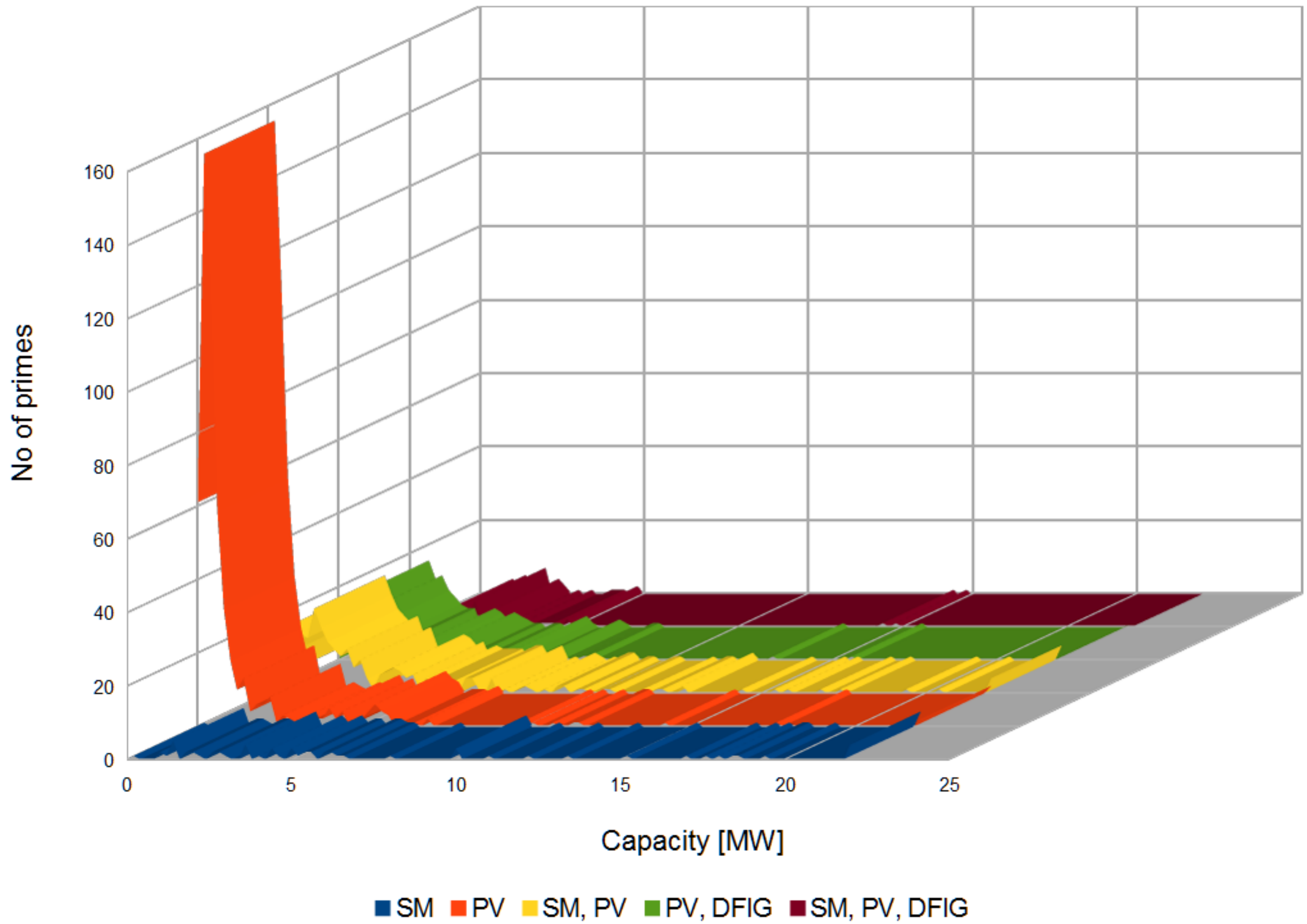
# WP3 – Risk assessment calculation

| 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.
- Groups of primary substations with more than 5% of the total population were only considered for risk assessment analysis.

# WP3 – Risk assessment calculation

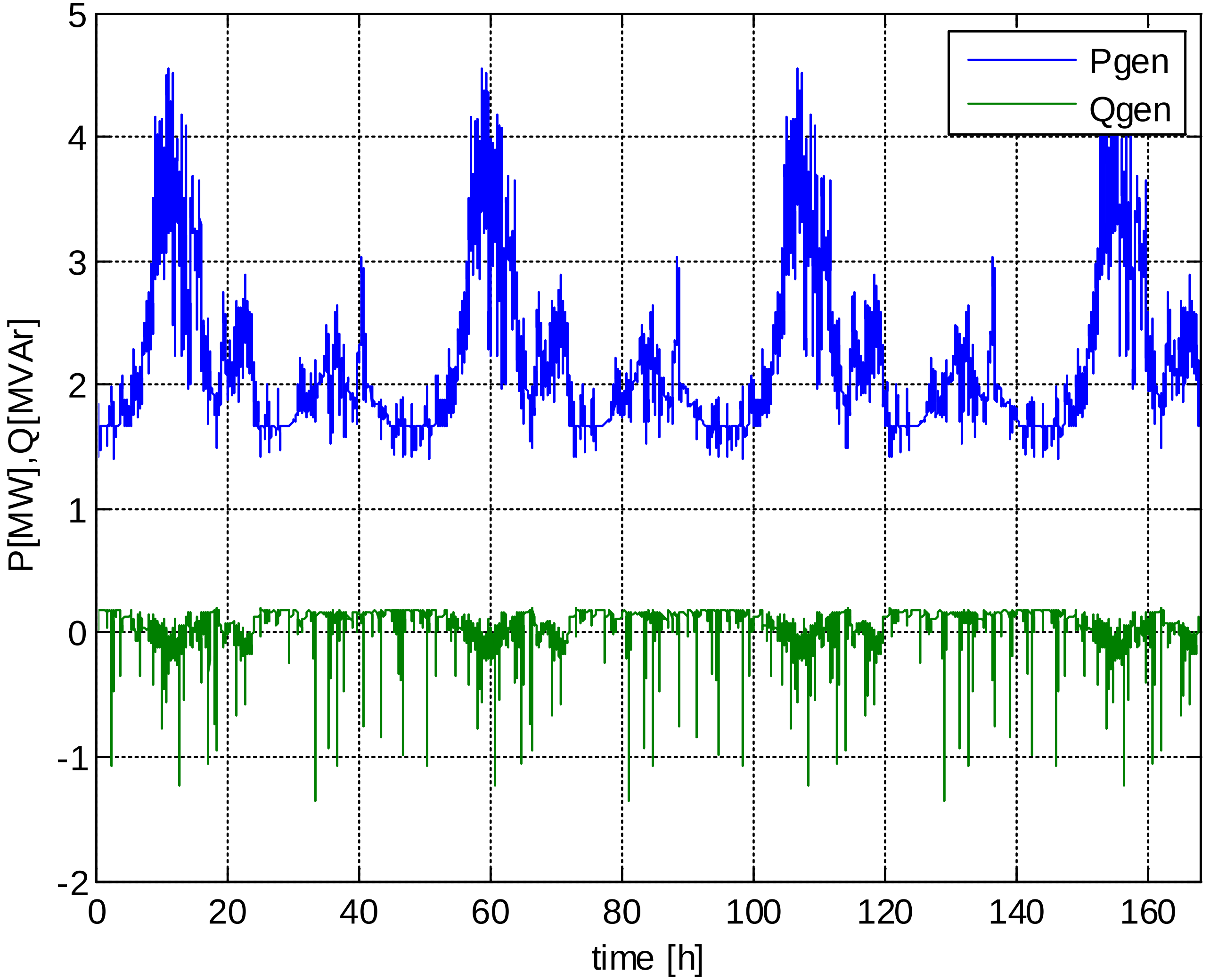
- Distribution of dominant groups.



# WP3 – Risk assessment calculation

## Generation profile mixing

### Example: 33% SM (fixed PQ), 33% PV (solar), 33% DFIG (wind)



# WP3 – Risk assessment calculation

## Methodology/assumptions

- Perform risk assessment based on the number of possible islands rather (substations) than number of generators.
- Represent each predominant island group with an equivalent NDZ. Five predominant have been identified. The largest population is formed by single generation PV for which ROCOF setting change will have no impact.
- Profiles for predominant groups are synthesised using the available generation profiles.
- In NDZ assessment and generation profile mixing it is assumed all technologies have equal contribution. Cumulative contributions of less than 10% are removed though. (discuss)
- Risk assessment will be performed systematically based on group capacity distribution in substations.

# WP3 – Risk assessment calculation

## Data still desirable

- Monitoring data
  - 1s resolution data from example 11kV feeder or substation in WPD with min load <5MW **(pending)**
  - 1s or 5s resolution data (P, Q) of small PV unit output in different seasons (summer, winter, mid-season) **(pending – contact from Michael has not responded)**
- Number of primes in WPD?

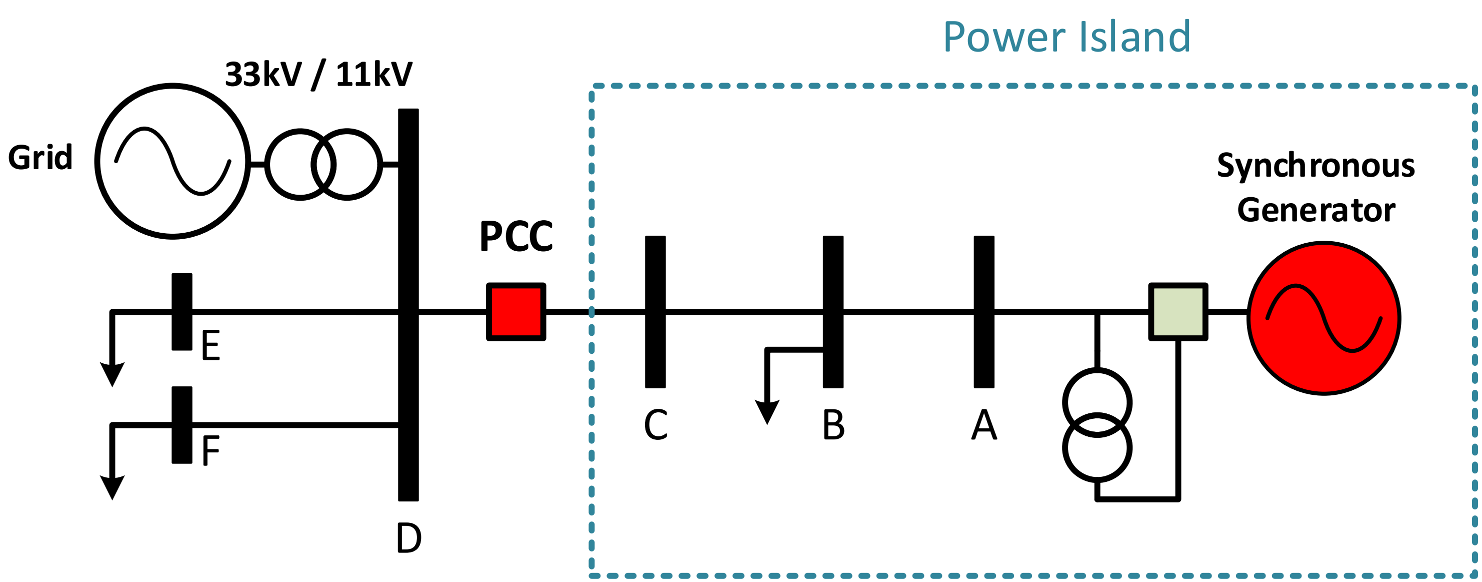
# WP2 – Simulation based characterisation of DG

- Most popular generation mixes have been considered.
- Synchronous, PV-Inverter, PMSG-Inverter, DFIG and Asynchronous based generation were modelled.

# WP2 – Simulation based characterisation of DG

**Individual Connection Stability Studies**

**Synchronous Generator**



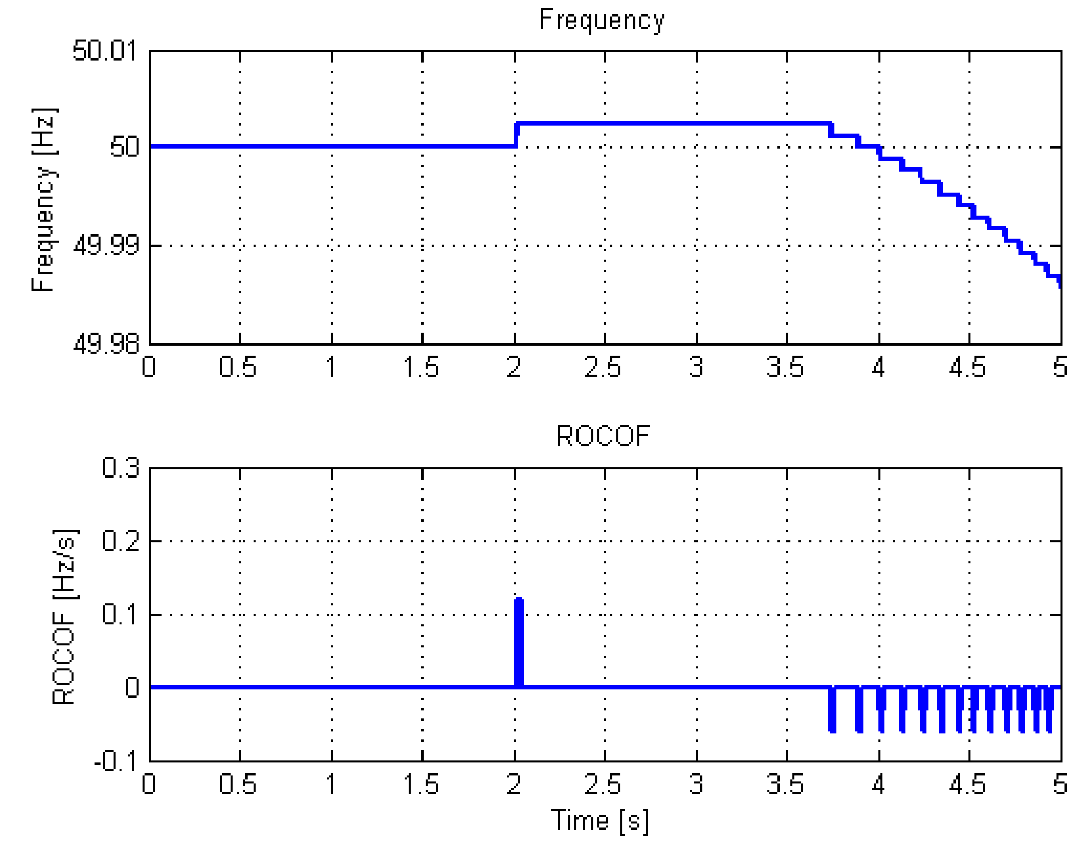
# WP2 – Simulation based characterisation of DG

**Synchronous Generator**

**Active Power Imbalance: 0%**
**Reactive Power Imbalance: 0%**

Synchronous generator can be Ssable during LOM event

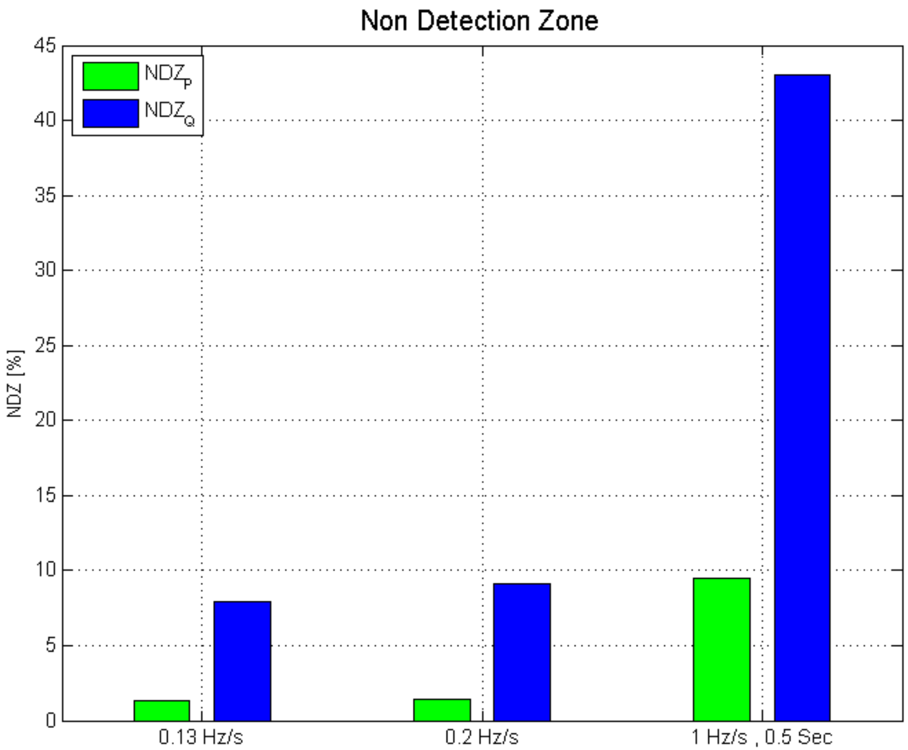
Assess Non Detection Zone for Active and Reactive Power.



# WP2 – Simulation based characterisation of DG

**Synchronous Generator**

Non Detection Zone Assessment

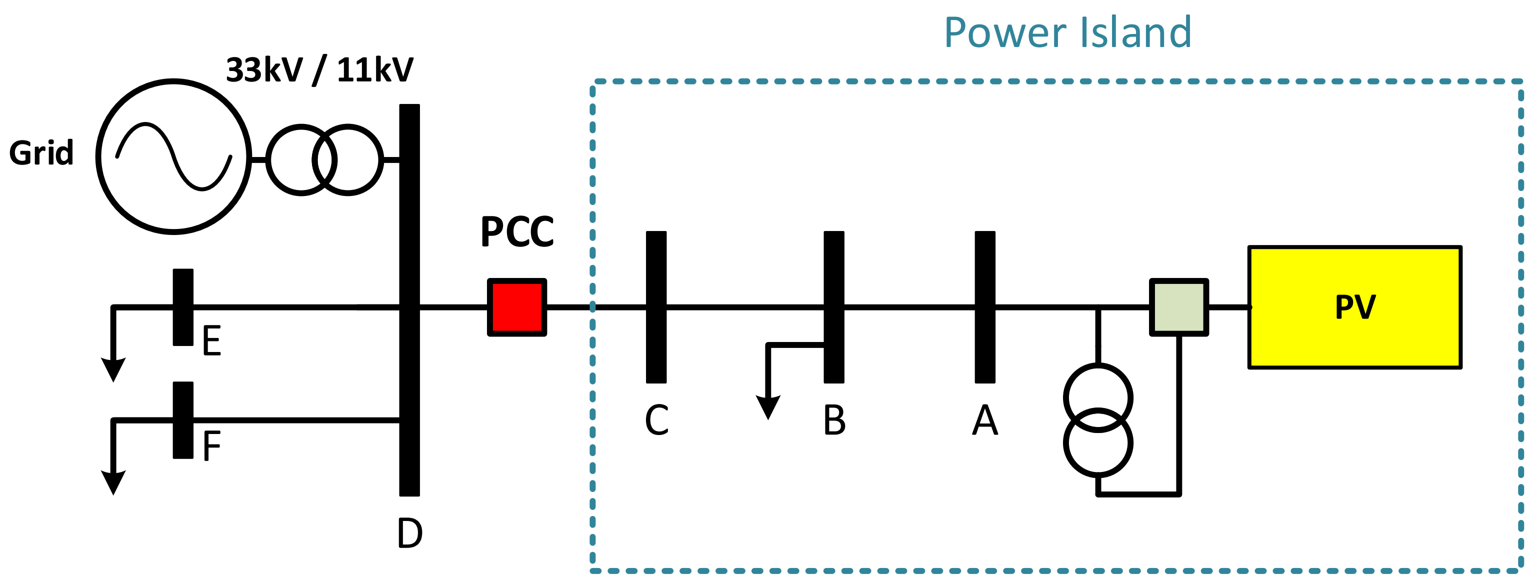



| | Setting Option 1 0.13 Hz/s , 0 Sec | Setting Option 2 0.2 Hz/s , 0 Sec | Setting Option 3 1.0 Hz/s , 0.5 Sec |
|---|---|---|---|
| NDZ-P [%] | 1.3 | 1.4 | 9.44 |
| NDZ-Q [%] | 7.9 | 9.14 | 43 |

# WP2 – Simulation based characterisation of DG

**Individual Connection Stability Studies**

**Photovoltaic Panels**

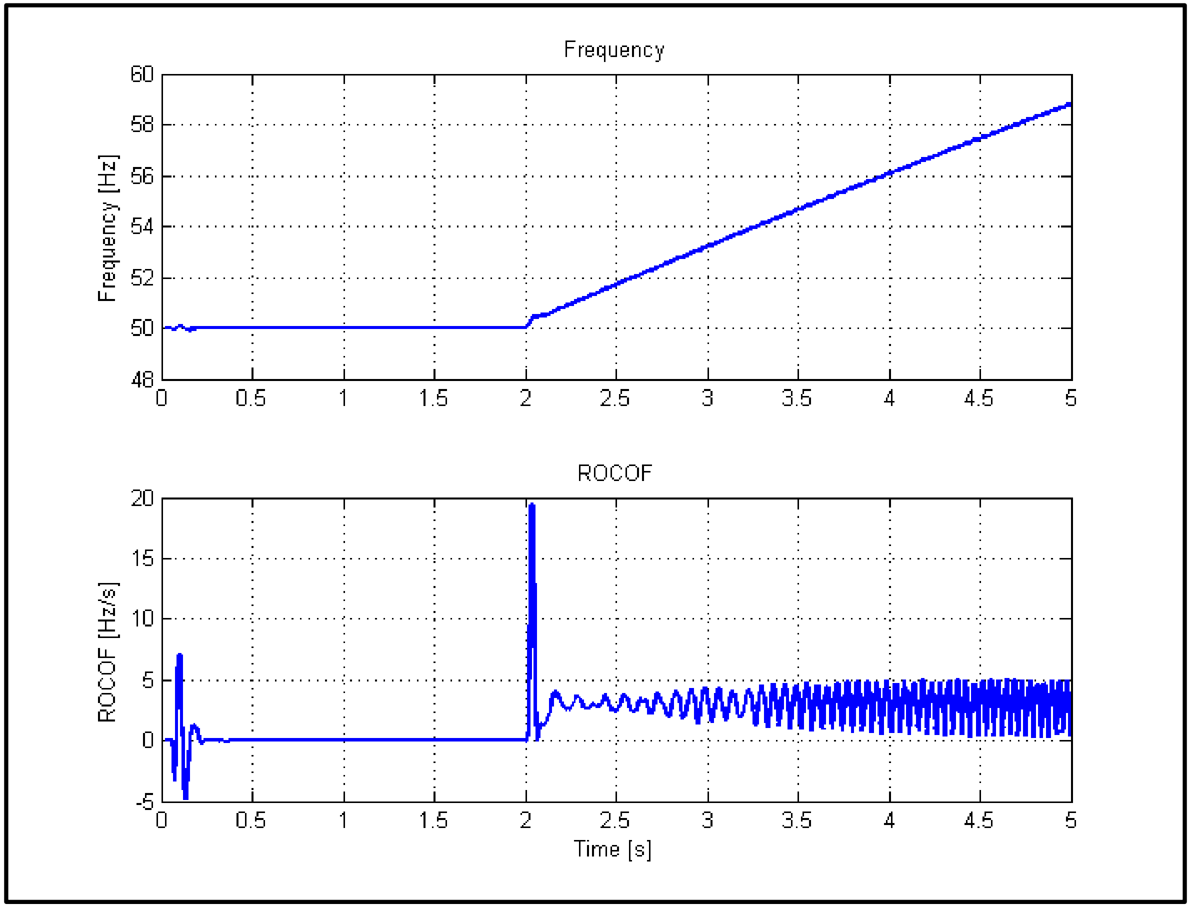


# WP2 – Simulation based characterisation of DG

**Active Power Imbalance: 0%**
**Reactive Power Imbalance: 0%**

Photovoltaic Panels are unstable during LOM event, even for complete Active and Reactive power balance at PCC.

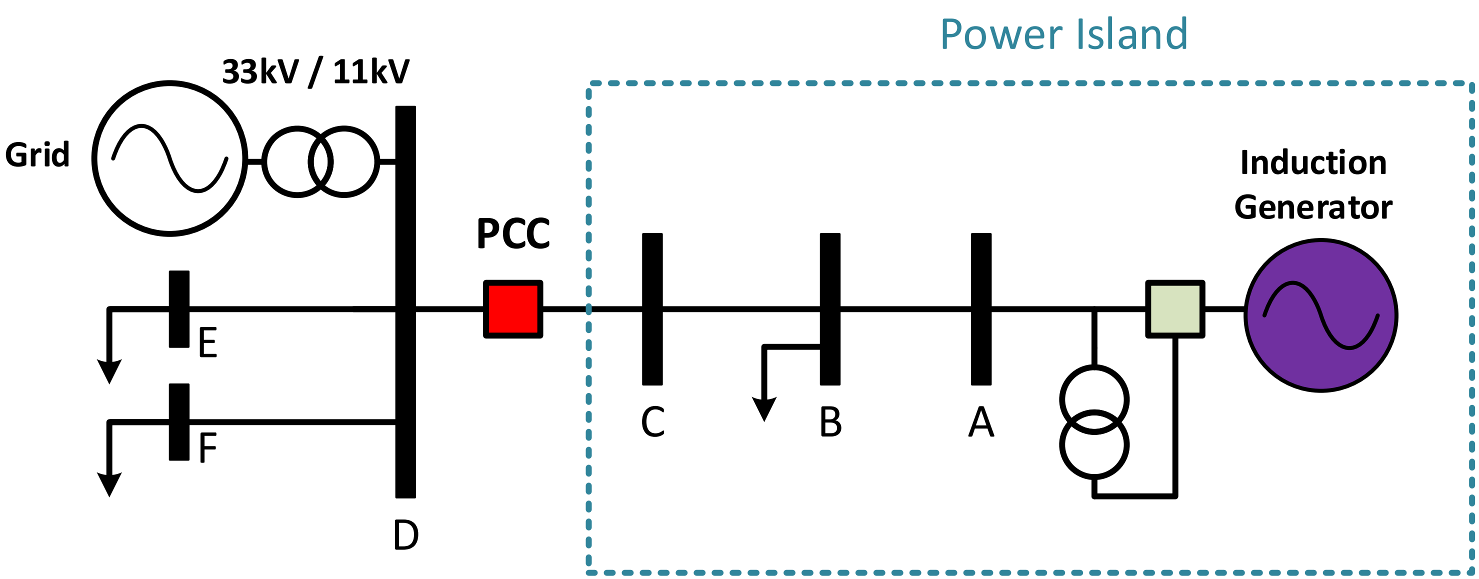
No NDZ



# WP2 – Simulation based characterisation of DG

**Individual Connection Stability Studies**

**Induction Generator**

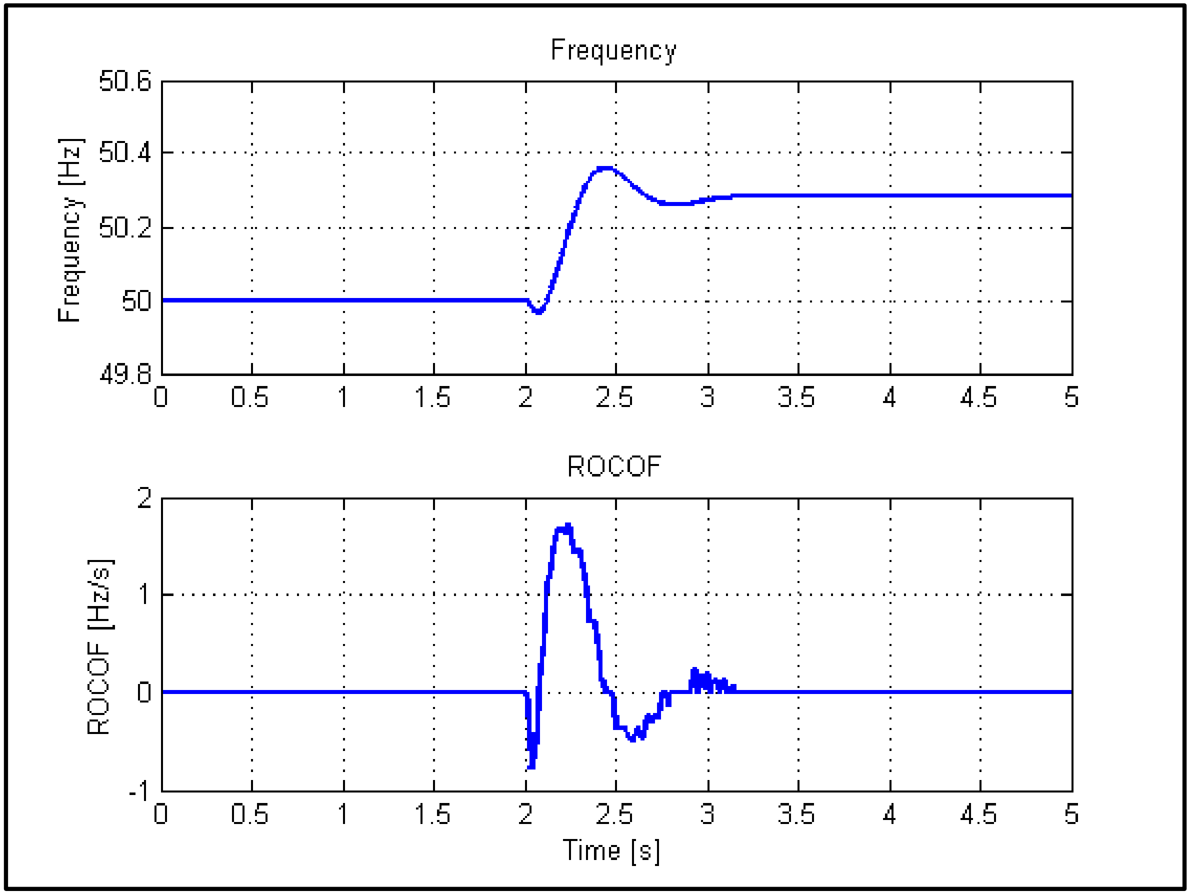


# WP2 – Simulation based characterisation of DG

**Active Power Imbalance: 0%**
**Reactive Power Imbalance: 0%**

Induction Generator creates high ROCOF + frequency shifts according to generator slip

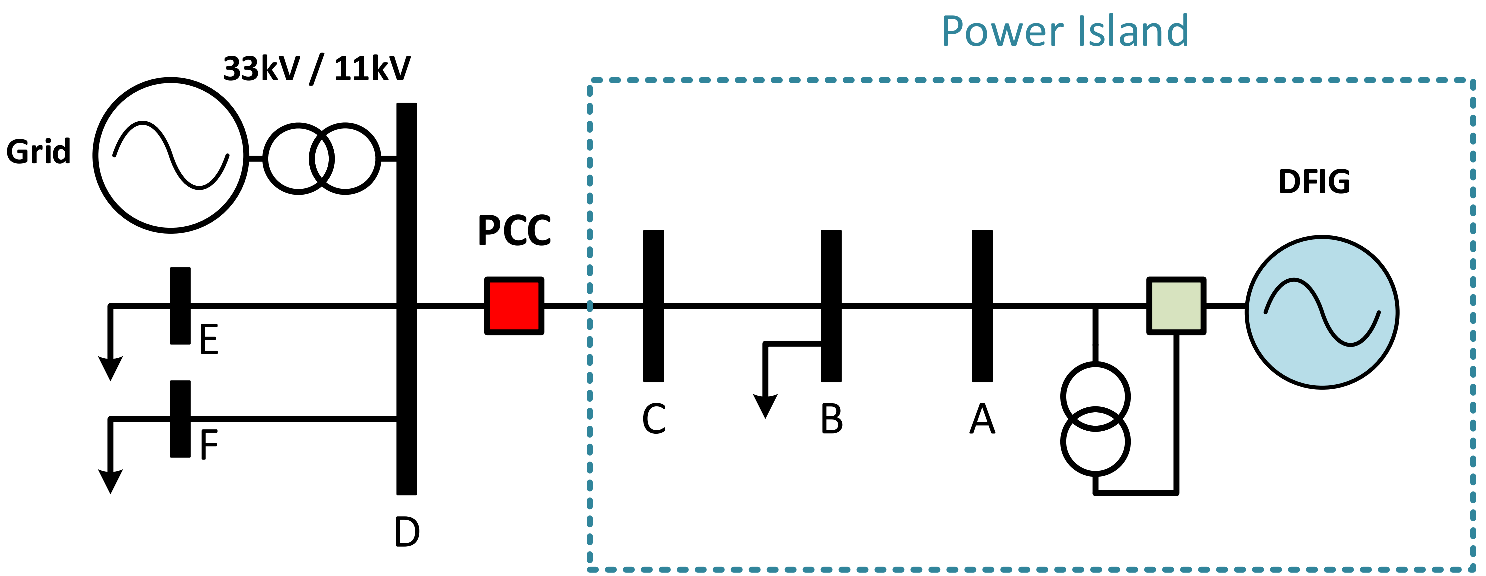
No NDZ



# WP2 – Simulation based characterisation of DG

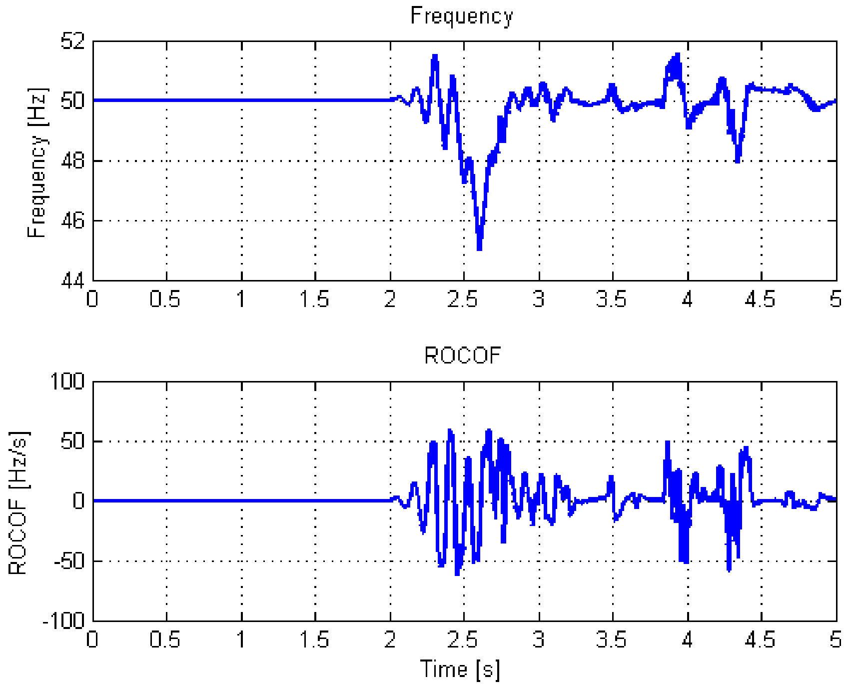
Individual Connection Stability Studies

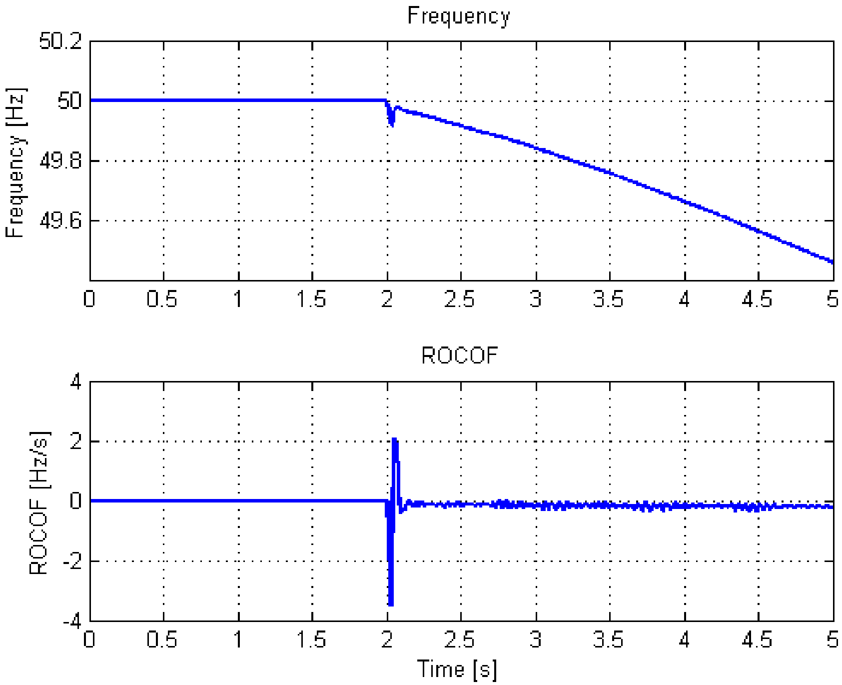
DFIG



# WP2 – Simulation based characterisation of DG

| Model 1 | Model 2 |
|---|---|
| **Active Power Imbalance: 0%**<br>**Reactive Power Imbalance: 0%** | **Active Power Imbalance: 0%**<br>**Reactive Power Imbalance: 0%** |

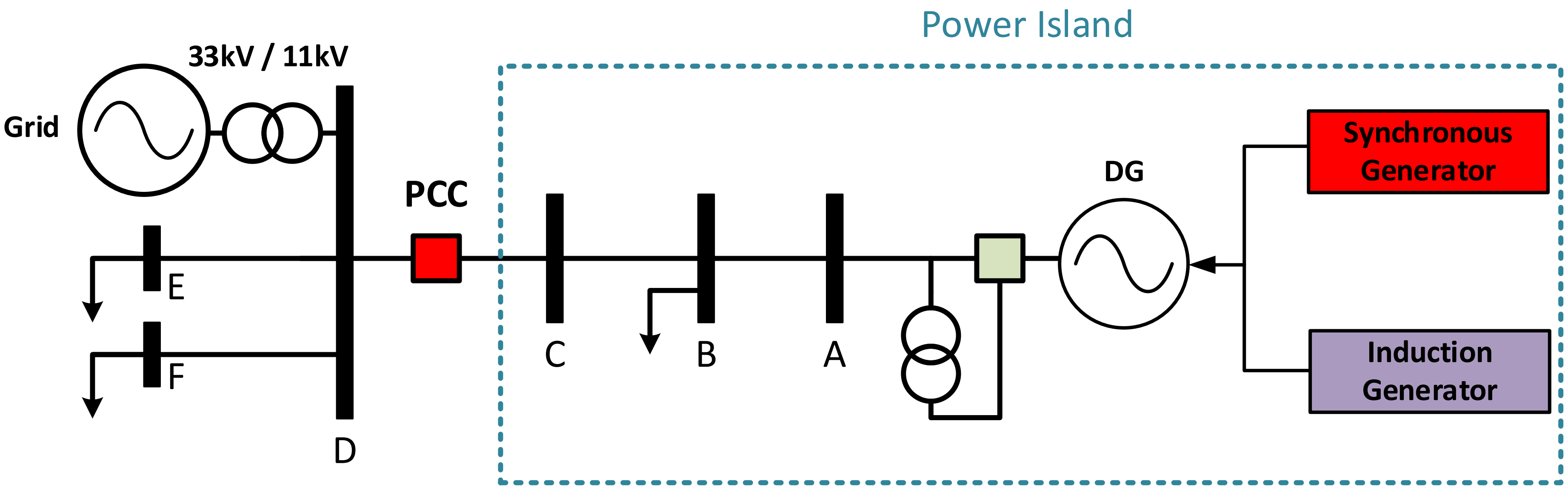


# WP2 – Simulation based characterisation of DG

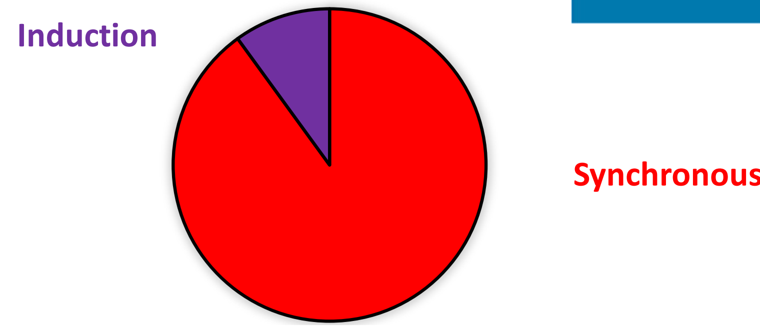
Generation Mix Stability Studies

Synchronous Generator & Induction Generator

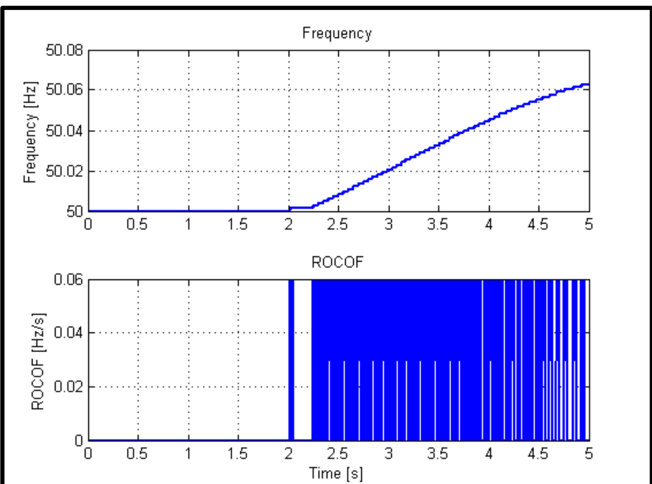


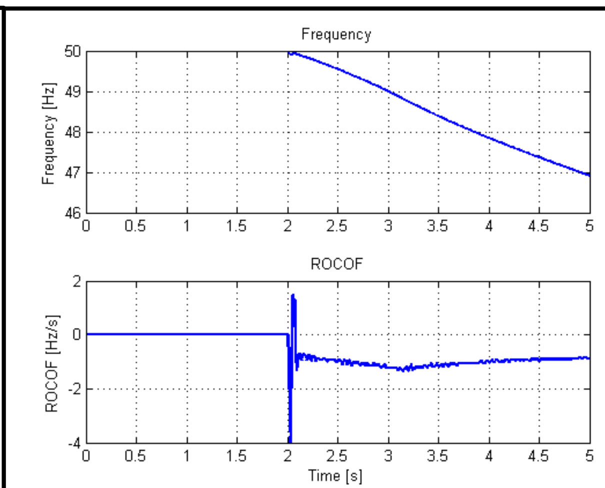
# WP2 – Simulation based characterisation of DG

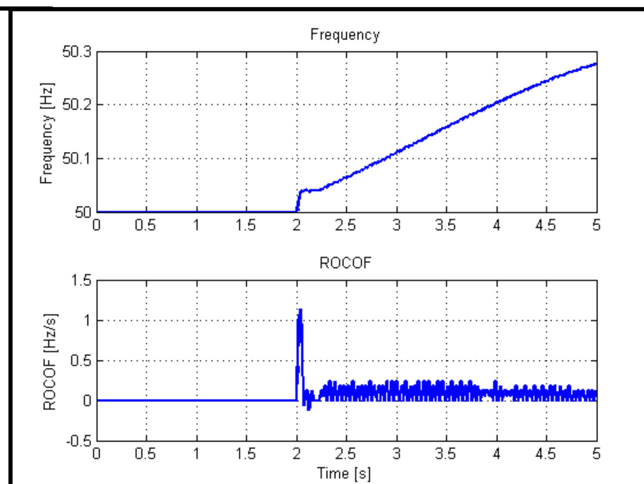
| Total Power : 2 MVA | |
|---|---|
| SG [%] | IG [%] |
| 90 | 10 |




| Active Power Imbalance: 0%<br>Reactive Power Imbalance: 0% | Active Power Imbalance: 5%<br>Reactive Power Imbalance: 0% | Active Power Imbalance: 0%<br>Reactive Power Imbalance: 5% |
|---|---|---|

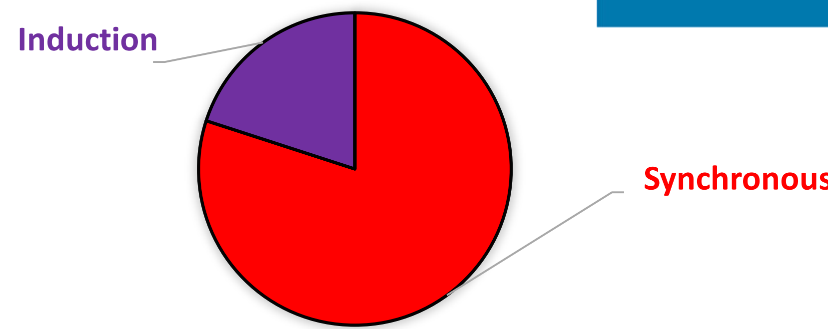


# WP2 – Simulation based characterisation of DG

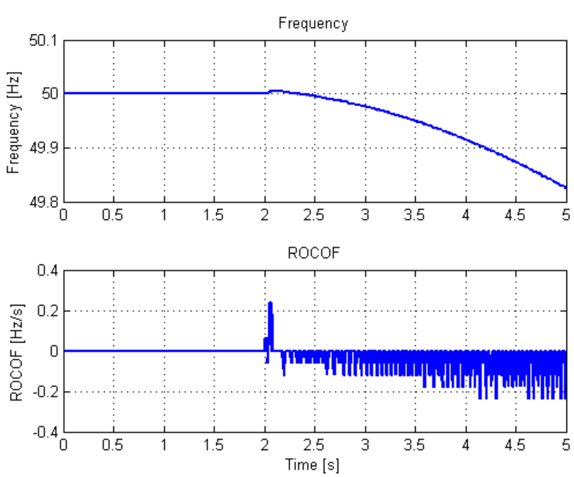
| Total Power : 2 MVA | |
|---|---|
| SG [%] | IG [%] |
| 80 | 20 |

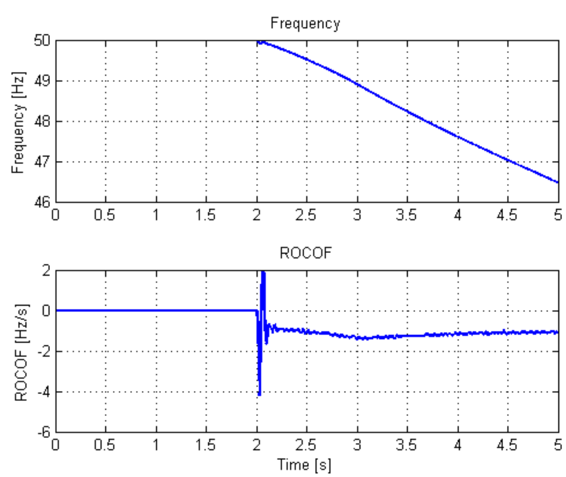


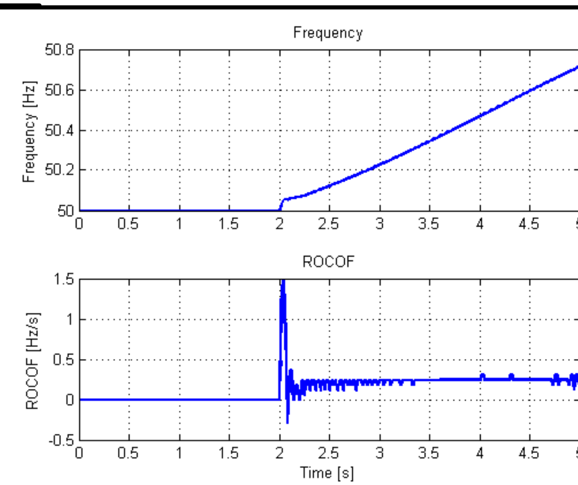

**Active Power Imbalance: 0%**
**Reactive Power Imbalance: 0%**

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

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

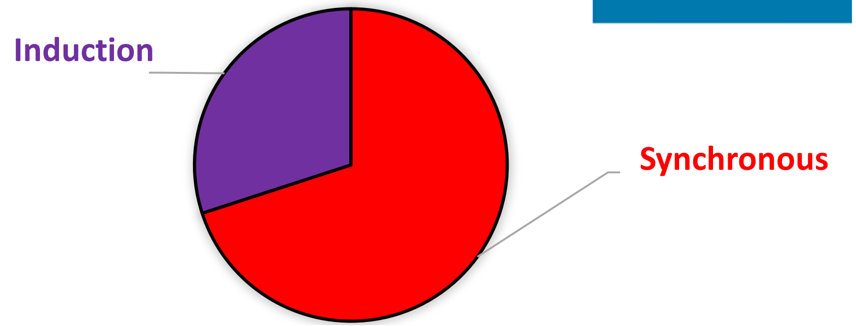


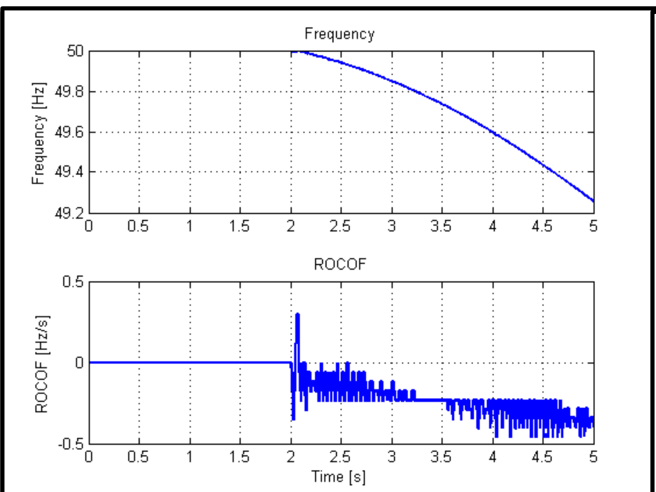



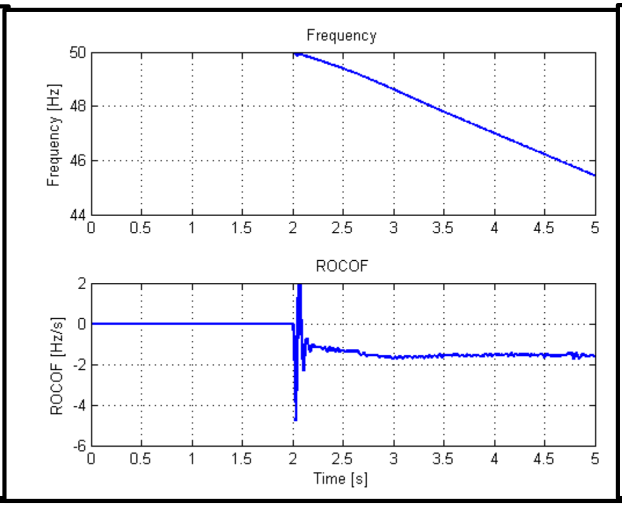
# WP2 – Simulation based characterisation of DG

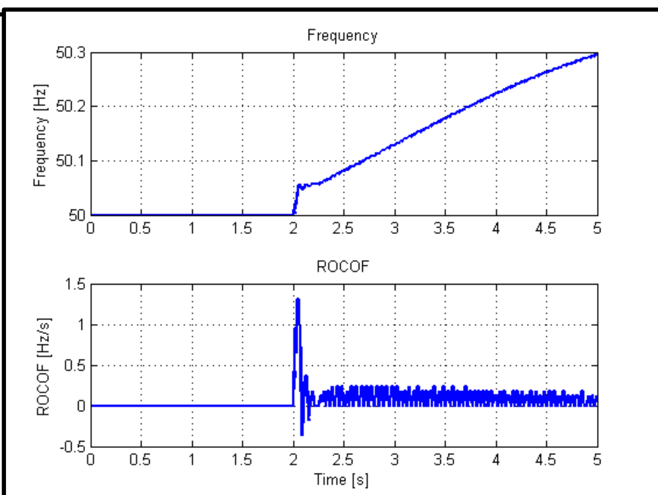
| Total Power : 2 MVA | |
|---|---|
| SG [%] | IG [%] |
| 70 | 30 |




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



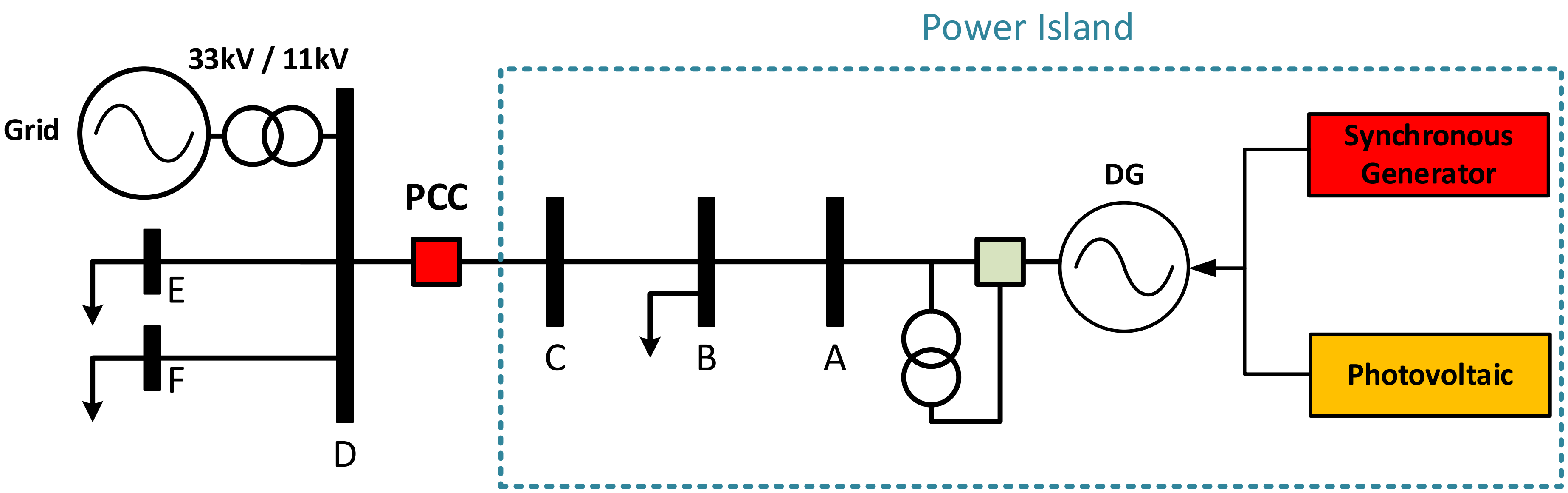



# WP2 – Simulation based characterisation of DG

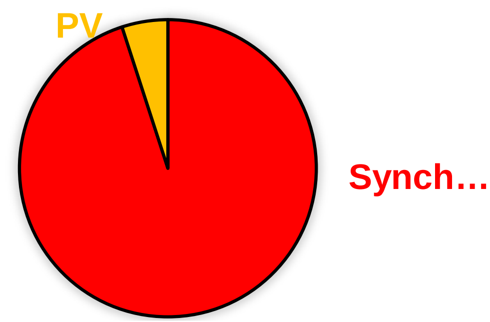
**Generation Mix Stability Studies**

**Synchronous Generator & Photovoltaic Panels**

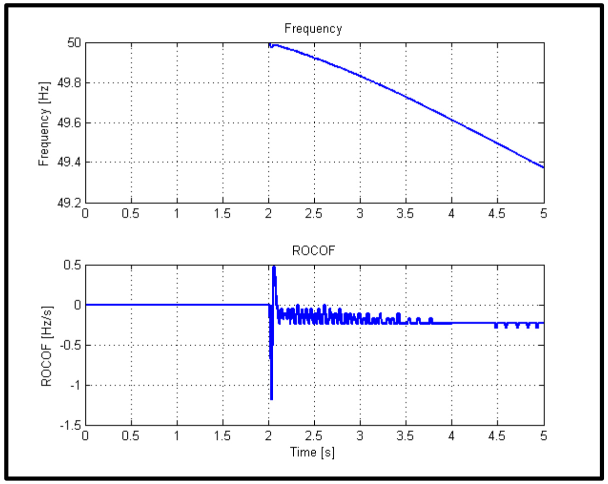


# WP2 – Simulation based characterisation of DG

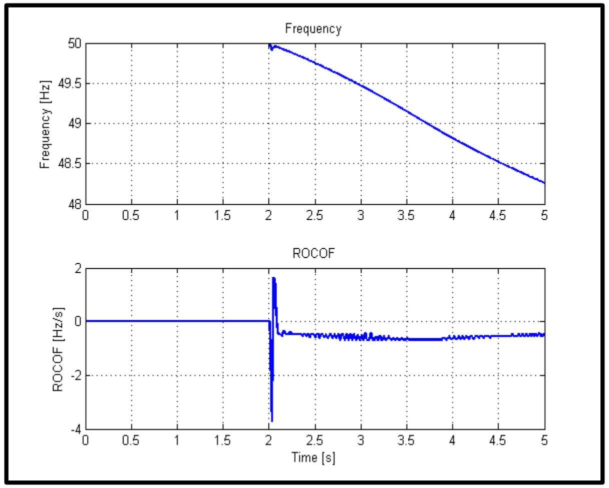
| Total Power : 2 MVA | |
|---|---|
| SG [%] | PV [%] |
| 95 | 5 |



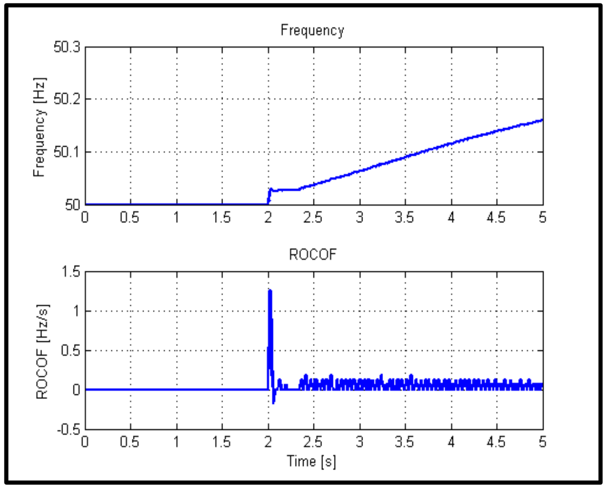

**Active Power Imbalance: 0%**
**Reactive Power Imbalance: 0%**




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



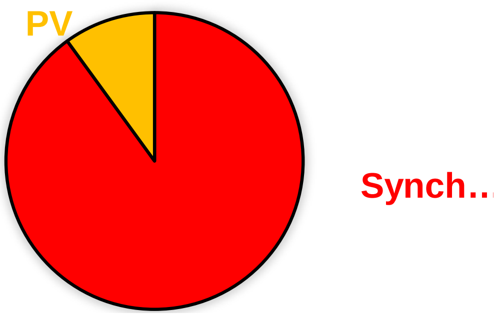

**Active Power Imbalance: 0%**
**Reactive Power Imbalance: 5%**



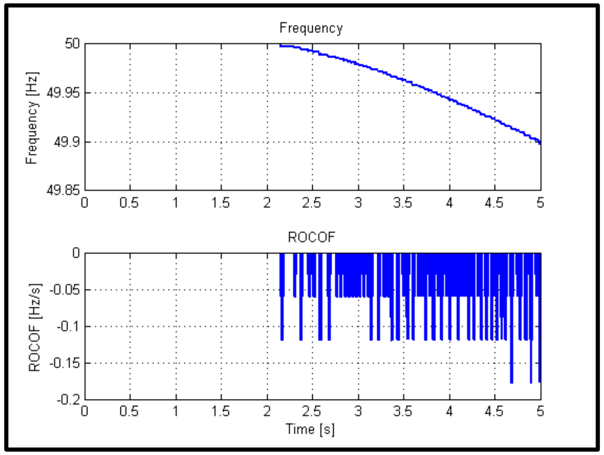
# WP2 – Simulation based characterisation of DG

University of Strathclyde Engineering

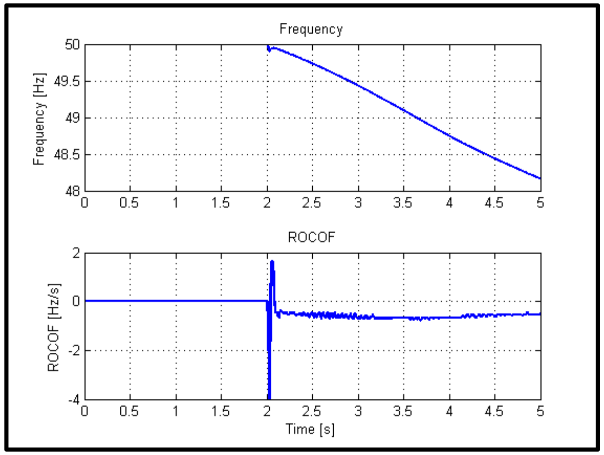
| Total Power : 2 MVA | |
|---|---|
| SG [%] | PV [%] |
| 90 | 10 |



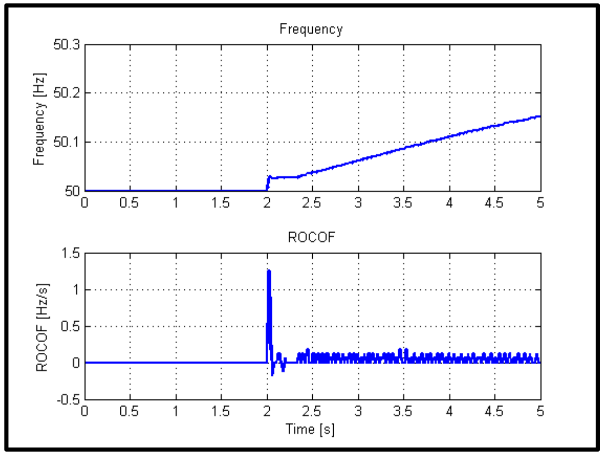

**Active Power Imbalance: 0%**
**Reactive Power Imbalance: 0%**




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

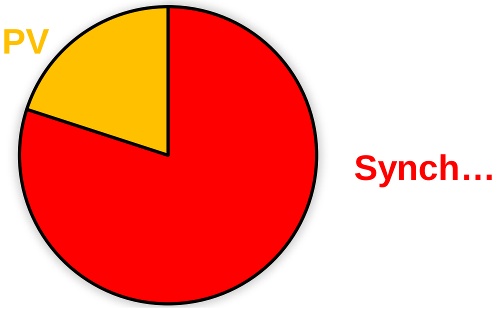



**Active Power Imbalance: 0%**
**Reactive Power Imbalance: 5%**

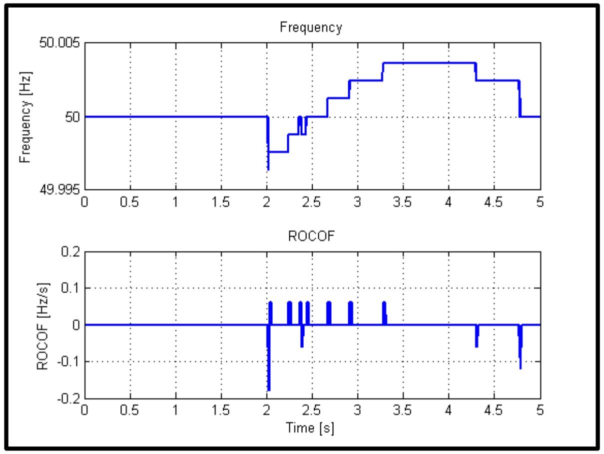


# WP2 – Simulation based characterisation of DG

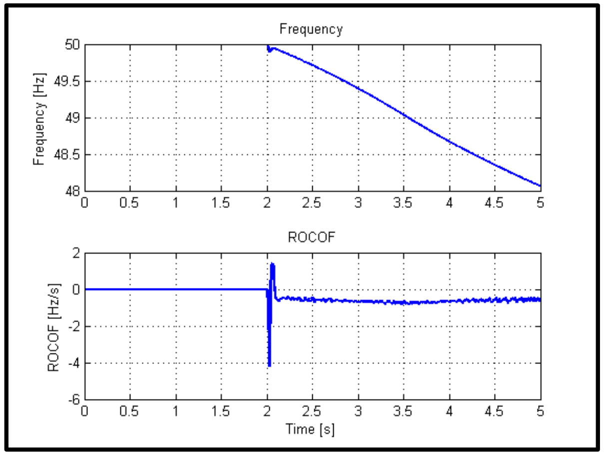
| Total Power : 2 MVA | |
|---|---|
| SG [%] | PV [%] |
| 80 | 20 |



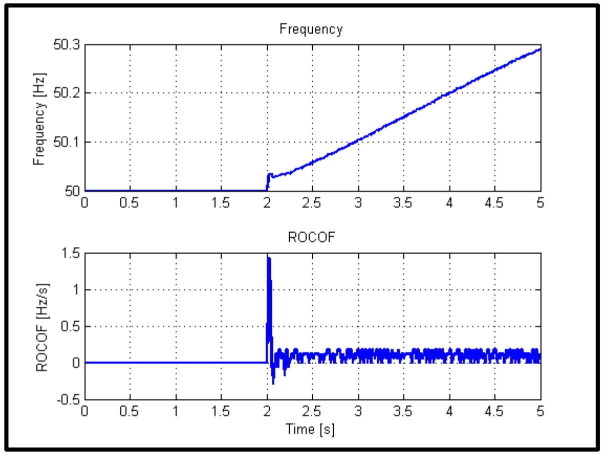

**Active Power Imbalance: 0%**
**Reactive Power Imbalance: 0%**




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

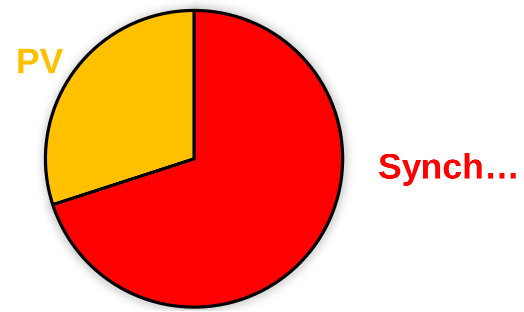



**Active Power Imbalance: 0%**
**Reactive Power Imbalance: 5%**

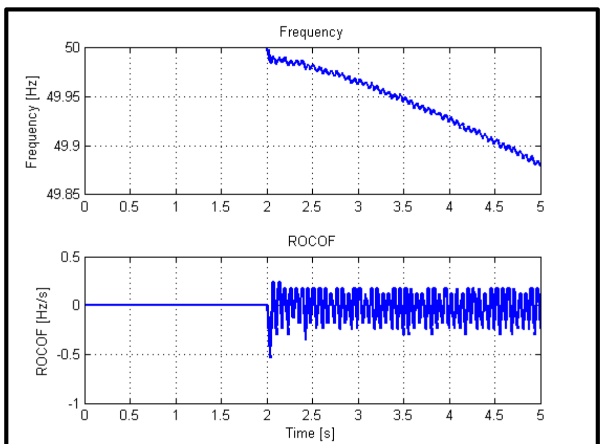


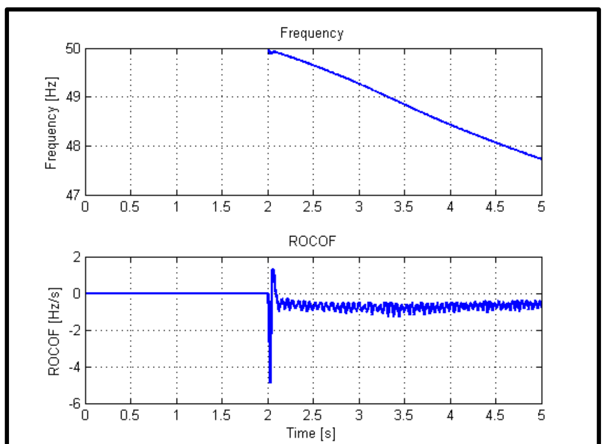
# WP2 – Simulation based characterisation of DG

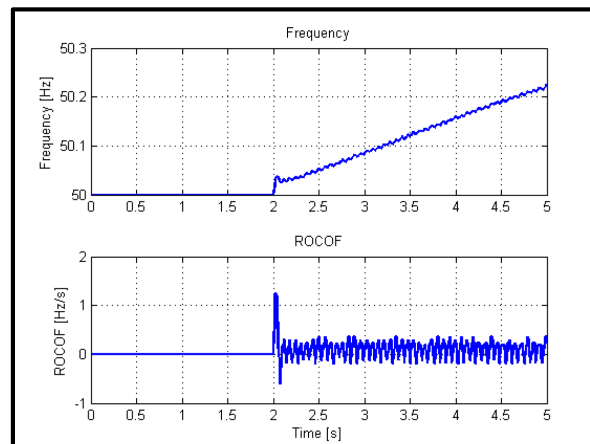
| Total Power : 2 MVA | |
|---|---|
| SG [%] | PV [%] |
| 70 | 30 |




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

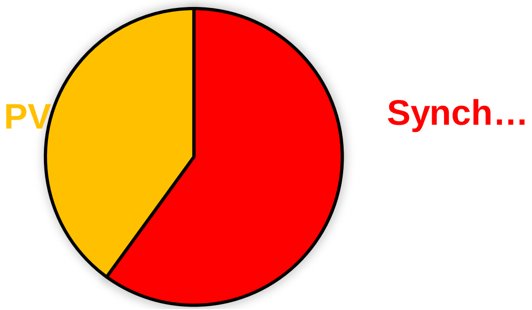


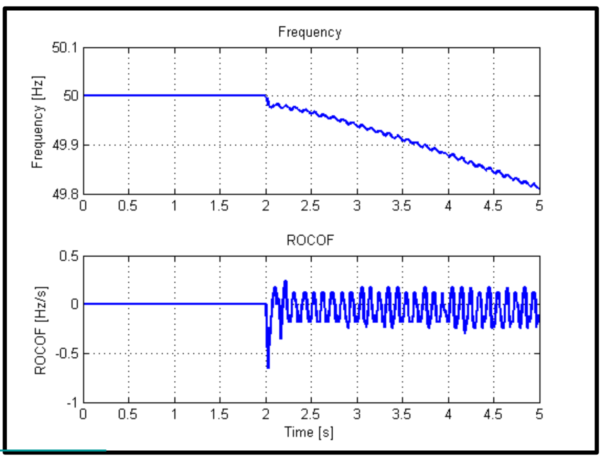



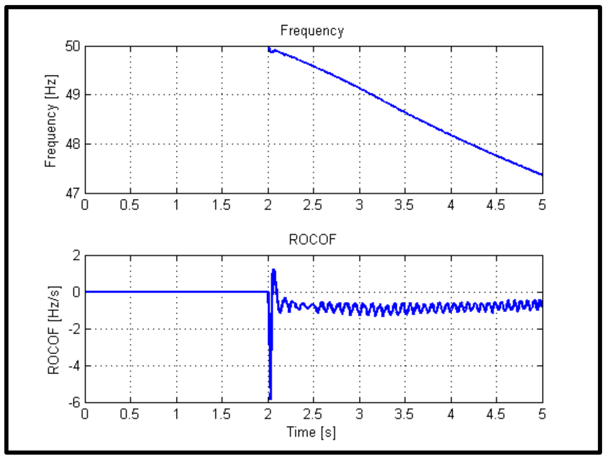
# WP2 – Simulation based characterisation of DG

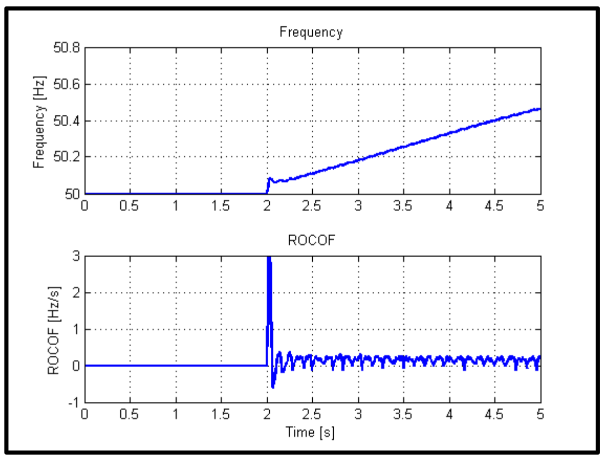
| Total Power : 2 MVA | |
|---|---|
| SG [%] | PV [%] |
| 60 | 40 |




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

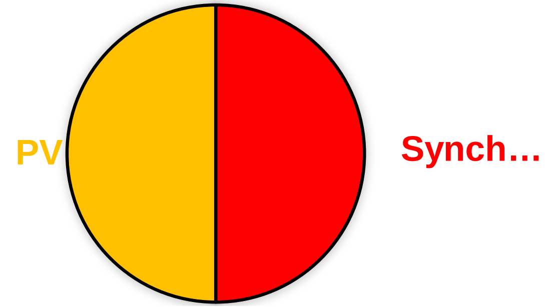


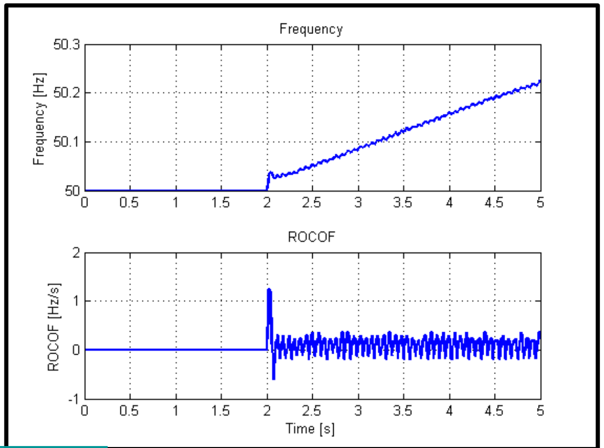



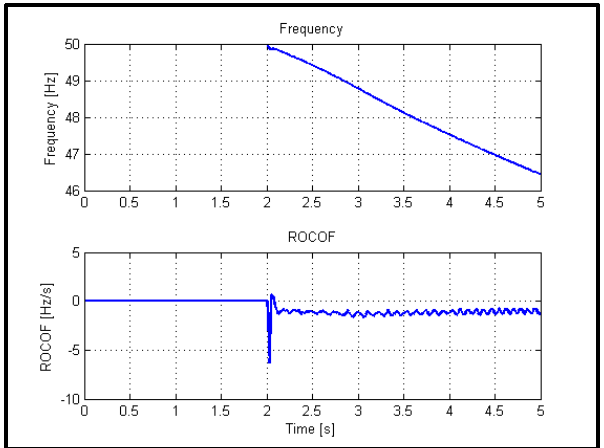
# WP2 – Simulation based characterisation of DG

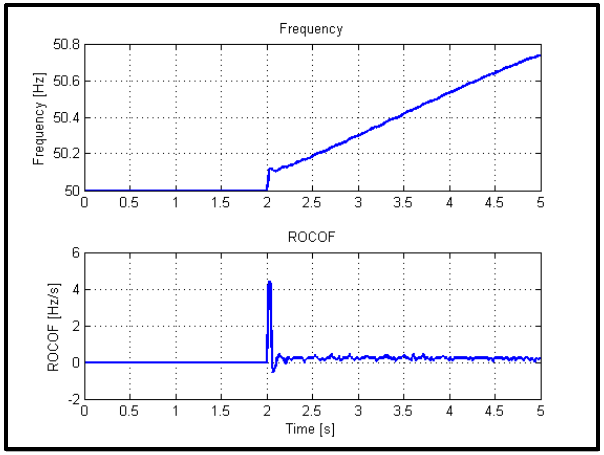
| Total Power : 2 MVA | |
|---|---|
| SG [%] | PV [%] |
| 50 | 50 |




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



# WP2 – Simulation based characterisation of DG

- ROCOF setting options

| LOM Option | LOM Protection Type | Settings |
|---|---|---|
| 1 | ROCOF | 0.13 Hz/s (no time delay) |
| 2 | ROCOF | 0.2 Hz/s (no time delay) |
| 3 (prev. 5) | ROCOF | 0.5 Hz/s (0.5s delay) |
| 4 (prev. 6) | ROCOF | 1.0 Hz/s (0.5s delay) |
| 5 (prev. 7) | V & f Only | G59 Recommended |

- Due to large amounts of testing and limited access to RTDS facility it is proposed to perform NDZ assessment using an existing ROCOF relay model (?).