Technical Report

Assessment of Increased Risks Imposed by a Relaxation of Loss-Of-Mains Protection Settings Applied to Generation Connected to the Electricity Network in Northern Ireland (Phase 1 – WP3)

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Abbreviations and symbols

BSP	- Bulk Supply Point
DRR	- Dynamic Reactive Response
FRC	- Fully-Rated Converter
IC	- Inverter Connected
IM	- Induction Machine
NIE	- Northern Ireland Electricity
NDZ	- Non-Detection Zone
LOM	- Loss-Of-Mains
WFPS	- Wind Farm Power Station
P_L, Q_L	- active and reactive power of the load
P_{DGG}, Q_{DGG}	- active and reactive power supplied by the group of distributed generators
NDZ_{PE}, NDZ_{QE}	- exporting NDZ (generator output is higher than the local load during LOM)
NDZ_{PI}, NDZ_{QI}	- importing NDZ (generator output is lower than the local load during LOM)
T_{NDZmax}	- maximum permissible duration of undetected islanding operation
n_{NDZ}	- number of detected NDZ periods
T_{load_record}	- total length of recorded load profile
$T_{NDZ(k)}$	- length of k-th NDZ period.
P_2	- probability of non-detection zone for generator group P_{DGG}, Q_{DGG}
P_3	- probability of non-detection zone duration being longer than T_{NDZmax}
$N_{LOG,1IP}$	- expected number of incidents of losing supply to a single islanding point in 1 year
n_{LOG}	- number of Loss-Of-Grid incidents experienced during the period of T_{LOG} in a population of n_{IP} islanding points
$N_{LOM,1DGG}$	- expected annual number of undetected islanding operations longer than the assumed maximum period T_{NDZmax} for a single DG
T_{NDZavr}	- overall average duration of the NDZ
T_{LOMavr}	- overall average duration of the undetected islanded condition
T_{ARmax}	- expected maximum time of auto-reclose scheme operation
$n_{DGG(m)}$	- number of all connected distributed generator groups in a given generation mix m
$p_{ROCOF(m)}$	- proportion of generators with ROCOF protection in a given generation mix m
$LF_{(m)}$	- load factor for a given generation mix m
$N_{LOM(m)}$	- expected number of undetected islanding incidents in 1 year (in generation mix m)
$T_{LOM(m)}$	- total aggregated time of undetected islanding conditions in 1 year (in generation mix m)
$P_{LOM(m)}$	- probability of the occurrence of an undetected island within a period of 1 year (in generation mix m)
N_{LOM}	- expected national number of undetected islanding incidents in 1 year
$N_{LOM,E}$	- annual rate of occurrence of undetected islanding incidents (with duration longer than $T_{NDZmax} = 0$ s)
$N_{LOM,AR}$	- annual rate of occurrence of undetected islanding incidents (with duration longer than $T_{NDZmax} = 29.5$ s)
T_{LOM}	- total aggregated time of undetected islanding conditions in 1 year
P_{LOM}	- overall probability of the occurrence of an undetected island within a period of 1 year
$P_{PER,E}$	- probability of a person in close proximity to an undetected energised islanded part of the system being killed
$P_{PER,G}$	- probability of a person in close proximity of the generator while in operation
IR	- annual probability related to individual risk

IR_E	- annual probability related to individual risk (injury or death of a person) from the energised parts of an undetected islanded network
P_{AR}	- probability of out-of-phase auto-reclosing action following the disconnection of a circuit supplying a primary substation
N_{OA}	- annual rate of occurrence of any generator being subjected to out-of-phase auto-reclosure during the islanding condition not detected by LOM protection
IR_{AR}	- annual probability related to individual risk from the generator destruction following an out-of-phase auto-reclosure
T_E	- expected average time between incidents (injury or death of a person) from the energised parts of an undetected islanded network [in years]
T_{OA}	- average time between the occurrences of out-of-phase auto-reclosure during the islanding condition not detected by LOM protection [in years]

Executive Summary

This document contains a report on Phase 1 of the work commissioned by Northern Ireland Electricity and undertaken by the University of Strathclyde to assess and quantify the levels of risks of undetected islands and the consequent risks to individuals' safety associated with proposed changes to Rate-Of-Change-Of-Frequency (ROCOF), Vector Shift (VS), Over Frequency (OF) and Under Voltage (UV) protection settings. The risk of potential equipment damage through unintentional out-of-phase auto-reclosing is also addressed.

The content of this report builds upon the activities of work packages WP1 and WP2 [1]. This report addresses WP3 (Phase 1) which includes analysis of all distributed generator (DG) capacities above 5 MW, and covers the predominant existing generating technologies, namely synchronous, inverter, induction and DFIG-based generation.

To achieve the objectives of quantifying and assessing risk, detailed dynamic simulations have been carried out to determine the potential islanding non-detection zone (NDZ) associated with different ROCOF and VS settings (eight different options were studied), and under a number of different islanding generation arrangements, including islanding of multiple generators.

The NDZ has been quantified in terms of the surplus/deficit power supplied by the DG prior to islanding and is expressed as a ratio of this power to the rating of the islanded DG (or the combined rating of multiple units when more than one generator is islanded). The dynamic simulation work uses a transient model of a fragment of the utility network including generation and a numerical model of a DG interface relay commonly used in the UK practice. Thus established NDZ levels have been subsequently utilised by the developed risk assessment methodology to determine the probability of islanding non-detection and to quantify the consequential associated risks. In addition to the NDZ data, the methodology makes use of recorded load profiles, and historical statistics relating to customer interruptions and network incidents.

During the NDZ assessment the operation of ROCOF, VS and G59 protection (Overvoltage - OV, Undervoltage - UV, Overfrequency - OF , Underfrequency – UF) has been considered. The combined NDZ values are established through assessment of the shared region of non-operation of all of these protection functions.

The key outcome of Phase 1 consists in the estimated risk figures, considering both the probability of individual risk (IR_E), and the expected annual rate of occurrence of out-of-phase auto-reclosure (N_{OA}). In particular, risk related to accidental electrocution (IR_E) during undetected islanding operation under the proposed ROCOF setting option 3 (1.5 Hz/s with a time delay of 300 ms) encroaches slightly onto the ALARP region. In this case additional safety measures (e.g. installation of the NVD protection) should be considered by the network operator to conform with the ALARP principle (i.e. to keep the risk As Low As Reasonably Practicable).

Even though the absolute risk figures are generally low, there is a significant difference in the probability of undetected islanded operation between the existing recommended ROCOF settings and the considered new setting options; the difference is up to three orders of magnitude. Therefore, the relative impact for the ROCOF-based protection of the proposed change can be considered high. It should also be noted that ROCOF protection becomes much less effective with the proposed setting options compared to existing practice, resulting in the increased reliance of LOM protection on the G59 frequency-based protection.

Considering both sensitivity and stability aspects the report recommends **1.5 Hz/s with a time delay of 300 ms** as the best compromise ROCOF setting recommendation. Detailed analysis of all load profiles indicated that the recommended setting should remain adequate even with significant DG penetration increase in the future.

The change of recommended setting for VS protection from 6° to 12° does not impose any notable change in the risk levels related to protection sensitivity. The values are higher but remain within the same order of magnitude. Therefore, considering the assessment of VS stability reported in WP2 [1] the recommended threshold angle setting should be **12°**.

The study used modified over-frequency protection setting (**52 Hz with 1s time delay**) and two stage under-voltage protection settings (**stage 1: 0.85 pu with 3s time delay, stage 2: 0.6 pu with 2 s time delay**). These settings meet the system stability criteria and voltage ride through requirements, and do not compromise the sensitivity of the LOM protection.

Regarding risk levels in the future, there is no straightforward correlation between the installed renewable generation capacity and the overall risk of undetected islanding. To address this issue the outcome of this study is based on the DG register which includes both already connected as well as contracted but not yet connected generation. The study indicates that in a network which has a relatively high DG penetration already, there might be little impact or even a reduction of the non-detection risk with additional DG connections. Furthermore, to safeguard the results against future ancillary services market and DG connection requirements, the generation models used in the NDZ assessment have fast-acting voltage and frequency controllers included which provides the worst case scenario in terms of detecting islanding conditions.

The identified high dependence of LOM protection on the operation of G59 frequency protection indicates that after the change both ROCOF and VS-based protections in many cases (up to 62%) will act as a backup rather than as the main LOM protection.

It should be noted that the risk levels calculated in this study are subject to a variety of initial assumptions. Due to a number of pessimistic assumptions used in the study, the absolute risk and rate-of-occurrence values presented in the report are likely to be overestimated. In particular, the assumption of the presence of voltage controllers on all connected generators, as well as the absence of network faults during islanding incidents, will have contributed to wider NDZ values being calculated, and consequently a higher probability of undetected islanding being stated than may actually be the case in practice.

Moreover, the risk levels considered in this report will be further reduced by the presence of neutral voltage displacement (NVD) protection (not considered in the calculations), the application of which is standard practice for all generation connected via a ground mounted substation that can export onto the NIE Networks' distribution system. When a single phase-to-earth fault initiates islanding, the operation of the NVD protection limits the duration of undetected islanded condition to 10 s (standard setting practice for NVD protection), and significantly reduces the risk of out-of-phase reclosure (which takes place 30 s after the fault). As single phase-to-earth faults form the majority of all distribution system faults (especially on overhead lines), NVD protection is a very effective way of reducing all risks related to undetected islanding.

Summary of risk figures for NIE Networks' distribution system obtained through averaging across all load profiles

LOM Option	LOM Setting [Hz/s] or [°]	Time Delay [s]	Individual risk of electrocution			Risk of out-of-phase reclosure		
			$N_{LOM,E}$	IR_E	T_E [years]	$N_{LOM,AR}$	N_{OA}	T_{OA} [years]
1	0.4	0	4.81E-04	9.97E-09	1.00E+08	1.99E-05	1.59E-05	62,961.13
2	2.0	0.2	1.95E-02	3.86E-06	2.59E+05	7.70E-03	6.16E-03	162.34
3*	**1.5**	**0.3**	**1.93E-02**	**3.86E-06**	**2.59E+05**	**7.69E-03**	**6.15E-03**	**162.50**
4	1.5	0.5	2.37E-02	4.29E-06	2.33E+05	8.56E-03	6.85E-03	146.03
5	1.0	0.8	2.46E-02	4.38E-06	2.28E+05	8.74E-03	6.99E-03	143.06
6	6	-	6.60E-03	1.85E-06	5.41E+05	3.69E-03	2.95E-03	338.85
7*	**12**	**-**	**6.60E-03**	**1.85E-06**	**5.41E+05**	**3.69E-03**	**2.95E-03**	**338.85**
8	-	-	3.12E-02	6.25E-06	1.60E+05	1.25E-02	9.97E-03	100.28

*Recommended ROCOF and VS settings (in bold).

Where:

$N_{LOM,E}$ - annual rate of occurrence of undetected islanding incidents (with duration longer than $T_{NDZmax} = 0$ s)

IR_E - annual probability related to individual risk (injury or death of a person) from the energised parts of an undetected islanded network

T_E - average duration between incidents (injury or death of a person) from the energised parts of an undetected islanded network [in years]

$N_{LOM,AR}$ - annual rate of occurrence of undetected islanding incidents (with duration longer than $T_{NDZmax} = 29.5$ s)

N_{OA} - annual rate of occurrence of any generator being subjected to out-of-phase auto-reclosure during the islanding condition not detected by LOM protection

T_{OA} - average duration between the occurrences of out-of-phase auto-reclosure during the islanding condition not detected by LOM protection [in years]

Recommended voltage and frequency protection settings

Voltage protection		Voltage [p.u]	Time Delay [s]
Under Voltage	Stage 1	0.85	3.0
	Stage 2	0.60	2.0
Over Voltage	Stage 1	1.10	0.5
Frequency protection		**Frequency [Hz]**	**Time Delay [s]**
Under Frequency	Stage 1	48	0.5
Over Frequency	Stage 1	52	1.0

1 Introduction

This document reports on the outcomes of the project "Assessment of Increased Risks Imposed by a Relaxation of Loss-Of-Mains Protection Settings Applied to Generation Connected to the Electricity Network in Northern Ireland".

The report covers Work Package 3 (WP3) – Investigation and quantification of the risks associated with the relaxation of the ROCOF settings for generation with registered installed capacity greater than 5MW.

The following sections describe in detail the available data, the risk assessment methodology, the results, key observations and recommendations related to the intended relaxation of the LOM protection settings.

A flowchart illustrating the dependencies of various work packages and tasks in the project is shown in Figure 1. The elements described in this report specifically are marked in green.

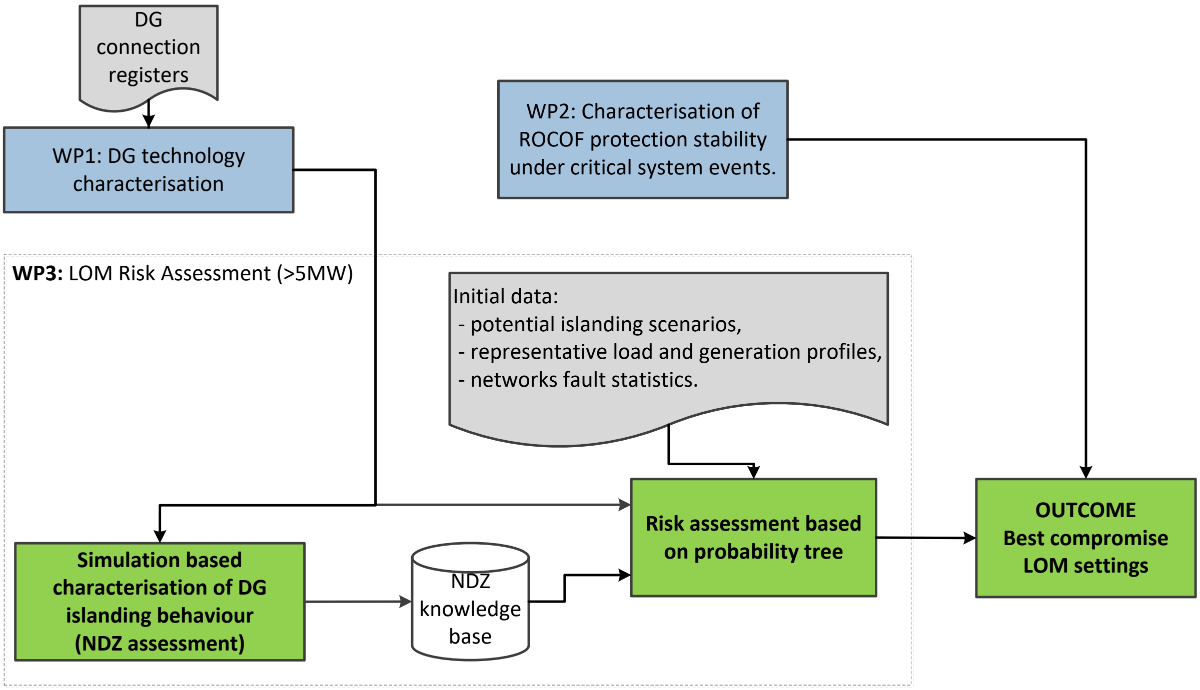


Figure 1: Project work packages and tasks

2 Distributed Generation Modelling

The network model used for the assessment of non-detection zone (NDZ) is based on a reduced section of a typical 33kV distribution network and is schematically presented in Figure 2. The potentially islanded section of the network incorporating the DG is connected through a Point of Common Coupling (PCC) to the main grid. An LOM condition is initiated by opening the circuit breaker at the PCC. The measured voltage (from which frequency is derived) at busbar 'A' forms an input to the relay model under test. The network is modelled using Matlab/Simulink with the SimPowerSystems toolbox. Additionally, a validated dynamic model of a commercially-available DG interface relay commonly used in the UK (MiCOM P341) has been utilised in this test [2]. A full record of network and various generating unit parameters are included in Appendix A.

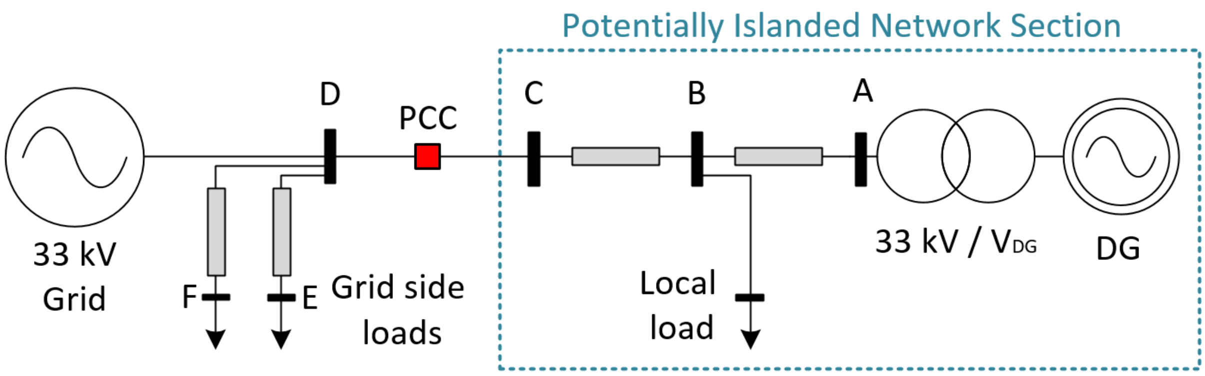


Figure 2: 33 kV Test Distribution Network

2.1 DG Models

2.1.1 Synchronous Machine

A synchronous machine is modelled as depicted in Figure 3. Both active power and voltage control schemes are employed for this machine. A standard IEEE governor/turbine model is also used [3] (available in the SimPowerSystems component library).

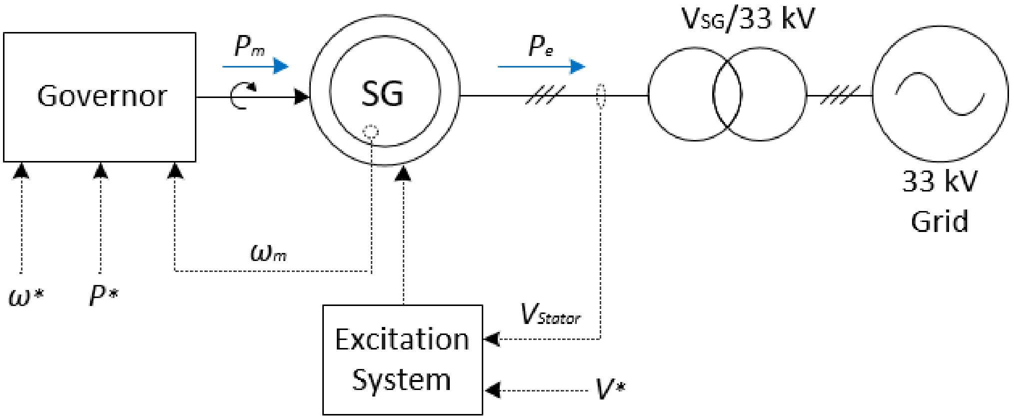


Figure 3: Synchronous Machine model

2.1.2 Doubly fed induction generator

A doubly fed induction generator (DFIG) is modelled as shown in Figure 4. The DFIG consists of a wound-rotor induction generator, driven by a wind turbine (WT) and an AC/DC/AC IGBT-based converter. The stator winding is connected through a transformer to the 33 kV (50 Hz) grid, while the rotor is fed at variable frequency through the converter.

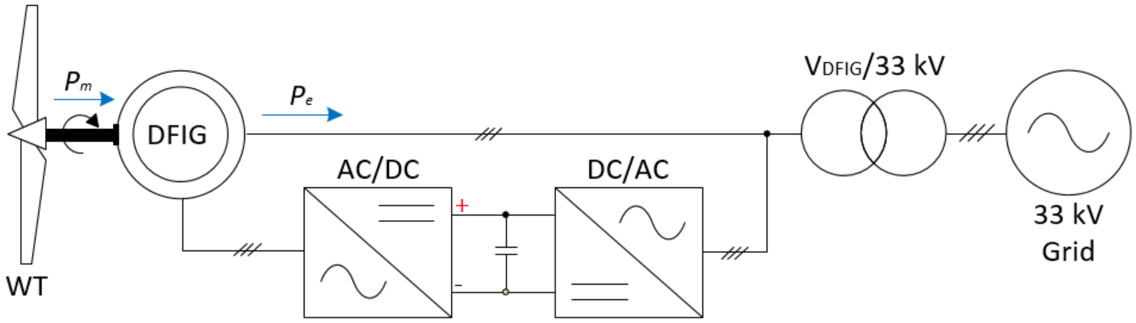


Figure 4: DFIG model

The regulation of active power to implement frequency droop (described later in Section 2.2.1) has been achieved through the pitch controller, while the voltage and reactive power regulation is achieved by adjusting the reference current i_q of the rotor-side converter.

2.1.3 Inverter Connected generation

Inverter-connected (IC) generation units such as photovoltaic panels (PV) or fully-rated converter (FRC) connected wind turbines are represented by an inverter model, connected to a DC voltage source as illustrated in Figure 5. Such an approach allows for more computationally-efficient simulation while preserving suitably-accurate dynamic characteristics on the grid side. Drooped P-f and V-Q controllers (explained in more detail in Section 2.2) are also included in the operation of the converter. The dynamics regarding the response of active and reactive power are tuned to meet the specified NIE Networks' connection requirements and are emulated using additional signal amplitude and rate limiters. This model also covers any potential future technologies such as battery storage, as long as their speed of response is not faster than that used in this analysis.

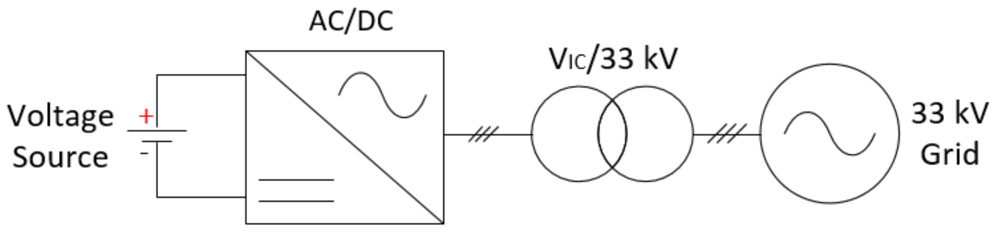


Figure 5: Inverter Connected generation model

2.1.4 Induction Machine

An induction machine (IM) is modelled as shown in Figure 6. The machine is driven by a wind turbine which feeds mechanical power to the generator. Additionally, a fixed capacitor bank is used for overall compensation purposes related to voltage and reactive power levels at the point of connection.

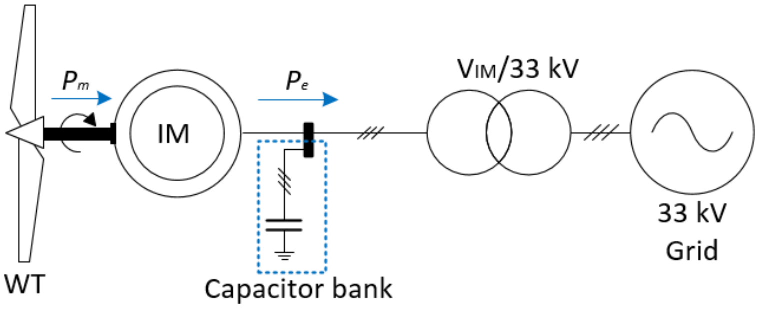


Figure 6: Induction Machine model

2.2 Controllers

2.2.1 Active Power – frequency (P-f) droop controller

A drooped power frequency controller is integrated with the DG system according to [4]. The active power output of each DG changes automatically in response to variations in the system frequency. The controller is operating on a nominal droop slope of 3.7% (e.g. a 27% change in generator output is expected for a 0.5Hz frequency deviation) and a frequency dead band is also included in the controller between 50.10Hz and 50.15 Hz, in line with Grid Code requirements.

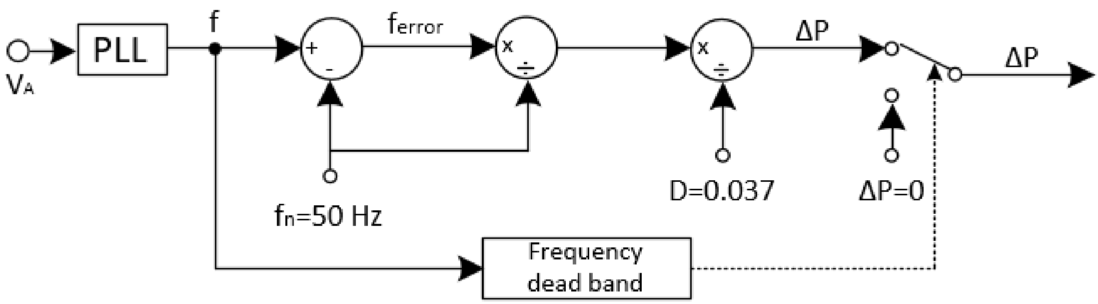


Figure 7: Power - frequency droop controller

2.2.2 Voltage – Reactive Power (V-Q) controller

The DG models have been set to operate with active power and voltage control enabled. The only exception to this is the induction machine-based generation, where no such controllers are present. Moreover, the Dynamic Reactive Response (DRR) service defined in the All Ireland DS3 System Services Decision Paper [5] requires the connected unit to deliver reactive power of at least 0.31p.u. (using the registered capacity as base) for voltage dips in excess of 30%. The reactive current response has to be supplied with a rise time of no greater than 40 ms and a settling time no greater than 300 ms. This functionality has been implemented in the model.

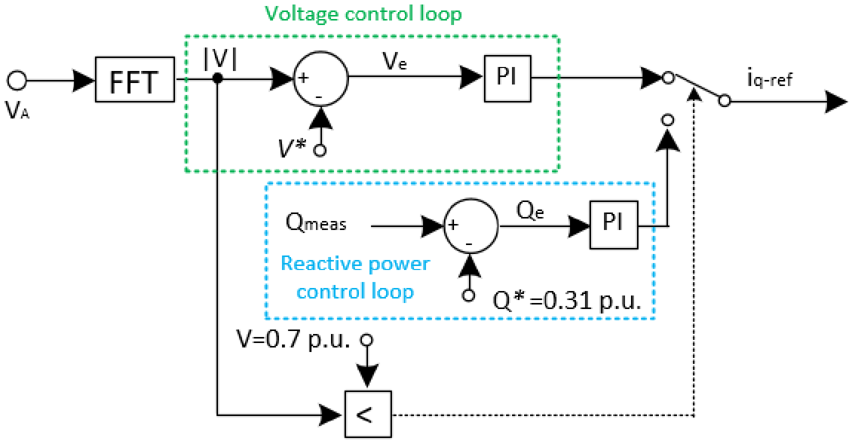


Figure 8: Voltage - Reactive Power controller

The voltage – reactive power controller design is illustrated in Figure 8. During normal operation, each DG is driven by the voltage control loop and the reactive power is adjusted according to the voltage set point (1.0 p.u.) and the measured busbar voltage V_A. When the voltage magnitude drops below 0.7 p.u. the controller reverts to using the reactive power control loop in order to deliver at least 0.31 p.u. of reactive power to the grid.

2.3 Generator model validation

2.3.1 Voltage – Reactive (V-Q) power response

In order to ensure the realistic response of the generator model, the recorded wind turbine test data (provided by NIE Networks) was used to validate the model. Figure 9 illustrates the recorded voltage and reactive power response to changes in voltage set-point for an 18.4MW wind farm power station. The same voltage set-points have been used as an input to the voltage controller of an 18.4 MW DFIG model. Simulation results are presented in Figure 10 showing the expected response.

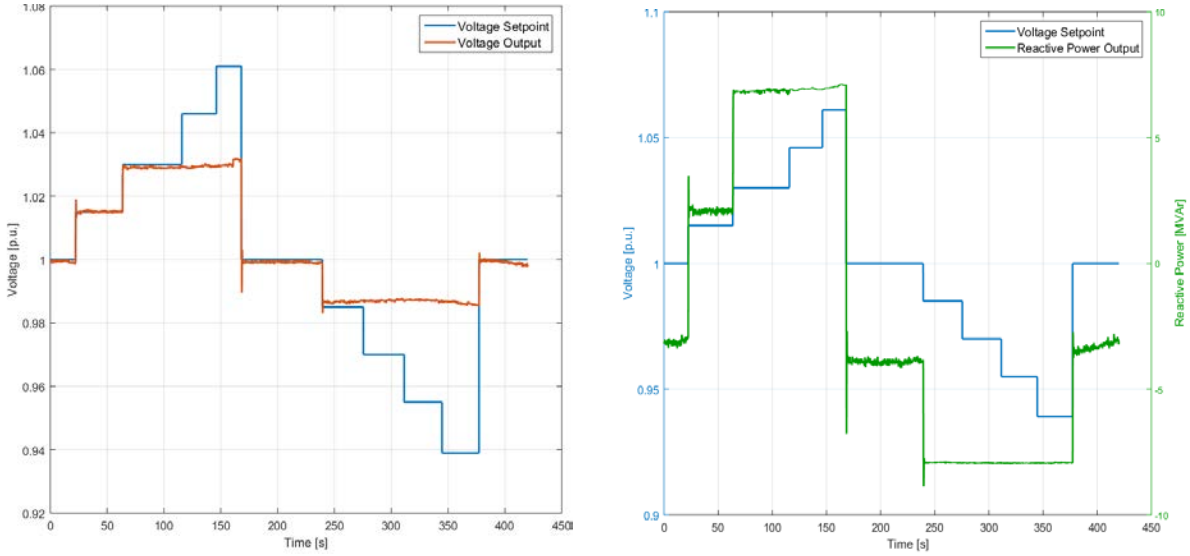


Figure 9: Recorded response to changes in voltage set-points for 18.4 MW WFPS

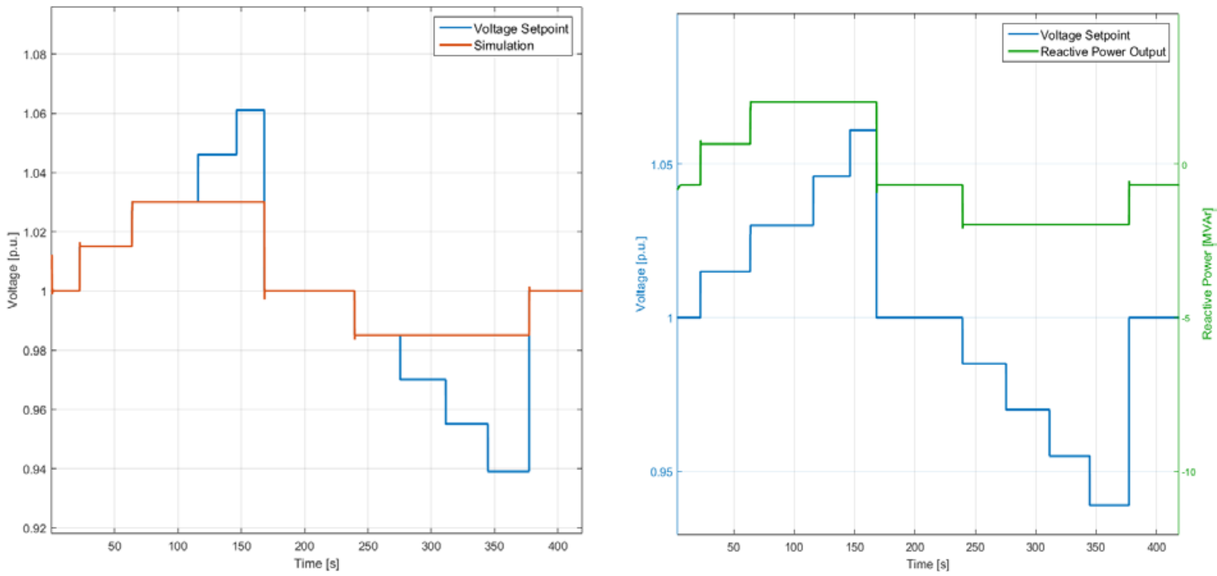


Figure 10: Simulated voltage response to changes in voltage set-points for 18.4 MW WFPS

The recorded and simulated voltage controller responses are presented in Figure 11. Additionally, a zoomed view of the traces at the points of transition between the two different regions is also included in Figure 12 for clarity. The comparison between the recorded and simulated waveforms shows that the simulated responses have slightly shorter rising and settling times which make the controller faster than it may be in reality. Such model responses have been deemed to be acceptable, as this will create a slightly more stable islanding scenario (compared to the slower actual recorded responses), and thus, would result in a slightly more pessimistic result in terms of calculated NDZ values (i.e. a wider NDZ than may be the case in reality will be calculated from the simulations). The notable differences in the reactive power responses between the model and the test record are due to the different value of the network source impedance between the test and simulation. However, the target voltage is achieved accurately in both cases.

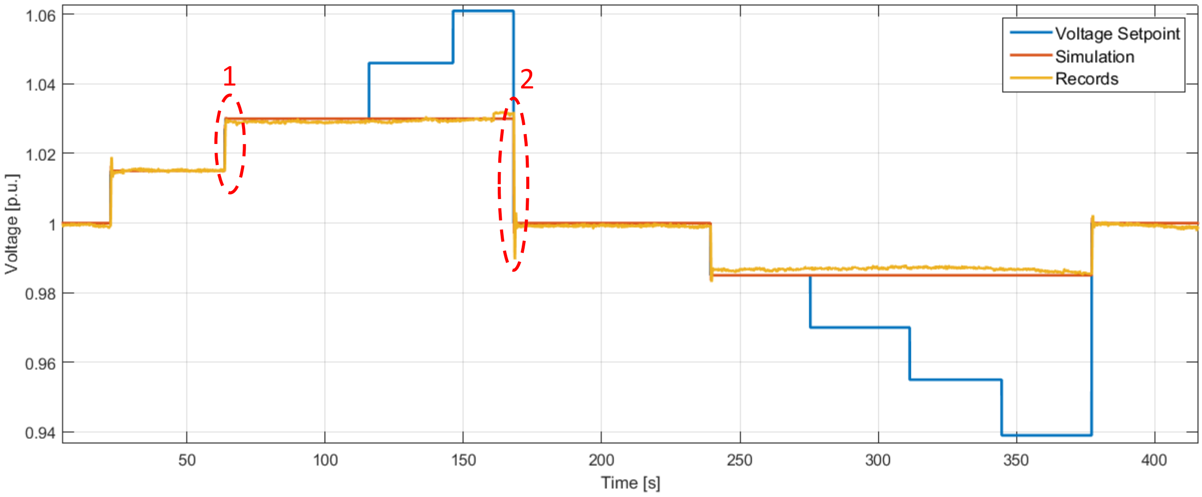
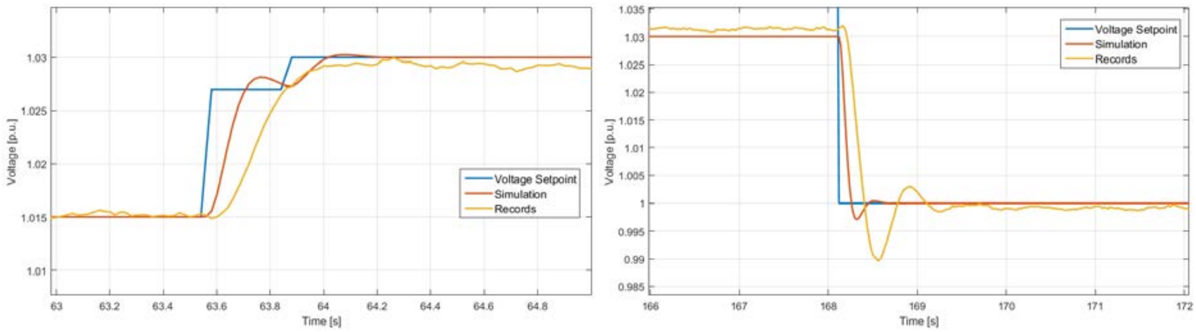


Figure 11: Simulated and recorded voltage response to changes in voltage set-points



a) zoomed region 1 b) zoomed region 2

Figure 12: Simulated and recorded voltage response – zoomed regions

2.3.2 Active Power – frequency (P-f) droop controller

In this test the P-f droop controller as described in section 2.2.1 has been validated. Two wind turbines were modelled including 42 MVA Fully Rated Converter (FRC) and 20 MVA DFIG, which correspond to the real test cases provided by SONI/NIE Networks. These tests had been performed by applying a frequency step change to the turbine controller while measuring the wind turbine power output. A droop of 3.7% was assumed in all simulations, and the maximum instantaneous output of the generator (prior to the applied frequency reference step change) was set to 100%. The following frequency step changes have been assumed in simulation:

- 50.0 Hz to 50.5 Hz (FRC and DFIG);
- 50.0 Hz to 51.0 Hz (FRC and DFIG);
- 50.0 Hz to 51.5 Hz (FRC only).

The output power was regulated by adjusting the turbine pitch angle. The generator active power was captured and compared against the available test records (provided by SONI) captured at 0.2 s, 5 s and 15 s after the frequency step change. The simulated and measured responses for the FRC (42 MVA) and the DFIG (20 MVA) are presented in Figure 13 and Figure 14 respectively. Even though it is not possible to fully appreciate the actual generator response from these three measurements only, it can be seen that the generator model responds somewhat faster but remains analogous to the metered data.

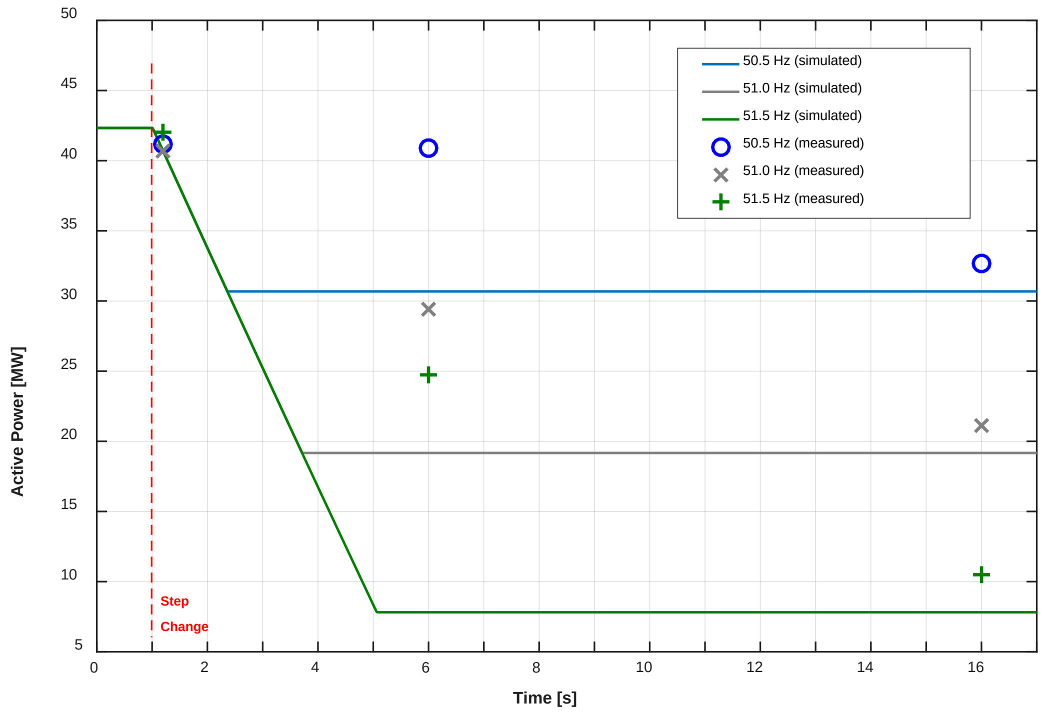


Figure 13:Simulated active power response for changes in frequency for FRC model (42 MVA)

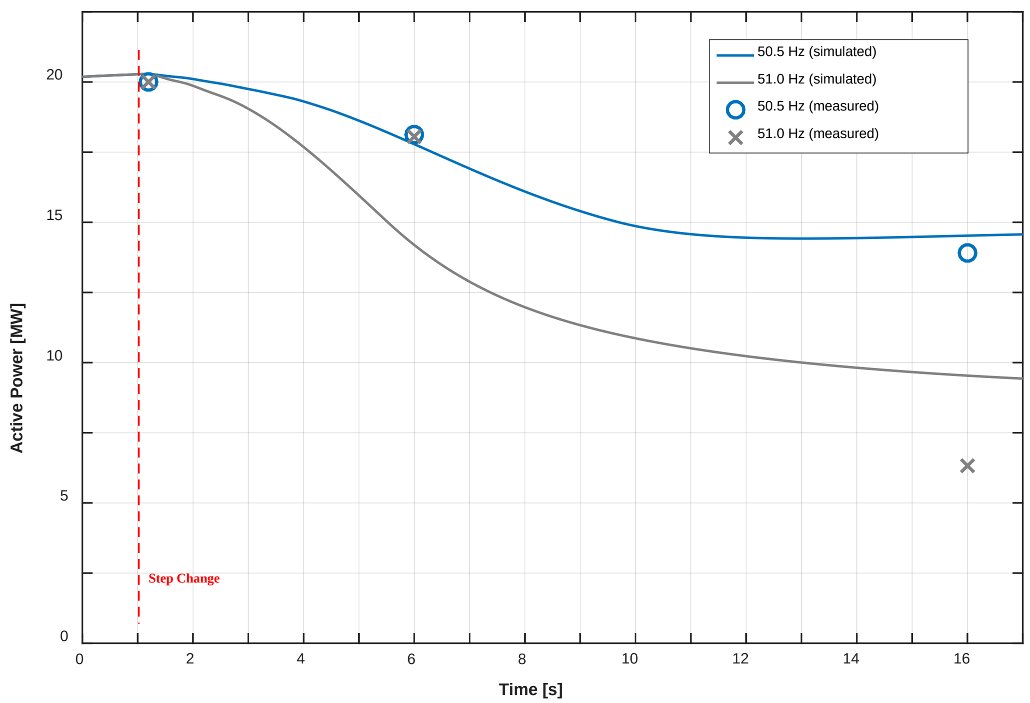


Figure 14: Simulated active power response for changes in frequency for DFIG model (20 MVA)

2.3.3 Reactive power response to voltage dips

This validation test was performed to ensure that the model properly responds to voltage dips and delivers the required DRR service. It was assumed that the reactive power of 31% of the registered capacity at nominal voltage is delivered for dips in excess of 30% with a rise time no greater than 40 ms and a settling time no greater than 300 ms (as defined in the DS3 System services document [5]).

In order to test the DRR function, the voltage controller described earlier in section 2.2.2 has been input with a voltage step change from 1.0 p.u. to 0.6 p.u at *t*=2 s. The reactive power response for the FRC (42 MVA) and for the DFIG (20 MVA) are depicted in Figure 15 and Figure 16 respectively. The response of both generator technologies has been found to be within the time and active power amplitude requirements.

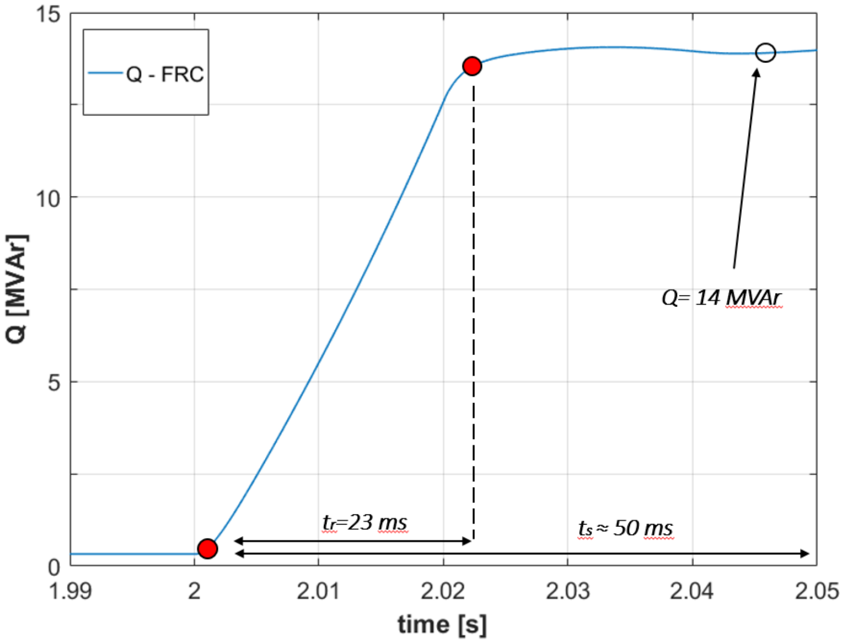


Figure 15: FRC (42 MVA) reactive power response

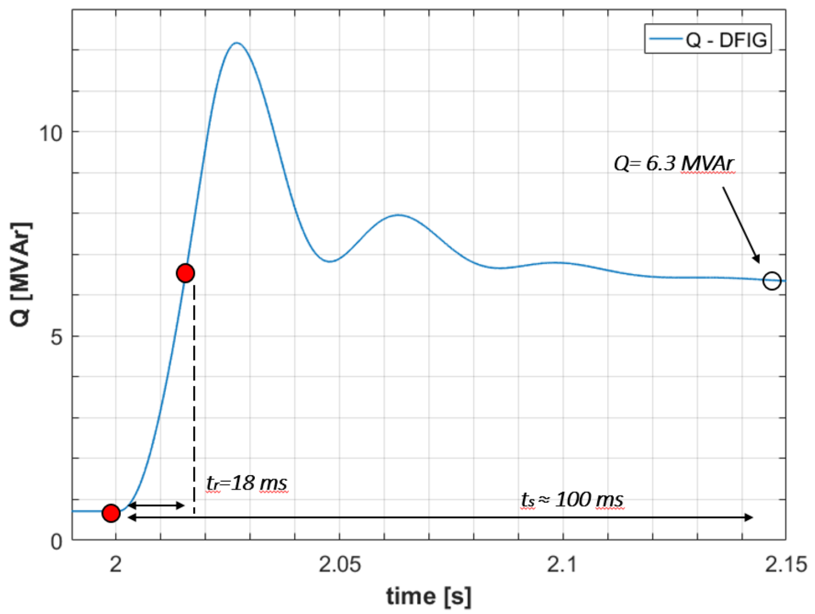


Figure 16: DFIG (20 MVA) reactive power response (zoomed)

3 Simulation-based NDZ evaluation

The objective of this simulation-based evaluation is to determine the non-detection zone (NDZ) of the ROCOF, VS and G59 (OV, UV, OF, UF) protection as a percentage of DG MVA rating. The level of active and reactive power imbalance at the point of common coupling (PCC) is adjusted independently to determine the NDZ.

3.1 Protection Setting Options

A dynamic model (validated in [2]) of a commercially available DG interface relay commonly used in UK practice (MiCOM P341) has been utilised in this test. Based on the DG protection setting records provided by NIE Networks this type of relay is used on the majority of existing wind farms with capacities greater than 5 MW. The NDZ was assessed separately for the following protective functions:

- ROCOF with five different setting options as indicated in Table 1.
- Voltage Vector Shift (VS) with two different setting options as indicated in Table 1.
- G59 protection including under and over voltage (OV, UV), and under and over frequency (OF, UF), according to most recent recommendations (with OF adjusted to 52 Hz with 1.0 s time delay, and with the suggested two stage UV settings to meet the RfG requirements [6]) as indicated in Table 2.

The tripping signal for each protection function is monitored separately to determine which functions (ROCOF/VS/ OV/UV/OF/UF) are activated for each test case and are recorded where appropriate.

Table 1: Assumed ROCOF and VS setting options

Setting Option	LOM protection type	Settings
1	ROCOF	0.4 Hz/z (no time delay)
2	ROCOF	2 Hz/s (200ms time delay)
3	ROCOF	1.5 Hz/s (300ms time delay)
4	ROCOF	1.5 Hz/s (500ms time delay)
5	ROCOF	1 Hz/s (800ms time delay)
6	Vector Shift	6°
7	Vector Shift	12°
8	UV/OV/UF/OF only	Settings as in Table 2

Table 2: G59 Voltage and Frequency protection settings

Voltage protection		Voltage [p.u]	Time Delay [s]
Under Voltage	Stage 1	0.85	3.0
	Stage 2	0.60	2.0
Over Voltage	Stage 1	1.10	0.5
Frequency protection		**Frequency [Hz]**	**Time Delay [s]**
Under Frequency	Stage 1	48	0.5
Over Frequency	Stage 1	52	1.0

3.2 NDZ assessment methodology

The NDZ was determined for both active and reactive power (including import and export) across the PCC. The pre-island imbalance of one type of power (e.g. active) is changed while holding the other type of power (e.g. reactive) in close balance by adjusting the local demand (and generator reactive power output if necessary). The power imbalance is expressed as a percentage of the DG rating. An automatic search routine developed specifically for this study was employed to iteratively change the power imbalances and monitor the relay trip response. With each incremental change in power imbalance across the PCC, the numerical relay model was injected with the simulated bus 'A' 3-phase voltage. The reported values of NDZ are expressed according to the following equations (1).

$$\begin{aligned} \boldsymbol{NDZ_{PI}} &= \frac{\boldsymbol{P_{PCCI}}}{\boldsymbol{S_{DG}}} \times \mathbf{100\%}, \quad & \boldsymbol{NDZ_{PE}} &= \frac{\boldsymbol{P_{PCCE}}}{\boldsymbol{S_{DG}}} \times \mathbf{100\%} \\ \boldsymbol{NDZ_{QI}} &= \frac{\boldsymbol{Q_{PCCI}}}{\boldsymbol{S_{DG}}} \times \mathbf{100\%}, \quad & \boldsymbol{NDZ_{QI}} &= \frac{\boldsymbol{Q_{PCCI}}}{\boldsymbol{S_{DG}}} \times \mathbf{100\%} \end{aligned} \tag{1}$$

Where:

NDZ_{PI}, NDZ_{PE} - Real power NDZ assessed for import and export respectively

NDZ_{QI}, NDZ_{QE} - Reactive power NDZ assessed for import and export respectively

P_{PCCI}, P_{PCCE} - maximum active power across the PCC at which there is no LOM protection operation within the pre-defined acceptable period (defined separately for import and export)

Q_{PCCI}, Q_{PCCE} - maximum reactive power across the PCC at which there is no LOM protection operation within the pre-defined acceptable period (defined separately for import and export)

S_{DG} - DG MVA Rating

The NDZ has been assessed for 15 different situations (termed here as generation mixes) which include single generators as well as groups of two, three and four different technologies as outlined in Table 3. These generation mixes have been established using the outcomes of the DG register analysis performed in WP1 of this work [1]. They represent various islanding groups encountered in scenario 1 (BSP islanding) and scenario 2 (33kV feeder islanding) considering all connected as well as contracted generation (Register 2 in [1]). In particular, as indicated in Table 3, scenario 1 is represented by 12 different generation mixes, and scenario 2 is represented by 5 mixes.

Table 3: DG Generation Mixes

No of technologies	Generation Mix	Islanding scenario	SM [%]	IC [%]	DFIG [%]	IM [%]	DG Capacity [MVA]
1	**1**	2	100	-	-	-	10
	2	1, 2	-	100	-	-	10
	3	1, 2	-	-	100	-	30
	4	2	-	-	-	100	10
2	**5**	1	70	30	-	-	30
	6	1	30	70	-	-	70
	7	1	-	50	50	-	100
	8	1	-	-	70	30	100
	9	1	-	-	30	70	100
	10	2			50	50	10
3	**11**	1	20	40	-	40	20
	12	1	50	-	30	20	20
	13	1	30	-	50	20	30
	14	1	-	35	50	15	125
4	**15**	1	15	30	30	25	60

3.3 NDZ Results

The combined NDZ results (with ROCOF, VS and G59 protection enabled) are summarised for all the 15 generation mixes in Tables 15 to 29 (Appendix B.1), while the complete set of NDZ results are presented in Appendix B.2, where NDZ values are shown for ROCOF, VS and G59 protection separately.

The results reveal that some generation mixes (i.e. mixes 2, 3, 7, 8, 13, 14) are unable to sustain stable operation for 30 s after being separated from the grid even with load/generation perfectly balanced and fast frequency response implemented. This is particularly the case with non-synchronous generation (i.e. DFIG, IM, and IC).

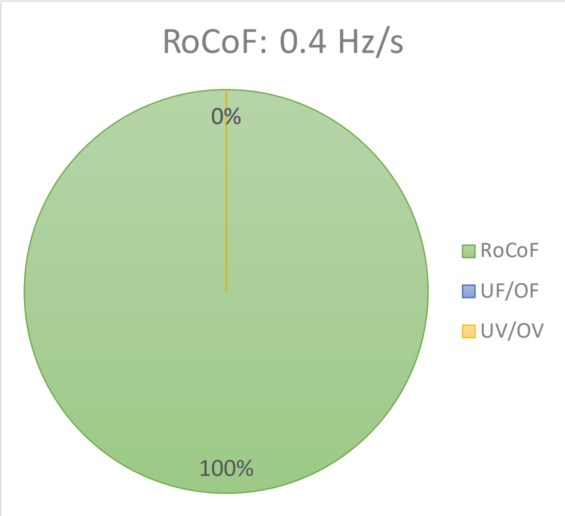
In order to provide further insight into the operation of the LOM protection under various setting options the percentage dependency of the LOM protection NDZ on the individual protection modules has been analysed considering two main LOM setups:

- ROCOF relay with Frequency and Voltage protection - Figure 17, and
- VS relay with Frequency and Voltage protection - Figure 18

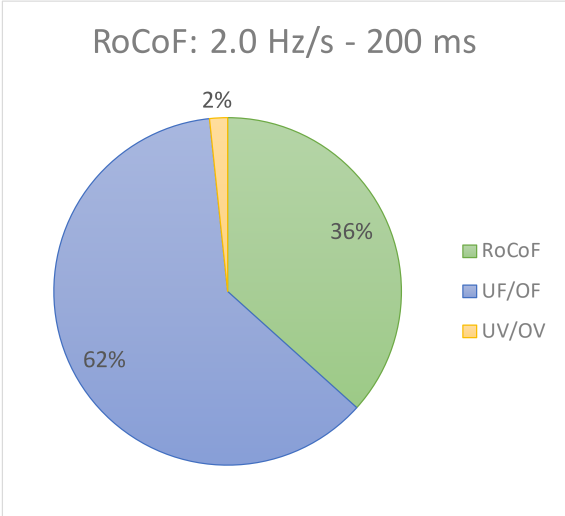
The charts show the percentage of the cases where each protection function has determined the width of the NDZ. These results are based on the inspection of all NDZ result included in Appendix B.1 considering 15 generation mixes and 4 NDZ boundaries (i.e. 60 NDZ cases).

It can be clearly seen in Figure 17 that when using ROCOF protection with the existing setting of 0.4Hz/s all NDZ values (100%) are determined by the ROCOF relay and other DG interface protection modules only provide a backup operation. However, with increased setting and additional time delay a significant proportion of NDZ values depend on frequency protection (ROCOF acting as backup in many cases).

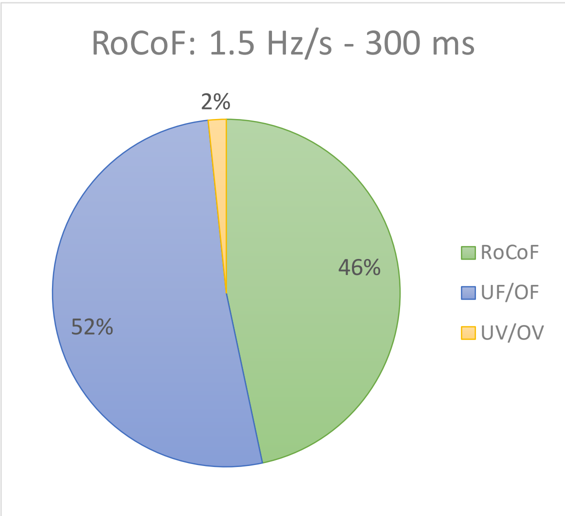
With respect to VS-based LOM protection, the difference between the setting of 6° and 12° is minor. However, it is worth noting that even with the existing setting of 6°, the NDZ width depends on frequency protection in more than 50% of cases (refer to Figure 18).



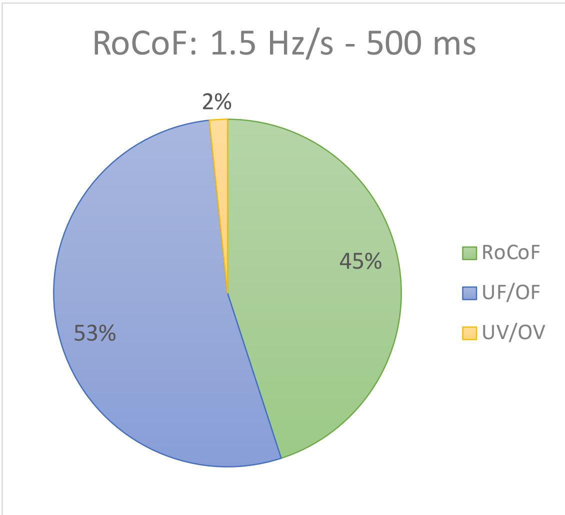
a) setting option 1



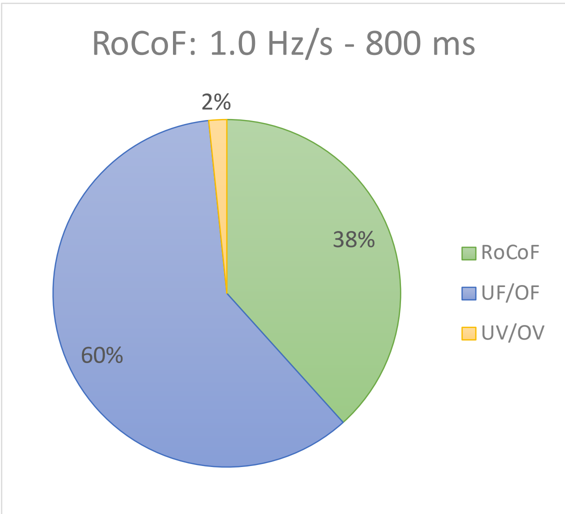
b) setting option 2



c) setting option 3

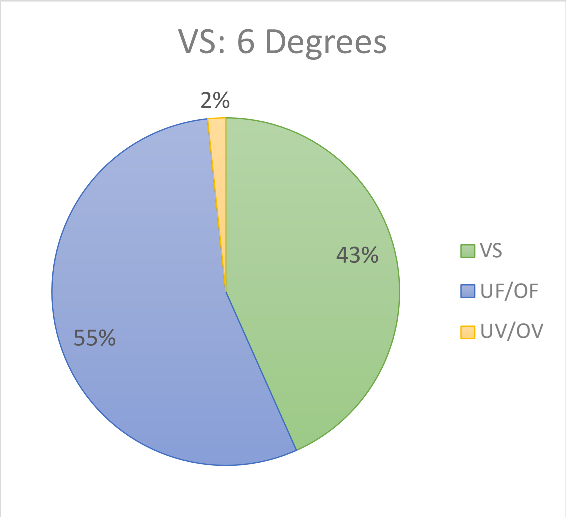


d) setting option 4

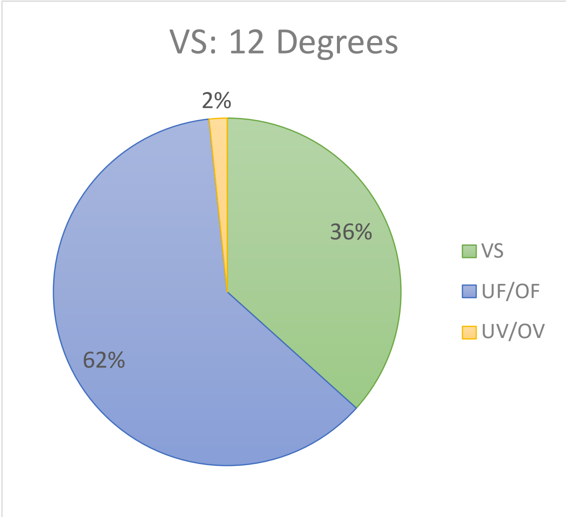


e) setting option 5

Figure 17: Combined ROCOF and G59 NDZ performance



a) setting option 6



b) setting option 7

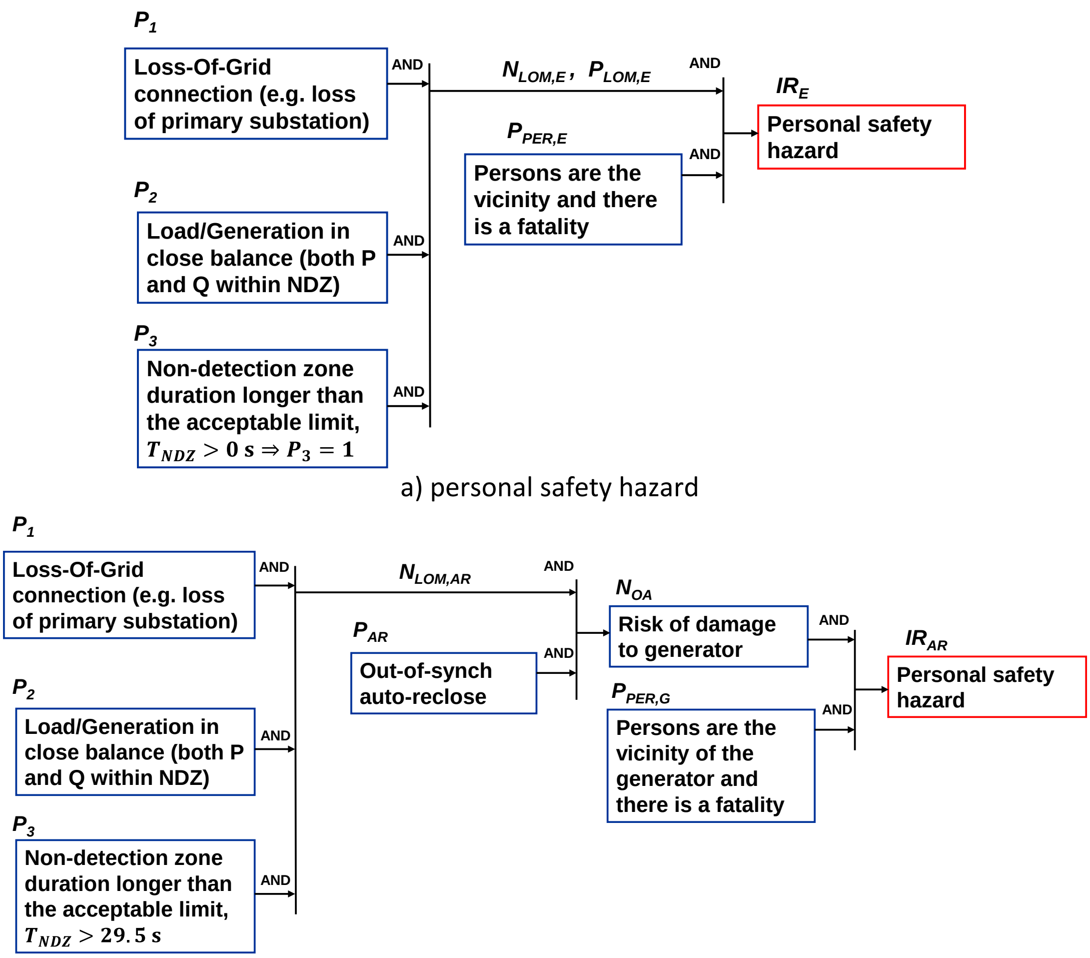
Figure 18: Combined VS and G59 NDZ performance

4 Risk level calculations for various values of NDZ

4.1 Risk calculation methodology

The risk calculation methodology adopted in this section is similar to the method previously applied in the GB system study [6]. This approach is based on a statistical analysis of a probability tree depicting perceived probability of specific hazards (including safety of people or damage to equipment).

The methodology makes a number of assumptions regarding the type of utility network, type and size of the distributed generators and generation technology (refer to section 4.2 for details). It utilises the width of the Non Detection Zone (NDZ) established through detailed dynamic simulation described earlier in sections 2 and 3 of this document. Recorded typical utility load profiles, generation profiles, as well as statistics of utility network incidents including loss of supply to Bulk Supply Points (islanding scenario 1) and loss of supply to individual 33kV feeders (islanding scenario 2) are also utilised to estimate probabilities of load-generation matching and islanding incidents.



b) generator damage hazard

Figure 19. LOM Safety Hazard Probability Tree

Additionally, detailed DG connection registers (supplied directly by NIE Networks) were utilised to establish the predominant types of generation mixes in the identified typical islanded situations. The outcome of this analysis has been reported in WP1 and included in the report [1].

By utilising the assumed fault tree presented in Figure 19, the calculations described in the following sub-sections of this report are performed to assess:

a) personal safety hazard (the term individual risk IR_E is used in this report to denote the annual probability of death resulting from an undetected LOM condition – as shown in Figure 19a), and
b) damage to generator occurring as a result of sustained undetected islanded operation of DG combined with likely out-of-phase auto-reclosure (the annual rate of occurrence of out-of-phase auto-reclosure N_{OA} is used in this report – as shown in Figure 19b).

In order to cover all possible islanding scenarios for the range of possible different generation mixes (refer to Table 3), the risk tree calculation is systematically repeated through all combinations of islanding situations and the final probability figures are obtained as a sum or weighted average of the individual results. The following subsections explain this process in more detail.

4.1.1 Expected number of LOM occurrences in a single islanding point

For a single islanding point (whether an entire substation or an individual circuit), the possibility of an undetected islanding situation arises from the loss of grid supply. Accordingly, the expected number of incidents of losing supply to an individual islanding point ($N_{LOG,1IP}$) during the period of one year can be estimated as follows:

$$N_{LOG,1IP} = \frac{n_{LOG}}{n_{IP} \cdot T_{LOG}} \tag{2}$$

where n_{LOG} is the total number of loss of supply incidents experienced during the period of T_{LOG} in a population of n_{IP} islanding points. The assumed values of n_{LOG} and n_{IP} for each islanding scenario have been derived from the network incident statistics, as described in section 4.2.1.

4.1.2 Load and generation profile analysis

For each generation mix and each islanding scenario $m = 1,2, \dots ,17$ (12 mixes in scenario 1 and 5 mixes in scenario 2 = 17 cases) the probabilities $P_{2(m)}$ and $P_{3(m)}$ (refer to Figure 19) are calculated jointly by systematic analysis of the example recorded load and generation profiles captured over a period of 1 week with 1s resolution. This is performed iteratively in two nested loops. The inner loop (iteration i) progresses through the whole duration of the given record, while the outer loop (iteration j) covers the range of generation mix capacities according to the histogram characteristic of the given mix of technologies. The histograms for all predominant generation mixes were derived from the available DG connection registers and presented in section 2.2 of the report [1]. In each capacity band j there is a certain number of islanding points $n_{IP(m,j)}$. It should be noted that generator maximum output and generator rating are synonymous in the context of this calculation.

Within the inner loop at each time step (iteration i), the instantaneous load values $P_{L(i)}$ and $Q_{L(i)}$ are compared with the scaled version of the generation profile ($P_{DGG(m,j,i)}$ and $Q_{DGG(m,j,i)}$) to check if the difference falls within the NDZ established for the specific generation mix. This condition is described by (3).

$$\begin{gathered} -NDZ_{PE(m)} < P_{L(i)} - P_{DGG(m,j,i)} < NDZP_{PI(m)} \\ \wedge \\ -NDZ_{QE(m)} < Q_{L(i)} - Q_{DGG(m,j,i)} < NDZ_{QI(m)} \end{gathered} \tag{3}$$

Where:

$P_{L(i)}, Q_{L(i)}$ - recorded samples of active and reactive load power

$P_{DGG(m,j,i)}, Q_{DGG(m,j,i)}$ - scaled active and reactive generation profile for the generation mix m and capacity band j

$NDZ_{PE(m)}, NDZ_{QE(m)}$ - NDZ when generator output is higher than the local load (export) for generation mix m

$NDZ_{PI(m)}, NDZ_{QI(m)}$ - NDZ when generator output is lower than the local load (import) for generation mix m

When consecutive samples conform to the conditions specified in equation (3), the time is accumulated until the local load exits the NDZ. After all NDZ instances (i.e. their durations) are recorded, the NDZ duration cumulative distribution function (CDF) is derived, an example of which is presented in Figure 20. As illustrated in the figure, the probability $P_{3(m,j)}$ that the NDZ is longer than T_{NDZmax} can easily be obtained from the CDF.

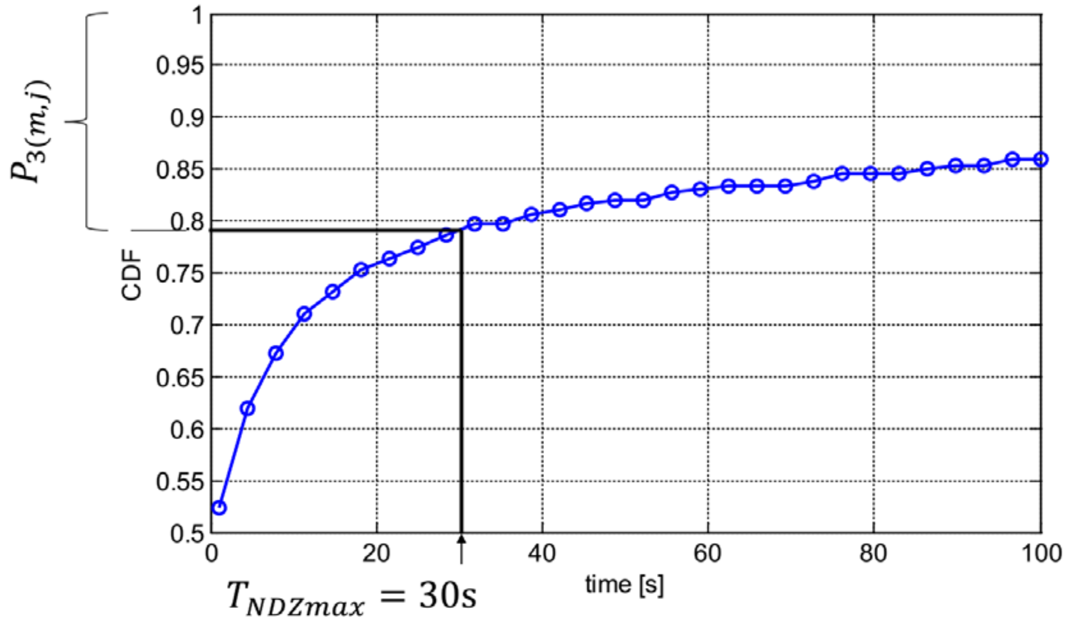


Figure 20. CDF of an example NDZ duration time

At the same time, the probability $P_{2(m,j)}$ of both *P* and *Q* being within the NDZ is also calculated as a sum of all recorded NDZ periods with respect to the total length of the recorded load profile (4).

$$P_{2(j)} = \sum_{k=1}^{n_{NDZ(m,j)}} \frac{T_{NDZ(m,j,k)}}{T_{load\_record}} \tag{4}$$

Where:

$n_{NDZ(m,j)}$ - number of detected NDZ periods within the capacity band *j*

T_{load_record} - total length of the recorded load profile

$T_{NDZ(m,j,k)}$ - length of k-th NDZ period.

Finally, the joint probability $P_{23(m,j)}$ for each capacity band *j* can be calculated as (5) which leads to the development of the probability density as shown in Figure 21.

$$P_{23(m,j)} = \frac{n_{DGG(m,j)}}{n_{DGG(m)}} P_{2(m,j)} \cdot P_{3(m,j)} \quad (5)$$

where:

$n_{DGG(m,j)}$ - number of DG islanding groups in the mix m and the capacity band j

$n_{DGG(m)}$ - total number of DG groups in the generation mix m

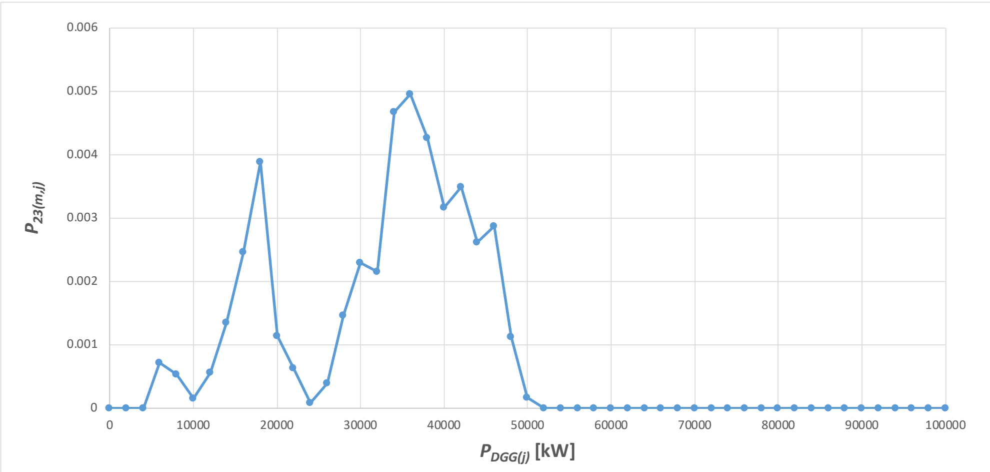


Figure 21. Non-detection zone probability at varying DG group capacity

Consequently, according to the principle of marginal probability [8], the combined probability $P_{23(m)}$, considering all DG groups of certain mix, is calculated using a simple summation as shown in (6).

$$P_{23(m)} = \sum_{j=1}^{n_{CB(m)}} P_{23(m,j)} \quad (6)$$

Where $n_{CB(m)}$ is the number of capacity bands.

The expected annual number of undetected islanding operations longer than the assumed maximum period T_{NDZmax} for an individual DG mix can be calculated as (7).

$$N_{LOM,1DGG(m)} = N_{LOG,1IP} \cdot P_{23(m)} \quad (7)$$

Additionally, the overall average duration of the NDZ for a given mix ($T_{NDZavr(m)}$) is calculated by adding all NDZ durations longer than T_{NDZmax} from all generator groups and dividing the sum by the total number of NDZ occurrences.

The above process described by equations (3)-(7) is repeated for all considered 17 islanding cases. The final figures of T_{NDZavr} are calculated as a weighted average (8) from all different generation mixes and islanding scenarios ($m = 1,2, \ldots ,12$ for scenarios 1 and $m = 13,14,..,17$ for scenario 2).

$$T_{NDZavr,s1} = \frac{\sum_{m=1}^{12} n_{DGG(m)} \cdot T_{NDZavr(m)}}{\sum_{m=1}^{12} n_{DGG(m)}}$$

$$T_{NDZavr,s2} = \frac{\sum_{m=13}^{17} n_{DGG(m)} \cdot T_{NDZavr(m)}}{\sum_{m=13}^{17} n_{DGG(m)}} \quad (8)$$

$$T_{NDZavr} = \frac{\sum_{m=1}^{17} n_{DGG(m)} \cdot T_{NDZavr(m)}}{\sum_{m=1}^{17} n_{DGG(m)}}$$

4.1.3 Calculation of national LOM probability figures and individual risk

In each case of generation mix m the expected annual number of undetected LOM events $N_{LOM(m)}$ and the probability of an undetected islanded system at any given time $P_{LOM(m)}$ are established. Firstly, using the known total number of connected DG groups ($n_{DGG(m)}$) with an assumed proportion of ROCOF based LOM protection ($p_{ROCOF(m)}$) and load factor ($LF_{(m)}$), the expected annual number of undetected islanding incidents can be estimated from:

$$N_{LOM(m)} = N_{LOM,1DG(m)} \cdot n_{DGG(m)} \cdot p_{ROCOF(m)} \cdot LF_{(m)} \tag{9}$$

The expected cumulative time of undetected islanding conditions for all considered DG groups $n_{DGG(m)}$ in mix m can be estimated using:

$$T_{LOM(m)} = N_{LOM(m)} \cdot (T_{LOMavr(m)} - T_{NDZmax}) \tag{10}$$

where $T_{LOMavr(m)}$ is the average time that an undetected island can be sustained in mix m. This time is selected as the minimum value between $T_{NDZavr(m)}$ and assumed maximum operation time of the auto-reclosing scheme (T_{ARmax}). It is assumed that sustained islanded operation following an auto-reclose operation is not possible.

Finally, the overall probability in mix m of an undetected islanded system at any given time and at specific assumed ROCOF settings is calculated as:

$$P_{LOM(m)} = \frac{T_{LOM(m)}}{T_a} \tag{11}$$

Where:

T_a – period of 1 year

The final figures of P_{LOM} and N_{LOM} are calculated as a direct sum of partial results obtained for individual generation mixes ($m = 1,2, \dots ,12$ for scenarios 1 and $m = 13,14, ..21$ for scenario 2).

$$P_{LOM,s1} = \sum_{m=1}^{12} P_{LOM(m)}$$

$$P_{LOM,s2} = \sum_{m=13}^{17} P_{LOM(m)}$$

$$P_{LOM} = \sum_{m=1}^{17} P_{LOM(m)} \tag{12}$$

$$N_{LOM} = \sum_{m=1}^{17} N_{LOM(m)}$$

For a single DG group with ROCOF protection in mix m, the probability can be calculated as:

$$P_{LOM,1DGG(m)} = \frac{P_{LOM(m)}}{n_{DGG(m)} \cdot p_{ROCOF(m)}} \quad (13)$$

In this case the final figures of $P_{LOM,DGG}$ are calculated as a weighted average (proportional to the number of DG groups) from all different generation mixes and islanding scenarios ($m = 1,2, \dots ,12$ for scenarios 1 and $m = 13,14, \dots ,17$ for scenario 2).

$$P_{LOM,1DGG,s1} = \frac{\sum_{m=1}^{12} n_{DGG(m)} \cdot P_{LOM,1DGG(m)}}{\sum_{m=1}^{12} n_{DGG(m)}}$$

$$P_{LOM,1DGG,s2} = \frac{\sum_{m=13}^{17} n_{DGG(m)} \cdot P_{LOM,1DGG(m)}}{\sum_{m=13}^{17} n_{DGG(m)}} \quad (14)$$

$$P_{LOM,1DGG} = \frac{\sum_{m=1}^{17} n_{DGG(m)} \cdot P_{LOM,1DGG(m)}}{\sum_{m=1}^{17} n_{DGG(m)}}$$

In order to ascertain whether the risk resulting from the proposed adjustment to the ROCOF settings is acceptable, the analysis and interpretation of the calculated N_{LOM} and P_{LOM} values is performed. Note that the values of N_{LOM} are calculated separately for the purposes of assessing the out-of-phase reclosures (denoted as $N_{LOM,AR}$) where $T_{NDZmax} = 30$ s was assumed, and for the purposes of individual risk assessment (denoted as $N_{LOM,E}$) where $T_{NDZmax} = 0$ s was assumed. The final risk calculation is performed in two steps:

1. Firstly, the annual expected number of out-of-phase auto-reclosures (N_{OA}) during the islanding condition (undetected by LOM protection) is calculated as follows:

$$N_{OA} = N_{LOM,AR} \cdot P_{AR} \quad (15)$$

   Where $N_{LOM,AR}$ is the expected annual number of undetected islanding incidents for out-of-phase reclosure assessment, and P_{AR} is the probability of an out-of-phase auto-reclosing action following the disconnection of a circuit supplying a primary substation. Considering that auto-reclosing action would occur in the vast majority of cases of losing supply to a primary substation (unless the system is wholly underground) and also considering the fact that reclosure with small angle differences may be safe, a value of $P_{AR} = 0.8$ was assumed.

2. Secondly, the annual probability values are calculated related to perceived individual risk (*IR*). Two sources of *IR* are considered: (a) the risk of a fatality due to accidental contact with any elements of the energised undetected island (IR_E), and (b) risk of physical injury or death resulting from the generator destruction following an out-of-phase auto-reclosure (IR_{AR}). These two indices are calculated as follows:

$$IR_E = N_{LOM,E} \cdot P_{PER,E} \quad (16)$$

$$IR_{AR} = N_{OA} \cdot P_{PER,G} \quad (17)$$

where $P_{PER,E}$ is the probability of a person being in close proximity to an undetected islanded part of the system and suffering a fatal injury at the same time, and $P_{PER,G}$ is the probability of a person being in close proximity of the generator while in operation and suffering fatal injury as a result of the generator being destroyed by an out-of-phase auto-reclosure. The resulting *IR* can be then compared with the general criteria for risk tolerability included in the Health and Safety at Work Act 1974 [9] which adopts the risk management principle often referred to as the 'ALARP' or 'As Low as Reasonably Practicable' principle. The ALARP region applies for IR levels between 10^{-6} and 10^{-4}. Risks with probabilities below 10^{-6} can generally be deemed as tolerable. A similar approach has already been used in the risk assessment of NVD protection requirement [10] as well as in the earlier GB system studies [7], [11].

The value of $P_{PER,E}$ needs further consideration. As statistics relating to injuries resulting directly from undetected islanded systems do not appear to exist, it is difficult to obtain an exact estimation of such occurrences. There may be statistics relating to injuries and fatalities from electric shock, but the link between these events and the root cause being an undetected island cannot be made. However, some rationale can be developed based on existing fault-related incidents in electricity networks. In Appendix 5 of the NVD report [10] the following statistics are presented:

- nearly 5% of all HV faults involve a proximity hazard,
- on average, there are 8.6 fatalities p.a. in GB due to close proximity to electricity networks,
- 90% of these fatalities involve the OHL network,
- there are 800 cases p.a. where people are in close proximity to HV OHL interruptions.

Therefore, $P_{PER,E}$ can be seen as a joint probability of $P_A = 0.05$ (a person being in the vicinity), and P_B (the person in the vicinity suffering a fatal injury). Based on the above points the probability of a fatality due to an HV OHL interruption would be $P_B = \frac{8.6 \cdot 0.9}{800} \cong 0.01$. However, such probability relates to injuries caused directly by the fault and not by the follow on period of undetected islanding. It needs to be emphasised that only additional risk caused by prolonged islanded operation should be included in the calculations for the purposes of assessing the risk of any aspect of the LOM protection. Assuming that the chance of contact with an energised island during the period of up to 30s (maximum realistic period of islanding due to delayed auto-reclose in the NIE Networks system) is the same as the chance of injury during the initial fault occurrence (i.e. 0.01), and also assuming that standard exponential probability distribution ($f(t) = \lambda\, e^{-\lambda t}$) applies during the islanding period following the fault, the following formula can be used to assess probability of injury from an islanded system.

$$P_{PER,E} = P_A \cdot P_B = P_A \cdot (1 - e^{-\lambda \cdot T_{LOMavr}}) \quad (18)$$

Where:

- $P_A = 0.05$
- $P_B = 1 - e^{-\lambda \cdot T_{LOMavr}}$ (according to cumulative distribution function of $f(t) = \lambda\, e^{-\lambda t}$)
- $T_{LOMavr} = \frac{P_{LOM,E} \cdot T_a}{N_{LOM,E}}$ in [s]

The constant λ is established from the assumption that $P_B(t \leq 30s)$ =0.01 which results in $\lambda = -\frac{\ln(1-0.01)}{30} = 3.3501 \times 10^{-4}$.

The probability $P_{PER,G}$ will depend on specific circumstances, generator location and regime of operation, and therefore, it is beyond the scope of this report to accurately quantify such probabilities. However, it can be generally assumed that while synchronous machines are seriously affected (possibly damaged) by the out-of-phase reclosure, other technologies, such as fixed speed induction machines or fully-rated inverter wind turbines can often ride through such reclosures without much impact on their lifespan. A short analysis which could assist in quantifying the impact of the out-of-phase reclosure on various generation groups/mixes is included in the concluding section 5.5.

The relative difference between the probability of an undetected islanding condition using existing recommended settings and the probability using the proposed settings provides further guidance as to the acceptability of the proposed setting options.

4.2 Initial assumptions and available data

The following assumptions and initial values were made in this study:

- Generation range considered has a capacity of greater than 5 MW;
- Generation output is represented by an example measured generation profile characteristic of a particular generation technology. Sample generation profiles for wind and biomass-based distributed generation were provided by NIE Networks.
- Inverter connected (IC) generation was assumed to be predominantly wind.
- The load factor (LF) was assumed to be 1 for all generation (worst case scenario).
- Based on the DG protection setting records provided by NIE Networks for the purposes of Phase 1 study it was assumed that the usage of ROCOF protection is 100%, 0%, 27% and 50% for Synchronous, inverter connected, DFIG and induction machine based generation respectively. Regarding VS protection the assumed percentages were as follows: 0% (SM), 100% (IC), 73% (DFIG) and 50% (IM). Other percentages related to various generation groupings have been derived as described in section 4.2.3.
- Detailed distribution of DG sizes, numbers, predominant groupings, as well as percentage contributions of individual generating technologies within the groups (generation mixes) were obtained from available NIE Networks connection registers and analysed within WP1 [1].
- Nine different load scenarios recorded on selected BSPs as well as other typical 33kV circuits and primary substations used as described in section 0.
- For the purposes of assessing the probability of out-of-phase reclosure, a period of $T_{NDZmax} =$ 29.5 s (i.e. 30 s minus 0.5 s to allow for standard protection grading time) was assumed as the maximum permissible duration of undetected islanding condition (i.e. no auto-reclosing with a time delays of less than T_{NDZmax} is expected to occur). However, in assessing individual risk, all islanding durations were included in the calculation, i.e. $T_{NDZmax} = 0$ s was used.
- As the time before the fault is cleared is not technically an islanded situation, it is not considered in this analysis. In other words, the network fault clearance time is assumed to have no impact on the risks associated with the adjustment of the LOM protection settings.
- It is assumed that the generator (or a group of generators) does not continue to supply the system after an out-of-phase auto-reclosing operation.
- A period of $T_{ARmax} = 30$ s was assumed as the maximum expected time of operation of the auto-reclosing scheme (in other words, regardless of load/generation balance, undetected stable island will not continue to operate longer than T_{ARmax} due to the impact of out-of-phase reclosure).
- The LOM event is simulated as a simple opening of a circuit breaker at the point of common coupling and no initiating fault is simulated prior to islanding (worst case scenario from the LOM detection perspective).

4.2.1 Potential islanding scenarios and estimated frequency of occurrence

Generation above 5MW can be connected either directly to a BSPs (trough a dedicated line) or as a teed connection to one of the 33kV feeders. Therefore, there are two possible scenarios which can lead to power islanding of one or more of the large generating units.

Scenario 1 considers the loss of grid supply to a BSP, while scenario 2 involves islanding of an individual 33 kV feeder. In order to assess the expected annual number of LOM occurrences at an individual islanding point NIE Networks provided a summary of the loss of grid supply incidents based on the company's NAFIRS system. These values are summarised in Table 4. Additionally, the following numbers of potential islanding points were assumed:

- scenario 1 – $n_{IP,s1} = 36$ (number of BSPs)
- scenario 2 – $n_{IP,s2} = 158$ (54 radial + 104 ring feeders from all BSPs)

Table 4. Loss of grid supply statistics for islanding scenario 1 and 2

	Islanding Scenario	Number of incidents					
		2010	2011	2012	2013	2014	Total n_{LOG}
No. of times supply has been lost to a BSP	1	1	4	3	6	2	**16**
No. of times 33kV feeder supplies have been lost	2	98	85	89	135	94	**501**

Consequently, using equation (2), the expected number of LOM occurrences in a single islanding point can be calculated for each scenario as follows:

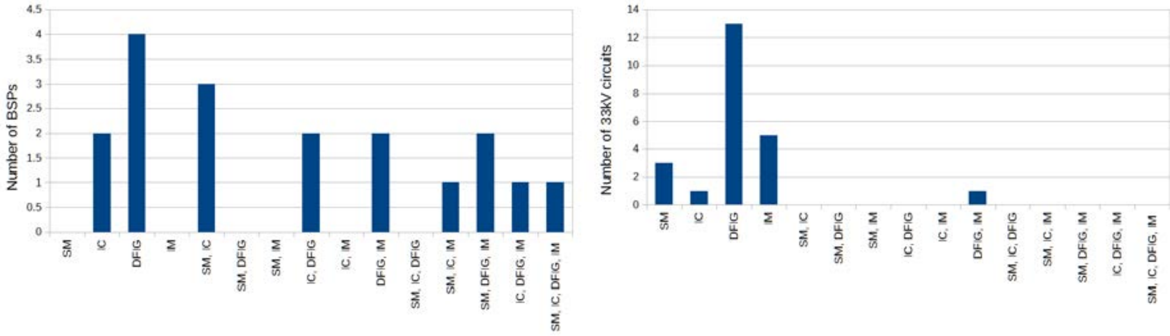
- scenario 1 – $N_{LOG,1IP,s1} = \frac{n_{LOG,s1}}{n_{IP,s1} \cdot T_{LOG,s1}} = \frac{16}{36 \cdot 5} = 0.0889$

- scenario 2 – $N_{LOG,1IP,s2} = \frac{n_{LOG,s2}}{n_{IP,s2} \cdot T_{LOG,s2}} = \frac{501}{158 \cdot 5} = 0.6342$

where n_{LOG} is the total number of loss of supply incidents experienced during the period of T_{LOG} (five years in this case) in a population of n_{IP} islanding points.

4.2.2 Establishing DG technology mixes

In order to establish the representative mixes of generation technologies with appropriate proportions of each generation in the mix, analysis of the DG register was performed previously and included in WP1 report [1]. In order to derive results which correspond to the most "forward looking" DG connection set, the register which combines existing and all contracted generation has been used in this study. A summary of the resulting mixes in scenario 1 and 2 are also presented in Figure 22.



a) scenario 1 b) scenario 2

Figure 22. Islanding groups based on DG Register 2 (connected + contracted DG)

Considering that there are nine different generating groups in scenario 1 and five groups in scenario 2, and also, taking into account the variation in the proportions of individual generating technologies in each group, a set of 15 different generation mixes have been established which cover all groupings in both islanding scenarios. This is summarised in Table 5 and used consistently in the NDZ assessment (refer to section 3.2). The same groupings are assumed in the risk assessment calculation included in section 4.3.

Table 5. Assumed generation groupings (mixes)

Grouping	Generation Mix	Used in islanding scenario
Single	1 (SM 100%)	2
	2 (IC 100%)	1, 2
	3 (DFIG 100%)	1, 2
	4 (IM 100%)	2
Groups of 2	5 (SM 70%, IC 30%)	1
	6 (SM 30%, IC 70%)	1
	7 (IC 50%, DFIG 50%)	1
	8 (DFIG 70%, IM 30%)	1
	9 (DFIG 30%, IM 70%)	1
	10 (DFIG 50%, IM 50%)	2
Groups of 3	11 (SM 20%, IC 40%, IM 40%)	1
	12 (SM 50%, DFIG 30%, IM 20%)	1
	13 (SM 30%, DFIG 50%, IM 20%)	1
	14 (IC 35%, DFIG 50%, IM 15%)	1
Groups of 4	15 (SM 15%, IC 30%, DFIG 30%, IM 25%)	1

4.2.3 Usage of ROCOF and VS within LOM protection scheme

When performing the assessment of the change of settings it is crucial that only those generating units which use a particular type of protection (ROCOF or VS in this case) are included in the final risk figures. Some generators use ROCOF while others use VS (and some use both).

Based on the DG protection setting records provided by NIE Networks it was assumed that the usage of ROCOF and VS protection in individual generating technologies is as follows:

- Synchronous – 100% ROCOF, 0% VS
- Inverter Connected – 0% ROCOF, 100% VS
- DFIG – 27% ROCOF, 73% VS
- Induction Generator – 50% ROCOF, 50% VS

For example, in ROCOF risk calculation, the power islands formed by inverter connected DG only will be excluded from calculations as none of such generators use ROCOF protection, and therefore, they are not affected by the change in ROCOF protection settings. When considering multi-generator islands, the level of ROCOF (or VS) protection usage has been derived under the assumption that an island is de-energised if at least one of the technologies is equipped with a ROCOF (or VS) relay. In terms of probability of an island (including *N* different technologies) being effectively protected by the specific type of LOM protection (either ROCOF or VS), this can be calculated as follows:

$$P_{ROCOF,VS\_OK} = 1 - P_{NO_{ROCOF,VS}} = 1 - \sum_{i=1}^{N} \left(1 - P_{ROCOF,VS(i)}\right) \quad (18)$$

where *N* is a number of different technologies in the group/mix.

Moreover, for more accurate estimation of risk, it is also assumed that in mixed DG islands where both ROCOF and VS protection are in use, the ROCOF protection is always more effective (due to narrower NDZ as evidenced from the results in Appendix B), and therefore, any change to VS settings would not affect the overall risk. Thus, DG islands equipped with VS protection only (as shown in the right hand side column of Table 6) were included in the risk calculation of the setting options 6 and 7.

Table 6. Assumed ROCOF usage in HV connected generation

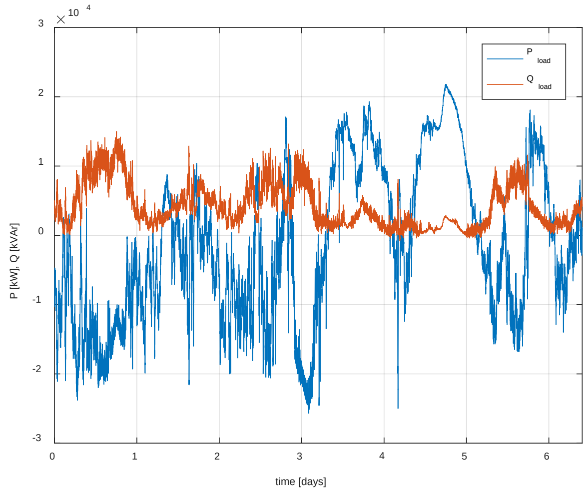
Grouping	Generation Mix	ROCOF Usage	VS Usage	How established?	VS usage applied in risk calculations
Single	1 (SM 100%)	1	0	Assumed	0
	2 (IC 100%)	0	1		1
	3 (DFIG 100%)	0.27	0.73		0.73
	4 (IM 100%)	0.5	0.5		0.5
Groups of 2	5 (SM 70%, IC 30%)	1	1	Derived using equation (18)	0
	6 (SM 30%, IC 70%)	1	1		0
	7 (IC 50%, DFIG 50%)	0.27	1		0.73
	8 (DFIG 70%, IM 30%)	0.63	0.87		0.37
	9 (DFIG 30%, IM 70%)	0.63	0.87		0.37
	10 (DFIG 50%, IM 50%)	0.63	0.87		0.37
Groups of 3	11 (SM 20%, IC 40%, IM 40%)	1	1		0
	12 (SM 50%, DFIG 30%, IM 20%)	1	0.87		0
	13 (SM 30%, DFIG 50%, IM 20%)	1	0.87		0
	14 (IC 35%, DFIG 50%, IM 15%)	0.63	1		0.37
Groups of 4	15 (SM 15%, IC 30%, DFIG 30%, IM 25%)	1	1		0

4.2.4 Load profile data

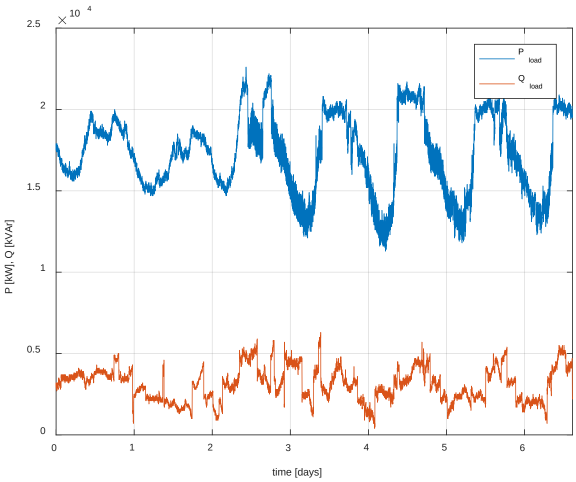
In order to cover a wide range of possible loading scenarios and capacities, ten different active and reactive (*P* and *Q*) load profiles have been included in this study. These profiles were recorded by NIE Networks and a number of GB DNOs at various distribution system substations. This section includes a brief description of each record including a graphical illustration of the *P* and *Q* traces.

4.2.4.1 Load profiles recorded at various BSPs (NIE Networks)

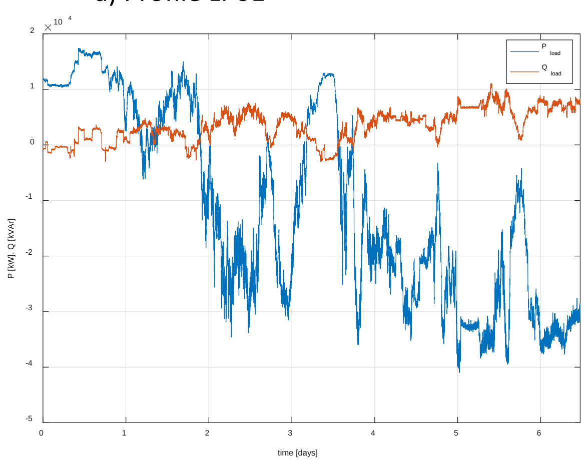
Four different load profiles (illustrated in Figure 23) were recorded by NIE Networks capturing the total network load experienced at various BSPs. High penetration of distributed generation is evident from these traces as the load (active power in particular) becomes negative over extended periods of time, indicating that energy is being exported to the transmission system. These four profiles were used in scenario 1 risk calculations where islanding of an entire BSP is considered. It should be noted that the load profile LP04 was used twice in the calculations, first combined with various mixes of generation profiles (similar to all other profiles LP01-LP03 and denoted in results as LP04), and secondly, without any additional generation profile added (denoted as LP05). The reason for this approach was to compare the case of the existing connected generation only (LP05) with the emulation of a potential future scenario where more DG connections are expected (LP04).



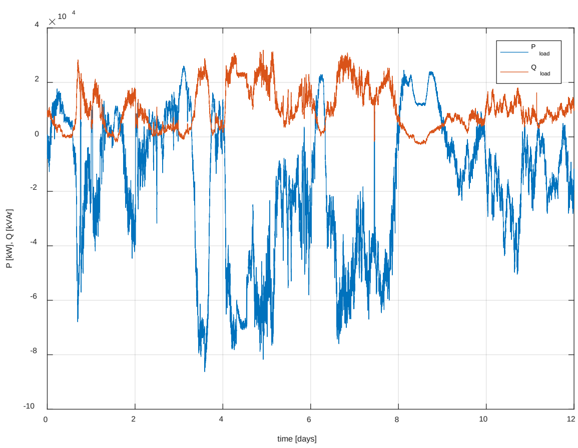
a) Profile LP01



b) Profile LP02



c) Profile LP03



d) Profile LP04/LP05

Figure 23. BSP Load Profiles – recorded between November 2015 and May 2016

4.2.4.2 Primary substation load profile (Western Power Distribution – WPD)

This record (provided originally by WPD for the purposes of GB system study [11]) has been measured on one of the two parallel-connected 33/11kV 24MVA transformers supplying an 11kV busbar at a primary substation which feeds a mixture of domestic, commercial and industrial load. The trace used in this study as LP06 is presented in Figure 24 where all the monitoring data values were doubled to obtain the full load of the primary substation assuming equal load sharing between both transformers at the primary substation. The load profile LP06 was used in islanding scenario 2.

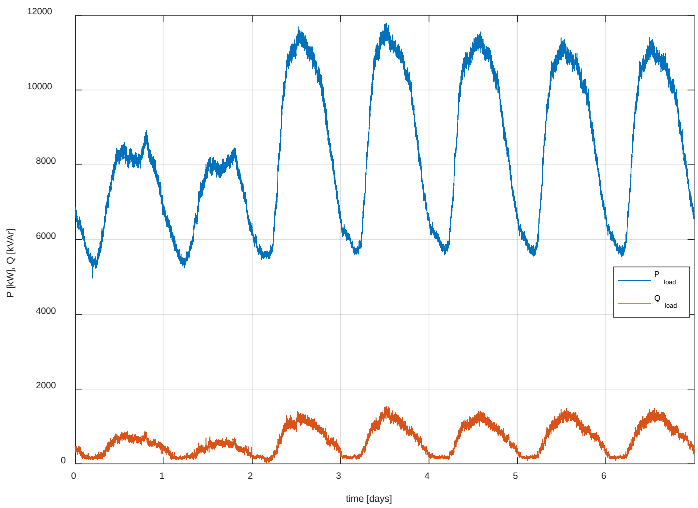


Figure 24. Primary substation load profile (LP06) – October 2014

4.2.4.3 Primary substation load profile (Electricity North West – ENW)

This record was obtained from the 6.6kV (2x11.5MVA) primary substation located in an urban area (load case LP07). The data was previously used in the GB system study [11] and originally recorded with 1s resolution over a period of four non-consecutive days (two weekdays and Saturday/Sunday) of the same week. For risk calculation purposes and in order to preserve a balance between weekdays and weekend days, the remaining “missing” weekdays were created by simply repeating the available Wednesday and/or Thursday records.

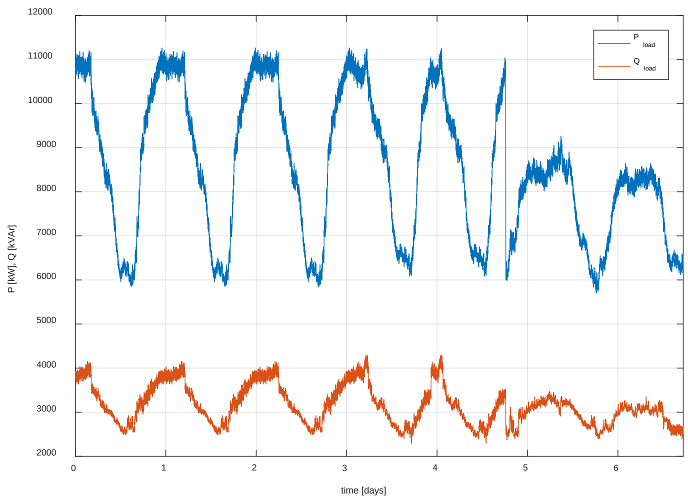
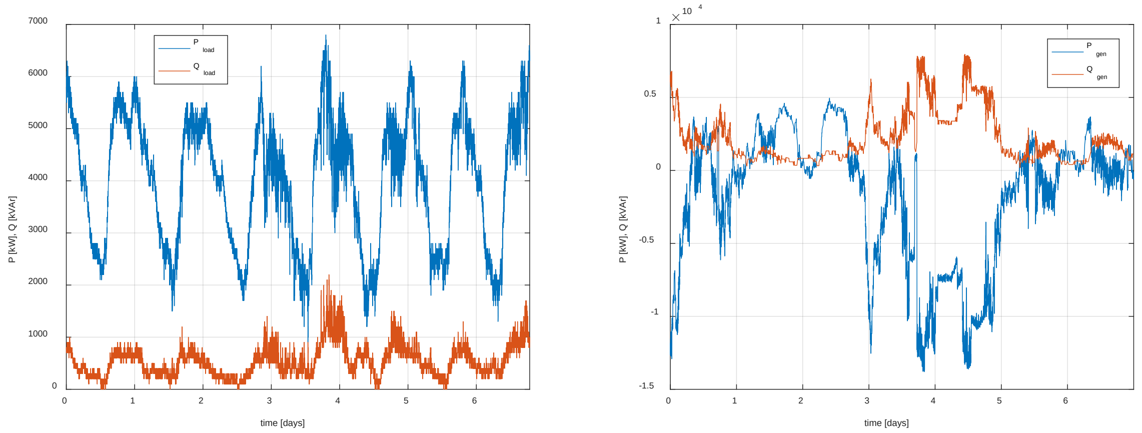


Figure 25. Urban substation load profile (LP07) – April 2013

4.2.4.4 33kV feeder load profiles (NIE Networks)

Two example load profiles recorded by NIE Networks on 33kV feeders were used as illustrated in Figure 26. Load profile LP08 is characterised by unidirectional power flow and is representative of a circuit with low penetration level of DG. Load profile LP09 features long periods of power export, and therefore, characterises feeders with high DG penetration levels. Similar to load profile LP04 in islanding scenario 1, the load profile LP09 was used twice in the calculation; firstly, combined with various mixes of generation profiles (denoted in results as LP09), and secondly, without any additional generation profile added (denoted as LP10). This is to compare the case of the existing connected generation only (LP09) with the emulation of the potential future case where more DG connections are expected (LP10).



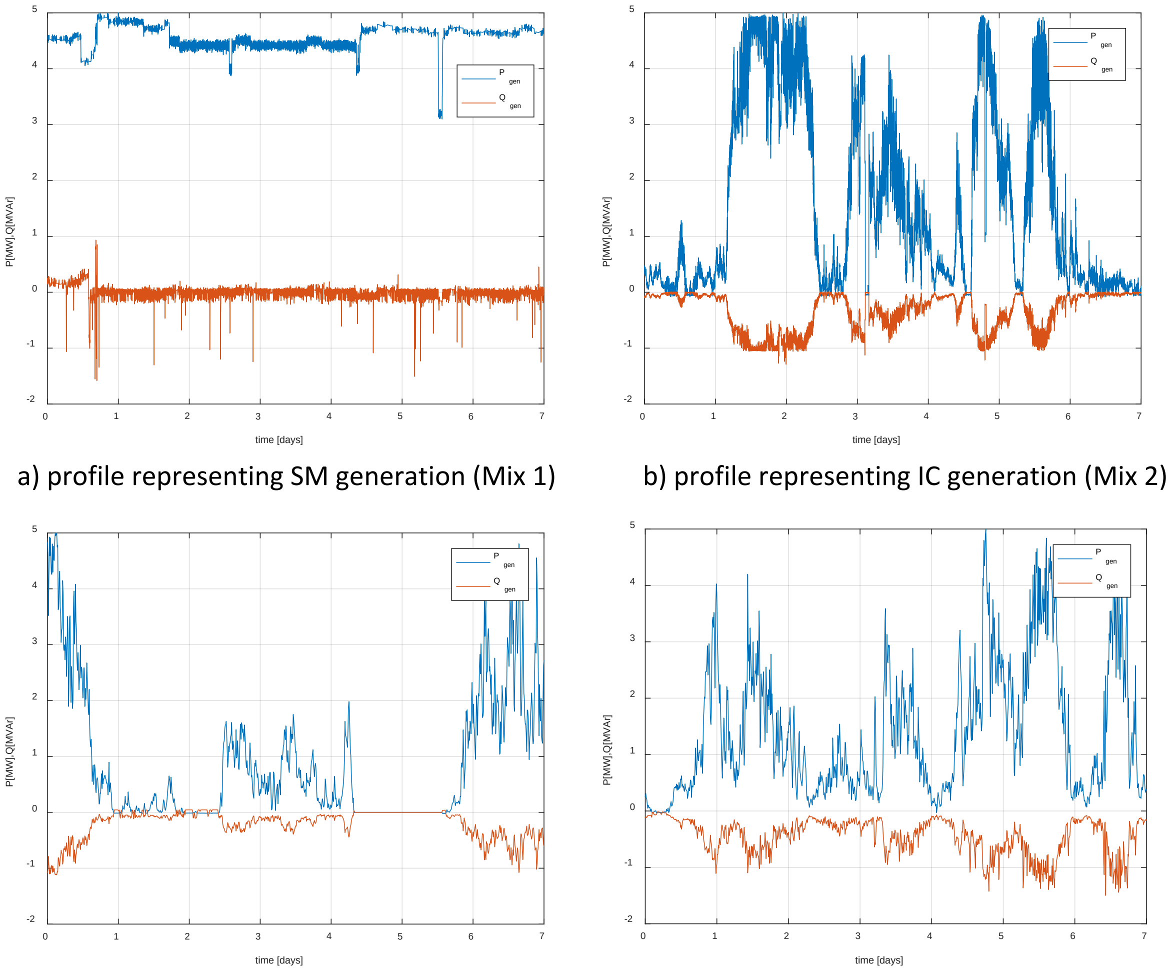
a) Profile LP08 b) Profile LP09/LP10

Figure 26. NIE Networks 33kV load profiles

4.2.5 DG generation profiles

In order to match detailed load profiles with realistic generation outputs, example profiles of different technologies were utilised in this work. In this phase two distinct categories of generating profiles were considered, namely: biomass or landfill gas (using synchronous generator), and wind (using DIFIG, IC or IM generators).

A number of generation profiles were provided by NIE Networks, four of which were selected to represent individual generating technologies as shown in Figure 27.



a) profile representing SM generation (Mix 1)

b) profile representing IC generation (Mix 2)

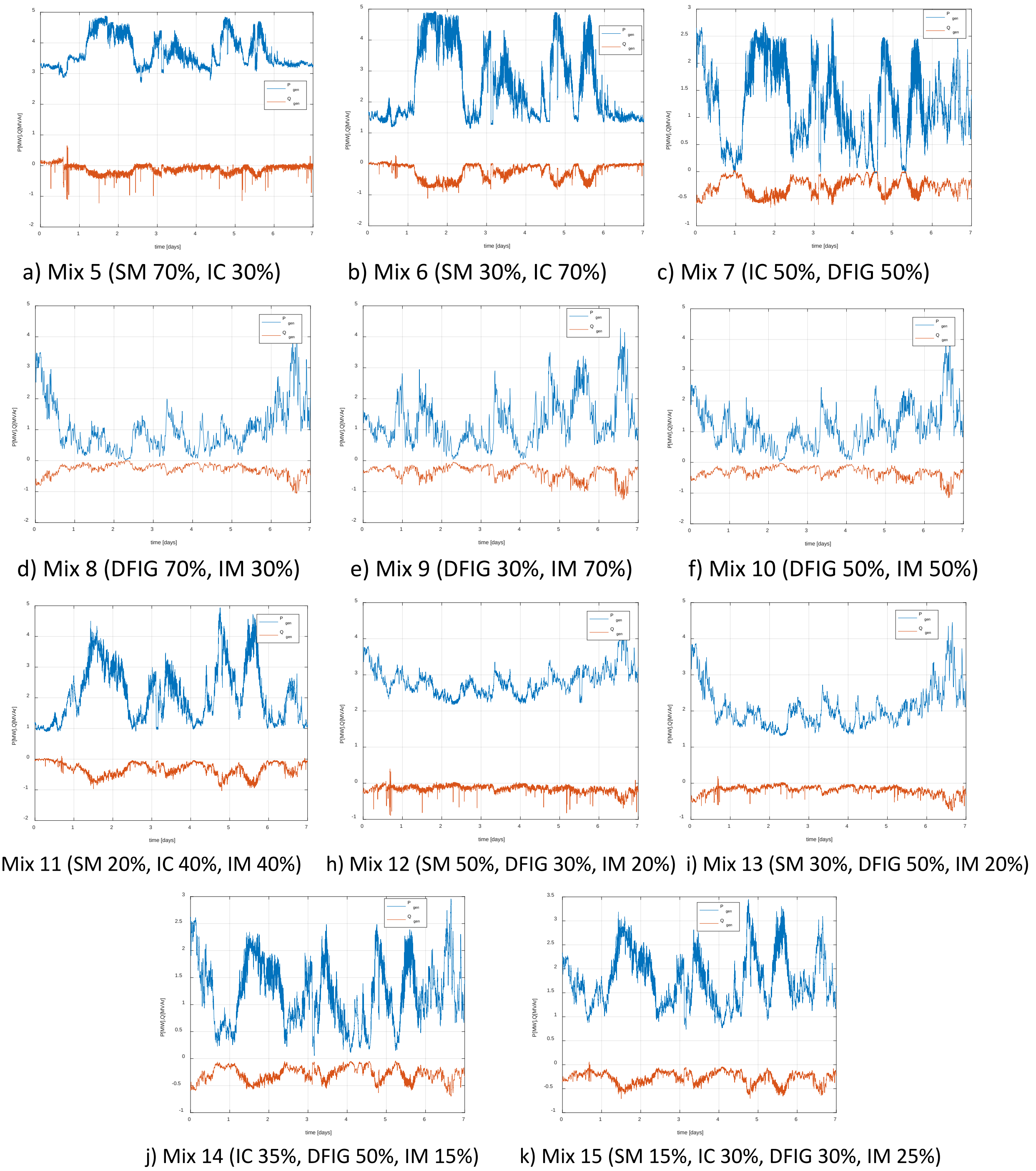
c) profile representing DFIG (Mix 3)

d) profile representing IM generation (Mix 4)

Figure 27. Weekly profiles representing individual generation technologies

For other generating mixes involving more than one technology, a number of merged generation profiles were created as illustrated in Figure 28. These profiles correspond to the generating mixes defined earlier in section 3.2 (refer to Table 3).

The profile merging was achieved by scaling the peak real power of individual records according to the relative contribution of each generation type in the mix. All profiles were then normalised to have a maximum real power at 5MW. This value, however, has no bearing on the results, as the profiles are rescaled again when the calculations perform iterations through the capacity bands of the generation distribution histograms (example of which is included in Figure 21).



a) Mix 5 (SM 70%, IC 30%) b) Mix 6 (SM 30%, IC 70%) c) Mix 7 (IC 50%, DFIG 50%)

d) Mix 8 (DFIG 70%, IM 30%) e) Mix 9 (DFIG 30%, IM 70%) f) Mix 10 (DFIG 50%, IM 50%)

g) Mix 11 (SM 20%, IC 40%, IM 40%) h) Mix 12 (SM 50%, DFIG 30%, IM 20%) i) Mix 13 (SM 30%, DFIG 50%, IM 20%)

j) Mix 14 (IC 35%, DFIG 50%, IM 15%) k) Mix 15 (SM 15%, IC 30%, DFIG 30%, IM 25%)

Figure 28. Mixed generation profile – SG/PV

4.3 Risk calculation results

The full numerical record of probability calculations performed for the two islanding scenarios (with 12 different generation mixes in scenario 1, and 5 mixes in scenarios 2), considering five load profiles in each scenario, and each of the eight LOM protection setting options, is included in Appendix C. The results take into account the fact that G59 (UF/OF/UV/OV) protection is always enabled and trips the generator in situations where ROCOF or VS relay sensitivity is poor. Additionally, for ease of analysis, all results are also presented graphically in Figures 29 to 38. It should be noted that in a number of cases the final probability was equal to zero. In order to represent this result on the graph using a logarithmic scale, a small value of 10^{-11} was used rather than zero. All other non-zero results were always higher than 10^{-11}, so this value can be used as an unambiguous indicator of a zero result.

4.3.1 Calculation of overall figures

Considering all load cases, generation mixes and islanding scenarios, the overall probability figures N_{LOM} and P_{LOM} have been obtained (based on results in Appendix C). Both probability of individual risk (IR_E) and expected annual rate of occurrence of out-of-phase auto-reclosure (N_{OA}) were calculated using the formulae (16) and (17). The figures were obtained in two different ways, first by using the worst load profile result (as presented in Table 7), and then by averaging the probability figures across all the profiles (Table 8).
The figures represent the probabilities of the perceived hazards (*IR* and *OA*) under eight different ROCOF protection setting options when applied to the existing and contracted generators in the NIE Networks distribution system with ratings above 5MW. It is important to bear in mind the following points when using these results to inform decision-making processes:

- The presented probability figures are based on connections registers at a specific point in time, which will become be out of date at some point in the future due to the growing number of DG installations (and changes in DG types).
- The probabilities will increase (or decrease) in proportion to the total number of separate islanding points as well as being dependent on the usage of dedicated ROCOF- and VS-based protection. However, due to generation grouping, the number of islanding points grows at a rate less than the growth rate of the total number of individual DG connections.
- The study does not include assessment of the impact of any changes in practice to move to or additionally use other forms of LOM protection (e.g. reverse reactive power).
- Wherever exact data has not been available, pessimistic assumptions have been made so that the final probability values will ideally never be lower than reality, but this also means that the final figures are potentially and probably higher than reality (a degree of pessimism is not necessarily a bad thing in this context).
- The results obtained from the worst case scenario (Table 7) are three to four times higher compared to the result based on averaged figures (Table 8). It is considered more appropriate to select the averaged figures as being more accurate.
- The results are expressed as probabilities of specific events or occurrences happening over a period of one year. By inverting these values, the average expected times between such occurrences are also calculated (i.e. T_E and T_{OA}).
- The individual risk IR_E includes the fatalities resulting from the direct contact with energised parts of the undetected islanded system and does not include the risk IR_{AR} defined in section 4.1.3 as the risk of physical injury or death resulting from the generator destruction following an out-of-phase auto-reclosure. The probability of such occurrences depends on specific circumstances, including generator location, technology and regime of operation, and is beyond the scope of this report. Therefore, the value IR_E is potentially an underestimate of the total individual risk.
- The risk of LOM settings adjustment must be considered for three different cases. Firstly, if ROCOF settings *only* are changed, then the risk figures (e.g. LOM option 3 in the table) apply under the assumption that no changes are made to VS. Secondly, if VS settings *only* are changed, then the risk figures (e.g. LOM option 7 in the table) apply under the assumption that no changes are made to ROCOF. Thirdly, if both ROCOF and VS settings are changed, then the resultant risk figures would be the sum of the ROCOF/VS-only changes (e.g. the summation of the risk figures for LOM options 3 and 7 in the table). Some example calculations are included in section 5.3.

Table 7. Worst load profile based risk figures for P_{LOM}, IR_E and N_{OA}

LOM Option	LOM Setting [Hz/s] or [°]	Time Delay [s]	Individual risk of electrocution			Risk of out-of-phase reclosure		
			$N_{LOM,E}$	IR_E	T_E [years]	$N_{LOM,AR}$	N_{OA}	T_{OA} [years]
1	0.4	0	2.00E-03	3.35E-08	2.99E+07	6.66E-05	5.33E-05	18,765.54
2	2.0	0.2	3.76E-02	1.15E-05	8.69E+04	2.30E-02	1.84E-02	54.40
3*	**1.5**	**0.3**	**3.75E-02**	**1.15E-05**	**8.69E+04**	**2.30E-02**	**1.84E-02**	**54.44**
4	1.5	0.5	4.52E-02	1.23E-05	8.10E+04	2.46E-02	1.97E-02	50.74
5	1.0	0.8	4.58E-02	1.24E-05	8.04E+04	2.48E-02	1.99E-02	50.37
6	6	-	1.68E-02	6.14E-06	1.63E+05	1.23E-02	9.81E-03	101.99
7*	**12**	**-**	**1.68E-02**	**6.14E-06**	**1.63E+05**	**1.23E-02**	**9.81E-03**	**101.99**
8	-	-	6.26E-02	1.86E-05	5.38E+04	3.71E-02	2.97E-02	33.70

Table 8. Risk figures obtained through averaging of all load profiles

LOM Option	LOM Setting [Hz/s] or [°]	Time Delay [s]	Individual risk of electrocution			Risk of out-of-phase reclosure		
			$N_{LOM,E}$	IR_E	T_E [years]	$N_{LOM,AR}$	N_{OA}	T_{OA} [years]
1	0.4	0	4.81E-04	9.97E-09	1.00E+08	1.99E-05	1.59E-05	62,961.13
2	2.0	0.2	1.95E-02	3.86E-06	2.59E+05	7.70E-03	6.16E-03	162.34
3*	**1.5**	**0.3**	**1.93E-02**	**3.86E-06**	**2.59E+05**	**7.69E-03**	**6.15E-03**	**162.50**
4	1.5	0.5	2.37E-02	4.29E-06	2.33E+05	8.56E-03	6.85E-03	146.03
5	1.0	0.8	2.46E-02	4.38E-06	2.28E+05	8.74E-03	6.99E-03	143.06
6	6	-	6.60E-03	1.85E-06	5.41E+05	3.69E-03	2.95E-03	338.85
7*	**12**	**-**	**6.60E-03**	**1.85E-06**	**5.41E+05**	**3.69E-03**	**2.95E-03**	**338.85**
8	-	-	3.12E-02	6.25E-06	1.60E+05	1.25E-02	9.97E-03	100.28

*Recommended ROCOF and VS settings (in bold).

Where:

$N_{LOM,E}$ - annual rate of occurrence of undetected islanding incidents (with duration longer than $T_{NDZmax} = 0$ s)

IR_E - annual probability related to individual risk (injury or death of a person) from the energised parts of an undetected islanded network

T_E - average duration between incidents (injury or death of a person) from the energised parts of an undetected islanded network [in years]

$N_{LOM,AR}$ - annual rate of occurrence of undetected islanding incidents (with duration longer than $T_{NDZmax} = 29.5$ s)

N_{OA} - annual rate of occurrence of any generator being subjected to out-of-phase auto-reclosure during the islanding condition not detected by LOM protection

T_{OA} - average duration between the occurrences of out-of-phase auto-reclosure during the islanding condition not detected by LOM protection [in years]

5 Conclusions and recommendations

From analyses of the results presented earlier in this report, the following general observations and recommendations can be made:

- The key outcome of Phase 1 consists of the estimated risk figures, considering both the probability of individual risk (IR_E), and the expected annual rate of occurrence of out-of-phase auto-reclosure (N_{OA}).

    a) In particular, risk related to accidental electrocution (IR_E) during the undetected islanding operation under the existing ROCOF protection practice lies in the broadly acceptable region according to the Health and Safety at Work Act 1974 [9] (i.e. in the order of 10^{-9} for setting option 1), while for the considered new settings this risk is significantly increased (i.e. in the order of 10^{-6} for setting option 3), and therefore, encroaches potentially onto the ALARP region. In this case additional safety measures (e.g. installation of NVD protection) should be considered by the network operator to conform with the ALARP principle (i.e. to keep the risk As Low As Reasonably Practicable).

    b) Regarding the expected annual occurrence of out-of-phase auto-reclosures (N_{OA}), in the worst case this would have a value of 0.00997 per annum (under setting option 8 where ROCOF and VS are both disabled; refer to Table 8), which means that one incident would be expected on average every $\frac{1}{0.00997} \cong 100.3$ years. Additional personal risk (IR_{AR}) can result from an element (albeit small) of the probability ($P_{PER,G}$) of a person being in close proximity of the generator while it is in operation and suffering a fatal injury as a result of the generator being destroyed by an out-of-phase auto-reclosure, but the exact estimation of such probabilities depends on the specific generating technology, geographical location, and many other factors, and therefore, is beyond the scope of this work.

- The risk levels calculated in this study are subject to a variety of initial assumptions, including the amount of connected generation, characterisation of the dynamic behaviour of generation, and characterisation of load/generation profiles. Due to a number of pessimistic assumptions used in the study, the absolute risk and rate-of-occurrence values presented in the report are likely to be overestimated. In particular, the assumption of the presence of voltage controllers on all connected generators, as well as the absence of network faults during islanding incidents, will have contributed to wider NDZ values being calculated, and consequently a higher probability of undetected islanding being stated than may actually be the case in practice.

- Moreover, the risk levels considered in this report can be further reduced by the presence of neutral voltage displacement (NVD) protection (not considered in the calculations) which is a standard practice for all generation connected via a ground mounted substation that can export onto the NIE Networks' distribution system. Such protection will limit the duration of those islanding incidents where single phase-to-earth fault is present in an unearthed islanded part of the network. The time delay setting used by NIE Networks in NVD protection is 10 s. Therefore, it can be assumed that in the case of single phase-to-earth fault the maximum duration of islanding condition (and thus individual risk) is 10 s (as opposed to 30 s which was assumed in the study). The disconnection of the generator by NVD protection also significanly reduces the risk of out-of-phase reclosure (which takes place 30 s after the fault). As single phase-to-earth faults form the majority of all distribution system faults (especially on overhead lines) the NVD protection is a very effective way of reducing all risks related to undetected islanding.

- The study used modified over-frequency protection setting (**52 Hz with 1s time delay**) and two stage under-voltage protection settings (**stage 1: 0.85 pu with 3s time delay, stage 2: 0.6 pu with 2 s time delay**). These settings meet the system stability criteria and voltage ride through requirements, and do not compromise the sensitivity of the LOM protection.

5.1 ROCOF protection

Observations specifically related to ROCOF protection can be summarised as follows:

- Even though the absolute risk figures are low, there is a significant difference in the probability of undetected islanded operation (up to three orders of magnitude based on the averaged figures include in Table 8) between the existing recommended ROCOF settings (setting option 1) and the considered new setting options 2, 3, 4 and 5. Therefore, the relative impact of the proposed change can be considered high.

- It also should be noted that ROCOF protection becomes much less effective with the proposed setting options (2, 3, 4 and 5) compared to the existing setting option 1 (0.4 Hz/s). When using any of the new suggested settings, the generator is disconnected by G59 protection (mainly frequency protection as opposed to ROCOF) in the majority of the islanding situations. As evidenced from the LOM performance analysis in section 3.3 (refer to Figure 17), in up to 62% of the cases the NDZ is determined by frequency protection. This is primarily due to the observed frequency fluctuations with certain generation mixes. One of the ways this effect can be mitigated is through the choice of a setting option with a shorter time delay setting, i.e. 300ms rather than 800ms.

- There is not a great deal of difference (in terms of performance and risk levels) across the four considered future setting options 2, 3, 4 and 5. However, the option which has the lowest impact on the perceived risks, while preserving the effectiveness of ROCOF protection operation, is option 3 (i.e. **1.5 Hz/s with a time delay of 300 ms**). Therefore, based on the outcomes of the Phase 1 study, as well as the results of an earlier ROCOF stability assessment reported in the report relating to WP2 [1], option 3 represents the best setting for ROCOF-based LOM protection.

5.2 VS protection

- The change of recommended setting for VS protection from 6° to 12° does not impose any notable change in the risk levels related to protection sensitivity. The values are higher but remain within the same order of magnitude.

- For both considered VS settings (option 6 and 7), the level of risk in terms of undetected islanding operation is comparable to that obtained for the new recommended ROCOF settings (options 2 to 5). The main reason for this similarity is high dependence of both types of LOM protection on the operation of G59 frequency protection to identify islanded conditions.

- Considering certain VS stability issues reported in the report for WP2 [1], the best recommended threshold angle setting would be **12°**, or else, VS protection could be replaced by ROCOF protection with setting option 3 (refer to example calculation of "Revision 3" in the following section 5.3)

5.3 Considering various G59 revision options

Using the results in Table 8 various G59 revision options can be considered and directly compared in terms of overall aggregated risk. For example, regarding the individual risk of electrocution the following calculations can be made:

a) Revision 1: Changing ROCOF protection to setting option 3 and VS to setting option 7

$$IR_{Ea)} = 3.86 \cdot 10^{-6} + 1.85 \cdot 10^{-6} = 5.71 \cdot 10^{-6}$$

b) Revision 2: Removing both ROCOF and VS protections and relying on G59 voltage and frequency protection only (setting option 8)

$$IR_{Eb)} = 6.25 \cdot 10^{-6}$$

c) Revision 3: Applying ROCOF protection with setting option 3 to all DG and removing VS from service. Assuming that on average 70% of potential islands with large scale generation currently use ROCOF the risk can be estimated as:

$$IR_{Ec)} = \frac{3.86 \cdot 10^{-6}}{0.7} = 5.51 \cdot 10^{-6}$$

As can be seen from the above example calculations small reduction of risk can potentially be gained from changing VS protection to ROCOF only. However, each revision option also needs to be weighed against the overall cost of implementation.

5.4 Future risk levels

Even though the study outcome reaches slightly into the future as the DG register used in the work includes both connected as well as contracted (but not yet connected) generation, it is fixed in time, and therefore, may not represent all future generation scenarios. Moreover, there is no straightforward correlation between the installed renewable generation capacity and the overall risk of undetected islanding. Therefore, any predictions of the renewable generation growth in Northern Ireland are not easily translatable into the probability of non-detection of islanded conditions. However, some insight into potential future risks can be gained by comparing the results of load profile LP04 and LP05. This profile has been recorded at a BSP with a particularly high DG penetration which causes frequent power exports from the distribution system to the transmission system (which will involve situations where the power "reverses" from flowing from transmission to distribution to the opposite direction), and therefore, potential for balanced load/generation (refer to Figure 23d). Such a scenario can be seen as representative of the load flow conditions in future power networks. Therefore, this particular profile was used in two ways, firstly combined with various mixes of generation profiles, and secondly, without any additional generation profile. The reason for this approach was to compare the case of the existing connected generation (LP05) with the case of further increasing DG penetration (LP04). When analysing the summary figures for LP04 and LP05 in Table 45 it can be seen that the current risks (represented by LP05) are actually slightly higher than the risks with additional generation added (represented by LP04). This is an indication that in a network which has a relatively high DG penetration already, there might be little impact or even a reduction of the non-detection risk with additional DG connections.

It is also worth noting that the identified high dependence of LOM protection on the operation of G59 frequency protection indicates that after the change both ROCOF and VS-based protections in many cases (up to 62%) will act as a backup rather than as the main LOM protection.

5.5 Relative contribution to risk of various generation groups and scenarios

To inform the decision making process further, and in particular, to provide additional guidance on the impact of out-of-phase reclosure, the individual percentage contributions to the overall number of out-of-phase incidents ($N_{LOM,AR}$) have been established for the proposed setting option 3, and presented in Table 9 (based on the detailed results included in Appendix C.2.). As discussed earlier at the end of section 4.1.3, various generating technologies are affected by out-of-phase reclosure in different ways. For example, the groups which are particularly vulnerable to such events are those including synchronous generators, i.e. generation mixes 1, 5, 6, 11, 12, 13 and 15. Those mixes contribute approximately 17.16% of all expected out-of-phase reclosures (calculated using the percentage values in the right hand side column in Table 9). Therefore, assuming hypothetically that other technologies are not affected the risk value would be reduced to $N_{LOM,AR} = 0.00769 \cdot 0.1716 = 0.00132$. Other assumptions related to potential damage to various DG technologies can be assessed in a similar manner using the percentage values in Table 9.

Table 9. Contribution of individual generation mixes to the overall number of LOM incidents (individual figures averaged across all load profiles) – setting option 3

Islanding Scenario	Generation Mix (m)	$N_{LOM,AR(m)}$	$N_{LOM,AR(m)}[\%]$
1	2 (IC 100%)	0.00000	0.0000
	3 (DFIG 100%)	0.00000	0.0000
	5 (SM 70%, IC 30%)	0.00028	3.6073
	6 (SM 30%, IC 70%)	0.00000	0.0000
	7 (IC 50%, DFIG 50%)	0.00000	0.0000
	8 (DFIG 70%, IM 30%)	0.00000	0.0000
	9 (DFIG 30%, IM 70%)	0.00047	6.1504
	11 (SM 20%, IC 40%, IM 40%)	0.00007	0.9313
	12 (SM 50%, DFIG 30%, IM 20%)	0.00007	0.9560
	13 (SM 30%, DFIG 50%, IM 20%)	0.00000	0.0000
	14 (IC 35%, DFIG 50%, IM 15%)	0.00000	0.0000
	15 (SM 15%, IC 30%, DFIG 30%, IM 25%)	0.00036	4.6664
2	1 (SM 100%)	0.00054	7.0055
	2 (IC 100%)	0.00000	0.0000
	3 (DFIG 100%)	0.00000	0.0000
	4 (IM 100%)	0.00000	0.0000
	10 (DFIG 50%, IM 50%)	0.00590	76.6831
	Total:	0.00769	100.00

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Appendix A: Simulation model parameters

Table 10: Line Parameters used in the 33kV network

11kV Distribution Lines		
Line Section	**Resistance (Ω)**	**Inductance (mH)**
A-B	0.169	0.17
B-C	0.169	0.17
D-E	0.67	0.56
D-F	0.613	0.45

Table 11: SM Parameters

General	
Nominal Voltage [V]	440
Nominal Frequency [Hz]	50
Pole Pairs	2
Inertia Constant [s]	1.5
Reactances [p.u.]	
Xd	2.24
Xd’	0.17
Xd’’	0.12
Xq	1.02
Xq’’	0.13
Xl	0.18
Excitation System / Governor	
Tr	0.02
Ka	465
Ta	0.002
Ke	1
Te	0.27
Tb	0
Tc	0
Kf	0.003
Tf	0.2
Efmin	-8
Efmax	8
Kp	0

Table 12: IC Parameters

Inverter	
Current Regulator Kp	2.4
Current Regulator Ki	200
Reactive Power Controller Kp	3
Reactive Power Controller Ki	300
AC Voltage Controller Kp	3
AC Voltage Controller Ki	100

Table 13: DFIG Parameters

General	
Nominal Voltage [V]	575
Nominal Frequency [Hz]	50
Pole Pairs	3
Inertia Constant [s]	4
Windings	
Stator Resistance [p.u.]	0.023
Stator Inductance [p.u.]	0.18
Rotor Resistance [p.u.]	0.016
Rotor Inductance [p.u.]	0.16
Magnetising Inductance [p.u.]	2.9
Rotor Side Converter	
Current Regulator Kp	0.6
Current Regulator Ki	8
Reactive Power Controller Kp	1
Reactive Power Controller Ki	50
AC Voltage Controller Kp	3
AC Voltage Controller Ki	200
Grid Side Converter	
VDC Regulator Kp	8
VDC Regulator Ki	400
Current Regulator Kp	0.83
Current Regulator Ki	5

Table 14: IM Parameters

General	
Nominal Voltage [V]	460
Nominal Frequency [Hz]	50
Pole Pairs	2
Inertia Constant [s]	5
Windings	
Stator Resistance [p.u.]	0.01965
Stator Inductance [p.u.]	0.0397
Rotor Resistance [p.u.]	0.01909
Rotor Inductance [p.u.]	0.0397
Mutual Inductance [p.u.]	3

Appendix B: NDZ Assessment results

B.1. Combined NDZ results (with ROCOF, VS and G59 protection enabled)

Note: Values denoted by * and # indicate that voltage or frequency protection operated first, resulting in a narrower NDZ than the ROCOF or VS protection (considering 30s as a maximum operation time).

Table 15: ROCOF and VS NDZ results for Generation Mix 1 (SM 100%)

Setting Option	Protection type and settings	NDZ_{PI}	NDZ_{PE}	NDZ_{QI}	NDZ_{QE}
1	ROCOF (0.4 Hz/s – no time delay)	0.308	0.385	1.286	0.977
2	ROCOF (2.0 Hz/s – 200 ms time delay)	2.485#	1.177#	3.33#	8.243#
3	ROCOF (1.5 Hz/s – 300 ms time delay)	2.485#	1.177#	3.33#	8.243#
4	ROCOF (1.5 Hz/s – 500 ms time delay)	2.485#	1.177#	3.33#	8.243#
5	ROCOF (1.0 Hz/s – 800 ms time delay)	2.485#	1.177#	3.33#	8.243#
6	VS (6°)	2.485#	1.177#	3.33#	8.243#
7	VS (12°)	2.485#	1.177#	3.33#	8.243#
8	G59 (UV/OV/UF/OF) only	2.485	1.177	3.33	8.243

Table 16: ROCOF and VS NDZ results for Generation Mix 2 (IC 100%)

Setting Option	Protection type and settings	NDZ_{PI}	NDZ_{PE}	NDZ_{QI}	NDZ_{QE}
1	ROCOF (0.4 Hz/s – no time delay)	0	0	0	0
2	ROCOF (2.0 Hz/s – 200 ms time delay)	0	0	0	0
3	ROCOF (1.5 Hz/s – 300 ms time delay)	0	0	0	0
4	ROCOF (1.5 Hz/s – 500 ms time delay)	0	0	0	0
5	ROCOF (1.0 Hz/s – 800 ms time delay)	0	0	0	0
6	VS (6°)	0	0	0	0
7	VS (12°)	0	0	0	0
8	G59 (UV/OV/UF/OF) only	0	0	0	0

Table 17: ROCOF and VS NDZ results for Generation Mix 3 (DFIG 100%)

Setting Option	Protection type and settings	NDZ_{PI}	NDZ_{PE}	NDZ_{QI}	NDZ_{QE}
1	ROCOF (0.4 Hz/s – no time delay)	0	0	0	0
2	ROCOF (2.0 Hz/s – 200 ms time delay)	0#	0#	0#	0#
3	ROCOF (1.5 Hz/s – 300 ms time delay)	0	0	0	0
4	ROCOF (1.5 Hz/s – 500 ms time delay)	0	0	0	0
5	ROCOF (1.0 Hz/s – 800 ms time delay)	0	0	0	0
6	VS (6°)	0#	0#	0#	0#
7	VS (12°)	0#	0#	0#	0#
8	G59 (UV/OV/UF/OF) only	0	0	0	0

Table 18: ROCOF and VS NDZ results for Generation Mix 4 (IM 100%)

Setting Option	Protection type and settings	NDZ_{PI}	NDZ_{PE}	NDZ_{QI}	NDZ_{QE}
1	ROCOF (0.4 Hz/s – no time delay)	2.97	2.716	0.906	0.807
2	ROCOF (2.0 Hz/s – 200 ms time delay)	5.934#	5.932#	1.811#	1.816#
3	ROCOF (1.5 Hz/s – 300 ms time delay)	5.934#	5.932#	1.811#	1.816#
4	ROCOF (1.5 Hz/s – 500 ms time delay)	5.934#	5.932#	1.811#	1.816#
5	ROCOF (1.0 Hz/s – 800 ms time delay)	5.934#	5.932#	1.811#	1.816#
6	VS (6°)	5.934#	5.932#	1.811#	1.816#
7	VS (12°)	5.934#	4.448#	1.811#	1.816#
8	G59 (UV/OV/UF/OF) only	5.934	4.448	1.811	1.816

Table 19: ROCOF and VS NDZ results for Generation Mix 5 (SM 70%, IC 30%)

Setting Option	Protection type and settings	NDZ_{PI}	NDZ_{PE}	NDZ_{QI}	NDZ_{QE}
1	ROCOF (0.4 Hz/s – no time delay)	0	0	0	0
2	ROCOF (2.0 Hz/s – 200 ms time delay)	10.778	7.862#	5.361	18.812
3	ROCOF (1.5 Hz/s – 300 ms time delay)	10.778	7.37	5.361	17.209
4	ROCOF (1.5 Hz/s – 500 ms time delay)	10.778	7.862	5.361	17.209
5	ROCOF (1.0 Hz/s – 800 ms time delay)	10.778	7.37	5.361	17.209
6	VS (6°)	10.778	7.862	5.361	2.475
7	VS (12°)	10.778#	7.862#	5.361	6.947
8	G59 (UV/OV/UF/OF) only	10.778	7.862	5.361	20.417

Table 20: ROCOF and VS NDZ results for Generation Mix 6 (SM 30%, IC 70%)

Setting Option	Protection type and settings	NDZ_{PI}	NDZ_{PE}	NDZ_{QI}	NDZ_{QE}
1	ROCOF (0.4 Hz/s – no time delay)	0	0	0	0
2	ROCOF (2.0 Hz/s – 200 ms time delay)	0.59	0.577	4.898	0.057
3	ROCOF (1.5 Hz/s – 300 ms time delay)	0	0	0	0
4	ROCOF (1.5 Hz/s – 500 ms time delay)	21.184#	6.333	4.898	3.049
5	ROCOF (1.0 Hz/s – 800 ms time delay)	21.184#	7.801#	4.898	6.959
6	VS (6°)	0.882	0.091	0.096	0.057
7	VS (12°)	1.173	7.801#	4.898#	0.057
8	G59 (UV/OV/UF/OF) only	21.184	7.801	4.898	15.027

Table 21: ROCOF and VS NDZ results for Generation Mix 7 (IC 50%, DFIG 50%)

Setting Option	Protection type and settings	NDZ_{PI}	NDZ_{PE}	NDZ_{QI}	NDZ_{QE}
1	ROCOF (0.4 Hz/s – no time delay)	0	0	0	0
2	ROCOF (2.0 Hz/s – 200 ms time delay)	0	0	0	0
3	ROCOF (1.5 Hz/s – 300 ms time delay)	0	0	0	0
4	ROCOF (1.5 Hz/s – 500 ms time delay)	0	0	0	0
5	ROCOF (1.0 Hz/s – 800 ms time delay)	0#	0#	0#	0#
6	VS (6°)	0	0	0	0
7	VS (12°)	0	0	0	0
8	G59 (UV/OV/UF/OF) only	0	0	0	0

Table 22: ROCOF and VS NDZ results for Generation Mix 8 (DFIG 70%, IM 30%)

Setting Option	Protection type and settings	NDZ_{PI}	NDZ_{PE}	NDZ_{QI}	NDZ_{QE}
1	ROCOF (0.4 Hz/s – no time delay)	0	0	0	0
2	ROCOF (2.0 Hz/s – 200 ms time delay)	0[#]	0[#]	0[#]	0[#]
3	ROCOF (1.5 Hz/s – 300 ms time delay)	0[#]	0[#]	0[#]	0[#]
4	ROCOF (1.5 Hz/s – 500 ms time delay)	0[#]	0[#]	0[#]	0[#]
5	ROCOF (1.0 Hz/s – 800 ms time delay)	0	0	0	0
6	VS (6°)	0[#]	0[#]	0[#]	0[#]
7	VS (12°)	0[#]	0[#]	0[#]	0[#]
8	G59 (UV/OV/UF/OF) only	0	0	0	0

Table 23: ROCOF and VS NDZ results for Generation Mix 9 (DFIG 30%, IM 70%)

Setting Option	Protection type and settings	NDZ_{PI}	NDZ_{PE}	NDZ_{QI}	NDZ_{QE}
1	ROCOF (0.4 Hz/s – no time delay)	0	0	0	0
2	ROCOF (2.0 Hz/s – 200 ms time delay)	3.108[#]	6.241[#]	6.105[#*]	7.306[#]
3	ROCOF (1.5 Hz/s – 300 ms time delay)	3.108[#]	6.241[#]	6.105[#*]	7.306[#]
4	ROCOF (1.5 Hz/s – 500 ms time delay)	3.108[#]	6.241[#]	6.105[#*]	7.306[#]
5	ROCOF (1.0 Hz/s – 800 ms time delay)	3.108[#]	6.241[#]	6.105[#*]	7.306[#]
6	VS (6°)	3.108[#]	6.241[#]	6.105[#*]	7.306[#]
7	VS (12°)	3.108[#]	6.241[#]	6.105[#*]	7.306[#]
8	G59 (UV/OV/UF/OF) only	3.108	6.241	6.105	7.306

Table 24: ROCOF and VS NDZ results for Generation Mix 10 (DFIG 50%, IM 50%)

Setting Option	Protection type and settings	NDZ_{PI}	NDZ_{PE}	NDZ_{QI}	NDZ_{QE}
1	ROCOF (0.4 Hz/s – no time delay)	0	0	0	0
2	ROCOF (2.0 Hz/s – 200 ms time delay)	1.788[#]	4.198[#]	10.963*	9.043[#]
3	ROCOF (1.5 Hz/s – 300 ms time delay)	1.788[#]	4.198[#]	10.963*	9.043[#]
4	ROCOF (1.5 Hz/s – 500 ms time delay)	1.788[#]	4.198[#]	10.963*	9.043[#]
5	ROCOF (1.0 Hz/s – 800 ms time delay)	1.788[#]	4.198[#]	10.963*	9.043[#]
6	VS (6°)	1.788[#]	4.198[#]	10.963*	9.043[#]
7	VS (12°)	1.788[#]	4.198[#]	10.963*	9.043[#]
8	G59 (UV/OV/UF/OF) only	1.788	4.198	11.955	9.043

Table 25: ROCOF and VS NDZ results for Generation Mix 11 (SM 20%, IC 40%, IM 40%)

Setting Option	Protection type and settings	NDZ_{PI}	NDZ_{PE}	NDZ_{QI}	NDZ_{QE}
1	ROCOF (0.4 Hz/s – no time delay)	6.947	4.136	3.836	3.741
2	ROCOF (2.0 Hz/s – 200 ms time delay)	12.841[#]	17.73[#]	4.071	95
3	ROCOF (1.5 Hz/s – 300 ms time delay)	12.841[#]	17.73[#]	4.071	75
4	ROCOF (1.5 Hz/s – 500 ms time delay)	12.841[#]	17.73[#]	4.071	85
5	ROCOF (1.0 Hz/s – 800 ms time delay)	12.841[#]	17.73	4.071	80
6	VS (6°)	12.841[#]	17.73[#]	4.071	8.043
7	VS (12°)	12.841[#]	17.73[#]	4.071	16.249
8	G59 (UV/OV/UF/OF) only	12.841	17.73	4.071	100

Table 26: ROCOF and VS NDZ results for Generation Mix 12 (SM 50%, DFIG 30%, IM 20%)

Setting Option	Protection type and settings	NDZ_{PI}	NDZ_{PE}	NDZ_{QI}	NDZ_{QE}
1	ROCOF (0.4 Hz/s – no time delay)	0	0	0	0
2	ROCOF (2.0 Hz/s – 200 ms time delay)	2.48#	0.567#	13.034#	7.432#
3	ROCOF (1.5 Hz/s – 300 ms time delay)	2.48#	0.567#	13.034#	7.432#
4	ROCOF (1.5 Hz/s – 500 ms time delay)	2.48#	0.567#	13.034#	7.432#
5	ROCOF (1.0 Hz/s – 800 ms time delay)	2.48#	0.567#	13.034#	7.432#
6	VS (6°)	2.48#	0.567#	13.034#	7.432#
7	VS (12°)	2.48#	0.567#	13.034#	7.432#
8	G59 (UV/OV/UF/OF) only	2.48	0.567	13.034	7.432

Table 27: ROCOF and VS NDZ results for Generation Mix 13 (SM 30%, DFIG 50%, IM 20%)

Setting Option	Protection type and settings	NDZ_{PI}	NDZ_{PE}	NDZ_{QI}	NDZ_{QE}
1	ROCOF (0.4 Hz/s – no time delay)	0	0	0	0
2	ROCOF (2.0 Hz/s – 200 ms time delay)	0#	0#	0#	0#
3	ROCOF (1.5 Hz/s – 300 ms time delay)	0#	0#	0#	0#
4	ROCOF (1.5 Hz/s – 500 ms time delay)	0#	0#	0#	0#
5	ROCOF (1.0 Hz/s – 800 ms time delay)	0#	0#	0#	0#
6	VS (6°)	0#	0#	0#	0#
7	VS (12°)	0#	0#	0#	0#
8	G59 (UV/OV/UF/OF) only	0	0	0	0

Table 28: ROCOF and VS NDZ results for Generation Mix 14 (IC 35%, DFIG 50%, IM 15%)

Setting Option	Protection type and settings	NDZ_{PI}	NDZ_{PE}	NDZ_{QI}	NDZ_{QE}
1	ROCOF (0.4 Hz/s – no time delay)	0	0	0	0
2	ROCOF (2.0 Hz/s – 200 ms time delay)	0	0	0	0
3	ROCOF (1.5 Hz/s – 300 ms time delay)	0	0	0	0
4	ROCOF (1.5 Hz/s – 500 ms time delay)	0	0	0	0
5	ROCOF (1.0 Hz/s – 800 ms time delay)	0	0	0	0
6	VS (6°)	0	0	0	0
7	VS (12°)	0	0	0	0
8	G59 (UV/OV/UF/OF) only	0	0	0	0

Table 29: ROCOF and VS NDZ results for Generation Mix 15 (SM 15%, IC 30%, DFIG 30%, IM 25%)

Setting Option	Protection type and settings	NDZ_{PI}	NDZ_{PE}	NDZ_{QI}	NDZ_{QE}
1	ROCOF (0.4 Hz/s – no time delay)	0	0	0	0
2	ROCOF (2.0 Hz/s – 200 ms time delay)	10.551#	11.619#	5.71	11.872
3	ROCOF (1.5 Hz/s – 300 ms time delay)	10.551#	11.619#	5.71	10.936
4	ROCOF (1.5 Hz/s – 500 ms time delay)	10.551#	11.619#	5.71	15.657
5	ROCOF (1.0 Hz/s – 800 ms time delay)	10.551#	11.619#	5.71	8.612
6	VS (6°)	0	0	0	0
7	VS (12°)	10.551	2.646	5.71	0.351
8	G59 (UV/OV/UF/OF) only	10.551	11.619	5.71	16.613

B.2. NDZ results for individual LOM protection elements

Table 30: NDZ results for Generation Mix 1 (SM 100%)

	NDZ_{PI}	NDZ_{PE}	NDZ_{QI}	NDZ_{QE}
ROCOF (0.4 Hz/s – no time delay)	0.308	0.385	1.286	0.977
ROCOF (2.0 Hz/s – 200 ms time delay)	11.88	5.93	13.934	24.576
ROCOF (1.5 Hz/s – 300 ms time delay)	8.42	3.454	9.614	28.141
ROCOF (1.5 Hz/s – 500 ms time delay)	8.915	3.454	9.614	31.711
ROCOF (1.0 Hz/s – 800 ms time delay)	5.453	1.771	5.288	17.488
VS (6°)	>50	49.642	>50	>50
VS (12°)	>50	>50	>50	>50
UV/OV	35.56	>50	>50	>50
UF/OF	2.485	1.177	3.33	8.243

Table 31: NDZ results for Generation Mix 2 (IC 100%)

	NDZ_{PI}	NDZ_{PE}	NDZ_{QI}	NDZ_{QE}
ROCOF (0.4 Hz/s – no time delay)	0	0	0	0
ROCOF (2.0 Hz/s – 200 ms time delay)	0	0	0	0
ROCOF (1.5 Hz/s – 300 ms time delay)	0	0	0	0
ROCOF (1.5 Hz/s – 500 ms time delay)	0	0	0	0
ROCOF (1.0 Hz/s – 800 ms time delay)	0	0	0	0
VS (6°)	0	0	0	0
VS (12°)	0	0	0	0
UV/OV	0	0	0	0
UF/OF	0	0	0	0

Table 32: NDZ results for Generation Mix 3 (DFIG 100%)

	NDZ_{PI}	NDZ_{PE}	NDZ_{QI}	NDZ_{QE}
ROCOF (0.4 Hz/s – no time delay)	0	0	0	0
ROCOF (2.0 Hz/s – 200 ms time delay)	>50	2.633	26.848	4.728
ROCOF (1.5 Hz/s – 300 ms time delay)	0	0	0	0
ROCOF (1.5 Hz/s – 500 ms time delay)	0	0	0	0
ROCOF (1.0 Hz/s – 800 ms time delay)	0	0	0	0
VS (6°)	>50	12.661	26.848	14.095
VS (12°)	>50	12.661	26.848	14.095
UV/OV	30.978	8.252	21.243	14.095
UF/OF	0	0	0	0

Table 33: NDZ results for Generation Mix 4 (IM 100%)

	NDZ_{PI}	NDZ_{PE}	NDZ_{QI}	NDZ_{QE}
ROCOF (0.4 Hz/s – no time delay)	2.97	2.716	0.906	0.807
ROCOF (2.0 Hz/s – 200 ms time delay)	14.819	12.864	5.026	3.784
ROCOF (1.5 Hz/s – 300 ms time delay)	11.859	9.892	3.772	3.027
ROCOF (1.5 Hz/s – 500 ms time delay)	11.859	9.892	3.772	3.027
ROCOF (1.0 Hz/s – 800 ms time delay)	7.416	6.922	2.515	2.522
VS (6°)	>50	>50	31.827	47.212
VS (12°)	>50	>50	31.827	>50
UV/OV	10.872	4.448	3.018	2.017
UF/OF	5.934	5.932	1.811	1.816

Table 34: NDZ results for Generation Mix 5 (SM 70%, IC 30%)

	NDZ_{PI}	NDZ_{PE}	NDZ_{QI}	NDZ_{QE}
ROCOF (0.4 Hz/s – no time delay)	0	0	0	0
ROCOF (2.0 Hz/s – 200 ms time delay)	10.778	8.354	5.361	18.812
ROCOF (1.5 Hz/s – 300 ms time delay)	10.778	7.37	5.361	17.209
ROCOF (1.5 Hz/s – 500 ms time delay)	10.778	7.862	5.361	17.209
ROCOF (1.0 Hz/s – 800 ms time delay)	10.778	7.37	5.361	17.209
VS (6°)	10.778	7.862	5.361	2.475
VS (12°)	11.756	14.762	5.361	6.947
UV/OV	13.71	>50	>50	>50
UF/OF	10.778	7.862	5.361	20.417

Table 35: NDZ results for Generation Mix 6 (SM 30%, IC 70%)

	NDZ_{PI}	NDZ_{PE}	NDZ_{QI}	NDZ_{QE}
ROCOF (0.4 Hz/s – no time delay)	0	0	0	0
ROCOF (2.0 Hz/s – 200 ms time delay)	0.59	0.577	4.898	0.057
ROCOF (1.5 Hz/s – 300 ms time delay)	0	0	0	0
ROCOF (1.5 Hz/s – 500 ms time delay)	23.086	6.333	4.898	3.049
ROCOF (1.0 Hz/s – 800 ms time delay)	23.086	8.291	4.898	6.959
VS (6°)	0.882	0.091	0.096	0.057
VS (12°)	1.173	18.619	5.269	0.057
UV/OV	23.086	23.565	5.269	31.326
UF/OF	21.184	7.801	4.898	15.027

Table 36: NDZ results for Generation Mix 7 (IC 50%, DFIG 50%)

	NDZ_{PI}	NDZ_{PE}	NDZ_{QI}	NDZ_{QE}
ROCOF (0.4 Hz/s – no time delay)	0	0	0	0
ROCOF (2.0 Hz/s – 200 ms time delay)	0	0	0	0
ROCOF (1.5 Hz/s – 300 ms time delay)	0	0	0	0
ROCOF (1.5 Hz/s – 500 ms time delay)	0	0	0	0
ROCOF (1.0 Hz/s – 800 ms time delay)	0.094	0.096	0.097	0.097
VS (6°)	0	0	0	0
VS (12°)	0	0	0	0
UV/OV	0	0	0	0
UF/OF	0	0	0	0

Table 37: NDZ results for Generation Mix 8 (DFIG 70%, IM 30%)

	NDZ_{PI}	NDZ_{PE}	NDZ_{QI}	NDZ_{QE}
ROCOF (0.4 Hz/s – no time delay)	0	0	0	0
ROCOF (2.0 Hz/s – 200 ms time delay)	>50	6.046	38.018	5.155
ROCOF (1.5 Hz/s – 300 ms time delay)	>50	0.739	30.428	1.016
ROCOF (1.5 Hz/s – 500 ms time delay)	>50	1.48	31.991	1.22
ROCOF (1.0 Hz/s – 800 ms time delay)	0	0	0	0
VS (6°)	>50	8.863	16.168	34.011
VS (12°)	>50	9.334	16.168	34.011
UV/OV	31.929	20.767	15.272	34.011
UF/OF	0	0	0	0

Table 38: NDZ results for Generation Mix 9 (DFIG 30%, IM 70%)

	NDZ_{PI}	NDZ_{PE}	NDZ_{QI}	NDZ_{QE}
ROCOF (0.4 Hz/s – no time delay)	0	0	0	0
ROCOF (2.0 Hz/s – 200 ms time delay)	>50	>50	11.085	13.729
ROCOF (1.5 Hz/s – 300 ms time delay)	>50	>50	11.085	12.648
ROCOF (1.5 Hz/s – 500 ms time delay)	>50	>50	19.809	12.648
ROCOF (1.0 Hz/s – 800 ms time delay)	>50	>50	14.027	11.571
VS (6°)	35.697	>50	8.109	16.998
VS (12°)	35.697	>50	8.109	16.998
UV/OV	32.007	17.372	6.105	11.571
UF/OF	3.108	6.241	6.105	7.306

Table 39: NDZ results for Generation Mix 10 (DFIG 50%, IM 50%)

	NDZ_{PI}	NDZ_{PE}	NDZ_{QI}	NDZ_{QE}
ROCOF (0.4 Hz/s – no time delay)	0	0	0	0
ROCOF (2.0 Hz/s – 200 ms time delay)	>50	>50	41.346	18.151
ROCOF (1.5 Hz/s – 300 ms time delay)	>50	12.864	27.718	17.135
ROCOF (1.5 Hz/s – 500 ms time delay)	>50	12.864	29.674	22.22
ROCOF (1.0 Hz/s – 800 ms time delay)	>50	7.911	23.796	18.151
VS (6°)	>50	47.646	19.862	22.22
VS (12°)	>50	>50	23.796	22.22
UV/OV	33.547	23.776	10.963	22.22
UF/OF	1.788	4.198	11.955	9.043

Table 40: NDZ results for Generation Mix 11 (SM 20%, IC 40%, IM 40%)

	NDZ_{PI}	NDZ_{PE}	NDZ_{QI}	NDZ_{QE}
ROCOF (0.4 Hz/s – no time delay)	6.947	4.136	3.836	3.741
ROCOF (2.0 Hz/s – 200 ms time delay)	13.823	21.695	4.071	95
ROCOF (1.5 Hz/s – 300 ms time delay)	13.823	18.721	4.071	75
ROCOF (1.5 Hz/s – 500 ms time delay)	13.823	21.695	4.071	85
ROCOF (1.0 Hz/s – 800 ms time delay)	13.823	17.73	4.071	80
VS (6°)	13.823	23.68	4.071	8.043
VS (12°)	13.823	47.573	4.071	16.249
UV/OV	13.823	47.573	4.071	>100
UF/OF	12.841	17.73	4.071	100

Table 41: NDZ results for Generation Mix 12 (SM 50%, DFIG 30%, IM 20%)

	NDZ_{PI}	NDZ_{PE}	NDZ_{QI}	NDZ_{QE}
ROCOF (0.4 Hz/s – no time delay)	0	0	0	0
ROCOF (2.0 Hz/s – 200 ms time delay)	14.739	13.767	25.752	17.691
ROCOF (1.5 Hz/s – 300 ms time delay)	15.718	7.358	22.387	17.691
ROCOF (1.5 Hz/s – 500 ms time delay)	15.718	7.358	22.387	28.573
ROCOF (1.0 Hz/s – 800 ms time delay)	9.841	2.927	16.451	24.926
VS (6°)	16.696	29.59	>50	19.492
VS (12°)	17.675	29.59	>50	35.93
UV/OV	4.69	43.488	>50	17.691
UF/OF	2.48	0.567	13.034	7.432

Table 42: NDZ results for Generation Mix 13 (SM 30%, DFIG 50%, IM 20%)

	NDZ_{PI}	NDZ_{PE}	NDZ_{QI}	NDZ_{QE}
ROCOF (0.4 Hz/s – no time delay)	0	0	0	0
ROCOF (2.0 Hz/s – 200 ms time delay)	6.366	4.858	24.148	27.417
ROCOF (1.5 Hz/s – 300 ms time delay)	6.853	1.925	20.789	27.417
ROCOF (1.5 Hz/s – 500 ms time delay)	16.564	2.414	20.789	29.31
ROCOF (1.0 Hz/s – 800 ms time delay)	8.798	0.264	16.55	25.533
VS (6°)	6.366	17.614	22.472	27.417
VS (12°)	6.366	17.614	22.472	27.417
UV/OV	6.366	37.367	>50	27.417
UF/OF	0	0	0	0

Table 43: NDZ results for Generation Mix 14 (IC 35%, DFIG 50%, IM 15%)

	NDZ_{PI}	NDZ_{PE}	NDZ_{QI}	NDZ_{QE}
ROCOF (0.4 Hz/s – no time delay)	0	0	0	0
ROCOF (2.0 Hz/s – 200 ms time delay)	0	0	0	0
ROCOF (1.5 Hz/s – 300 ms time delay)	0	0	0	0
ROCOF (1.5 Hz/s – 500 ms time delay)	0	0	0	0
ROCOF (1.0 Hz/s – 800 ms time delay)	0	0	0	0
VS (6°)	0	0	0	0
VS (12°)	0	0	0	0
UV/OV	0	0	0	0
UF/OF	0	0	0	0

Table 44: NDZ results for Generation Mix 15 (SM 15%, IC 30%, DFIG 30%, IM 25%)

	NDZ_{PI}	NDZ_{PE}	NDZ_{QI}	NDZ_{QE}
ROCOF (0.4 Hz/s – no time delay)	0	0	0	0
ROCOF (2.0 Hz/s – 200 ms time delay)	11.504	12.594	5.71	11.872
ROCOF (1.5 Hz/s – 300 ms time delay)	11.504	12.594	5.71	10.936
ROCOF (1.5 Hz/s – 500 ms time delay)	11.504	12.594	5.71	15.657
ROCOF (1.0 Hz/s – 800 ms time delay)	11.504	12.594	5.71	8.612
VS (6°)	0	0	0	0
VS (12°)	10.551	2.646	5.71	0.351
UV/OV	10.551	12.594	5.71	>50
UF/OF	10.551	11.619	5.71	16.613

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Appendix C: Full record of risk assessment results

C.1. Summary Results

Table 45. LOM risk assessment results for islanding scenario 1 (loss of supply to BSP)

Load Profile	Setting Option	$T_{NDZavr,s1}$ [min]	$N_{LOM,1DGG,s1}$	$P_{LOM,1DGG,s1}$	$N_{LOM,AR,s1}$	$P_{LOM,E,s1}$	$N_{LOM,E,s1}$
LP01	1	9.15	3.99E-08	3.80E-14	4.19E-07	3.99E-13	5.37E-05
	2	102.79	3.97E-05	3.78E-11	4.17E-04	3.97E-10	3.81E-03
	3	91.77	3.99E-05	3.80E-11	4.19E-04	3.99E-10	3.74E-03
	4	151.40	6.59E-05	6.27E-11	6.92E-04	6.58E-10	5.58E-03
	5	152.80	7.21E-05	6.86E-11	7.57E-04	7.20E-10	5.71E-03
	6	23.24	8.87E-06	8.43E-12	6.65E-05	6.33E-11	6.67E-04
	7	23.24	8.87E-06	8.43E-12	6.65E-05	6.33E-11	6.67E-04
	8	99.14	4.57E-05	4.34E-11	8.22E-04	7.82E-10	6.38E-03
LP02	1	18.78	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	2	136.81	7.29E-05	6.93E-11	7.65E-04	7.28E-10	6.06E-03
	3	125.49	7.04E-05	6.70E-11	7.39E-04	7.03E-10	5.80E-03
	4	155.01	1.03E-04	9.84E-11	1.09E-03	1.03E-09	8.69E-03
	5	154.68	1.24E-04	1.17E-10	1.30E-03	1.23E-09	9.62E-03
	6	19.22	2.64E-05	2.51E-11	1.98E-04	1.88E-10	1.13E-03
	7	19.22	2.64E-05	2.51E-11	1.98E-04	1.88E-10	1.13E-03
	8	99.61	8.30E-05	7.90E-11	1.49E-03	1.42E-09	1.07E-02
LP03	1	54.27	2.17E-06	2.06E-12	2.28E-05	2.17E-11	2.55E-04
	2	298.68	9.11E-05	8.67E-11	9.57E-04	9.10E-10	4.73E-03
	3	287.45	9.27E-05	8.82E-11	9.73E-04	9.26E-10	4.62E-03
	4	350.65	2.36E-04	2.25E-10	2.48E-03	2.36E-09	1.14E-02
	5	365.43	2.81E-04	2.67E-10	2.95E-03	2.81E-09	1.38E-02
	6	30.16	1.36E-05	1.29E-11	1.02E-04	9.67E-11	5.66E-04
	7	30.16	1.36E-05	1.29E-11	1.02E-04	9.67E-11	5.66E-04
	8	230.14	1.79E-04	1.70E-10	3.22E-03	3.07E-09	1.47E-02
LP04	1	22.81	3.91E-06	3.72E-12	4.10E-05	3.90E-11	3.20E-04
	2	146.21	8.62E-05	8.20E-11	9.05E-04	8.61E-10	4.40E-03
	3	139.14	8.50E-05	8.09E-11	8.92E-04	8.49E-10	4.24E-03
	4	194.89	1.36E-04	1.30E-10	1.43E-03	1.36E-09	6.81E-03
	5	197.43	1.32E-04	1.26E-10	1.39E-03	1.32E-09	7.13E-03
	6	15.77	2.12E-05	2.02E-11	1.59E-04	1.51E-10	7.07E-04
	7	15.77	2.12E-05	2.02E-11	1.59E-04	1.51E-10	7.07E-04
	8	121.90	8.66E-05	8.24E-11	1.56E-03	1.48E-09	7.85E-03
LP05	1	45.35	4.46E-22	4.24E-28	4.68E-21	4.45E-27	2.11E-05
	2	304.28	3.11E-04	2.96E-10	3.27E-03	3.11E-09	1.41E-02
	3	296.50	3.09E-04	2.94E-10	3.25E-03	3.09E-09	1.40E-02
	4	479.51	4.69E-04	4.46E-10	4.92E-03	4.68E-09	2.17E-02
	5	486.41	4.86E-04	4.63E-10	5.11E-03	4.86E-09	2.23E-02
	6	14.57	1.13E-04	1.07E-10	8.45E-04	8.03E-10	3.19E-03
	7	14.57	1.13E-04	1.07E-10	8.45E-04	8.03E-10	3.19E-03
	8	290.17	3.31E-04	3.15E-10	5.97E-03	5.68E-09	2.55E-02

Table 46. LOM risk assessment results for islanding scenario 2 (loss of individual 33kV feeder)

Load Profile	Setting Option	$T_{NDZavr,s2}$ [min]	$N_{LOM,1DGG,s2}$	$P_{LOM,1DGG,s2}$	$N_{LOM,AR,s2}$	$P_{LOM,E,s2}$	$N_{LOM,E,s2}$
LP06	1	11.77	2.67E-06	2.54E-12	2.56E-05	2.43E-11	1.68E-03
	2	71.32	2.70E-04	2.57E-10	2.59E-03	2.46E-09	1.73E-02
	3	71.32	2.70E-04	2.57E-10	2.59E-03	2.46E-09	1.73E-02
	4	71.32	2.70E-04	2.57E-10	2.59E-03	2.46E-09	1.73E-02
	5	71.32	2.70E-04	2.57E-10	2.59E-03	2.46E-09	1.73E-02
	6	14.69	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	7	14.69	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	8	38.33	1.13E-04	1.07E-10	2.59E-03	2.46E-09	1.73E-02
LP07	1	0.00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	2	0.00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	3	0.00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	4	0.00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	5	0.00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	6	0.00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	7	0.00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	8	0.00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
LP08	1	10.31	9.87E-07	9.39E-13	9.47E-06	9.01E-12	7.58E-05
	2	37.95	5.46E-04	5.20E-10	5.24E-03	4.99E-09	1.82E-02
	3	37.95	5.46E-04	5.20E-10	5.24E-03	4.99E-09	1.82E-02
	4	37.95	5.46E-04	5.20E-10	5.24E-03	4.99E-09	1.82E-02
	5	37.95	5.46E-04	5.20E-10	5.24E-03	4.99E-09	1.82E-02
	6	8.04	2.22E-04	2.11E-10	2.97E-03	2.83E-09	1.01E-02
	7	8.04	2.22E-04	2.11E-10	2.97E-03	2.83E-09	1.01E-02
	8	20.52	3.57E-04	3.40E-10	8.22E-03	7.82E-09	2.83E-02
LP09	1	0.00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	2	48.52	4.84E-04	4.60E-10	4.64E-03	4.42E-09	5.26E-03
	3	48.52	4.84E-04	4.60E-10	4.64E-03	4.42E-09	5.26E-03
	4	48.52	4.84E-04	4.60E-10	4.64E-03	4.42E-09	5.26E-03
	5	48.52	4.84E-04	4.60E-10	4.64E-03	4.42E-09	5.26E-03
	6	20.13	2.01E-04	1.91E-10	2.69E-03	2.56E-09	3.05E-03
	7	20.13	2.01E-04	1.91E-10	2.69E-03	2.56E-09	3.05E-03
	8	31.98	3.19E-04	3.03E-10	7.33E-03	6.97E-09	8.31E-03
LP10	1	0.00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	2	550.30	2.05E-03	1.95E-09	1.97E-02	1.88E-08	2.35E-02
	3	550.30	2.05E-03	1.95E-09	1.97E-02	1.88E-08	2.35E-02
	4	550.30	2.05E-03	1.95E-09	1.97E-02	1.88E-08	2.35E-02
	5	550.30	2.05E-03	1.95E-09	1.97E-02	1.88E-08	2.35E-02
	6	263.53	8.52E-04	8.10E-10	1.14E-02	1.09E-08	1.36E-02
	7	263.53	8.52E-04	8.10E-10	1.14E-02	1.09E-08	1.36E-02
	8	383.22	1.35E-03	1.29E-09	3.11E-02	2.96E-08	3.71E-02

Table 47. Summary LOM risk assessment results – based on maximum load profile figures

LOM Scenario	Setting Option	T_{NDZavr} [min]	$N_{LOM,1DGG}$	$P_{LOM,1DGG}$	$N_{LOM,AR}$	$P_{LOM,E}$	$N_{LOM,E}$
S1	1	54.3	3.91E-06	3.72E-12	4.10E-05	3.90E-11	3.20E-04
	2	304.3	3.11E-04	2.96E-10	3.27E-03	3.11E-09	1.41E-02
	3	296.5	3.09E-04	2.94E-10	3.25E-03	3.09E-09	1.40E-02
	4	479.5	4.69E-04	4.46E-10	4.92E-03	4.68E-09	2.17E-02
	5	486.4	4.86E-04	4.63E-10	5.11E-03	4.86E-09	2.23E-02
	6	30.2	1.13E-04	1.07E-10	8.45E-04	8.03E-10	3.19E-03
	7	30.2	1.13E-04	1.07E-10	8.45E-04	8.03E-10	3.19E-03
	8	290.2	3.31E-04	3.15E-10	5.97E-03	5.68E-09	2.55E-02
S2	1	11.77	2.67E-06	2.54E-12	2.56E-05	2.43E-11	1.68E-03
	2	550.30	2.05E-03	1.95E-09	1.97E-02	1.88E-08	2.35E-02
	3	550.30	2.05E-03	1.95E-09	1.97E-02	1.88E-08	2.35E-02
	4	550.30	2.05E-03	1.95E-09	1.97E-02	1.88E-08	2.35E-02
	5	550.30	2.05E-03	1.95E-09	1.97E-02	1.88E-08	2.35E-02
	6	263.53	8.52E-04	8.10E-10	1.14E-02	1.09E-08	1.36E-02
	7	263.53	8.52E-04	8.10E-10	1.14E-02	1.09E-08	1.36E-02
	8	383.22	1.35E-03	1.29E-09	3.11E-02	2.96E-08	3.71E-02
Combined S1 & S2	1	33.97	3.31E-06	3.15E-12	6.66E-05	6.34E-11	2.00E-03
	2	421.78	1.14E-03	1.09E-09	2.30E-02	2.19E-08	3.76E-02
	3	417.71	1.14E-03	1.09E-09	2.30E-02	2.18E-08	3.75E-02
	4	513.32	1.23E-03	1.17E-09	2.46E-02	2.34E-08	4.52E-02
	5	516.92	1.23E-03	1.17E-09	2.48E-02	2.36E-08	4.58E-02
	6	179.78	5.86E-04	5.58E-10	1.23E-02	1.17E-08	1.68E-02
	7	179.78	5.86E-04	5.58E-10	1.23E-02	1.17E-08	1.68E-02
	8	342.37	9.05E-04	8.61E-10	3.71E-02	3.53E-08	6.26E-02

Table 48. Summary LOM risk assessment results – based on average load profile figures

LOM Scenario	Setting Option	T_{NDZavr} [min]	$N_{LOM,1DGG}$	$P_{LOM,1DGG}$	$N_{LOM,AR}$	$P_{LOM,E}$	$N_{LOM,E}$
S1	1	30.07	1.22E-06	1.16E-12	1.28E-05	1.22E-11	1.30E-04
	2	197.75	1.20E-04	1.14E-10	1.26E-03	1.20E-09	6.62E-03
	3	188.07	1.19E-04	1.14E-10	1.25E-03	1.19E-09	6.47E-03
	4	266.29	2.02E-04	1.92E-10	2.12E-03	2.02E-09	1.08E-02
	5	271.35	2.19E-04	2.08E-10	2.30E-03	2.19E-09	1.17E-02
	6	20.59	3.65E-05	3.47E-11	2.74E-04	2.61E-10	1.25E-03
	7	20.59	3.65E-05	3.47E-11	2.74E-04	2.61E-10	1.25E-03
	8	168.19	1.45E-04	1.38E-10	2.61E-03	2.49E-09	1.30E-02
S2	1	4.42	7.30E-07	6.95E-13	7.01E-06	6.67E-12	3.51E-04
	2	141.62	6.71E-04	6.38E-10	6.44E-03	6.12E-09	1.29E-02
	3	141.62	6.71E-04	6.38E-10	6.44E-03	6.12E-09	1.29E-02
	4	141.62	6.71E-04	6.38E-10	6.44E-03	6.12E-09	1.29E-02
	5	141.62	6.71E-04	6.38E-10	6.44E-03	6.12E-09	1.29E-02
	6	61.28	2.55E-04	2.42E-10	3.42E-03	3.25E-09	5.35E-03
	7	61.28	2.55E-04	2.42E-10	3.42E-03	3.25E-09	5.35E-03
	8	94.81	4.28E-04	4.08E-10	9.85E-03	9.37E-09	1.82E-02
Combined S1 & S2	1	17.82	9.88E-07	9.40E-13	1.99E-05	1.89E-11	4.81E-04
	2	170.94	3.83E-04	3.64E-10	7.70E-03	7.32E-09	1.95E-02
	3	165.88	3.83E-04	3.64E-10	7.69E-03	7.32E-09	1.93E-02
	4	206.75	4.26E-04	4.05E-10	8.56E-03	8.14E-09	2.37E-02
	5	209.39	4.35E-04	4.14E-10	8.74E-03	8.31E-09	2.46E-02
	6	46.68	1.77E-04	1.68E-10	3.69E-03	3.51E-09	6.60E-03
	7	46.68	1.77E-04	1.68E-10	3.69E-03	3.51E-09	6.60E-03
	8	127.03	3.04E-04	2.89E-10	1.25E-02	1.19E-08	3.12E-02

C.2. Detailed results for different generation mixes and load profiles

Table 49. LOM risk assessment results (islanding scenario 1, load profile LP01)

Generation Mix (m)	Setting Option	$T_{NDZavr(m)}$ [min]	$N_{LOM,1DGG(m)}$	$P_{LOM,1DGG(m)}$	$N_{LOM,AR(m)}$	$P_{LOM,E(m)}$	$N_{LOM,E(m)}$
1	1	0.00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	2	0.00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	3	0.00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	4	0.00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	5	0.00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	6	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	7	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	8	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
2	1	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	2	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	3	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	4	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	5	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	6	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	7	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	8	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
3	1	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	2	142.92	7.89E-05	7.51E-11	1.18E-04	1.13E-10	7.33E-04
	3	139.08	8.02E-05	7.63E-11	1.20E-04	1.14E-10	7.25E-04
	4	142.92	7.89E-05	7.51E-11	1.18E-04	1.13E-10	7.33E-04
	5	139.08	8.02E-05	7.63E-11	1.20E-04	1.14E-10	7.25E-04
	6	142.39	7.89E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	7	142.34	7.89E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	8	142.92	7.89E-05	7.51E-11	1.18E-04	1.13E-10	7.33E-04
4	1	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	2	73.32	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.86E-05
	3	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	4	413.59	1.83E-04	1.74E-10	2.75E-04	2.61E-10	1.83E-03
	5	427.22	2.26E-04	2.15E-10	3.38E-04	3.22E-10	1.97E-03
	6	0.00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	7	279.76	1.29E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	8	427.22	2.26E-04	2.15E-10	3.38E-04	3.22E-10	1.97E-03
5	1	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	2	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	3	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	4	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	5	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	6	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	7	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	8	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
6	1	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	2	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	3	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	4	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	5	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	6	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	7	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	8	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00

Generation Mix (m)	Setting Option	$T_{NDZavr(m)}$ [min]	$N_{LOM,1DGG(m)}$	$P_{LOM,1DGG(m)}$	$N_{LOM,AR(m)}$	$P_{LOM,E(m)}$	$N_{LOM,E(m)}$
7	1	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	2	475.42	1.81E-04	1.73E-10	1.15E-04	1.09E-10	1.15E-03
	3	475.42	1.81E-04	1.73E-10	1.15E-04	1.09E-10	1.15E-03
	4	475.42	1.81E-04	1.73E-10	1.15E-04	1.09E-10	1.15E-03
	5	475.42	1.81E-04	1.73E-10	1.15E-04	1.09E-10	1.15E-03
	6	475.42	1.81E-04	1.73E-10	6.65E-05	6.33E-11	6.67E-04
	7	475.42	1.81E-04	1.73E-10	6.65E-05	6.33E-11	6.67E-04
	8	475.42	1.81E-04	1.73E-10	1.81E-04	1.73E-10	1.82E-03
8	1	96.03	4.19E-07	3.99E-13	4.19E-07	3.99E-13	5.37E-05
	2	191.71	4.53E-06	4.31E-12	4.53E-06	4.31E-12	2.20E-04
	3	191.71	4.53E-06	4.31E-12	4.53E-06	4.31E-12	2.20E-04
	4	191.71	4.53E-06	4.31E-12	4.53E-06	4.31E-12	2.20E-04
	5	191.71	4.53E-06	4.31E-12	4.53E-06	4.31E-12	2.20E-04
	6	191.71	4.53E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	7	191.71	4.53E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	8	191.71	4.53E-06	4.31E-12	4.53E-06	4.31E-12	2.20E-04
9	1	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	2	89.26	1.70E-05	1.62E-11	1.70E-05	1.62E-11	2.44E-04
	3	89.26	1.70E-05	1.62E-11	1.70E-05	1.62E-11	2.44E-04
	4	89.26	1.70E-05	1.62E-11	1.70E-05	1.62E-11	2.44E-04
	5	89.26	1.70E-05	1.62E-11	1.70E-05	1.62E-11	2.44E-04
	6	89.26	1.70E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	7	89.26	1.70E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	8	89.26	1.70E-05	1.62E-11	1.70E-05	1.62E-11	2.44E-04
10	1	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	2	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	3	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	4	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	5	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	6	0.00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	7	0.00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	8	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
11	1	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	2	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	3	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	4	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	5	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	6	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	7	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	8	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
12	1	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	2	172.87	1.62E-04	1.54E-10	1.62E-04	1.54E-10	1.40E-03
	3	172.87	1.62E-04	1.54E-10	1.62E-04	1.54E-10	1.40E-03
	4	172.87	1.62E-04	1.54E-10	1.62E-04	1.54E-10	1.40E-03
	5	172.87	1.62E-04	1.54E-10	1.62E-04	1.54E-10	1.40E-03
	6	0.00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	7	138.75	3.22E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	8	172.87	1.62E-04	1.54E-10	1.62E-04	1.54E-10	1.40E-03

Table 50. LOM risk assessment results (islanding scenario 1, load profile LP02)

Generation Mix (m)	Setting Option	$T_{NDZavr(m)}$ [min]	$N_{LOM,1DGG(m)}$	$P_{LOM,1DGG(m)}$	$N_{LOM,AR(m)}$	$P_{LOM,E(m)}$	$N_{LOM,E(m)}$
1	1	0.00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	2	0.00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	3	0.00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	4	0.00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	5	0.00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	6	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	7	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	8	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
2	1	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	2	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	3	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	4	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	5	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	6	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	7	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	8	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
3	1	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	2	139.22	1.94E-05	1.84E-11	2.91E-05	2.76E-11	2.46E-04
	3	122.71	1.99E-05	1.89E-11	2.98E-05	2.83E-11	2.44E-04
	4	139.22	1.94E-05	1.84E-11	2.91E-05	2.76E-11	2.46E-04
	5	122.71	1.99E-05	1.89E-11	2.98E-05	2.83E-11	2.44E-04
	6	139.22	1.94E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	7	139.22	1.94E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	8	139.22	1.94E-05	1.84E-11	2.91E-05	2.76E-11	2.46E-04
4	1	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	2	62.77	1.78E-05	1.70E-11	2.68E-05	2.55E-11	2.56E-04
	3	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	4	190.14	2.32E-04	2.21E-10	3.48E-04	3.31E-10	2.89E-03
	5	204.37	3.72E-04	3.54E-10	5.58E-04	5.30E-10	3.81E-03
	6	0.00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	7	186.93	3.35E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	8	204.37	3.72E-04	3.54E-10	5.58E-04	5.30E-10	3.81E-03
5	1	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	2	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	3	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	4	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	5	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	6	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	7	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	8	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
6	1	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	2	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	3	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	4	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	5	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	6	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	7	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	8	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00

Generation Mix (m)	Setting Option	$T_{NDZavr(m)}$ [min]	$N_{LOM,1DGG(m)}$	$P_{LOM,1DGG(m)}$	$N_{LOM,AR(m)}$	$P_{LOM,E(m)}$	$N_{LOM,E(m)}$
7	1	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	2	393.19	5.40E-04	5.13E-10	3.42E-04	3.25E-10	1.95E-03
	3	393.19	5.40E-04	5.13E-10	3.42E-04	3.25E-10	1.95E-03
	4	393.19	5.40E-04	5.13E-10	3.42E-04	3.25E-10	1.95E-03
	5	393.19	5.40E-04	5.13E-10	3.42E-04	3.25E-10	1.95E-03
	6	393.19	5.40E-04	5.13E-10	1.98E-04	1.88E-10	1.13E-03
	7	393.19	5.40E-04	5.13E-10	1.98E-04	1.88E-10	1.13E-03
	8	393.19	5.40E-04	5.13E-10	5.40E-04	5.13E-10	3.08E-03
8	1	197.21	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	2	492.13	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	3	492.13	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	4	492.13	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	5	492.13	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	6	492.13	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	7	492.13	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	8	492.13	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
9	1	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	2	110.14	2.35E-04	2.24E-10	2.35E-04	2.24E-10	2.37E-03
	3	110.14	2.35E-04	2.24E-10	2.35E-04	2.24E-10	2.37E-03
	4	110.14	2.35E-04	2.24E-10	2.35E-04	2.24E-10	2.37E-03
	5	110.14	2.35E-04	2.24E-10	2.35E-04	2.24E-10	2.37E-03
	6	110.14	2.35E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	7	110.14	2.35E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	8	110.14	2.35E-04	2.24E-10	2.35E-04	2.24E-10	2.37E-03
10	1	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	2	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	3	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	4	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	5	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	6	0.00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	7	0.00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	8	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
11	1	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	2	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	3	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	4	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	5	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	6	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	7	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	8	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
12	1	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	2	282.24	1.32E-04	1.26E-10	1.32E-04	1.26E-10	1.24E-03
	3	282.24	1.32E-04	1.26E-10	1.32E-04	1.26E-10	1.24E-03
	4	282.24	1.32E-04	1.26E-10	1.32E-04	1.26E-10	1.24E-03
	5	282.24	1.32E-04	1.26E-10	1.32E-04	1.26E-10	1.24E-03
	6	0.00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	7	169.15	8.95E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	8	282.24	1.32E-04	1.26E-10	1.32E-04	1.26E-10	1.24E-03

Table 51. LOM risk assessment results (islanding scenario 1, load profile LP3)

Generation Mix (m)	Setting Option	$T_{NDZavr(m)}$ [min]	$N_{LOM,1DGG(m)}$	$P_{LOM,1DGG(m)}$	$N_{LOM,AR(m)}$	$P_{LOM,E(m)}$	$N_{LOM,E(m)}$
1	1	0.00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	2	0.00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	3	0.00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	4	0.00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	5	0.00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	6	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	7	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	8	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
2	1	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	2	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	3	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	4	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	5	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	6	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	7	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	8	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
3	1	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	2	426.56	1.04E-04	9.87E-11	1.56E-04	1.48E-10	9.70E-04
	3	413.75	1.17E-04	1.11E-10	1.76E-04	1.67E-10	9.46E-04
	4	421.47	1.04E-04	9.87E-11	1.56E-04	1.48E-10	9.70E-04
	5	413.75	1.17E-04	1.11E-10	1.76E-04	1.67E-10	9.46E-04
	6	266.42	8.99E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	7	349.91	9.35E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	8	433.07	1.04E-04	9.87E-11	1.56E-04	1.48E-10	9.70E-04
4	1	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	2	66.19	2.37E-06	2.26E-12	3.56E-06	3.39E-12	7.98E-05
	3	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	4	435.40	1.02E-03	9.67E-10	1.53E-03	1.45E-09	6.70E-03
	5	545.89	1.32E-03	1.25E-09	1.98E-03	1.88E-09	9.16E-03
	6	0.00	1.18E-22	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	7	203.82	2.15E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	8	580.49	1.44E-03	1.37E-09	2.17E-03	2.06E-09	9.48E-03
5	1	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	2	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	3	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	4	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	5	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	6	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	7	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	8	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
6	1	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	2	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	3	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	4	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	5	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	6	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	7	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	8	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00

Generation Mix (m)	Setting Option	$T_{NDZavr(m)}$ [min]	$N_{LOM,1DGG(m)}$	$P_{LOM,1DGG(m)}$	$N_{LOM,AR(m)}$	$P_{LOM,E(m)}$	$N_{LOM,E(m)}$
7	1	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	2	616.94	2.77E-04	2.64E-10	1.76E-04	1.67E-10	9.78E-04
	3	616.94	2.77E-04	2.64E-10	1.76E-04	1.67E-10	9.78E-04
	4	616.94	2.77E-04	2.64E-10	1.76E-04	1.67E-10	9.78E-04
	5	616.94	2.77E-04	2.64E-10	1.76E-04	1.67E-10	9.78E-04
	6	616.94	2.77E-04	2.64E-10	1.02E-04	9.67E-11	5.66E-04
	7	616.94	2.77E-04	2.64E-10	1.02E-04	9.67E-11	5.66E-04
	8	616.94	2.77E-04	2.64E-10	2.77E-04	2.64E-10	1.54E-03
8	1	569.81	2.28E-05	2.17E-11	2.28E-05	2.17E-11	2.55E-04
	2	1337.43	2.17E-04	2.06E-10	2.17E-04	2.06E-10	1.27E-03
	3	1337.43	2.17E-04	2.06E-10	2.17E-04	2.06E-10	1.27E-03
	4	1337.43	2.17E-04	2.06E-10	2.17E-04	2.06E-10	1.27E-03
	5	1337.43	2.17E-04	2.06E-10	2.17E-04	2.06E-10	1.27E-03
	6	1340.04	2.16E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	7	1337.43	2.17E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	8	1337.43	2.17E-04	2.06E-10	2.17E-04	2.06E-10	1.27E-03
9	1	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	2	134.01	8.02E-05	7.63E-11	8.02E-05	7.63E-11	3.81E-04
	3	134.01	8.02E-05	7.63E-11	8.02E-05	7.63E-11	3.81E-04
	4	134.01	8.02E-05	7.63E-11	8.02E-05	7.63E-11	3.81E-04
	5	134.01	8.02E-05	7.63E-11	8.02E-05	7.63E-11	3.81E-04
	6	134.01	8.02E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	7	134.01	8.02E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	8	134.01	8.02E-05	7.63E-11	8.02E-05	7.63E-11	3.81E-04
10	1	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	2	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	3	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	4	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	5	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	6	0.00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	7	0.00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	8	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
11	1	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	2	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	3	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	4	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	5	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	6	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	7	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	8	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
12	1	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	2	534.84	3.25E-04	3.09E-10	3.25E-04	3.09E-10	1.05E-03
	3	535.38	3.25E-04	3.09E-10	3.25E-04	3.09E-10	1.05E-03
	4	534.38	3.25E-04	3.09E-10	3.25E-04	3.09E-10	1.05E-03
	5	535.42	3.25E-04	3.09E-10	3.25E-04	3.09E-10	1.05E-03
	6	0.00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	7	459.48	1.13E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	8	533.75	3.25E-04	3.09E-10	3.25E-04	3.09E-10	1.05E-03

Table 52. LOM risk assessment results (islanding scenario 1, load profile LP4)

Generation Mix (m)	Setting Option	$T_{NDZavr(m)}$ [min]	$N_{LOM,1DGG(m)}$	$P_{LOM,1DGG(m)}$	$N_{LOM,AR(m)}$	$P_{LOM,E(m)}$	$N_{LOM,E(m)}$
1	1	0.00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	2	0.00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	3	0.00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	4	0.00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	5	0.00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	6	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	7	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	8	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
2	1	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	2	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	3	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	4	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	5	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	6	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	7	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	8	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
3	1	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	2	253.71	1.64E-04	1.56E-10	2.45E-04	2.34E-10	8.06E-04
	3	251.79	1.57E-04	1.49E-10	2.35E-04	2.24E-10	7.91E-04
	4	253.71	1.64E-04	1.56E-10	2.45E-04	2.34E-10	8.06E-04
	5	251.79	1.57E-04	1.49E-10	2.35E-04	2.24E-10	7.91E-04
	6	220.76	1.63E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	7	244.53	1.64E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	8	253.71	1.64E-04	1.56E-10	2.45E-04	2.34E-10	8.06E-04
4	1	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	2	47.56	1.52E-06	1.45E-12	2.28E-06	2.17E-12	1.44E-04
	3	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	4	388.35	3.52E-04	3.35E-10	5.28E-04	5.03E-10	2.55E-03
	5	408.04	3.31E-04	3.15E-10	4.97E-04	4.73E-10	2.89E-03
	6	32.00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	7	176.34	2.03E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	8	408.04	3.31E-04	3.15E-10	4.97E-04	4.73E-10	2.89E-03
5	1	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	2	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	3	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	4	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	5	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	6	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	7	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	8	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
6	1	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	2	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	3	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	4	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	5	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	6	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	7	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	8	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00

Generation Mix (m)	Setting Option	$T_{NDZavr(m)}$ [min]	$N_{LOM,1DGG(m)}$	$P_{LOM,1DGG(m)}$	$N_{LOM,AR(m)}$	$P_{LOM,E(m)}$	$N_{LOM,E(m)}$
7	1	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	2	322.57	4.33E-04	4.12E-10	2.74E-04	2.61E-10	1.22E-03
	3	322.57	4.33E-04	4.12E-10	2.74E-04	2.61E-10	1.22E-03
	4	322.57	4.33E-04	4.12E-10	2.74E-04	2.61E-10	1.22E-03
	5	322.57	4.33E-04	4.12E-10	2.74E-04	2.61E-10	1.22E-03
	6	322.57	4.33E-04	4.12E-10	1.59E-04	1.51E-10	7.07E-04
	7	322.57	4.33E-04	4.12E-10	1.59E-04	1.51E-10	7.07E-04
	8	322.57	4.33E-04	4.12E-10	4.33E-04	4.12E-10	1.93E-03
8	1	239.53	4.10E-05	3.90E-11	4.10E-05	3.90E-11	3.20E-04
	2	569.94	1.27E-04	1.21E-10	1.27E-04	1.21E-10	9.85E-04
	3	569.94	1.27E-04	1.21E-10	1.27E-04	1.21E-10	9.85E-04
	4	569.94	1.27E-04	1.21E-10	1.27E-04	1.21E-10	9.85E-04
	5	569.94	1.27E-04	1.21E-10	1.27E-04	1.21E-10	9.85E-04
	6	569.94	1.27E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	7	569.94	1.27E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	8	569.94	1.27E-04	1.21E-10	1.27E-04	1.21E-10	9.85E-04
9	1	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	2	87.78	3.25E-05	3.09E-11	3.25E-05	3.09E-11	2.58E-04
	3	87.78	3.25E-05	3.09E-11	3.25E-05	3.09E-11	2.58E-04
	4	87.78	3.25E-05	3.09E-11	3.25E-05	3.09E-11	2.58E-04
	5	87.78	3.25E-05	3.09E-11	3.25E-05	3.09E-11	2.58E-04
	6	87.78	3.25E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	7	87.78	3.25E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	8	87.78	3.25E-05	3.09E-11	3.25E-05	3.09E-11	2.58E-04
10	1	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	2	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	3	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	4	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	5	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	6	0.00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	7	0.00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	8	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
11	1	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	2	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	3	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	4	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	5	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	6	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	7	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	8	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
12	1	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	2	221.28	2.23E-04	2.12E-10	2.23E-04	2.12E-10	9.88E-04
	3	221.28	2.23E-04	2.12E-10	2.23E-04	2.12E-10	9.88E-04
	4	221.28	2.23E-04	2.12E-10	2.23E-04	2.12E-10	9.88E-04
	5	221.28	2.23E-04	2.12E-10	2.23E-04	2.12E-10	9.88E-04
	6	0.00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	7	187.89	1.54E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	8	221.28	2.23E-04	2.12E-10	2.23E-04	2.12E-10	9.88E-04

Table 53. LOM risk assessment results (islanding scenario 1, load profile LP5)

Generation Mix (m)	Setting Option	$T_{NDZavr(m)}$ [min]	$N_{LOM,1DGG(m)}$	$P_{LOM,1DGG(m)}$	$N_{LOM,AR(m)}$	$P_{LOM,E(m)}$	$N_{LOM,E(m)}$
1	1	0.00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	2	0.00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	3	0.00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	4	0.00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	5	0.00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	6	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	7	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	8	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
2	1	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	2	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	3	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	4	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	5	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	6	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	7	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	8	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
3	1	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	2	762.09	5.61E-04	5.34E-10	8.41E-04	8.00E-10	3.82E-03
	3	757.79	5.51E-04	5.24E-10	8.26E-04	7.86E-10	3.78E-03
	4	762.09	5.61E-04	5.34E-10	8.41E-04	8.00E-10	3.82E-03
	5	757.79	5.51E-04	5.24E-10	8.26E-04	7.86E-10	3.78E-03
	6	762.03	5.61E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	7	762.09	5.61E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	8	762.09	5.61E-04	5.34E-10	8.41E-04	8.00E-10	3.82E-03
4	1	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	2	50.18	2.01E-06	1.92E-12	3.02E-06	2.87E-12	8.07E-05
	3	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	4	1276.76	1.11E-03	1.05E-09	1.66E-03	1.58E-09	7.67E-03
	5	1329.37	1.24E-03	1.18E-09	1.86E-03	1.77E-09	8.32E-03
	6	0.00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	7	232.81	7.59E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	8	1329.37	1.24E-03	1.18E-09	1.86E-03	1.77E-09	8.32E-03
5	1	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	2	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	3	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	4	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	5	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	6	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	7	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	8	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
6	1	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	2	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	3	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	4	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	5	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	6	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	7	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	8	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00

Generation Mix (m)	Setting Option	$T_{NDZavr(m)}$ [min]	$N_{LOM,1DGG(m)}$	$P_{LOM,1DGG(m)}$	$N_{LOM,AR(m)}$	$P_{LOM,E(m)}$	$N_{LOM,E(m)}$
7	1	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	2	298.09	2.30E-03	2.19E-09	1.46E-03	1.39E-09	5.50E-03
	3	298.09	2.30E-03	2.19E-09	1.46E-03	1.39E-09	5.50E-03
	4	298.09	2.30E-03	2.19E-09	1.46E-03	1.39E-09	5.50E-03
	5	298.09	2.30E-03	2.19E-09	1.46E-03	1.39E-09	5.50E-03
	6	298.09	2.30E-03	2.19E-09	8.45E-04	8.03E-10	3.19E-03
	7	298.09	2.30E-03	2.19E-09	8.45E-04	8.03E-10	3.19E-03
	8	298.09	2.30E-03	2.19E-09	2.30E-03	2.19E-09	8.69E-03
8	1	476.21	4.68E-21	4.45E-27	4.68E-21	4.45E-27	2.11E-05
	2	921.64	9.21E-06	8.76E-12	9.21E-06	8.76E-12	1.04E-04
	3	921.64	9.21E-06	8.76E-12	9.21E-06	8.76E-12	1.04E-04
	4	921.64	9.21E-06	8.76E-12	9.21E-06	8.76E-12	1.04E-04
	5	921.64	9.21E-06	8.76E-12	9.21E-06	8.76E-12	1.04E-04
	6	921.64	9.21E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	7	921.64	9.21E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	8	921.64	9.21E-06	8.76E-12	9.21E-06	8.76E-12	1.04E-04
9	1	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	2	107.14	2.83E-06	2.70E-12	2.83E-06	2.70E-12	1.18E-04
	3	107.14	2.83E-06	2.70E-12	2.83E-06	2.70E-12	1.18E-04
	4	107.14	2.83E-06	2.70E-12	2.83E-06	2.70E-12	1.18E-04
	5	107.14	2.83E-06	2.70E-12	2.83E-06	2.70E-12	1.18E-04
	6	107.14	2.83E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	7	107.14	2.83E-06	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	8	107.14	2.83E-06	2.70E-12	2.83E-06	2.70E-12	1.18E-04
10	1	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	2	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	3	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	4	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	5	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	6	0.00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	7	0.00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	8	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
11	1	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	2	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	3	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	4	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	5	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	6	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	7	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	8	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
12	1	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	2	758.98	9.53E-04	9.06E-10	9.53E-04	9.06E-10	4.45E-03
	3	758.98	9.53E-04	9.06E-10	9.53E-04	9.06E-10	4.45E-03
	4	758.98	9.53E-04	9.06E-10	9.53E-04	9.06E-10	4.45E-03
	5	758.98	9.53E-04	9.06E-10	9.53E-04	9.06E-10	4.45E-03
	6	0.00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	7	648.93	7.85E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	8	758.98	9.53E-04	9.06E-10	9.53E-04	9.06E-10	4.45E-03

Table 54. LOM risk assessment results (islanding scenario 2, load profile LP06)

Generation Mix (m)	Setting Option	$T_{NDZavr(m)}$ [min]	$N_{LOM,1DGG(m)}$	$P_{LOM,1DGG(m)}$	$N_{LOM,AR(m)}$	$P_{LOM,E(m)}$	$N_{LOM,E(m)}$
1	1	37.67	8.53E-06	8.11E-12	2.56E-05	2.43E-11	1.68E-03
	2	114.84	8.63E-04	8.21E-10	2.59E-03	2.46E-09	1.73E-02
	3	114.84	8.63E-04	8.21E-10	2.59E-03	2.46E-09	1.73E-02
	4	114.84	8.63E-04	8.21E-10	2.59E-03	2.46E-09	1.73E-02
	5	114.84	8.63E-04	8.21E-10	2.59E-03	2.46E-09	1.73E-02
	6	114.84	8.63E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	7	114.84	8.63E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	8	114.84	8.63E-04	8.21E-10	2.59E-03	2.46E-09	1.73E-02
2	1	0.00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	2	0.00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	3	0.00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	4	0.00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	5	0.00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	6	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	7	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	8	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
3	1	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	2	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	3	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	4	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	5	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	6	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	7	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	8	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
4	1	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	2	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	3	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	4	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	5	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	6	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	7	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	8	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
5	1	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	2	537.00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	3	537.00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	4	537.00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	5	537.00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	6	537.00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	7	537.00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	8	537.00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

Table 55. LOM risk assessment results (islanding scenario 2, load profile LP07)

Generation Mix (m)	Setting Option	$T_{NDZavr(m)}$ [min]	$N_{LOM,1DGG(m)}$	$P_{LOM,1DGG(m)}$	$N_{LOM,AR(m)}$	$P_{LOM,E(m)}$	$N_{LOM,E(m)}$
1	1	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	2	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	3	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	4	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	5	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	6	0.00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	7	0.00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	8	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
2	1	0.00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	2	0.00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	3	0.00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	4	0.00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	5	0.00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	6	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	7	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	8	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
3	1	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	2	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	3	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	4	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	5	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	6	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	7	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	8	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
4	1	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	2	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	3	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	4	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	5	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	6	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	7	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	8	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
5	1	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	2	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	3	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	4	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	5	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	6	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	7	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	8	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00

Table 56. LOM risk assessment results (islanding scenario 2, load profile LP8)

Generation Mix (m)	Setting Option	$T_{NDZavr(m)}$ [min]	$N_{LOM,1DGG(m)}$	$P_{LOM,1DGG(m)}$	$N_{LOM,AR(m)}$	$P_{LOM,E(m)}$	$N_{LOM,E(m)}$
1	1	33.00	3.16E-06	3.00E-12	9.47E-06	9.01E-12	7.58E-05
	2	59.44	3.50E-05	3.33E-11	1.05E-04	9.98E-11	7.47E-04
	3	59.44	3.50E-05	3.33E-11	1.05E-04	9.98E-11	7.47E-04
	4	59.44	3.50E-05	3.33E-11	1.05E-04	9.98E-11	7.47E-04
	5	59.44	3.50E-05	3.33E-11	1.05E-04	9.98E-11	7.47E-04
	6	59.44	3.50E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	7	59.44	3.50E-05	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	8	59.44	3.50E-05	3.33E-11	1.05E-04	9.98E-11	7.47E-04
2	1	0.00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	2	0.00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	3	0.00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	4	0.00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	5	0.00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	6	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	7	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	8	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
3	1	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	2	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	3	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	4	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	5	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	6	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	7	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	8	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
4	1	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	2	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	3	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	4	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	5	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	6	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	7	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	8	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
5	1	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	2	293.74	8.11E-03	7.72E-09	5.14E-03	4.89E-09	1.75E-02
	3	293.74	8.11E-03	7.72E-09	5.14E-03	4.89E-09	1.75E-02
	4	293.74	8.11E-03	7.72E-09	5.14E-03	4.89E-09	1.75E-02
	5	293.74	8.11E-03	7.72E-09	5.14E-03	4.89E-09	1.75E-02
	6	293.74	8.11E-03	7.72E-09	2.97E-03	2.83E-09	1.01E-02
	7	293.74	8.11E-03	7.72E-09	2.97E-03	2.83E-09	1.01E-02
	8	293.74	8.11E-03	7.72E-09	8.11E-03	7.72E-09	2.76E-02

Table 57. LOM risk assessment results (islanding scenario 2, load profile LP9)

Generation Mix (m)	Setting Option	$T_{NDZavr(m)}$ [min]	$N_{LOM,1DGG(m)}$	$P_{LOM,1DGG(m)}$	$N_{LOM,AR(m)}$	$P_{LOM,E(m)}$	$N_{LOM,E(m)}$
1	1	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	2	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	3	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	4	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	5	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	6	0.00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	7	0.00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	8	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
2	1	0.00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	2	0.00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	3	0.00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	4	0.00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	5	0.00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	6	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	7	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	8	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
3	1	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	2	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	3	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	4	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	5	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	6	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	7	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	8	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
4	1	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	2	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	3	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	4	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	5	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	6	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	7	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	8	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
5	1	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	2	735.48	7.33E-03	6.97E-09	4.64E-03	4.42E-09	5.26E-03
	3	735.48	7.33E-03	6.97E-09	4.64E-03	4.42E-09	5.26E-03
	4	735.48	7.33E-03	6.97E-09	4.64E-03	4.42E-09	5.26E-03
	5	735.48	7.33E-03	6.97E-09	4.64E-03	4.42E-09	5.26E-03
	6	735.48	7.33E-03	6.97E-09	2.69E-03	2.56E-09	3.05E-03
	7	735.48	7.33E-03	6.97E-09	2.69E-03	2.56E-09	3.05E-03
	8	735.48	7.33E-03	6.97E-09	7.33E-03	6.97E-09	8.31E-03

Table 58. LOM risk assessment results (islanding scenario 2, load profile LP10)

Generation Mix (m)	Setting Option	$T_{NDZavr(m)}$ [min]	$N_{LOM,1DGG(m)}$	$P_{LOM,1DGG(m)}$	$N_{LOM,AR(m)}$	$P_{LOM,E(m)}$	$N_{LOM,E(m)}$
1	1	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	2	550.83	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	3	550.83	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	4	550.83	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	5	550.83	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	6	550.83	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	7	550.83	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	8	550.83	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
2	1	0.00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	2	0.00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	3	0.00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	4	0.00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	5	0.00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	6	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	7	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	8	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
3	1	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	2	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	3	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	4	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	5	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	6	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	7	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	8	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
4	1	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	2	1357.99	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	3	1357.99	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	4	1357.99	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	5	1357.99	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	6	1357.99	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	7	1357.99	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	8	1357.99	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
5	1	0.00	0.00E+00	-0.00E+00	0.00E+00	0.00E+00	0.00E+00
	2	371.65	3.11E-02	2.96E-08	1.97E-02	1.88E-08	2.35E-02
	3	371.65	3.11E-02	2.96E-08	1.97E-02	1.88E-08	2.35E-02
	4	371.65	3.11E-02	2.96E-08	1.97E-02	1.88E-08	2.35E-02
	5	371.65	3.11E-02	2.96E-08	1.97E-02	1.88E-08	2.35E-02
	6	371.65	3.11E-02	2.96E-08	1.14E-02	1.09E-08	1.36E-02
	7	371.65	3.11E-02	2.96E-08	1.14E-02	1.09E-08	1.36E-02
	8	371.65	3.11E-02	2.96E-08	3.11E-02	2.96E-08	3.71E-02

C.3. Result figures

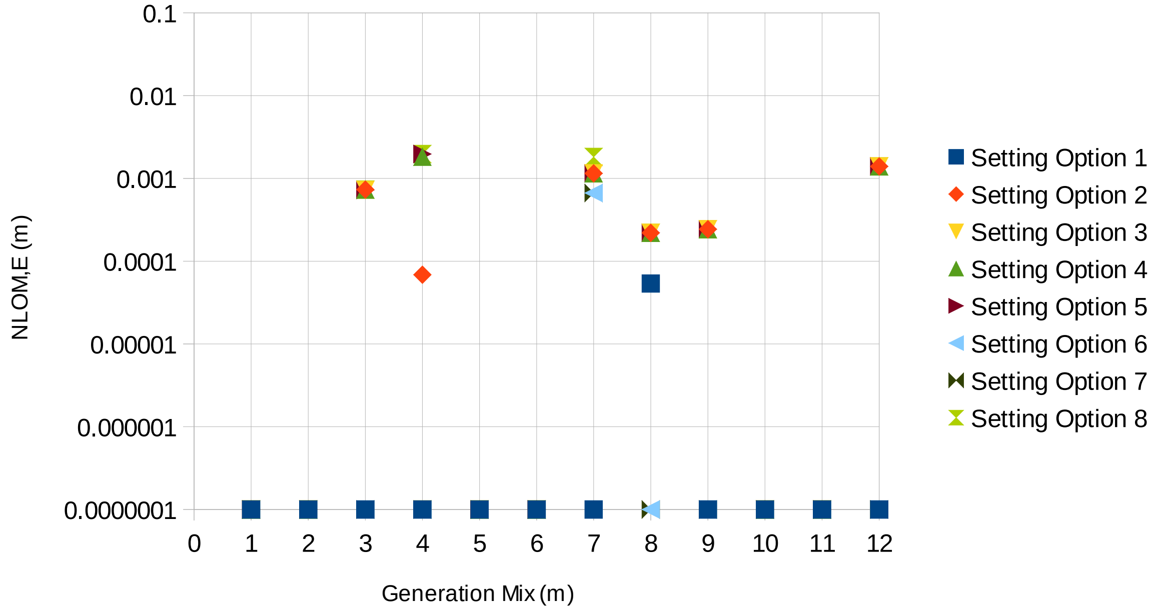

Figure 29. Probability $N_{LOM,E}$ of undetected islanding operation – Scenario 1, Load Profile LP01

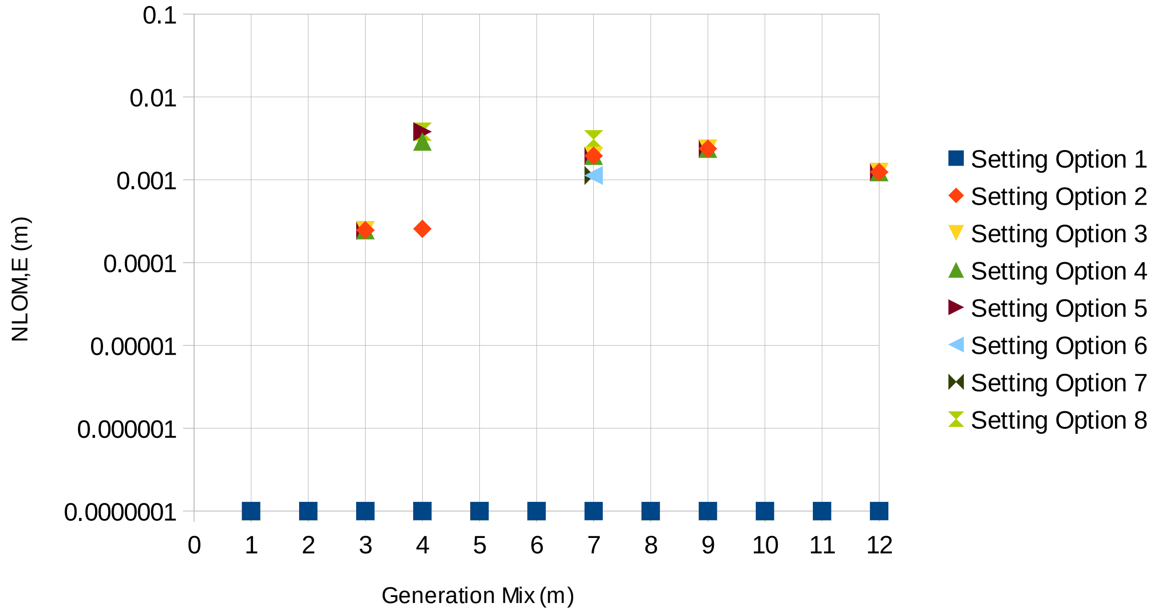

Figure 30. Probability $N_{LOM,E}$ of undetected islanding operation – Scenario 1, Load Profile LP02

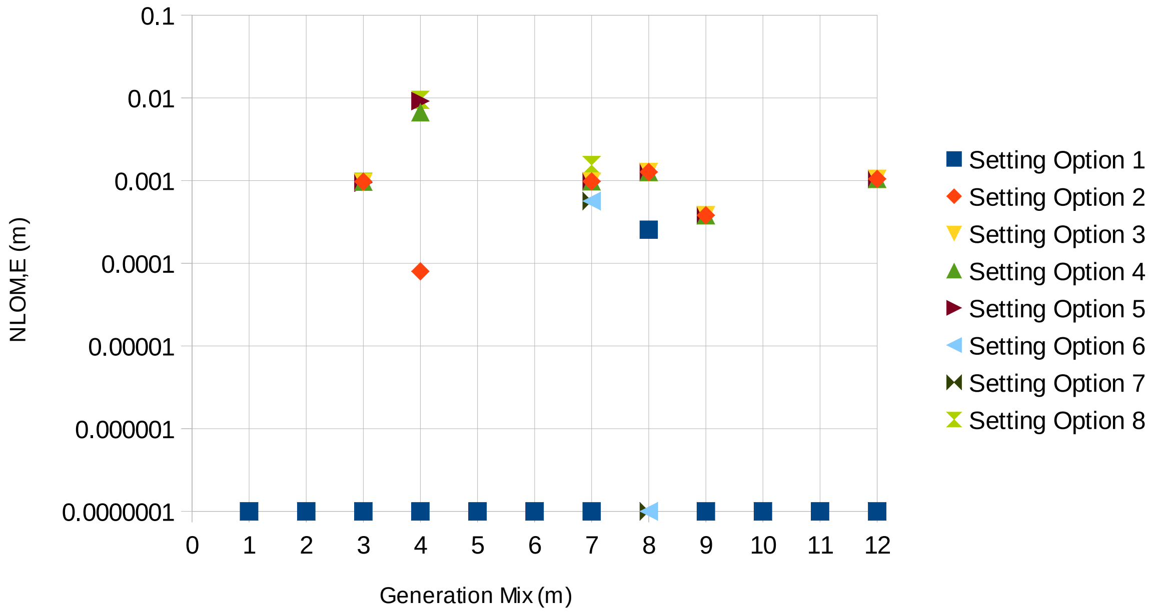

Figure 31. Probability $N_{LOM,E}$ of undetected islanding operation – Scenario 1, Load Profile LP03

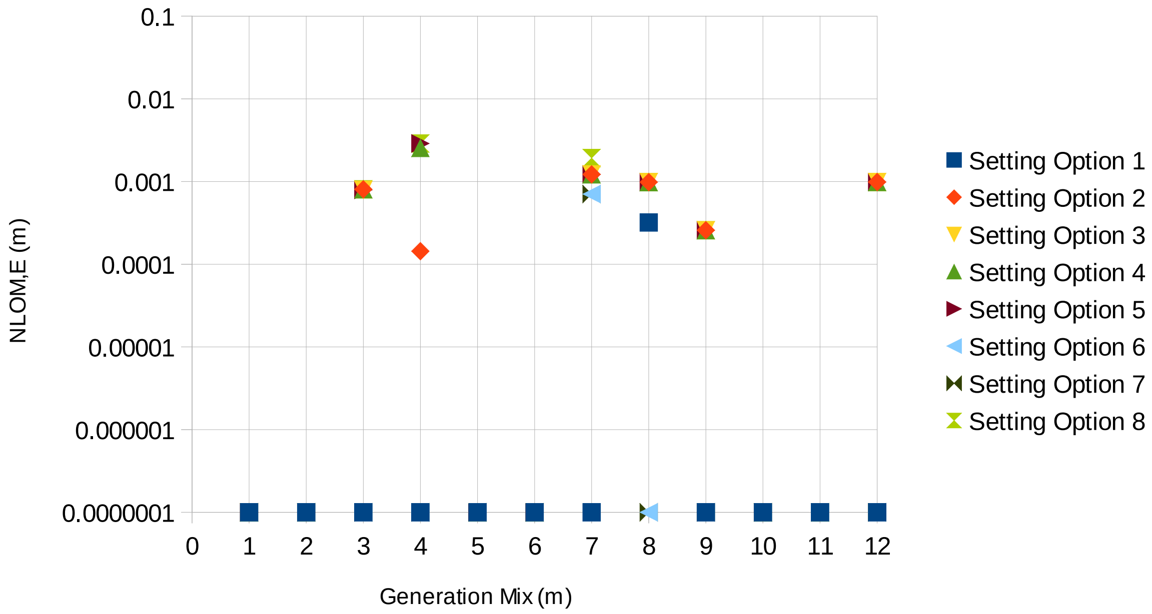

Figure 32. Probability $N_{LOM,E}$ of undetected islanding operation – Scenario 1, Load Profile LP04

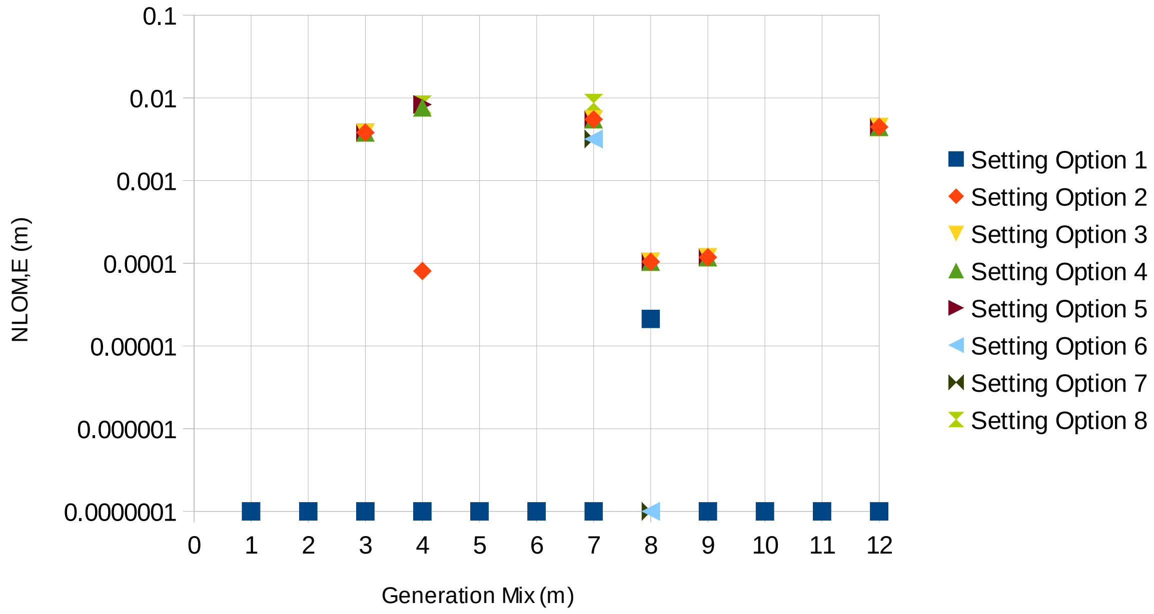

Figure 33. Probability $N_{LOM,E}$ of undetected islanding operation – Scenario 1, Load Profile LP05

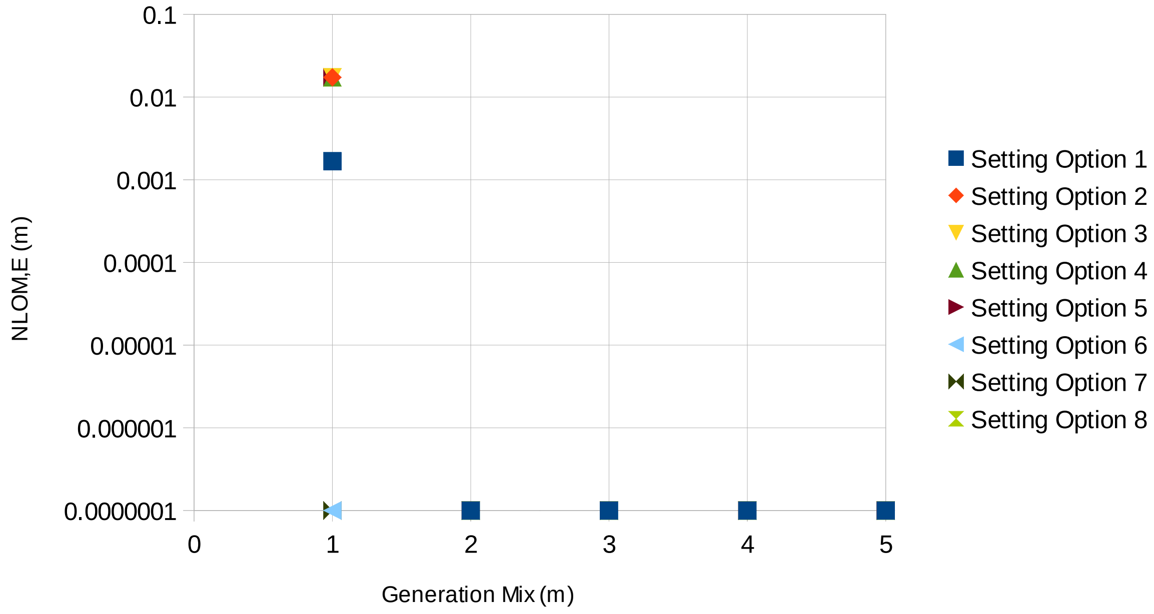

Figure 34. Probability $N_{LOM,E}$ of undetected islanding operation – Scenario 2, Load Profile LP06

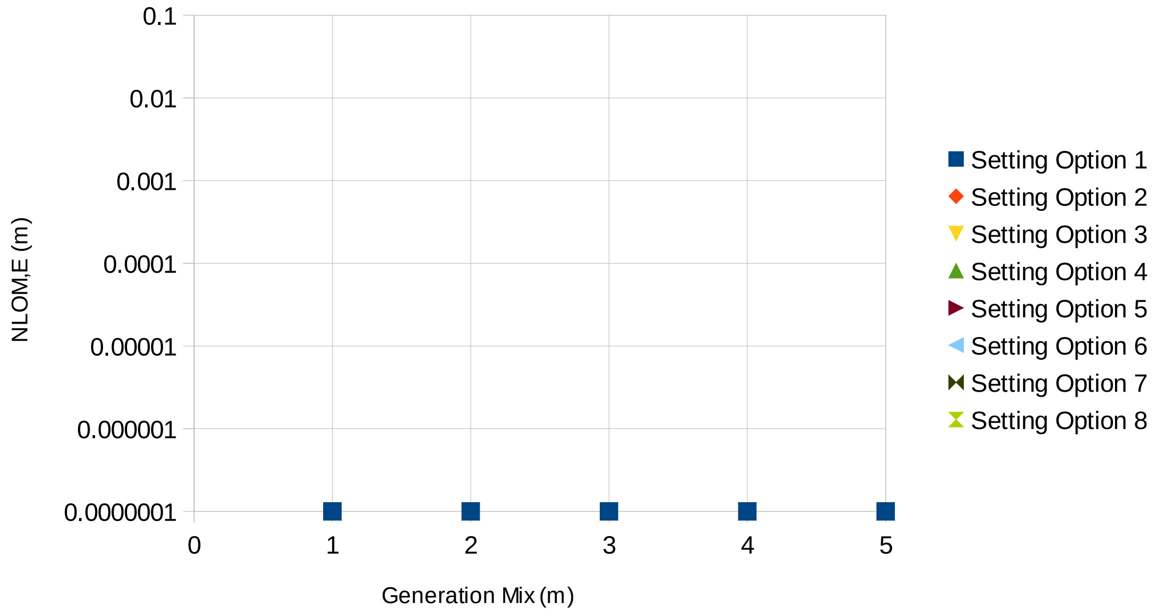

Figure 35. Probability $N_{LOM,E}$ of undetected islanding operation – Scenario 2, Load Profile LP07

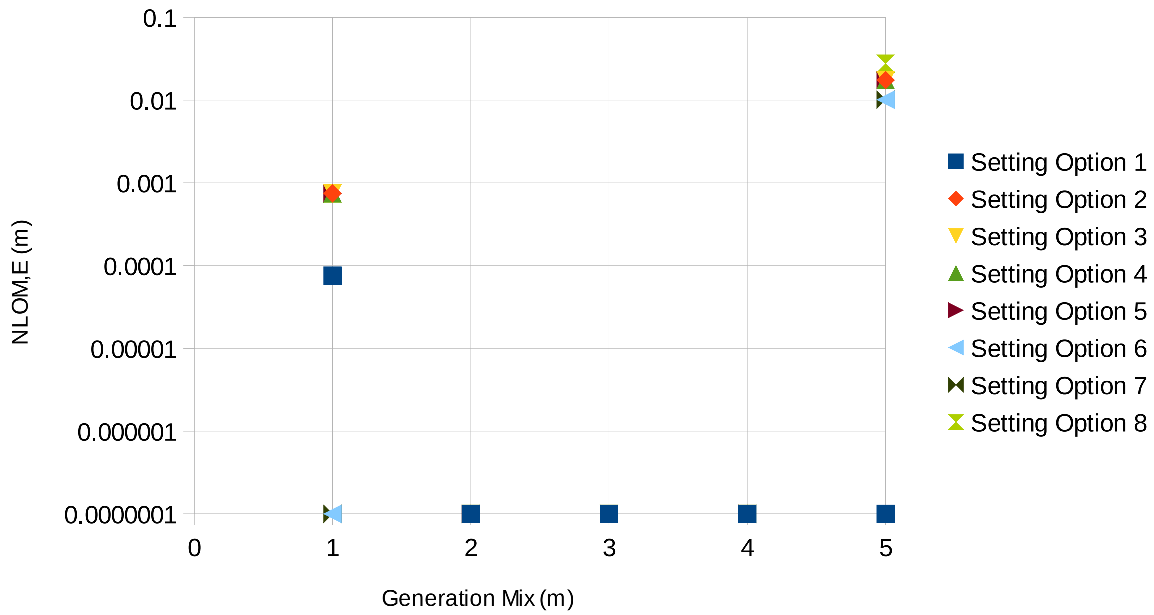

Figure 36. Probability $N_{LOM,E}$ of undetected islanding operation – Scenario 2, Load Profile LP08

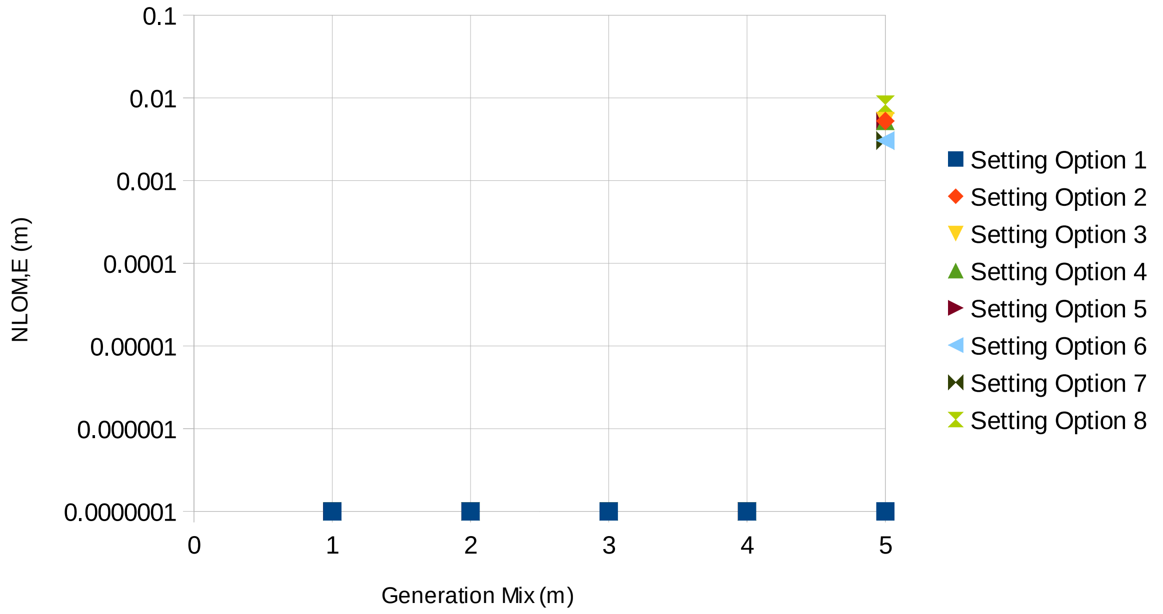

Figure 37. Probability $N_{LOM,E}$ of undetected islanding operation – Scenario 2, Load Profile LP09

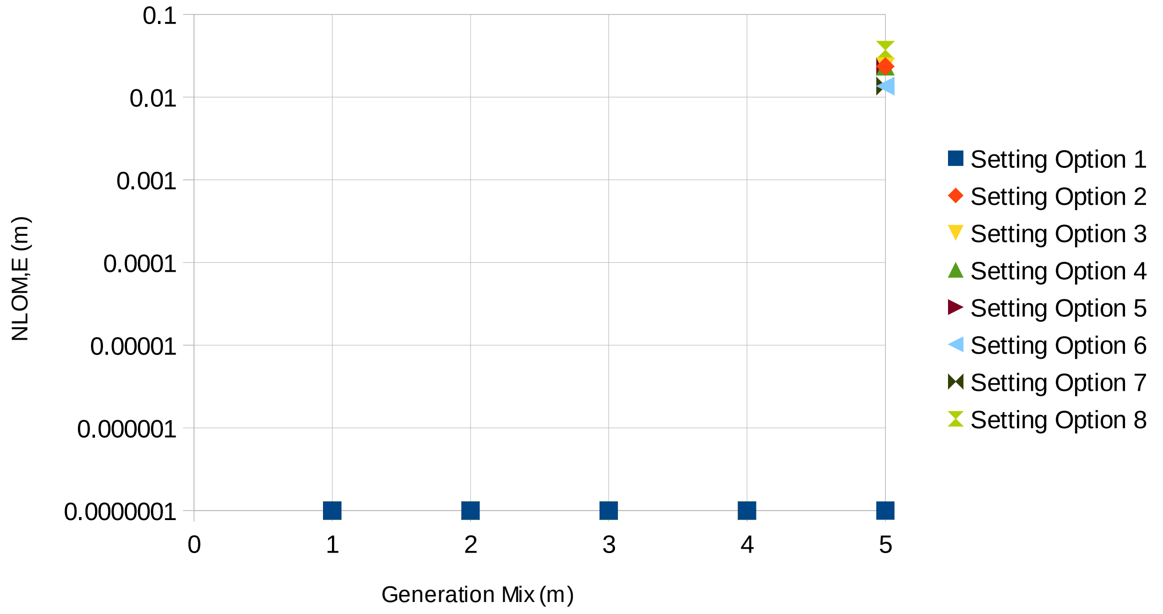

Figure 38. Probability $N_{LOM,E}$ of undetected islanding operation – Scenario 2, Load Profile LP10