Frequency Changes during Large Disturbances and their Impact on the Total System

Volume 4

This document contains the University of Strathclyde Assessment of Risks Resulting from the Adjustment of ROCOF based Loss of Mains Protection Settings.

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Technical Report

Assessment of Risks Resulting from the Adjustment of ROCOF Based Loss of Mains Protection Settings

Phase I

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Abbreviations and symbols

NDZ	- Non-Detection Zone
LOM	- Loss-Of-Mains
P_L, Q_L	- active and reactive power of the load
P_{DG}, Q_{DG}	- active and reactive power supplied by the distributed generator
$NDZP_a, NDZQ_a$	- accelerating NDZ (generator output is higher than the local load during LOM)
$NDZP_d, NDZQ_d$	- decelerating 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 supplying power P_{DG}, Q_{DG}
P_3	- probability of non-detection zone duration being longer than T_{NDZmax}
$N_{LOG,1SS}$	- expected number of incidents of losing supply to a primary substation in 1 year
n_{LOG}	- number of Loss-Of-Grid incidents experienced during the period of T_{LOG} in a population of n_{PRIME} primary substations
$N_{LOM,1DG}$	- 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_{DG}	- number of all connected distributed generators in UK
p_{ROCOF}	- proportion of generators with ROCOF based LOM protection
LF	- generator load factor (understood as proportion of time the generator is connected to the network at rated output)
N_{LOM}	- expected national number of undetected islanding incidents in 1 year
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	- probability related to individual risk
IR_E	- probability related to individual risk from the energised parts of an undetected islanded network
IR_{OA}	- probability related to individual risk from generator damage following an out-of-phase auto-reclosure
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

Executive Summary

There are growing concerns relating to reduced inertia within power systems in the future and the impact this may have on the stable connection of distributed generation (DG). In particular, achieving a balance between sensitive and stable operation of ROCOF based loss of mains (LOM) protection for DG is becoming more difficult. Changing the recommended LOM settings to enhance the stability of DG interface protection can potentially increase the likelihood of islanding non-detection. Consequently, the risks associated with islanding non-detection may be increased.

The work reported in this document assesses and quantifies the risks associated with proposed changes to ROCOF protection settings from the point of view of individuals' safety and equipment damage through out-of-phase auto-reclosing. This ascertains whether the risk of non-detection, under the proposed setting changes, is acceptable in light of the Health and Safety at Work act 1974 and other related utility policies and guidelines. To achieve this, experimental work has been carried out to determine the potential islanding non-detection zone (NDZ) associated with different ROCOF settings. This work has considered synchronous DG connected using different control regimes.

The NDZ reflects the surplus/deficit power supplied by the DG prior to islanding and is expressed as a ratio of this power to the DG rating. The experimental work uses a hardware in the loop testing approach which incorporates a DG interface relay commonly used in the UK. The NDZ data has been utilised by the developed risk assessment methodology to determine the probability of islanding non-detection and consequently the associated risks. In addition to the NDZ data, the methodology makes use of annual load profiles and statistics relating to incidences of loss of primary substation supplies.

The report evaluates the potential impact of the proposed ROCOF setting adjustments on distributed generation with capacities of between 5MW and 50MW only (Phase I). Smaller scale generation (including PV) is expected to be evaluated in follow-on phases of this work.

It has been shown that the DG control mode has a significant impact on its ability to sustain an island and consequently the size of the NDZ. This is particularly evident when the generator is capable of providing reactive power to the islanded network with higher ROCOF settings. It has also been shown that there are significant increases in the probability of non-detection of islanding if the ROCOF settings are increased from prevailing recommended levels (as is being proposed). However, it is concluded that the calculated risk to individuals remain mostly within acceptable levels under the proposed setting changes when applied to generators within the 5-50MW range. The report does not attempt to quantify the consequences of the out-of-phase auto-reclosing, and therefore, the calculated annual rates of occurrence need further analysis to aid the decision process.

1 Introduction

This report describes the outcomes of work conducted at the University of Strathclyde to assess the risks associated with the adjustment of ROCOF based loss of mains (LOM) protection settings. This work has been commissioned by the joint working group of the UK Grid Code Review Panel (GCRP) and Distribution Code Review Panel (DCRP) which addresses the issue of system integrity under anticipated future low inertia conditions. Under such system scenarios, much higher maximum rates of change of frequency are expected. These ROCOF values are anticipated to be in excess of the existing protection settings recommendations included in G59/2 [1]. In order to prevent large amounts of distributed generation (DG) from spuriously tripping in reaction to non-LOM transients, the recommendation of increased ROCOF settings are presently being debated.

To inform this debate, the main objective of the work is to evaluate the risk to DNO networks and individuals (i.e. members of the public and/or personnel) associated with increasing the applied ROCOF protection settings (currently 0.125Hz/s) to 0.5Hz/s and 1Hz/s. This also takes into account the optional application of a ROCOF time delay of 500ms and a frequency dead-band setting of 49.5Hz to 50.5Hz (i.e. frequency range where operation of ROCOF is blocked).

The report contains two main sections corresponding to the work packages (WP) initially proposed prior to the commencement of the work:

- WP1 – Simulation based assessment of Non Detection Zone (NDZ): in this section, the NDZ is determined experimentally under varying ROCOF settings using hardware in the loop testing of a physical LOM protection relay with a real time simulation of the power network and distributed generator behaviour.
- WP2 – Calculation of probability of specific hazards at various ROCOF settings: in this section, a generic NDZ/risk characteristic is established based on the obtained NDZ values, available load profiles, and a few other assumptions.

1.1 Methodology

In order to meet the objectives outlined above, the work adopts the risk assessment methodology similar to the one previously applied by the researchers at Strathclyde to verify the requirement for NVD protection [2]. However, the underlying assumptions and risk tree used in this methodology are tailored to the specifics of this work. This methodology is illustrated in Figure 1.

A number of assumptions are made with regards to the network configuration including load representation, generation technology and its control. These are used to experimentally (through real time simulation) determine the extent of NDZ for different ROCOF setting options.

Furthermore, load profile data and annual fault statistics are utilised to estimate probabilities of islanding incidents and occurrences of balance conditions between local load and distributed generation output. Together, these are used to assess the risk of LOM non detection with the aid of the developed risk tree.

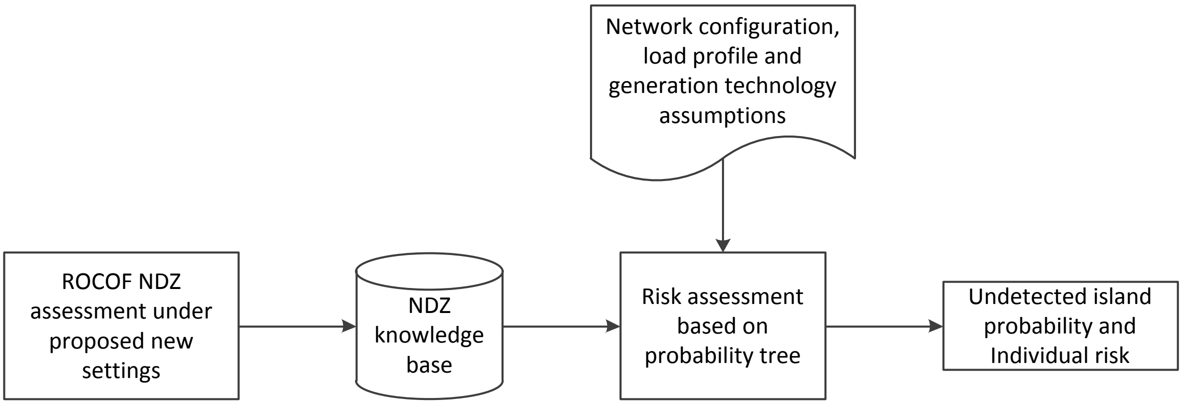

Figure 1. Risk assessment methodology

2 WP1 – Simulation based assessment of NDZ

2.1 WP1 overview

This section describes the main results and approach through which the NDZ has been experimentally determined for a range of ROCOF settings. A total of 11 test cases, corresponding to 11 setting options, have been performed on a 30MVA synchronous DG connected to a 33kV distribution network. Three spot tests have also been performed on a 3MVA synchronous DG connected to an 11kV network.

2.2 Network modelling

The network model used for the test is based on a reduced section of 33kV and 11kV distribution network, based on a typical UK network. The test 33kV network is depicted in Figure 2, while the 11kV network is shown in Figure 3. These models were used previously to evaluate the performance of LOM protection and to recommend suitable settings in [1] but have been adapted for the use in this study. The potentially islanded section of 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 PCC. The measured voltage (from which frequency is derived) at busbar 'A' is input to the relay under test. The network is modelled using a real-time digital simulator (RTDS) to allow credible testing of the physical LOM protection relay. Commercially available DG interface relay commonly used in UK practice has been utilised in this test. The network parameters are detailed in Appendix A.

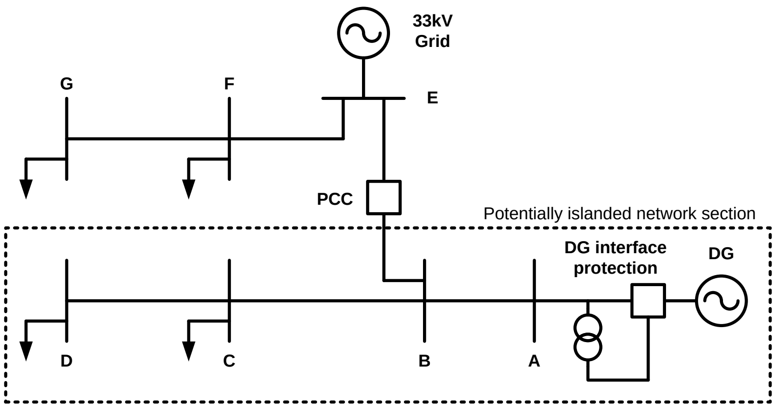

Figure 2. 33kV test network

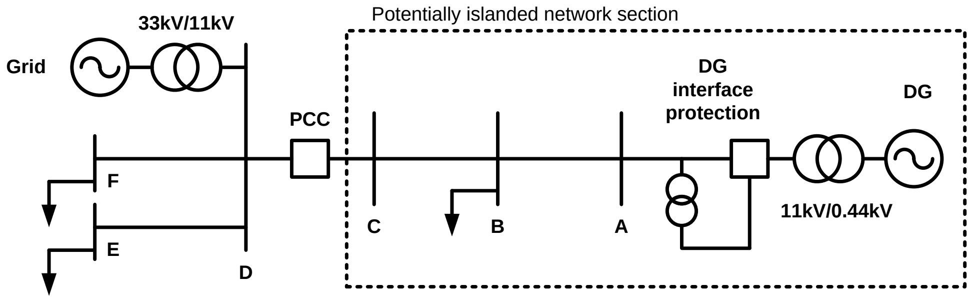

Figure 3. 11kV test network

The tests are carried out with two types of local load models: fixed power and fixed impedance; with a power factor of 0.98.

2.3 DG models and controls

For the first phase of testing, a synchronous machine based DG is modelled. The DG ratings used are 30MVA and 3MVA. The 3MVA generator is connected to the grid through a step up transformer. In this case, the interface transformer HV connection is not earthed [3]. Since no faults are applied in this work, the test results will not be affected by the absence of a transformer HV earthing point. Generator parameters are detailed in Appendix B. Two control modes are employed for:

- Fixed active power and voltage control (P-V control).
- Fixed active power control at unity power factor (P-pf control).

A standard IEEE governor/turbine model is used which is obtained from the RSCAD component library [4]. The block diagram for the governor control is depicted in Figure 4. The excitation control is achieved through combining voltage and reactive power control to either maintain a unity power factor or achieve fixed voltage control as shown in Figure 5 [5]. Controller parameters are detailed in Appendix C.

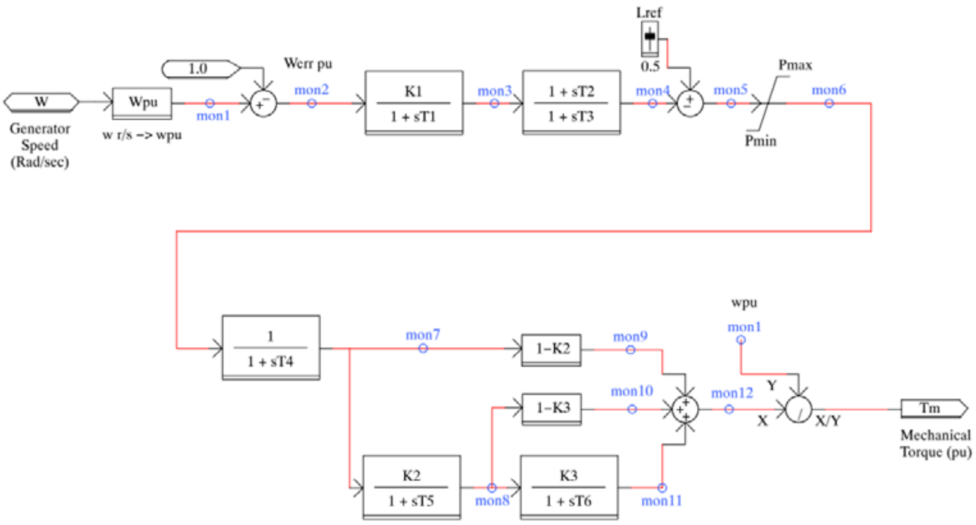

Figure 4. IEEE standard governor/turbine model [4]

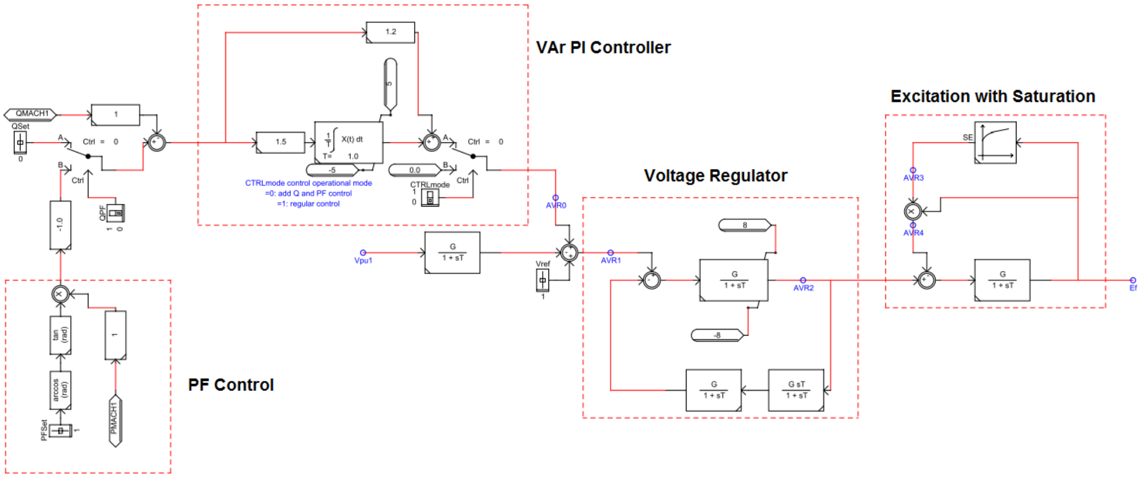

Figure 5. Combined reactive power and power factor control for generator excitation [5]

2.4 Experimental NDZ evaluation

The objective of this experimental evaluation is to determine the non-detection zone (NDZ) of the ROCOF protection relay as a percentage of DG MVA rating. The imbalance of active and reactive power through the PCC is adjusted independently to determine the NDZ for a range of ROCOF settings. Adjustments to the imbalance of power are achieved by changing the total local demand (i.e. load C and load D) while maintaining a constant pre-islanding DG output of 90% active power of its rating.

2.4.1 Hardware test setup

A commercial generator interface protection IED typically found in UK installations is used for testing. The following protection functions are enabled for all test cases:

- ROCOF.
- Under and over voltage (OV, UV), two stages.
- Under and over frequency (OF, UF), two stages.

The trip relay for each protection function is monitored separately to determine which functions (OV/UV/OF/UF/ROCOF) actually tripped for each test case and are recorded where appropriate. However, the assessment of NDZ focuses primarily on establishing ROCOF performance, but in cases where other elements have a narrower NDZ than the ROCOF element, then this is noted. The ROCOF settings used are summarised in Table 1. A frequency dead-band setting is used in some of the test cases. This inhibits ROCOF operation if the measured frequency lies within this band regardless of the measured rate of change of frequency. The voltage and frequency settings are summarised in Table 2.

The protection IED is tested using a hardware in the loop setup (HIL) as shown in Figure 6. Voltage measurements obtained from the RTDS are amplified to a nominal 110V before inputting into the relay. Disturbance records can be extracted from the IED if necessary (e.g. records of tripping out with the NDZ).

Table 1. ROCOF settings used for testing

Setting Options		Setting (Hz/s)	Delay (s)	Frequency dead-band (Hz)
proposed settings	1	0.5	0	0
	2	0.5	0.5	0
	3	1	0	0
	4	1	0.5	0
	5	0.5	0	49.5 – 50.5
	6	0.5	0.5	49.5 – 50.5
	7	1	0	49.5 – 50.5
	8	1	0.5	49.5 – 50.5
existing settings	9	0.12	0	0
	10	0.13	0	0
	11	0.2	0	0

Table 2. Voltage and frequency protection settings [1]

Protection functions	Settings	Delay (s)
UV stage 1	$V_{\phi\text{-}\phi}$-13%	2.5
UV stage 2	$V_{\phi\text{-}\phi}$-20%	0.5
OV stage 1	$V_{\phi\text{-}\phi}$+10%	1
OV stage 2	$V_{\phi\text{-}\phi}$+13%	0.5
UF stage 1	47.5Hz	20
UF stage 2	47Hz	0.5
OF stage 1	51.5Hz	90
OF stage 2	52Hz	0.5

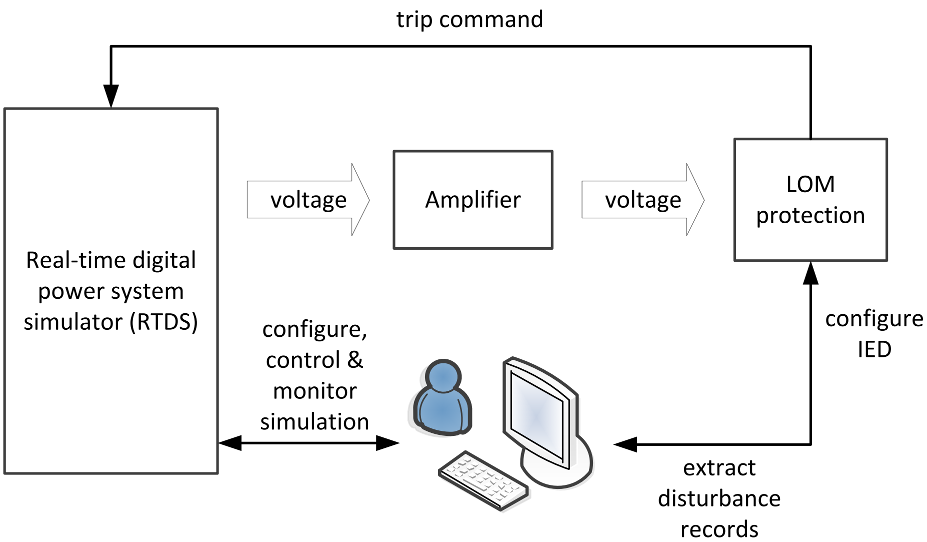

Figure 6. Hardware test setup for testing

2.4.2 Determining the NDZ

The NDZ is determined for both active and reactive power import and export across the PCC. The imbalance of one type of power is changed while holding the other type of power imbalance at 0% by adjusting the local demand (and generator reactive power output if necessary). The power imbalance is expressed as a percentage of the DG MVA rating. An automatic search routine developed specifically for this study is employed to iteratively change the power imbalances, inject the relay and monitor its trip response. With each incremental change in power imbalance across the PCC, the relay is injected with bus 'A' voltages to ascertain whether the level of imbalance lies within the NDZ. The reported values of NDZ are expressed according to (1):

$$NDZ_P = \frac{P_{pcc}}{S_{DG}} \times 100\%$$
$$NDZ_Q = \frac{Q_{pcc}}{S_{DG}} \times 100\% \qquad (1)$$

P_{PCC} and Q_{PCC} are the real and reactive power imbalances across the PCC. S_{DG} is the DG MVA rating.

2.5 NDZ assessment results

The main results for the experimental NDZ assessment are included in this section.

Table 3 summarises the NDZ values for the 30MVA synchronous generator due to active power imbalance. The NDZ values are shown for power import (DG decelerates after LOM) and power export (DG accelerates after LOM) across the PCC prior to islanding. These correspond to generator deceleration and acceleration respectively post islanding. The results are depicted for all ROCOF setting options, load models and generator control modes described earlier.

It can be seen from Table 3 that the maximum NDZ is around 18% for setting option 8. This is the case for the majority of control and load configurations. This is expected as setting 8 has the highest pickup level (with a dead band applied) as well as a time delay. The results are consistent for all PV control mode test cases where higher setting thresholds result in larger NDZ boundaries. ROCOF protection exhibits high sensitivity to islanding events before which power was imported from the grid and the generator was operating in P-pf control mode.

The results in Table 3 are also depicted in Figure 7 for comparison. The results are shown in groups of four control mode/load type pairs for each setting option. An NDZ was also determined for voltage protection during P-pf operation for fixed impedance loads. The associated NDZ values are summarised in Table 4.

Table 3. 30MVA synchronous generator ROCOF NDZ results summary for active power imbalance

	ROCOF NDZ [%] (deceleration)				ROCOF NDZ [%] (acceleration)			
Control mode	PV		P/PF		PV		P/PF	
Setting Option	Fixed power load	Fixed impedance load	Fixed power load	Fixed impedance load	Fixed power load	Fixed impedance load	Fixed power load	Fixed impedance load
1	5.94	6.9	0	0.17	-6.1	-7.11	-0.562	0
2	7.24	7.61	0	0.62	-7.16	-7.56	-7.73	-0.51
3	11.53	14.12	0	0.35	-12.35	-13.91	-13.76	-0.41
4	14.62	15.97	0	1.16	-14.55	-15.2	-16.67	-0.75
5	8.42	8.76	0	0.84	-8.44	-8.82	-9.89	-0.41
6	10.19	11.28	0	1.08	-10.56	-12.43	-12.19	-1.84
7	12.51	14.2	0	0.8	-13.13	-14.24	-15.66	-0.53
8	18.87	18.52	0	2.02	-17.65	-18.24	-18.75	-2.3
9	1.22	1.69	0	0	-1.31	-1.67	0	0
10	1.53	1.82	0	0	-1.55	-1.79	0	0
11	2.35	2.89	0	0	-2.37	-2.85	0	0

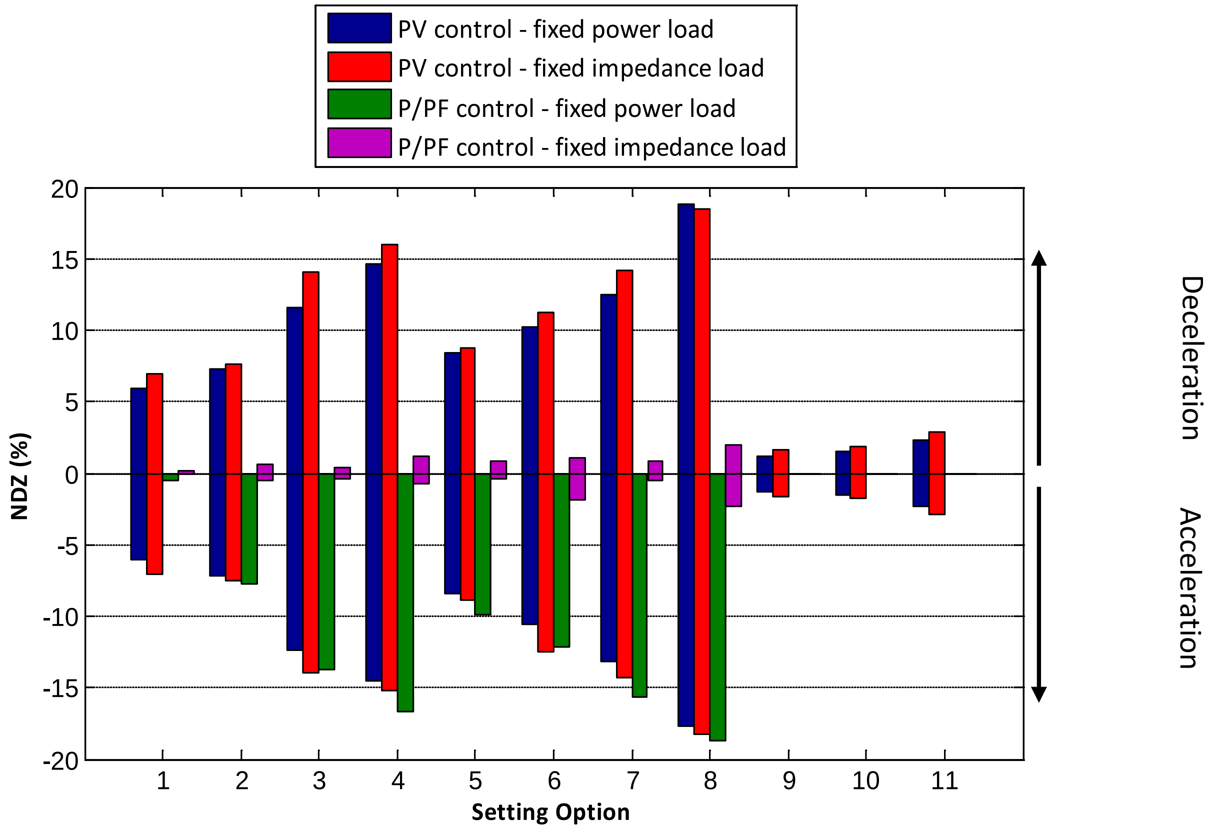

Figure 7. 30MVA synchronous generator ROCOF NDZ results for active power imbalance

Table 4. 30MVA synchronous generator voltage protection NDZ results summary for active power imbalance

	UV NDZ [%] (deceleration)		OV NDZ [%] (acceleration)	
Control mode	P/PF		P/PF	
Setting Option	Fixed power load	Fixed impedance load	Fixed power load	Fixed impedance load
1	0	2.31	0	no trip
2	0	2.94	0	-2.62
3	0	2.15	0	-2.09
4	0	2.28	0	-1.87
5	0	3.94	0	-2.06
6	0	2.11	0	-1.64
7	0	2.06	0	-2.2
8	0	2.1	0	no trip
9	0	no trip	0	no trip
10	0	no trip	0	no trip
11	0	no trip	0	no trip

The NDZ values for the 30MVA synchronous generator due to reactive power imbalance are shown in Table 5 and also depicted in Figure 8. A similar behaviour of ROCOF protection to the previous case is exhibited. The NDZ boundaries, however, are much larger where a maximum NDZ of 100% can be observed for PV control mode. This is attributed to the loose coupling between reactive power and system frequency. Nevertheless, beyond a certain point the generator will not be able to support the network voltage which leads to instability. NDZ values for voltage protection are shown in Table 6.

Table 5. 30MVA synchronous generator ROCOF NDZ results summary for reactive power imbalance

	ROCOF NDZ [%] (deceleration)				ROCOF NDZ [%] (acceleration)			
Control mode	PV		P/PF		PV		P/PF	
Setting Option	Fixed power load	Fixed impedance load	Fixed power load	Fixed impedance load	Fixed power load	Fixed impedance load	Fixed power load	Fixed impedance load
1	23.57	13.35	0	0	-17.6	-11.28	-19.76	-0.11
2	70.63	66.05	0	0.21	-88.91	-74.33	-20.02	-0.173
3	35.47	28.58	0	0.1	-38.87	-22.39	-27.05	0.167
4	87.67	88.48	0	0.38	-95.7	-99.92	-28.33	-0.44
5	54.22	52	0	0.38	-92.33	-42.17	-19.58	-0.174
6	84.15	85.38	0	0.48	-95.58	-81.27	-19.94	-0.64
7	61.08	60.7	0	0.11	-92.48	-48.03	-27.49	-0.25
8	99.97	99.99	0	0.52	-95.95	-100	-28.15	-0.64
9	4.8	2.64	0	0	-5.73	-2.9	0	0
10	4.1	3.23	0	0	-6.89	-3.6	0	0
11	6.99	4.6	0	0	-11.18	-4.67	0	0

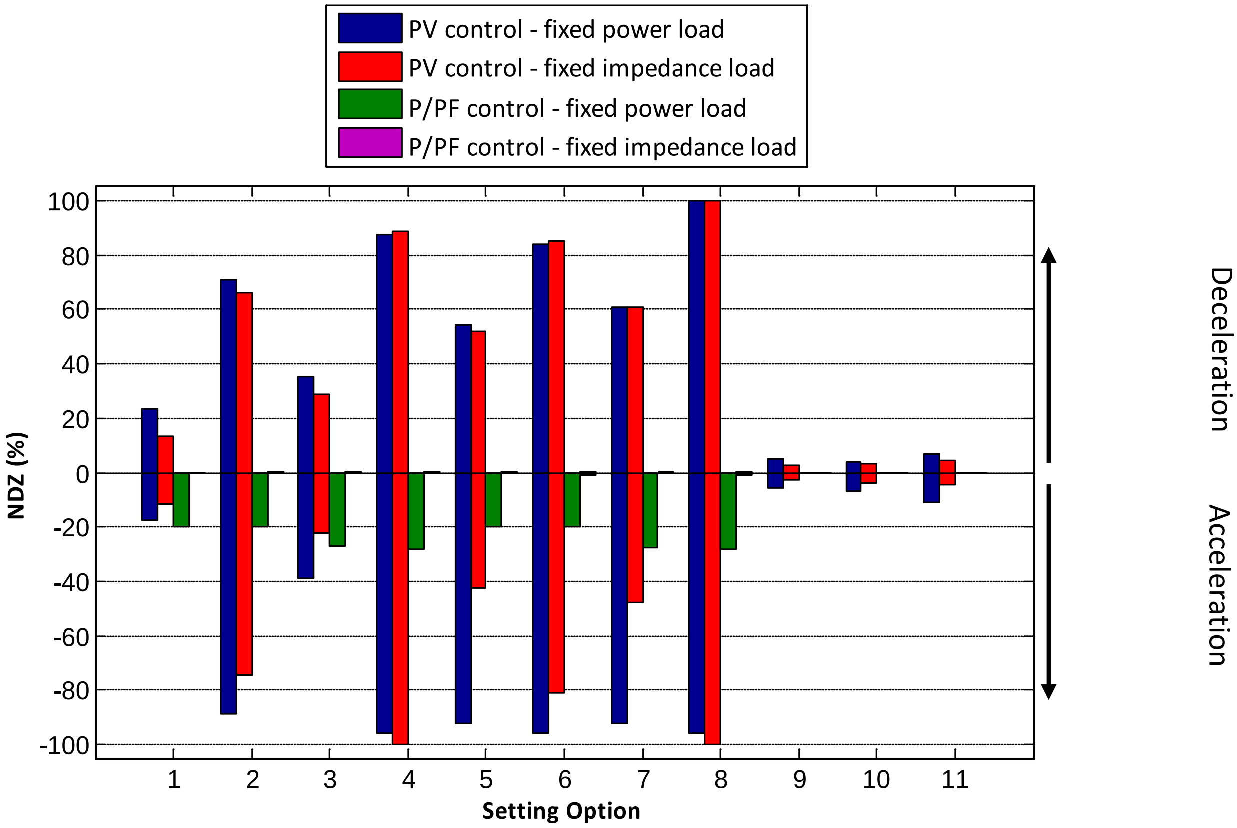

Figure 8. 30MVA synchronous generator ROCOF NDZ results for reactive power imbalance

Table 6. 30MVA synchronous generator voltage protection NDZ results summary for reactive power imbalance

	UV NDZ [%] (deceleration)		OV NDZ [%] (acceleration)	
Control mode	P/PF		P/PF	
Setting Option	Fixed power load	Fixed impedance load	Fixed power load	Fixed impedance load
1	0	0.66	0	no trip
2	0	1.63	0	-0.59
3	0	0.86	0	-0.57
4	0	0.84	0	-0.56
5	0	0.54	0	-0.54
6	0	0.7	0	-0.67
7	0	0.94	0	-0.53
8	0	0.59	0	-0.71
9	0	no trip	0	no trip
10	0	no trip	0	no trip
11	0	no trip	0	no trip

The remainder of the results are for the 3MVA generator where spot tests have been made for three setting options (1, 6 and 10). Table 7 summarises the NDZ values for these tests for active power imbalance. These are also depicted in Figure 9. The smaller generator size, and consequently lower inertia, makes it inherently unstable against disturbances. This is evident in the generally smaller NDZ boundaries compared to the larger 30MVA generator.

Finally, the NDZ values for reactive power imbalance related to the 3MVA generator are summarised in Table 8 and depicted in Figure 10.

Table 7. 3MVA synchronous generator ROCOF NDZ results summary for active power imbalance

	ROCOF NDZ [%] (deceleration)				ROCOF NDZ [%] (acceleration)			
Control mode	PV		P/PF		PV		P/PF	
Setting Option	Fixed power load	Fixed impedance load	Fixed power load	Fixed impedance load	Fixed power load	Fixed impedance load	Fixed power load	Fixed impedance load
1	3.28	3.31	0	1.98	-3.17	-2.76	-2.36	-2
6	8.17	9.62	0	2.34	-7.96	-8.97	-7.25	-1.64
10	0.74	0.6	0	0.47	-0.68	-0.8	-0.67	-0.22

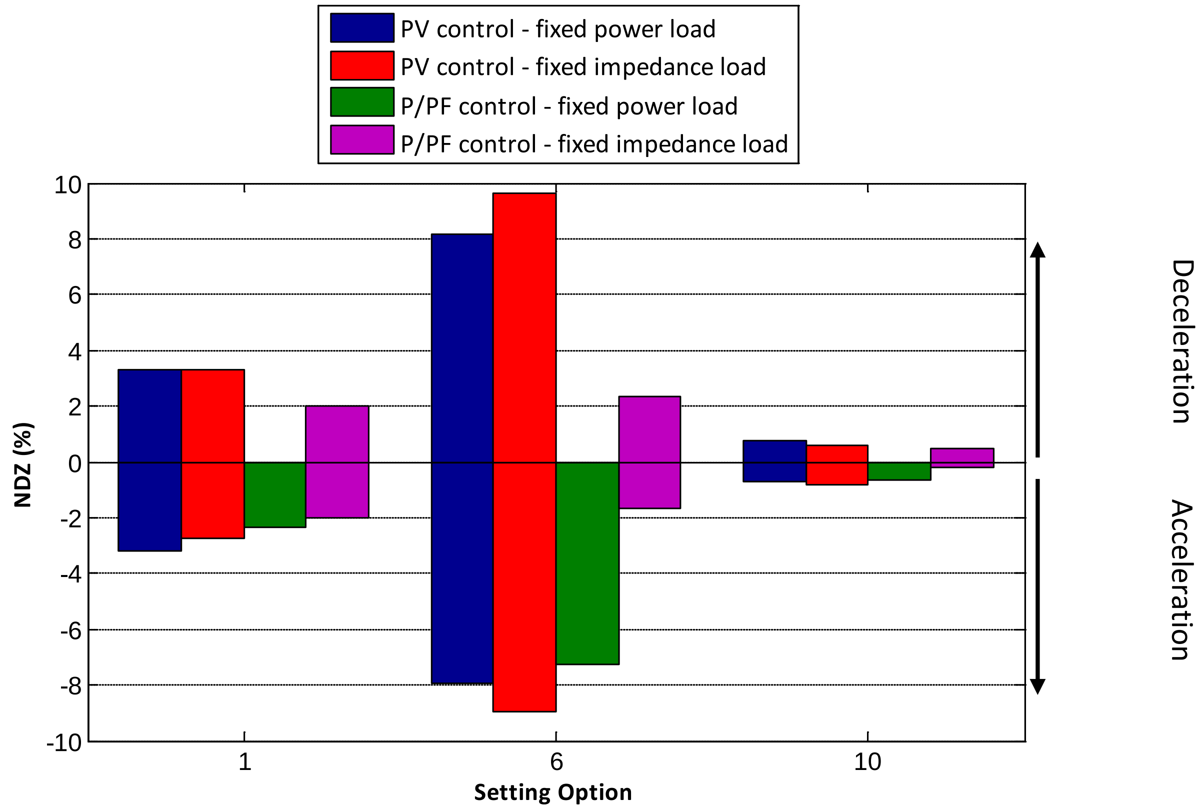

Figure 9. 3MVA synchronous generator ROCOF NDZ results for active power imbalance

Table 8. 3MVA synchronous generator ROCOF NDZ results summary for reactive power imbalance

	ROCOF NDZ [%] (deceleration)				ROCOF NDZ [%] (acceleration)			
Control mode	PV		P/PF		PV		P/PF	
Setting Option	Fixed power load	Fixed impedance load	Fixed power load	Fixed impedance load	Fixed power load	Fixed impedance load	Fixed power load	Fixed impedance load
1	41.53	8.26	0	3.13	-49.13	-8.72	-49.63	-3.17
6	51.2	38.23	0	63.53	-62.9	-45.53	-49.78	-0.71
10	7.33	2.11	0	0	-8.63	-1.55	0	0

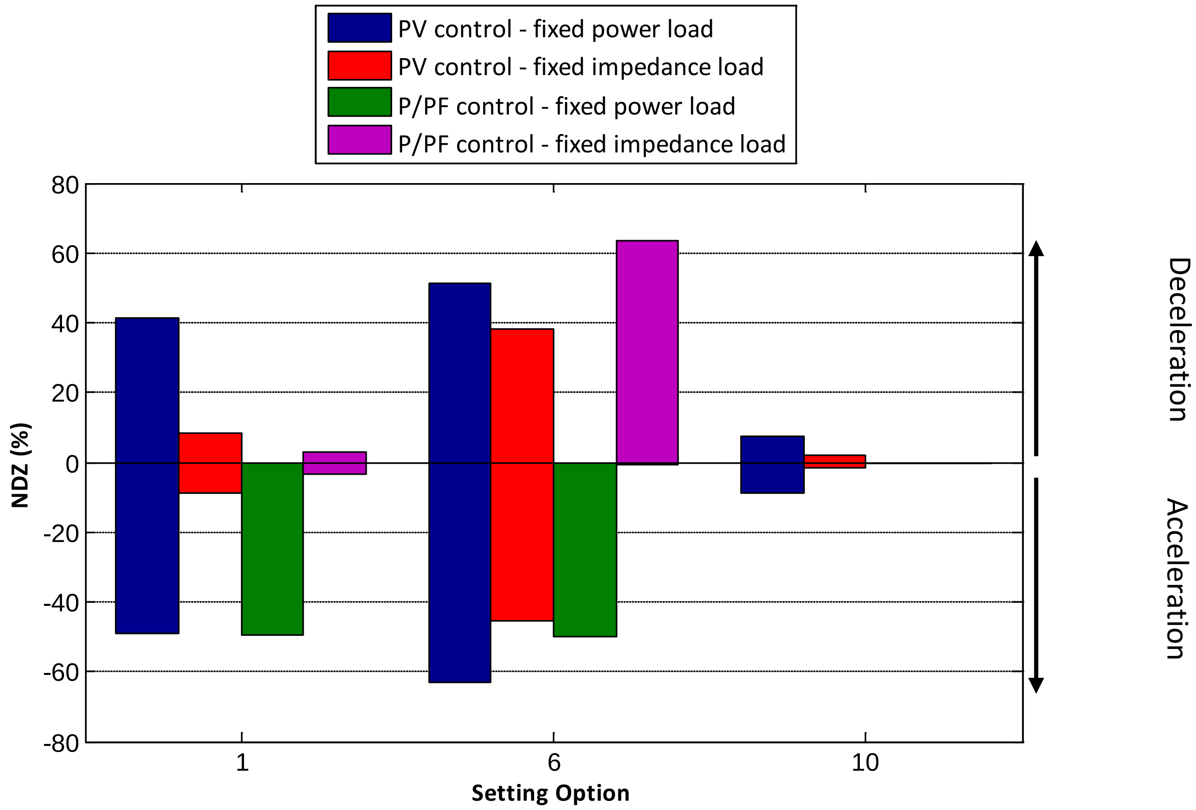

Figure 10. 3MVA synchronous generator ROCOF NDZ results for reactive power imbalance

3 WP2 – Risk level calculation at varying NDZ

3.1 Risk Calculation Methodology

The risk calculation methodology adopted in this work is similar to the method previously applied to verify the requirement for NVD protection [2]. This approach is based on a statistical analysis of the 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 generator and generator technology (refer to section 3.2 for details). It utilises the width of the Non Detection Zone (NDZ) established through laboratory testing and described earlier in in this document (WP1). Recorded typical utility load profiles and statistics of loss of supply to primary substations are also utilised to estimate probabilities of islanding incidents and load-generation matching. Assuming that the fault tree as presented in Figure 11 is used, the calculations, as described in the following sections of the document, are performed to assess:

a) personal safety hazard (the term Individual Risk IR is used in this report to denote the annual probability of death resulting from an undetected LOM condition), 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).

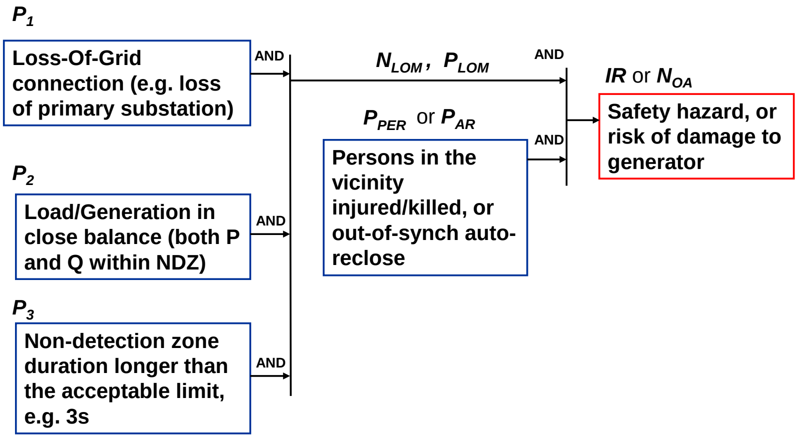

Figure 11. LOM Safety Hazard Probability Tree

3.1.1 Expected number of LOM occurrences in a single primary substation

For the purposes of this study (i.e. considering generator sizes between 5MW and 50MW) it was assumed that potential undetected islanding situations can only result from the loss of grid supply to primary substation. Other downstream faults involving isolation of individual 11kV circuits would typically not contain sufficient amount of islanded load to form balanced conditions with any of the generators considered in this report.

Accordingly, the expected number of incidents of losing supply to an individual primary substation during the period of one year can be estimated as follows:

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

where n_{LOG} is a number of loss of supply incidents experienced during the period of T_{LOG} in a population of n_{PRIME} primary substations.

3.1.2 Load/Generation balance within NDZ for a period longer than 3s (*P₂* and *P₃*)

Probabilities P_2 and P_3 are calculated jointly by systematic analysis of the example primary substation recorded load profiles. This is performed iteratively in two nested loops. The inner loop (iteration i) progresses through the whole duration of the given load record, while the outer loop (iteration j) covers the range of generator outputs between 5MW and 50MW in 1MW increments. In each 1MW band (termed here as generator group j) there is a certain assumed number of DGs $n_{DG(j)}$. This number is based on the actual distribution of synchronous machine based DG ratings as derived from the UK DG survey [6] and presented later in section 3.2.3 of this report. It should be noted that generator output and generator rating are synonymous in the context of this calculation as constant 100% generator loading at near unity *pf* is assumed in the analysis.

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 assumed fixed output of the distributed generator from the outer loop ($P_{DG(j)}$ and $Q_{DG(j)}$) to check if the difference falls within the assumed NDZ. This condition is described by (3).

$$NDZP_a < P_{L(i)} - P_{DG(j)} < NDZP_d \wedge NDZQ_a < Q_{L(i)} - Q_{DG(j)} < NDZQ_d \tag{3}$$

Where:

$P_{L(i)}, Q_{L(i)}$	- recorded samples of active and reactive load power
$P_{DG(j)}, Q_{DG(j)}$	- fixed active and reactive power of the generation group *j*
$NDZP_a, NDZQ_a$	- accelerating non detection zone (generator output is higher than the local load)
$NDZP_d, NDZQ_d$	- decelerating non detection zone (generator output is lower than the local load)

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 12. As illustrated in the figure, the probability $P_{3(j)}$ that the NDZ is longer than T_{NDZmax} can easily be obtained from the CDF.

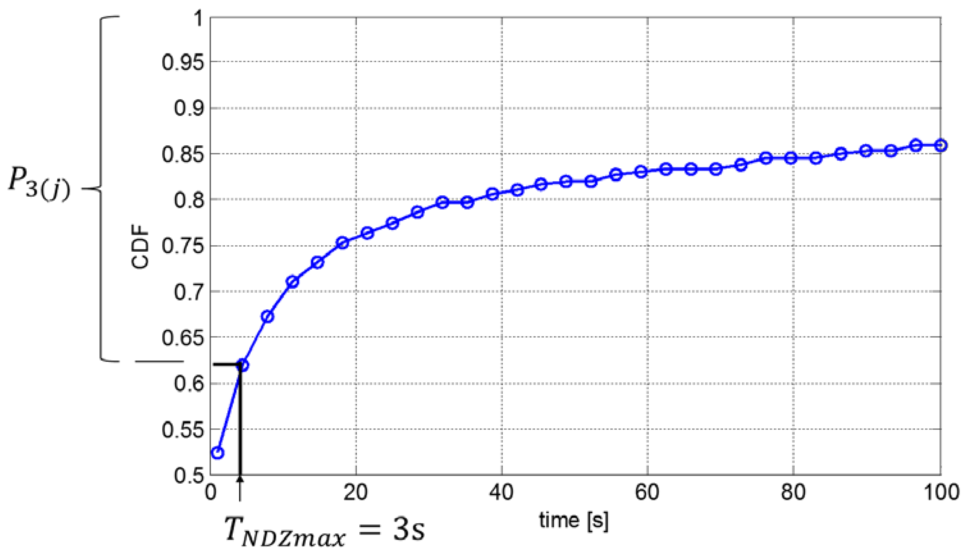

Figure 12. CDF of an example NDZ duration time

At the same time, the probability $P_{2(j)}$ of the load (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).

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

Where:

$n_{NDZ(j)}$	- number of detected NDZ periods within generation group *j*
T_{load_record}	- total length of the recorded load profile
$T_{NDZ(j)(k)}$	- length of k-th NDZ period.

Finally, the joint probability $P_{23(j)}$ for each generation group *j* can be calculated as (5) which leads to the development of the probability characteristic as shown in Figure 13.

$$P_{23(j)} = \frac{n_{DG(j)}}{n_{DG}} P_{2(j)} \cdot P_{3(j)} \tag{5}$$

where:

$n_{DG(j)}$	- number of generators in group *j*
n_{DG}	- total number of generators included in the study

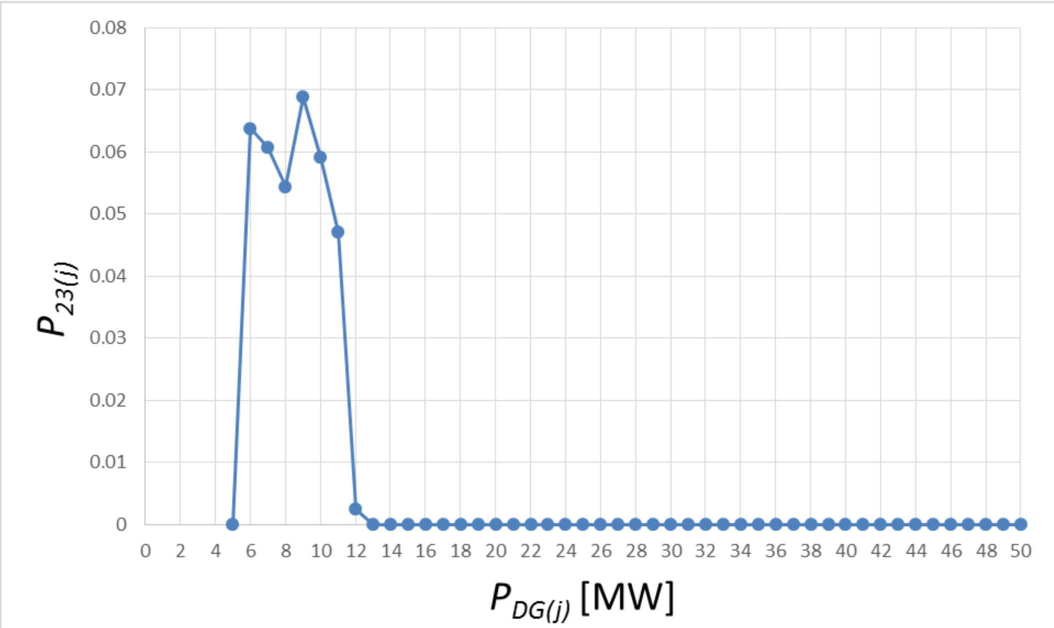

Figure 13. Non-detection zone probability at varying levels of generator output

Consequently, according to the principle of the marginal probability, the combined probability P_{23}, considering all generator sizes, is calculated using simple summation (6).

$$P_{23} = \sum_{j=1}^{n_{DGG}} P_{23(j)} \tag{6}$$

Where $n_{DGG} = 46$ is the number of generator groups.

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

$$N_{LOM,1DG} = N_{LOG,1SS} \cdot P_{23} \tag{7}$$

Additionally, the overall average duration of the NDZ (T_{NDZavr}) 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.

3.1.3 Calculation of national LOM probability figures and individual risk

Using the known total number of connected generators (n_{DG}) with an assumed proportion of ROCOF based LOM protection (p_{ROCOF}) and generator load factor (LF), the expected annual number of undetected islanding incidents (within mainland UK) can be estimated from:

$$N_{LOM} = N_{LOM,1DG} \cdot n_{DG} \cdot p_{ROCOF} \cdot LF \tag{8}$$

The expected cumulative time of undetected islanding conditions for all considered generators can be estimated using:

$$T_{LOM} = N_{LOM} \cdot (T_{LOMavr} - T_{NDZmax}) \tag{9}$$

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

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

$$P_{LOM} = \frac{T_{LOM}}{T_a} \tag{10}$$

Where:

T_a – period of 1 year

For a single generator with ROCOF protection, the probability can be calculated as:

$$P_{LOM,1DG} = \frac{P_{LOM}}{n_{DG} \cdot p_{ROCOF}} \tag{11}$$

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 in two ways:

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:

$$N_{OA} = N_{LOM} \cdot P_{AR} \tag{12}$$

where P_{AR} is the probability of out-of-phase auto-reclosing action following the disconnection of a circuit supplying a primary substation. Considering that in the vast majority of cases of losing supply to a primary substation auto-reclosing action would occur and also considering the fact that reclosure with small angle difference may be safe, the 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:

$$IR_E = P_{LOM} \cdot P_{PER,E} \tag{13}$$

$$IR_{AR} = N_{OA} \cdot P_{PER,G} \tag{14}$$

where $P_{PER,E}$ is the probability of a person in close proximity to an undetected islanded part of the system being killed, 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 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 which adopts the risk management principle often referred to as the 'ALARP' or 'As Low as Reasonably Practicable'. 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 [2] where the value of $P_{PER,E} = 10^{-2}$ was used. However, 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 quantify such probabilities.

The relative difference in the probability of undetected islanding condition under the existing recommended settings and the new proposed settings provides further guidance as to the acceptability of the proposed setting options.

3.2 Initial assumptions and available data

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

- Generation range considered 5MW – 50MW;
- Generation output is constant and equal to the rated power of the machine, with the output assumed to be generated at a power factor of $pf = 0.99\ (lagging)$. This is based on the sample generation profile provided by ScottishPower Manweb (SPM) and included in section 3.2.2.
- On average the generator load factor is *LF*=2/3 (i.e. generator is in operation 16 hours a day).
- 50% of all connected generators are assumed to be equipped with ROCOF relays ($p_{ROCOF} = 0.5$). The remaining generators have other forms of LOM protection.
- Detailed distribution of DG sizes and numbers in the UK were obtained from [6] (also refer to section 3.2.3 of this document for more details). Only DGs based on synchronous machine were considered in risk calculations (in the study the total number of generators $n_{DG} = 183$ is assumed based on [6]).
- Eight different load scenarios recorded in typical primary substations in the UK were used as described in section 3.2.1.

- A period of $T_{NDZmax} = 3$s was assumed as the maximum permissible duration of undetected islanding condition (i.e. no auto-reclosing faster than T_{NDZmax} is expected to occur).
- A period of $T_{ARmax} = 20$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).
- It is assumed that the generator does not continue to supply the system after an out-of-phase auto-reclosing operation.
- Potential undetected islanding situation can only result from the loss of grid supply to primary substation or supply point. The following primary substation incident records were available:
  a. ENW – in a population of 440 substations there were 96 loss of supply incidents during the period of 7 years,
  b. Northern Powergrid – in a population of 613 substations (including supply point sites) there were 258 loss of supply incidents during the period of 10 years.

  The combined figures were used to calculate expected annual number of LOM occurrences in a single substation according to equation (2) ($N_{LOG,1SS} = 0.0375$).

3.2.1 Available load profile data

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

3.2.1.1 Load Case 1 (SSE)

This record (using data provided by SSE) has been obtained from a 33kV substation feeding a mix of residential and industrial loads. The trace is presented in Figure 14 and is a combination of six days sampled evenly over a period of one year (i.e. one day of data recorded every two months). The original sampling period was 5s, but for the purposes of NDZ risk calculation, it has been re-sampled with a 1s time step using linear interpolation between the existing measurement points. It must be noted that this specific recorder was configured to only record new data when changes of load were greater than 1% of substation transformer capacity. In practice, with two transformer substations sharing the load and with smaller capacity DG connected, this needs a 3 to 5 % change in load (on the DG rating base) to register a change. Therefore, short term small load fluctuations which could affect the NDZ risk calculation are not recorded.

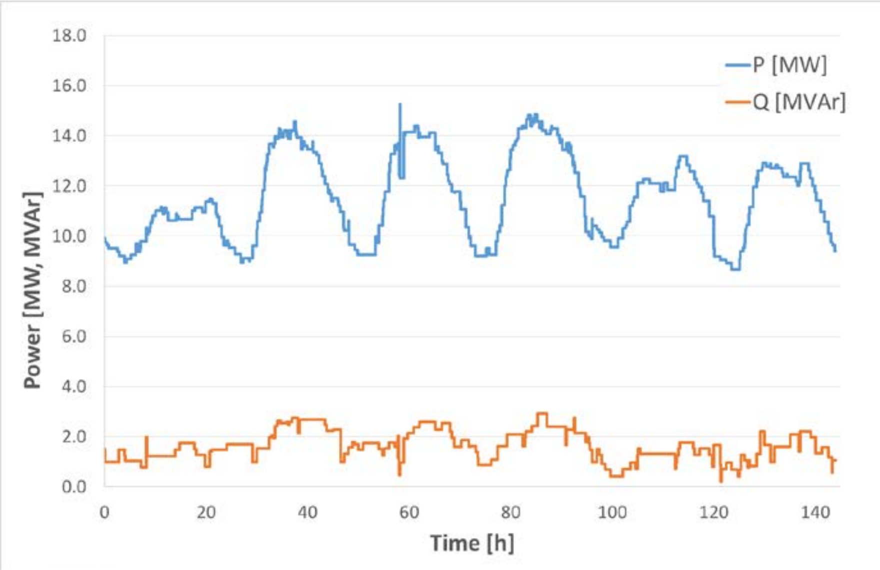

Figure 14. Load Case 1 (SSE) - mix of residential and industrial loads.

3.2.1.2 Load Case 2 (SPM)

This load trace is a summated combined load from three rural primary substations recorded simultaneously over a period of one day (Monday, 3 March 2013). As before, the original sampling period was 5s but this was subsequently resampled to obtain 1s resolution using linear interpolation between existing points.

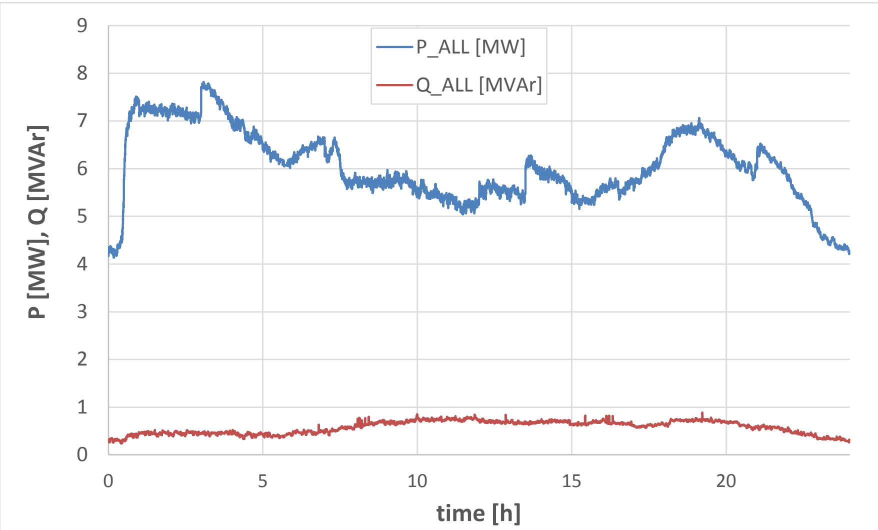

Figure 15. Load Case 2 (SPM) – combination of 3 rural substations

3.2.1.3 Load Case 3, 4, 5 and 6 (SPM)

Four different load profiles of varying peak demand (termed as Load Case 3, 4, 5, and 6 respectively) were formed using the SPM data recorded from an interconnected 33kV area with nine primary transformers. These load cases are illustrated in the following figures 16 to 19. The data was originally recorded with 30 minute time resolution over a period of 1 year but subsequently resampled with a 2 minute time step using linear interpolation.

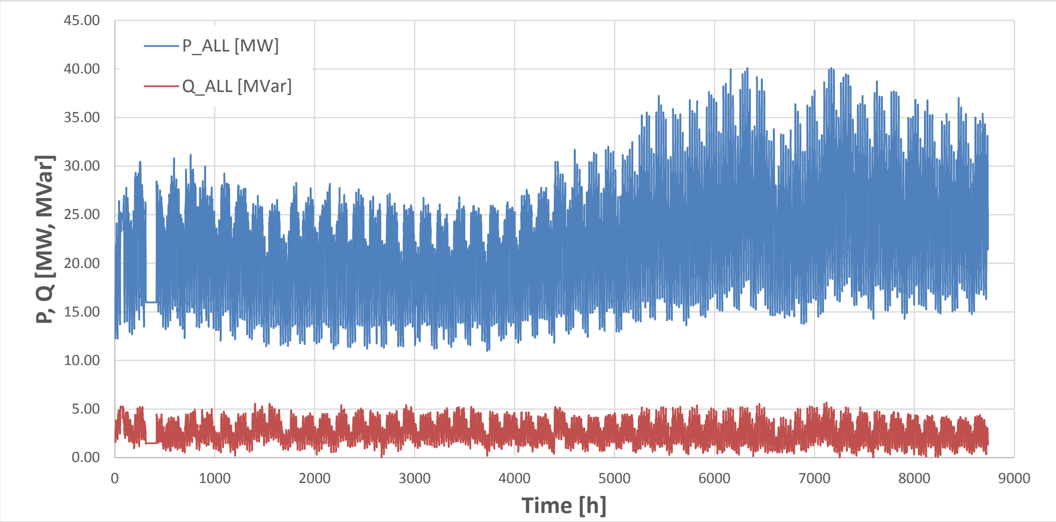

Figure 16. Load Case 3 (SPM) – combination of 9 interconnected primary transformers

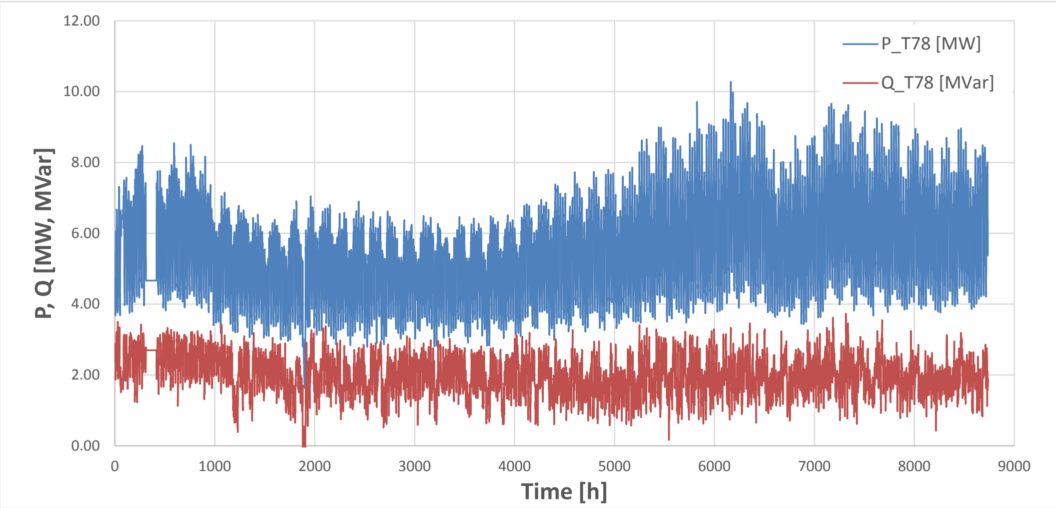

Figure 17. Load Case 4 (SPM) – combination of 3 rural substations

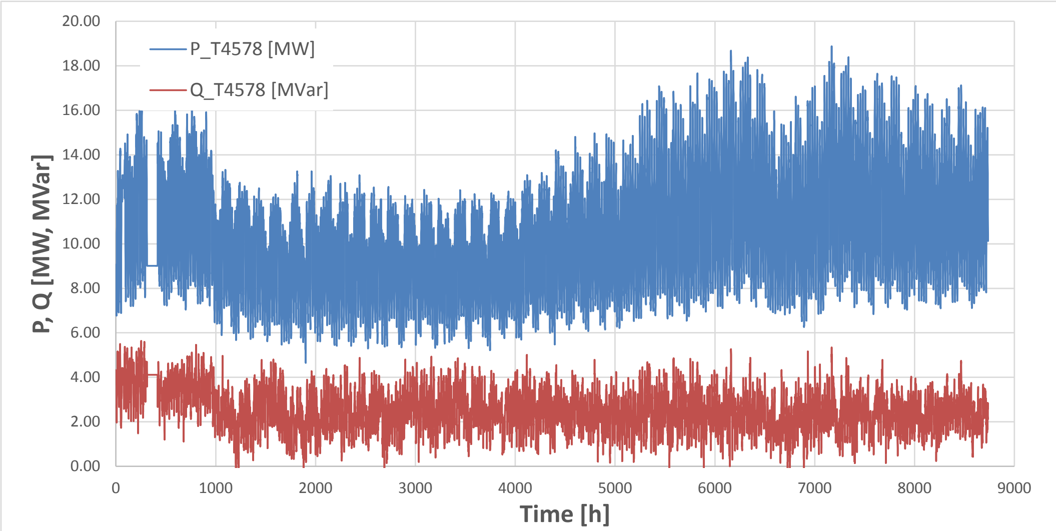

Figure 18. Load Case 5 (SPM) – combination of 3 rural substations

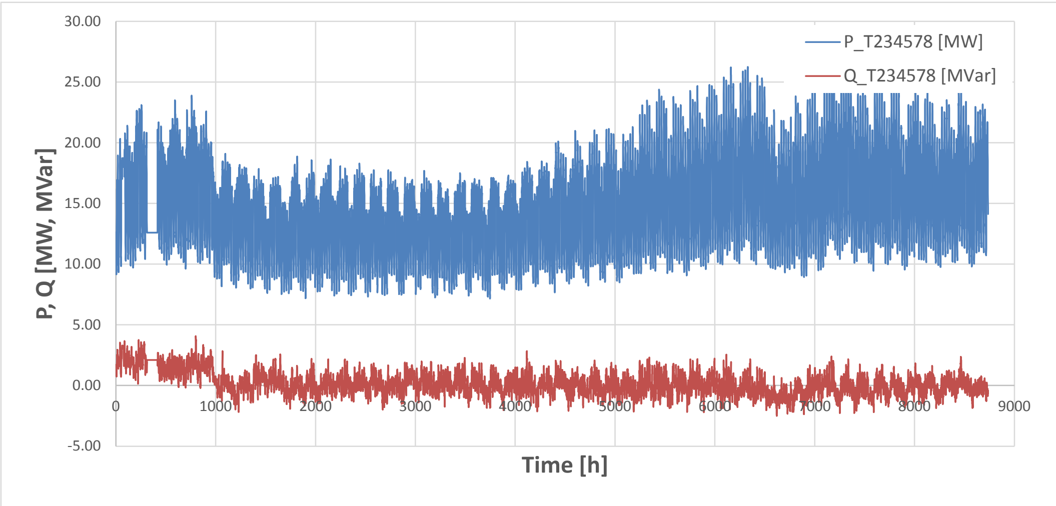

Figure 19. Load Case 6 (SPM) – combination of 3 rural substations

3.2.1.4 Load Case 7 and 8 (ENW)

These two records were obtained from the 6.6kV (2x11.5MVA) primary substations located in urban (Load Case 7) and suburban areas (Load Case 8). The data was originally recorded with 1s resolution over a period of four non-consecutive days (two weekdays and Saturday/Sunday) of the same week. For the risk calculation purposes and to preserve a balance between weekdays and weekend days, the remaining weekdays were created by repeating the available Wednesday and/or Thursday records.

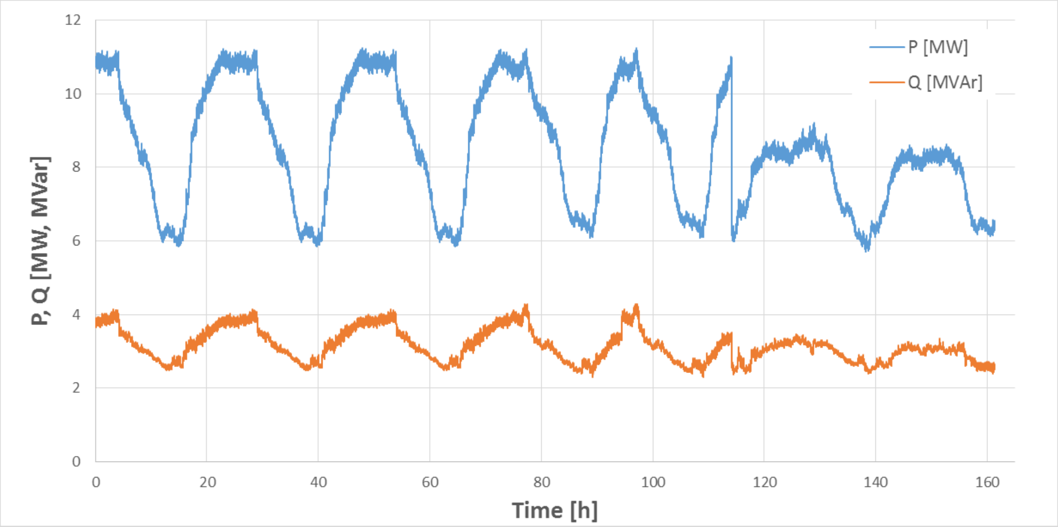

Figure 20. Load Case 7 (ENW) – urban substation

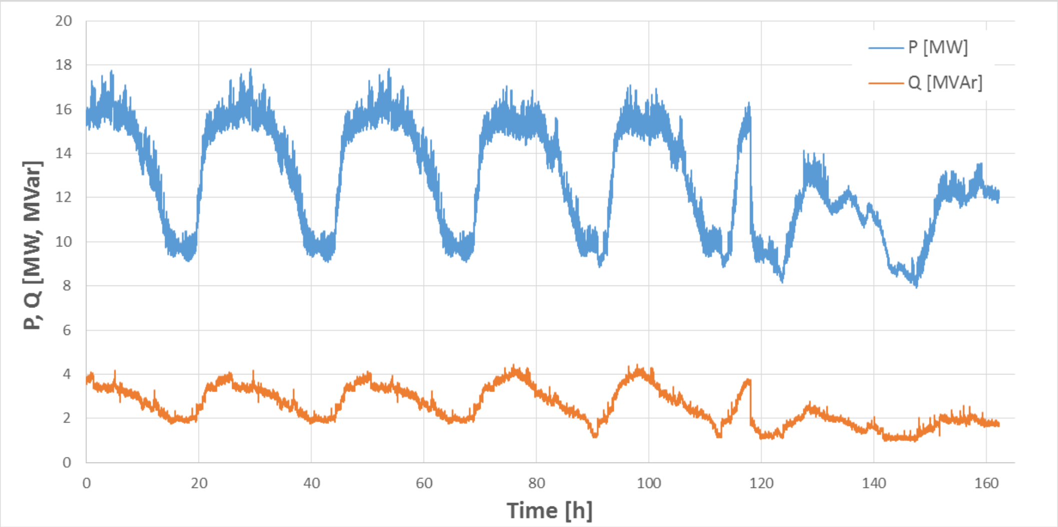

Figure 21. Load Case 8 (ENW) – suburban substation

3.2.2 Example DG profile

An example measured annual profile for of a 30MW DG was available as illustrated in Figure 22. It can be seen that the generator output is mostly constant and close to the installed capacity of the unit. The average power factor calculated from this data is 0.994 (lagging), i.e. the generator seems to be providing a very small amount of reactive power to the network (this should not be the case, and it could be that a measurement error is causing this to appear to be the case).

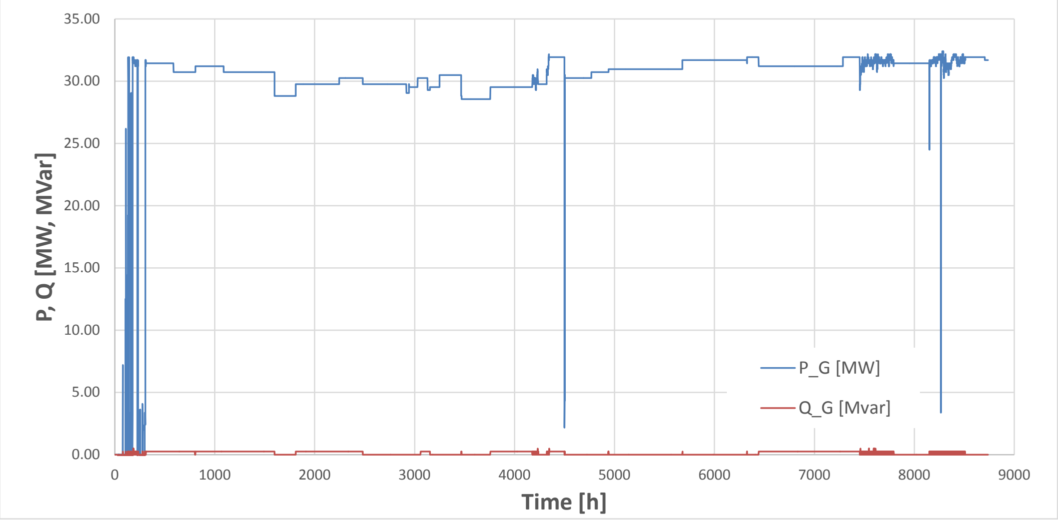

Figure 22. 30MW DG generation profile

3.2.3 UK generation between 5MW and 50MW.

Available records relating to UK-installed DG with capacities of 5 and 50MW [6] has been utilised to adequately represent the distribution of generator ratings. The histogram representing the distribution of synchronous machine based generation sizes is presented in Figure 23. The total capacity of this group of generators is currently 3236MW (74.3% of all DG in the UK falls within the 5-50MW range of ratings), with $n_{DG} = 183$ individual sites. These statistics are further used in marginal probability and overall risk calculations.

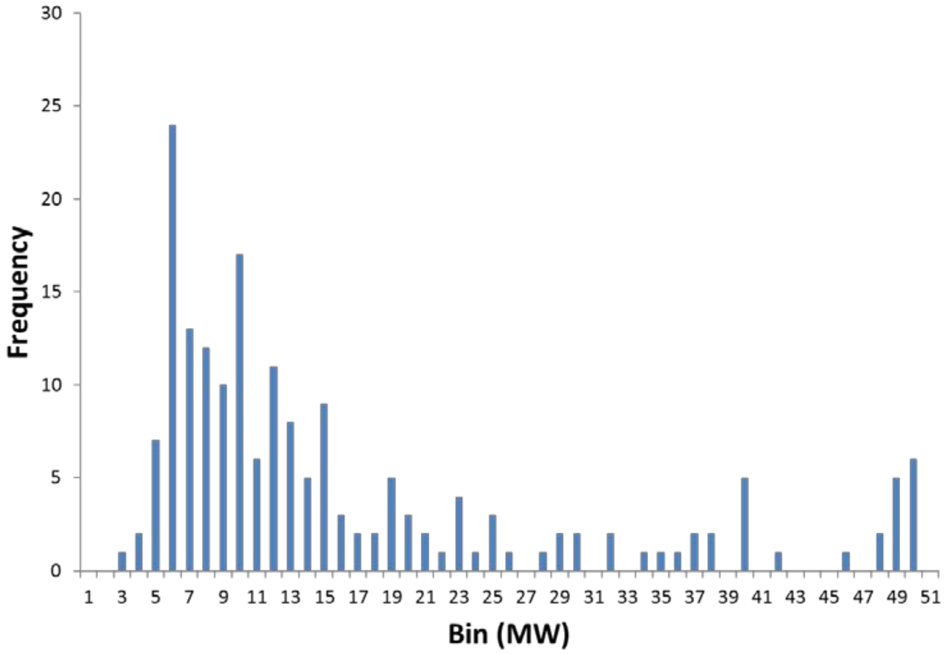

Figure 23. Histogram representing existing synchronous generator based DG in UK

3.3 Risk calculation results

The full numerical record of probability calculations performed on the eight available load profiles, considering eleven assumed setting options, two generator control types (P-V and P-pf), and two load models (fixed impedance and fixed power) is included in Appendix D. The results are initially presented considering ROCOF response only, and then also considering the overall response of DG interface protection including UV/OV and UF/OF modules (set according to G59/2 recommendation). Additionally, for ease of analysis, all results are also presented graphically in figures 25 to 32. 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.

It can be observed that scenarios with low 30min sampling resolution (load case 3, 4, 5, 6) result in probabilities which are approximately 2 orders of magnitude higher than those obtained from load cases 2, 7, 8 (sampled with 1s resolution). This issue is investigated further to verify if indeed the difference in the result originates from the low sampling rate or is due to some other factor(s).

Similarly, load case 1 also suffers from a similar effect due to the low measurement resolution of the data.

3.3.1 Sensitivity to sampling rate

In order to further verify the sensitivity of the results to sampling frequency, Load Case 8 was down sampled twice (to 5s and to 30min resolution respectively), and the probability of NDZ calculation was repeated with the result as shown in Figure 24. It can be seen that the same effect of increased probability by 2 orders of magnitude is manifested when both 1s and 30min data are used. Since the results presented in Figure 24 are all based on the same load profile, the only influencing factor is the sampling rate. Although an increase in the calculated probability is visible for case with 5s resolution data, the difference can be seen as acceptable.

Therefore, the final outcome, further discussion, conclusions and recommendations from this study are only based on the results obtained from load cases 2, 7 and 8 where data is sampled with 1s resolution.

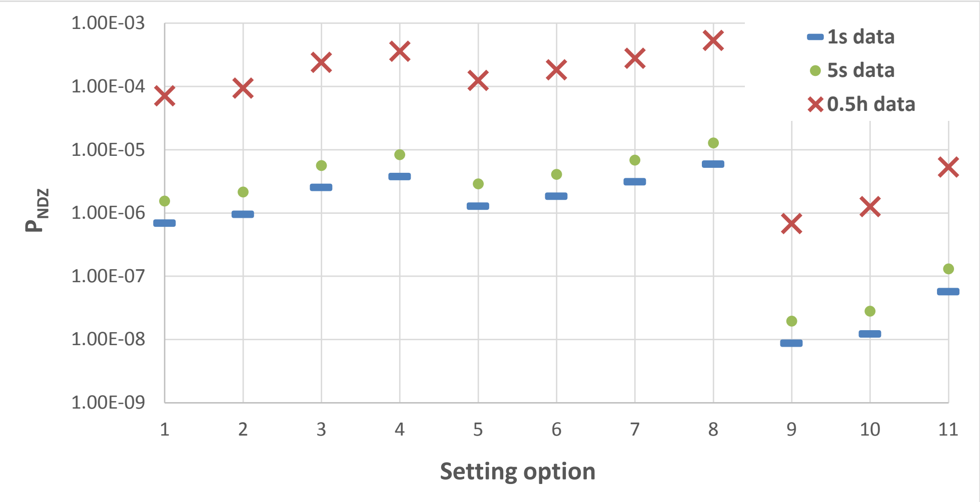

Figure 24. Impact of sampling frequency on NDZ probability calculation

3.3.2 Calculation of overall worst case based figures

Considering Load Cases 2, 7 and 8, the worst case probability figures N_{LOM} and P_{LOM} have been obtained (based on results in Appendix D) and both probability of Individual Risk (IR_E) and expected annual rate of occurrence of Out-of-phase Auto-reclosure (N_{OA}) calculated using the formulae (12) and (13). The results are presented in Table 9 and Table 10 for P-V and P-pf controlled generators respectively.

Table 9. Worst load profile based figures for P_{LOM}, IR_E and N_{OA} (generator in P-V control mode)

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

Table 10. Worst load profile based figures for P_{LOM}, IR_E and N_{OA} (generator in P-pf control mode)

Setting Option	ROCOF [Hz/s]	Time Delay [s]	Dead Band applied	N_{LOM}	P_{LOM}	IR_E	N_{OA}
1	0.5	0	No	0.00E+00	0.00E+00	0.00E+00	0.00E+00
2	0.5	0.5	No	1.03E-04	1.43E-11	1.43E-13	8.26E-05
3	1	0	No	0.00E+00	0.00E+00	0.00E+00	0.00E+00
4	1	0.5	No	5.70E-04	1.57E-10	1.57E-12	4.56E-04
5	0.5	0	Yes	2.21E-04	4.00E-11	4.00E-13	1.77E-04
6	0.5	0.5	Yes	9.79E-04	3.92E-10	3.92E-12	7.83E-04
7	1	0	Yes	1.27E-04	1.97E-11	1.97E-13	1.01E-04
8	1	0.5	Yes	2.00E-03	1.03E-09	1.03E-11	1.60E-03
9	0.12	0	No	0.00E+00	0.00E+00	0.00E+00	0.00E+00
10	0.13	0	No	0.00E+00	0.00E+00	0.00E+00	0.00E+00
11	0.2	0	No	0.00E+00	0.00E+00	0.00E+00	0.00E+00

As a consequence of the assumed initial conditions and the scope of the study, the above figures represent the probabilities of the perceived hazards (*IR* and *OA*) under eleven different ROCOF protection setting options when applied to all existing synchronous generators in UK with ratings between 5MW and 50MW. 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 183 existing connections, 50% assumed to have ROCOF based LOM protection and all assumed to be in operation for an average of 16 hours each day (*LF*=2/3). In the future, all probabilities will increase (or decrease) in proportion to the total number of separate DG connections using ROCOF.
- The results do not attempt to assess the change of ROCOF settings on other smaller generators (<5MW). Due to the large numbers of such connections and higher anticipated number of LOM incidents for these installations, the overall risk is expected to be consequently higher too.
- The study does not include the assessment of the impact of the change of protection practice to other forms of LOM protection (e.g. vector shift).
- Wherever exact data was not available, pessimistic assumptions were always made so that the final probability values will ideally never be lower than reality.
- The results are expressed as probabilities of specific events or occurrences happening within a period of one year. By inverting these values, the average expected time between such occurrences can be calculated.

4 Conclusions

When analysing the results the following observations can be made:

- The generator control strategy has a fundamental impact on its ability to sustain islanded operation.
- The probability of sustained islanded operation is highly unlikely with any protection settings, when the existing prevailing control strategy based on fixed real power output and unity *pf* is applied.
- There is a significant difference (between one and two orders of magnitude) in the probability of undetected islanded operation between the existing recommended ROCOF settings (setting options 9 to 11) and all considered new setting options 1 to 8.
- There are differences among the proposed setting options 1 to 8, but these are less pronounced than those between the existing G59/2 settings 9 to 11 and the setting options 1 to 8.
- When analysing the response of the relay with all G59/2 protection modules enabled, it can be observed that the NDZ is determined by the sensitive operation of the ROCOF module which sends a tripping signal before voltage or frequency protection operates (in the vast majority of cases). It is only in the case where the generator is in P-V control mode and the load is represented as fixed power, that the operation of the OV relay determines the NDZ width rather than ROCOF. This can be observed for example in load profiles 2 (Figure 26) and 8 (Figure 32).
- The Individual Risk (IR_E) resulting from the undetected energised islanded system (based on the worst case results) lies within the broadly acceptable region for all setting options according to the Health and Safety at Work Act 1974, i.e. the probability of a safety hazard is significantly less than 10^{-6} (at least 3 orders of magnitude).

- The rate of occurrence of out-of-phase auto-reclosing (N_{OA}) appears to be high and cannot be neglected, particularly for P-V controlled generators. Further assessment of the anticipated costs and individual risks associated with out-of-phase auto-recourse is required.
- The calculated probability levels for P-pf control regime (prevailing current operation mode) are 2 to 5 orders of magnitudes lower than corresponding values for the P-V controller generator.

5 References

[1] Electricity Networks Association, "ER G59/2: Recommendations for the Connection of Generating Plant to the Distribution Systems of Licensed Distribution Network Operators," 2010.

[2] Distribution Code Review Panel G59 NVD Working Group, “Embedded generation interface protection: Assessment of risks arising from relaxation in the application of neutral voltage displacement (NVD) interface protection.” Energy Networks Association, 31-Dec-2009.

[3] Electricity Networks Association, "ER G59/2: Recommendations for the Connection of Generating Plant to the Distribution Systems of Licensed Distribution Network Operators," 2010.

[4] RTDS Technologies, "RSCAD power system users manual," 2006.

[5] Adam Dyśko, Andrew MacKay, Graeme Burt, "Neutral Voltage Displacement Protection Requirement for DG," DTI Centre for Sustainable Electricity and Distributed Generation 2009.

[6] Distribution Code Review Panel, “Progress of Distributed Generators in changing frequency protection settings to comply with ER G59/2” – Ref. DCRP_12_02_04, June 2012

Appendix A: Network model data

33kV Distribution lines

	Resistance (Ω)	Inductance (mH)
Line A-B	0.167	6.55
Line B-C	0.167	6.55
Line C-D	0.167	6.55
Line E-F	1.155	7.1
Line F-G	1.155	7.1

11kV Distribution Lines

	Resistance (Ω)	Inductance (mH)
Line A-B	0.169	0.17
Line B-C	0.169	0.17
Line D-E	0.67	0.56
Line D-F	0.613	0.45

33kV/11kV transformer (grid interface transformer)

Rating (MVA)	15
Rated frequency (Hz)	50
Leakage inductance (PU)	0.15

0.44kV/11kV transformer (DG interface transformer)

Rating (MVA)	3
Rated frequency (Hz)	50
Leakage reactance (PU)	0.1

Appendix B: Synchronous generator data

General parameters

	33kV connected generator	11kV connected generator
Rated MVA	30MVA	3MVA
Rated voltage	33kV	440V
Rated frequency	50Hz	50Hz

Generator reactances (PU):

	33kV connected generator	11kV connected generator
Xd	2.25	3.326
Xd’	0.38	0.22
Xd”	0.23	0.107
Xq	1.14	1.644
Xq’	0.38	1.644
Xq”	0.23	0.23

Time constants (s):

	33kV connected generator	11kV connected generator
Tdo’	8.5	12.5
Tdo”	0.06	0.05
Tqo’	3	1
Tqo”	0.13	0.05

Inertia H (s):

33kV connected generator	3
11kV connected generator	1.3

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Appendix C: Generator controller data

Voltage regulator parameters:

	33kV connected generator	11kV connected generator
Gain	60	60
Time constant (s)	0.001	0.01
Limits	+/-8	+/-8

Excitation parameters:

Gain	1
Time constant (s)	1e-4
E1	7
SE1	0.05
E2	8
SE2	0.4

Reactive power PI controller:

P gain	1.2
I gain	1.5

Governor gains:

K1	14.3
K2	0.7
K3	1

Governor time constants (s):

T1	1
T2	1
T3	0.02
T4	0.673
T5	3
T6	0.45

Appendix D. Full record of risk assessment results

D.1. Results based on ROCOF response only

Table 11. LOM risk assessment results assuming for P-V controlled generator

Load Case	Setting Option	Fixed power load				Fixed impedance load			
		T_{NDZavr} [min]	$N_{LOM,1DG}$	$P_{LOM,1DG}$	P_{LOM}	T_{NDZavr} [min]	$N_{LOM,1DG}$	$P_{LOM,1DG}$	P_{LOM}
1	1	141.18	2.64E-03	1.12E-09	1.02E-07	157.43	3.05E-03	1.29E-09	1.18E-07
	2	160.92	3.15E-03	1.33E-09	1.22E-07	180.16	3.50E-03	1.48E-09	1.36E-07
	3	285.16	5.37E-03	2.27E-09	2.08E-07	321.03	6.19E-03	2.62E-09	2.39E-07
	4	313.77	6.42E-03	2.71E-09	2.48E-07	329.11	6.84E-03	2.89E-09	2.65E-07
	5	184.90	3.94E-03	1.67E-09	1.52E-07	195.02	4.08E-03	1.73E-09	1.58E-07
	6	250.43	4.78E-03	2.02E-09	1.85E-07	280.97	5.34E-03	2.26E-09	2.06E-07
	7	296.79	5.72E-03	2.42E-09	2.21E-07	314.67	6.26E-03	2.65E-09	2.42E-07
	8	425.18	7.97E-03	3.37E-09	3.08E-07	424.16	8.06E-03	3.41E-09	3.12E-07
	9	34.75	3.33E-04	1.41E-10	1.29E-08	30.31	1.68E-04	7.09E-11	6.49E-09
	10	38.58	3.82E-04	1.61E-10	1.48E-08	44.67	3.50E-04	1.48E-10	1.35E-08
	11	61.11	8.80E-04	3.72E-10	3.41E-08	62.06	8.47E-04	3.58E-10	3.28E-08
2	1	3.34	2.36E-03	9.98E-10	9.13E-08	4.59	2.69E-03	1.14E-09	1.04E-07
	2	5.14	2.79E-03	1.18E-09	1.08E-07	5.28	2.92E-03	1.23E-09	1.13E-07
	3	8.88	4.80E-03	2.03E-09	1.86E-07	9.49	5.50E-03	2.32E-09	2.13E-07
	4	9.61	5.74E-03	2.43E-09	2.22E-07	12.35	6.12E-03	2.59E-09	2.37E-07
	5	5.30	3.32E-03	1.40E-09	1.28E-07	5.24	3.39E-03	1.43E-09	1.31E-07
	6	5.92	4.04E-03	1.71E-09	1.56E-07	8.92	4.74E-03	2.00E-09	1.83E-07
	7	8.48	5.18E-03	2.19E-09	2.01E-07	9.12	5.33E-03	2.25E-09	2.06E-07
	8	11.69	6.43E-03	2.72E-09	2.49E-07	11.95	6.78E-03	2.87E-09	2.62E-07
	9	0.82	2.36E-04	9.99E-11	9.14E-09	0.44	4.97E-05	2.10E-11	1.92E-09
	10	0.94	3.14E-04	1.33E-10	1.22E-08	0.69	1.26E-04	5.33E-11	4.88E-09
	11	1.19	6.84E-04	2.89E-10	2.65E-08	1.50	5.18E-04	2.19E-10	2.00E-08
3	1	112.89	1.31E-03	5.54E-10	5.07E-08	129.55	1.51E-03	6.38E-10	5.84E-08
	2	133.92	1.56E-03	6.60E-10	6.04E-08	140.78	1.64E-03	6.95E-10	6.36E-08
	3	224.15	2.59E-03	1.09E-09	1.00E-07	261.04	3.03E-03	1.28E-09	1.17E-07
	4	271.64	3.16E-03	1.34E-09	1.22E-07	290.00	3.38E-03	1.43E-09	1.31E-07
	5	157.60	1.83E-03	7.73E-10	7.07E-08	164.52	1.91E-03	8.06E-10	7.37E-08
	6	193.92	2.25E-03	9.50E-10	8.69E-08	222.73	2.57E-03	1.09E-09	9.93E-08
	7	239.88	2.78E-03	1.17E-09	1.07E-07	265.57	3.08E-03	1.30E-09	1.19E-07
	8	339.60	3.99E-03	1.68E-09	1.54E-07	342.98	4.01E-03	1.70E-09	1.55E-07
	9	24.75	2.05E-04	8.68E-11	7.95E-09	33.21	1.56E-04	6.59E-11	6.03E-09
	10	28.60	2.76E-04	1.17E-10	1.07E-08	35.79	2.05E-04	8.67E-11	7.93E-09
	11	43.56	5.06E-04	2.14E-10	1.96E-08	54.47	4.13E-04	1.75E-10	1.60E-08
4	1	115.12	1.40E-03	5.91E-10	5.41E-08	100.92	7.60E-04	3.21E-10	2.94E-08
	2	148.99	2.15E-03	9.07E-10	8.30E-08	156.21	2.25E-03	9.50E-10	8.70E-08
	3	224.16	3.43E-03	1.45E-09	1.33E-07	229.15	3.67E-03	1.55E-09	1.42E-07
	4	283.02	4.25E-03	1.80E-09	1.64E-07	300.03	4.51E-03	1.91E-09	1.75E-07
	5	171.19	2.48E-03	1.05E-09	9.60E-08	176.55	2.58E-03	1.09E-09	9.99E-08
	6	207.43	3.04E-03	1.28E-09	1.17E-07	234.86	3.49E-03	1.47E-09	1.35E-07
	7	250.68	3.75E-03	1.58E-09	1.45E-07	279.06	4.14E-03	1.75E-09	1.60E-07
	8	361.99	5.30E-03	2.24E-09	2.05E-07	365.25	5.40E-03	2.28E-09	2.09E-07
	9	23.40	2.50E-05	1.06E-11	9.66E-10	30.63	2.04E-05	8.62E-12	7.89E-10
	10	28.59	2.62E-05	1.11E-11	1.01E-09	37.08	2.66E-05	1.12E-11	1.03E-09
	11	42.46	8.32E-05	3.52E-11	3.22E-09	45.05	5.46E-05	2.31E-11	2.11E-09

Table 10. Continued…

Load Case	Setting Option	Fixed power load				Fixed impedance load			
		T_{NDZavr} [min]	$N_{LOM,1DG}$	$P_{LOM,1DG}$	P_{LOM}	T_{NDZavr} [min]	$N_{LOM,1DG}$	$P_{LOM,1DG}$	P_{LOM}
5	1	111.15	2.36E-03	9.99E-10	9.14E-08	113.05	1.98E-03	8.37E-10	7.66E-08
	2	138.78	3.06E-03	1.29E-09	1.18E-07	146.51	3.22E-03	1.36E-09	1.25E-07
	3	228.17	5.06E-03	2.14E-09	1.96E-07	260.76	5.81E-03	2.45E-09	2.25E-07
	4	280.88	6.23E-03	2.63E-09	2.41E-07	299.86	6.63E-03	2.80E-09	2.57E-07
	5	162.96	3.59E-03	1.52E-09	1.39E-07	170.03	3.74E-03	1.58E-09	1.45E-07
	6	200.57	4.42E-03	1.87E-09	1.71E-07	228.40	5.06E-03	2.14E-09	1.96E-07
	7	246.50	5.48E-03	2.32E-09	2.12E-07	273.76	6.08E-03	2.57E-09	2.35E-07
	8	347.68	7.75E-03	3.28E-09	3.00E-07	351.00	7.82E-03	3.31E-09	3.03E-07
	9	24.39	1.63E-04	6.90E-11	6.31E-09	28.14	1.27E-04	5.38E-11	4.92E-09
	10	29.27	1.91E-04	8.08E-11	7.40E-09	30.74	1.64E-04	6.92E-11	6.33E-09
	11	42.05	4.14E-04	1.75E-10	1.60E-08	46.18	3.45E-04	1.46E-10	1.33E-08
6	1	99.05	1.39E-03	5.89E-10	5.39E-08	87.60	6.54E-04	2.76E-10	2.53E-08
	2	135.29	2.42E-03	1.02E-09	9.36E-08	141.98	2.55E-03	1.08E-09	9.86E-08
	3	223.39	3.99E-03	1.69E-09	1.54E-07	230.30	4.18E-03	1.77E-09	1.62E-07
	4	272.13	4.86E-03	2.05E-09	1.88E-07	288.60	5.19E-03	2.20E-09	2.01E-07
	5	157.30	2.83E-03	1.20E-09	1.09E-07	164.35	2.95E-03	1.25E-09	1.14E-07
	6	193.56	3.47E-03	1.47E-09	1.34E-07	221.90	3.96E-03	1.67E-09	1.53E-07
	7	239.88	4.28E-03	1.81E-09	1.65E-07	265.29	4.74E-03	2.00E-09	1.83E-07
	8	340.04	6.08E-03	2.57E-09	2.35E-07	342.69	6.13E-03	2.59E-09	2.37E-07
	9	24.83	2.44E-05	1.03E-11	9.43E-10	32.43	9.14E-06	3.86E-12	3.53E-10
	10	29.28	4.44E-05	1.88E-11	1.72E-09	33.44	1.46E-05	6.19E-12	5.67E-10
	11	40.76	2.10E-04	8.89E-11	8.13E-09	43.68	3.96E-05	1.67E-11	1.53E-09
7	1	1.98	7.55E-04	3.19E-10	2.92E-08	0.00	0.00E+00	0.00E+00	0.00E+00
	2	2.75	1.71E-03	7.22E-10	6.61E-08	2.68	1.84E-03	7.77E-10	7.11E-08
	3	6.10	3.18E-03	1.35E-09	1.23E-07	6.51	2.92E-03	1.23E-09	1.13E-07
	4	8.19	3.47E-03	1.47E-09	1.34E-07	8.56	3.65E-03	1.54E-09	1.41E-07
	5	2.74	2.05E-03	8.69E-10	7.95E-08	2.69	2.22E-03	9.37E-10	8.57E-08
	6	4.04	2.80E-03	1.18E-09	1.08E-07	6.22	3.14E-03	1.33E-09	1.21E-07
	7	7.18	3.27E-03	1.38E-09	1.26E-07	7.80	3.47E-03	1.47E-09	1.34E-07
	8	5.46	4.36E-03	1.84E-09	1.69E-07	6.08	4.56E-03	1.93E-09	1.77E-07
	9	0.00	0.00E+00	0.00E+00	0.00E+00	0.00	0.00E+00	0.00E+00	0.00E+00
	10	0.00	0.00E+00	0.00E+00	0.00E+00	0.00	0.00E+00	0.00E+00	0.00E+00
	11	0.00	0.00E+00	0.00E+00	0.00E+00	0.00	0.00E+00	0.00E+00	0.00E+00
8	1	1.85	1.32E-03	5.56E-10	5.09E-08	2.11	1.57E-03	6.63E-10	6.07E-08
	2	2.16	1.59E-03	6.70E-10	6.13E-08	2.22	1.67E-03	7.08E-10	6.48E-08
	3	3.57	2.48E-03	1.05E-09	9.60E-08	4.44	2.78E-03	1.17E-09	1.07E-07
	4	4.58	2.91E-03	1.23E-09	1.13E-07	4.78	3.07E-03	1.30E-09	1.19E-07
	5	2.55	1.81E-03	7.65E-10	7.00E-08	2.64	1.85E-03	7.81E-10	7.15E-08
	6	2.99	2.18E-03	9.23E-10	8.44E-08	3.59	2.45E-03	1.04E-09	9.49E-08
	7	4.10	2.65E-03	1.12E-09	1.03E-07	4.48	2.84E-03	1.20E-09	1.10E-07
	8	5.65	3.63E-03	1.53E-09	1.40E-07	5.58	3.64E-03	1.54E-09	1.41E-07
	9	0.36	1.05E-04	4.43E-11	4.05E-09	0.48	9.89E-05	4.18E-11	3.83E-09
	10	0.45	1.13E-04	4.79E-11	4.38E-09	0.53	1.22E-04	5.17E-11	4.73E-09
	11	0.59	3.99E-04	1.69E-10	1.54E-08	0.73	2.40E-04	1.01E-10	9.28E-09

Table 12. LOM risk assessment results assuming for P-pf controlled generator

Load Case	Setting Option	Fixed power load				Fixed impedance load			
		T_{NDZavr} [min]	$N_{LOM,1DG}$	$P_{LOM,1DG}$	P_{LOM}	T_{NDZavr} [min]	$N_{LOM,1DG}$	$P_{LOM,1DG}$	P_{LOM}
1	1	1.50E+03	2.16E-05	9.13E-12	8.35E-10	0.00	0.00E+00	0.00E+00	0.00E+00
	2	4.26E+03	1.00E-03	4.25E-10	3.89E-08	14.91	3.77E-06	1.60E-12	1.46E-10
	3	6.58E+03	1.90E-03	8.02E-10	7.34E-08	0.00	0.00E+00	0.00E+00	0.00E+00
	4	7.44E+03	2.24E-03	9.49E-10	8.68E-08	23.99	1.48E-05	6.24E-12	5.71E-10
	5	4.89E+03	1.31E-03	5.56E-10	5.08E-08	24.93	1.19E-06	5.01E-13	4.59E-11
	6	5.68E+03	1.64E-03	6.93E-10	6.34E-08	20.57	2.35E-05	9.94E-12	9.09E-10
	7	6.75E+03	2.13E-03	9.00E-10	8.24E-08	14.91	3.30E-06	1.40E-12	1.28E-10
	8	8.05E+03	2.62E-03	1.11E-09	1.01E-07	30.46	3.44E-05	1.45E-11	1.33E-09
	9	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00	0.00E+00	0.00E+00	0.00E+00
	10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00	0.00E+00	0.00E+00	0.00E+00
	11	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00	0.00E+00	0.00E+00	0.00E+00
2	1	1.09E+01	4.36E-05	7.26E-12	6.64E-10	0.00	0.00E+00	0.00E+00	0.00E+00
	2	2.12E+02	1.67E-03	7.07E-10	6.47E-08	0.00	0.00E+00	0.00E+00	0.00E+00
	3	5.17E+02	3.12E-03	1.32E-09	1.21E-07	0.00	0.00E+00	0.00E+00	0.00E+00
	4	6.12E+02	3.59E-03	1.52E-09	1.39E-07	0.22	2.16E-07	4.57E-14	4.18E-12
	5	2.45E+02	2.34E-03	9.87E-10	9.03E-08	0.00	0.00E+00	0.00E+00	0.00E+00
	6	3.96E+02	2.96E-03	1.25E-09	1.14E-07	0.17	1.66E-07	2.46E-14	2.25E-12
	7	5.65E+02	3.49E-03	1.48E-09	1.35E-07	0.00	0.00E+00	0.00E+00	0.00E+00
	8	5.41E+02	4.05E-03	1.71E-09	1.57E-07	0.24	1.65E-06	3.88E-13	3.55E-11
	9	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00	0.00E+00	0.00E+00	0.00E+00
	10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00	0.00E+00	0.00E+00	0.00E+00
	11	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00	0.00E+00	0.00E+00	0.00E+00
3	1	3.06E+02	4.97E-05	2.10E-11	1.92E-09	2.36	1.64E-07	6.91E-14	6.33E-12
	2	3.88E+03	7.07E-04	2.99E-10	2.73E-08	7.59	3.68E-06	1.55E-12	1.42E-10
	3	7.00E+03	1.30E-03	5.48E-10	5.02E-08	0.00	0.00E+00	0.00E+00	0.00E+00
	4	8.61E+03	1.59E-03	6.74E-10	6.17E-08	13.41	1.31E-05	5.53E-12	5.06E-10
	5	4.98E+03	9.17E-04	3.88E-10	3.55E-08	9.43	5.77E-06	2.44E-12	2.23E-10
	6	6.20E+03	1.14E-03	4.83E-10	4.42E-08	19.78	2.72E-05	1.15E-11	1.05E-09
	7	8.05E+03	1.49E-03	6.30E-10	5.76E-08	8.07	4.38E-06	1.85E-12	1.69E-10
	8	9.80E+03	1.82E-03	7.70E-10	7.04E-08	24.17	4.21E-05	1.78E-11	1.63E-09
	9	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00	0.00E+00	0.00E+00	0.00E+00
	10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00	0.00E+00	0.00E+00	0.00E+00
	11	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00	0.00E+00	0.00E+00	0.00E+00
4	1	2.80E+02	6.44E-07	2.72E-13	2.49E-11	2.00	2.14E-08	9.03E-15	8.27E-13
	2	2.24E+03	1.50E-05	6.35E-12	5.81E-10	7.43	2.63E-07	1.11E-13	1.02E-11
	3	3.08E+03	4.46E-05	1.89E-11	1.73E-09	0.00	0.00E+00	0.00E+00	0.00E+00
	4	3.66E+03	6.65E-05	2.81E-11	2.57E-09	12.21	1.38E-06	5.83E-13	5.34E-11
	5	2.39E+03	2.31E-05	9.77E-12	8.94E-10	8.83	5.51E-07	2.33E-13	2.13E-11
	6	2.88E+03	3.53E-05	1.49E-11	1.36E-09	13.22	2.81E-06	1.19E-12	1.09E-10
	7	3.50E+03	6.03E-05	2.55E-11	2.33E-09	5.00	3.38E-07	1.43E-13	1.31E-11
	8	3.63E+03	7.99E-05	3.38E-11	3.09E-09	16.00	5.04E-06	2.13E-12	1.95E-10
	9	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00	0.00E+00	0.00E+00	0.00E+00
	10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00	0.00E+00	0.00E+00	0.00E+00
	11	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00	0.00E+00	0.00E+00	0.00E+00

Table 11. Continued…

Load Case	Setting Option	Fixed power load				Fixed impedance load			
		T_{NDZavr} [min]	$N_{LOM,1DG}$	$P_{LOM,1DG}$	P_{LOM}	T_{NDZavr} [min]	$N_{LOM,1DG}$	$P_{LOM,1DG}$	P_{LOM}
5	1	4.03E+02	2.22E-05	9.38E-12	8.58E-10	2.00	9.94E-08	4.20E-14	3.85E-12
	2	3.30E+03	3.02E-04	1.28E-10	1.17E-08	3.98	2.15E-06	9.07E-13	8.30E-11
	3	4.87E+03	5.85E-04	2.47E-10	2.26E-08	0.00	0.00E+00	0.00E+00	0.00E+00
	4	5.43E+03	7.36E-04	3.11E-10	2.85E-08	7.66	8.45E-06	3.57E-12	3.27E-10
	5	3.92E+03	3.97E-04	1.68E-10	1.54E-08	5.39	3.68E-06	1.55E-12	1.42E-10
	6	4.45E+03	5.11E-04	2.16E-10	1.98E-08	11.62	1.97E-05	8.32E-12	7.62E-10
	7	5.26E+03	6.80E-04	2.88E-10	2.63E-08	4.14	2.42E-06	1.02E-12	9.37E-11
	8	5.86E+03	8.54E-04	3.61E-10	3.30E-08	13.59	3.10E-05	1.31E-11	1.20E-09
	9	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00	0.00E+00	0.00E+00	0.00E+00
	10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00	0.00E+00	0.00E+00	0.00E+00
	11	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00	0.00E+00	0.00E+00	0.00E+00
6	1	3.46E+02	7.58E-05	3.20E-11	2.93E-09	4.00	3.29E-09	1.39E-15	1.27E-13
	2	4.31E+03	1.04E-03	4.42E-10	4.04E-08	5.78	9.12E-08	3.86E-14	3.53E-12
	3	8.12E+03	2.24E-03	9.47E-10	8.67E-08	0.00	0.00E+00	0.00E+00	0.00E+00
	4	1.00E+04	2.75E-03	1.16E-09	1.07E-07	12.35	3.32E-07	1.40E-13	1.28E-11
	5	5.44E+03	1.31E-03	5.52E-10	5.05E-08	7.80	1.31E-07	5.56E-14	5.09E-12
	6	6.67E+03	1.65E-03	6.98E-10	6.39E-08	14.44	6.97E-07	2.95E-13	2.70E-11
	7	9.35E+03	2.57E-03	1.09E-09	9.94E-08	6.44	8.88E-08	3.75E-14	3.43E-12
	8	1.14E+04	3.10E-03	1.31E-09	1.20E-07	19.15	1.26E-06	5.33E-13	4.88E-11
	9	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00	0.00E+00	0.00E+00	0.00E+00
	10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00	0.00E+00	0.00E+00	0.00E+00
	11	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00	0.00E+00	0.00E+00	0.00E+00
7	1	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00	0.00E+00	0.00E+00	0.00E+00
	2	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00	0.00E+00	0.00E+00	0.00E+00
	3	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00	0.00E+00	0.00E+00	0.00E+00
	4	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00	0.00E+00	0.00E+00	0.00E+00
	5	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00	0.00E+00	0.00E+00	0.00E+00
	6	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00	0.00E+00	0.00E+00	0.00E+00
	7	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00	0.00E+00	0.00E+00	0.00E+00
	8	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00	0.00E+00	0.00E+00	0.00E+00
	9	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00	0.00E+00	0.00E+00	0.00E+00
	10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00	0.00E+00	0.00E+00	0.00E+00
	11	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00	0.00E+00	0.00E+00	0.00E+00
8	1	6.29E+00	3.36E-06	2.33E-13	2.14E-11	0.00	0.00E+00	0.00E+00	0.00E+00
	2	5.12E+01	1.59E-04	6.72E-11	6.15E-09	0.12	1.69E-06	1.56E-13	1.43E-11
	3	7.47E+01	3.22E-04	1.36E-10	1.24E-08	0.00	0.00E+00	0.00E+00	0.00E+00
	4	9.47E+01	4.14E-04	1.75E-10	1.60E-08	0.19	9.34E-06	1.72E-12	1.57E-10
	5	6.78E+01	2.15E-04	9.11E-11	8.34E-09	0.15	3.62E-06	4.37E-13	4.00E-11
	6	6.76E+01	2.61E-04	1.10E-10	1.01E-08	0.26	1.72E-05	4.62E-12	4.23E-10
	7	9.17E+01	3.85E-04	1.63E-10	1.49E-08	0.13	2.08E-06	2.15E-13	1.97E-11
	8	9.74E+01	4.95E-04	2.09E-10	1.92E-08	0.32	3.28E-05	1.12E-11	1.03E-09
	9	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00	0.00E+00	0.00E+00	0.00E+00
	10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00	0.00E+00	0.00E+00	0.00E+00
	11	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00	0.00E+00	0.00E+00	0.00E+00

D.2. Results based on combined ROCOF, UV/OV and UF/OF response

Table 13. LOM risk assessment results assuming for P-V controlled generator (no difference from ROCOF only results)

Load Case	Setting Option	Fixed power load				Fixed impedance load			
		T_{NDZavr} [min]	$N_{LOM,1DG}$	$P_{LOM,1DG}$	P_{LOM}	T_{NDZavr} [min]	$N_{LOM,1DG}$	$P_{LOM,1DG}$	P_{LOM}
1	1	141.18	2.64E-03	1.12E-09	1.02E-07	157.43	3.05E-03	1.29E-09	1.18E-07
	2	160.92	3.15E-03	1.33E-09	1.22E-07	180.16	3.50E-03	1.48E-09	1.36E-07
	3	285.16	5.37E-03	2.27E-09	2.08E-07	321.03	6.19E-03	2.62E-09	2.39E-07
	4	313.77	6.42E-03	2.71E-09	2.48E-07	329.11	6.84E-03	2.89E-09	2.65E-07
	5	184.90	3.94E-03	1.67E-09	1.52E-07	195.02	4.08E-03	1.73E-09	1.58E-07
	6	250.43	4.78E-03	2.02E-09	1.85E-07	280.97	5.34E-03	2.26E-09	2.06E-07
	7	296.79	5.72E-03	2.42E-09	2.21E-07	314.67	6.26E-03	2.65E-09	2.42E-07
	8	425.18	7.97E-03	3.37E-09	3.08E-07	424.16	8.06E-03	3.41E-09	3.12E-07
	9	34.75	3.33E-04	1.41E-10	1.29E-08	30.31	1.68E-04	7.09E-11	6.49E-09
	10	38.58	3.82E-04	1.61E-10	1.48E-08	44.67	3.50E-04	1.48E-10	1.35E-08
	11	61.11	8.80E-04	3.72E-10	3.41E-08	62.06	8.47E-04	3.58E-10	3.28E-08
2	1	3.34	2.36E-03	9.98E-10	9.13E-08	4.59	2.69E-03	1.14E-09	1.04E-07
	2	5.14	2.79E-03	1.18E-09	1.08E-07	5.28	2.92E-03	1.23E-09	1.13E-07
	3	8.88	4.80E-03	2.03E-09	1.86E-07	9.49	5.50E-03	2.32E-09	2.13E-07
	4	9.61	5.74E-03	2.43E-09	2.22E-07	12.35	6.12E-03	2.59E-09	2.37E-07
	5	5.30	3.32E-03	1.40E-09	1.28E-07	5.24	3.39E-03	1.43E-09	1.31E-07
	6	5.92	4.04E-03	1.71E-09	1.56E-07	8.92	4.74E-03	2.00E-09	1.83E-07
	7	8.48	5.18E-03	2.19E-09	2.01E-07	9.12	5.33E-03	2.25E-09	2.06E-07
	8	11.69	6.43E-03	2.72E-09	2.49E-07	11.95	6.78E-03	2.87E-09	2.62E-07
	9	0.82	2.36E-04	9.99E-11	9.14E-09	0.44	4.97E-05	2.10E-11	1.92E-09
	10	0.94	3.14E-04	1.33E-10	1.22E-08	0.69	1.26E-04	5.33E-11	4.88E-09
	11	1.19	6.84E-04	2.89E-10	2.65E-08	1.50	5.18E-04	2.19E-10	2.00E-08
3	1	112.89	1.31E-03	5.54E-10	5.07E-08	129.55	1.51E-03	6.38E-10	5.84E-08
	2	133.92	1.56E-03	6.60E-10	6.04E-08	140.78	1.64E-03	6.95E-10	6.36E-08
	3	224.15	2.59E-03	1.09E-09	1.00E-07	261.04	3.03E-03	1.28E-09	1.17E-07
	4	271.64	3.16E-03	1.34E-09	1.22E-07	290.00	3.38E-03	1.43E-09	1.31E-07
	5	157.60	1.83E-03	7.73E-10	7.07E-08	164.52	1.91E-03	8.06E-10	7.37E-08
	6	193.92	2.25E-03	9.50E-10	8.69E-08	222.73	2.57E-03	1.09E-09	9.93E-08
	7	239.88	2.78E-03	1.17E-09	1.07E-07	265.57	3.08E-03	1.30E-09	1.19E-07
	8	339.60	3.99E-03	1.68E-09	1.54E-07	342.98	4.01E-03	1.70E-09	1.55E-07
	9	24.75	2.05E-04	8.68E-11	7.95E-09	33.21	1.56E-04	6.59E-11	6.03E-09
	10	28.60	2.76E-04	1.17E-10	1.07E-08	35.79	2.05E-04	8.67E-11	7.93E-09
	11	43.56	5.06E-04	2.14E-10	1.96E-08	54.47	4.13E-04	1.75E-10	1.60E-08
4	1	115.12	1.40E-03	5.91E-10	5.41E-08	100.92	7.60E-04	3.21E-10	2.94E-08
	2	148.99	2.15E-03	9.07E-10	8.30E-08	156.21	2.25E-03	9.50E-10	8.70E-08
	3	224.16	3.43E-03	1.45E-09	1.33E-07	229.15	3.67E-03	1.55E-09	1.42E-07
	4	283.02	4.25E-03	1.80E-09	1.64E-07	300.03	4.51E-03	1.91E-09	1.75E-07
	5	171.19	2.48E-03	1.05E-09	9.60E-08	176.55	2.58E-03	1.09E-09	9.99E-08
	6	207.43	3.04E-03	1.28E-09	1.17E-07	234.86	3.49E-03	1.47E-09	1.35E-07
	7	250.68	3.75E-03	1.58E-09	1.45E-07	279.06	4.14E-03	1.75E-09	1.60E-07
	8	361.99	5.30E-03	2.24E-09	2.05E-07	365.25	5.40E-03	2.28E-09	2.09E-07
	9	23.40	2.50E-05	1.06E-11	9.66E-10	30.63	2.04E-05	8.62E-12	7.89E-10
	10	28.59	2.62E-05	1.11E-11	1.01E-09	37.08	2.66E-05	1.12E-11	1.03E-09
	11	42.46	8.32E-05	3.52E-11	3.22E-09	45.05	5.46E-05	2.31E-11	2.11E-09

Table 12. Continued…

Load Case	Setting Option	Fixed power load				Fixed impedance load			
		T_{NDZavr} [min]	$N_{LOM,1DG}$	$P_{LOM,1DG}$	P_{LOM}	T_{NDZavr} [min]	$N_{LOM,1DG}$	$P_{LOM,1DG}$	P_{LOM}
5	1	111.15	2.36E-03	9.99E-10	9.14E-08	113.05	1.98E-03	8.37E-10	7.66E-08
	2	138.78	3.06E-03	1.29E-09	1.18E-07	146.51	3.22E-03	1.36E-09	1.25E-07
	3	228.17	5.06E-03	2.14E-09	1.96E-07	260.76	5.81E-03	2.45E-09	2.25E-07
	4	280.88	6.23E-03	2.63E-09	2.41E-07	299.86	6.63E-03	2.80E-09	2.57E-07
	5	162.96	3.59E-03	1.52E-09	1.39E-07	170.03	3.74E-03	1.58E-09	1.45E-07
	6	200.57	4.42E-03	1.87E-09	1.71E-07	228.40	5.06E-03	2.14E-09	1.96E-07
	7	246.50	5.48E-03	2.32E-09	2.12E-07	273.76	6.08E-03	2.57E-09	2.35E-07
	8	347.68	7.75E-03	3.28E-09	3.00E-07	351.00	7.82E-03	3.31E-09	3.03E-07
	9	24.39	1.63E-04	6.90E-11	6.31E-09	28.14	1.27E-04	5.38E-11	4.92E-09
	10	29.27	1.91E-04	8.08E-11	7.40E-09	30.74	1.64E-04	6.92E-11	6.33E-09
	11	42.05	4.14E-04	1.75E-10	1.60E-08	46.18	3.45E-04	1.46E-10	1.33E-08
6	1	99.05	1.39E-03	5.89E-10	5.39E-08	87.60	6.54E-04	2.76E-10	2.53E-08
	2	135.29	2.42E-03	1.02E-09	9.36E-08	141.98	2.55E-03	1.08E-09	9.86E-08
	3	223.39	3.99E-03	1.69E-09	1.54E-07	230.30	4.18E-03	1.77E-09	1.62E-07
	4	272.13	4.86E-03	2.05E-09	1.88E-07	288.60	5.19E-03	2.20E-09	2.01E-07
	5	157.30	2.83E-03	1.20E-09	1.09E-07	164.35	2.95E-03	1.25E-09	1.14E-07
	6	193.56	3.47E-03	1.47E-09	1.34E-07	221.90	3.96E-03	1.67E-09	1.53E-07
	7	239.88	4.28E-03	1.81E-09	1.65E-07	265.29	4.74E-03	2.00E-09	1.83E-07
	8	340.04	6.08E-03	2.57E-09	2.35E-07	342.69	6.13E-03	2.59E-09	2.37E-07
	9	24.83	2.44E-05	1.03E-11	9.43E-10	32.43	9.14E-06	3.86E-12	3.53E-10
	10	29.28	4.44E-05	1.88E-11	1.72E-09	33.44	1.46E-05	6.19E-12	5.67E-10
	11	40.76	2.10E-04	8.89E-11	8.13E-09	43.68	3.96E-05	1.67E-11	1.53E-09
7	1	1.98	7.55E-04	3.19E-10	2.92E-08	0.00	0.00E+00	0.00E+00	0.00E+00
	2	2.75	1.71E-03	7.22E-10	6.61E-08	2.68	1.84E-03	7.77E-10	7.11E-08
	3	6.10	3.18E-03	1.35E-09	1.23E-07	6.51	2.92E-03	1.23E-09	1.13E-07
	4	8.19	3.47E-03	1.47E-09	1.34E-07	8.56	3.65E-03	1.54E-09	1.41E-07
	5	2.74	2.05E-03	8.69E-10	7.95E-08	2.69	2.22E-03	9.37E-10	8.57E-08
	6	4.04	2.80E-03	1.18E-09	1.08E-07	6.22	3.14E-03	1.33E-09	1.21E-07
	7	7.18	3.27E-03	1.38E-09	1.26E-07	7.80	3.47E-03	1.47E-09	1.34E-07
	8	5.46	4.36E-03	1.84E-09	1.69E-07	6.08	4.56E-03	1.93E-09	1.77E-07
	9	0.00	0.00E+00	0.00E+00	0.00E+00	0.00	0.00E+00	0.00E+00	0.00E+00
	10	0.00	0.00E+00	0.00E+00	0.00E+00	0.00	0.00E+00	0.00E+00	0.00E+00
	11	0.00	0.00E+00	0.00E+00	0.00E+00	0.00	0.00E+00	0.00E+00	0.00E+00
8	1	1.85	1.32E-03	5.56E-10	5.09E-08	2.11	1.57E-03	6.63E-10	6.07E-08
	2	2.16	1.59E-03	6.70E-10	6.13E-08	2.22	1.67E-03	7.08E-10	6.48E-08
	3	3.57	2.48E-03	1.05E-09	9.60E-08	4.44	2.78E-03	1.17E-09	1.07E-07
	4	4.58	2.91E-03	1.23E-09	1.13E-07	4.78	3.07E-03	1.30E-09	1.19E-07
	5	2.55	1.81E-03	7.65E-10	7.00E-08	2.64	1.85E-03	7.81E-10	7.15E-08
	6	2.99	2.18E-03	9.23E-10	8.44E-08	3.59	2.45E-03	1.04E-09	9.49E-08
	7	4.10	2.65E-03	1.12E-09	1.03E-07	4.48	2.84E-03	1.20E-09	1.10E-07
	8	5.65	3.63E-03	1.53E-09	1.40E-07	5.58	3.64E-03	1.54E-09	1.41E-07
	9	0.36	1.05E-04	4.43E-11	4.05E-09	0.48	9.89E-05	4.18E-11	3.83E-09
	10	0.45	1.13E-04	4.79E-11	4.38E-09	0.53	1.22E-04	5.17E-11	4.73E-09
	11	0.59	3.99E-04	1.69E-10	1.54E-08	0.73	2.40E-04	1.01E-10	9.28E-09

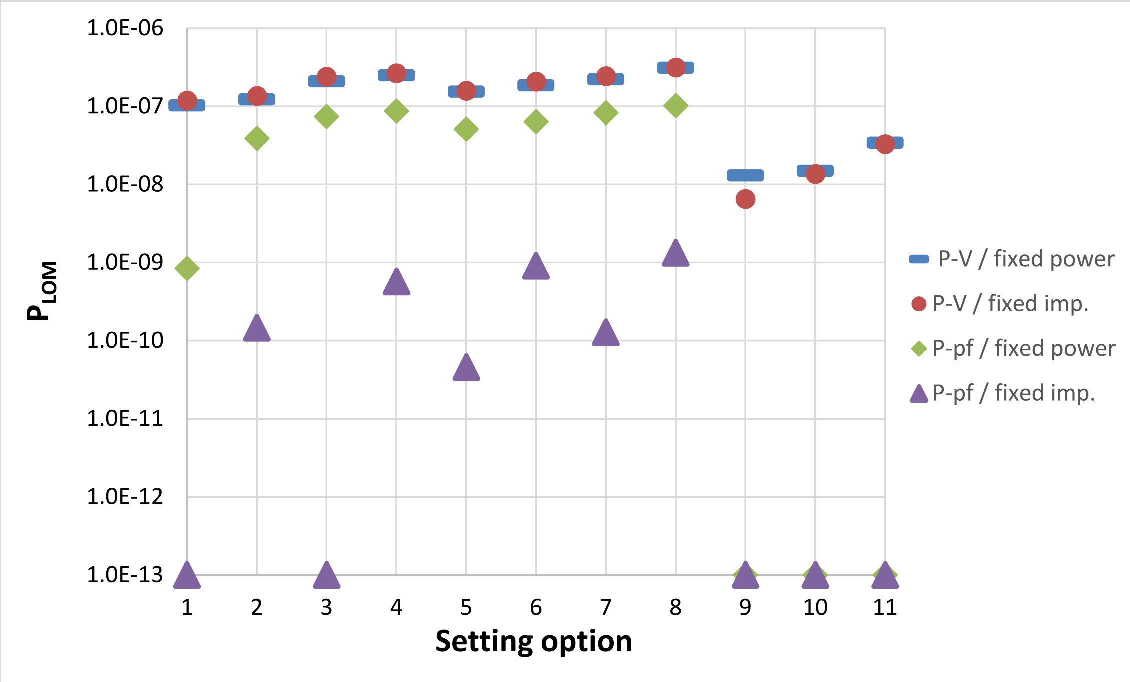
Table 14. LOM risk assessment results assuming for P-pf controlled generator (difference from ROCOF only results highlighted in bold)

Load Case	Setting Option	Fixed power load				Fixed impedance load			
		T_{NDZavr} [min]	$N_{LOM,1DG}$	$P_{LOM,1DG}$	P_{LOM}	T_{NDZavr} [min]	$N_{LOM,1DG}$	$P_{LOM,1DG}$	P_{LOM}
1	1	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	0.00	0.00E+00	0.00E+00	0.00E+00
	2	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	14.91	3.77E-06	1.60E-12	1.46E-10
	3	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	0.00	0.00E+00	0.00E+00	0.00E+00
	4	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	23.99	1.48E-05	6.24E-12	5.71E-10
	5	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	24.93	1.19E-06	5.01E-13	4.59E-11
	6	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	**20.56**	**2.35E-05**	**9.93E-12**	**9.09E-10**
	7	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	14.91	3.30E-06	1.40E-12	1.28E-10
	8	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	30.46	3.44E-05	1.45E-11	1.33E-09
	9	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00	0.00E+00	0.00E+00	0.00E+00
	10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00	0.00E+00	0.00E+00	0.00E+00
	11	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00	0.00E+00	0.00E+00	0.00E+00
2	1	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	0.00	0.00E+00	0.00E+00	0.00E+00
	2	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	0.00	0.00E+00	0.00E+00	0.00E+00
	3	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	0.00	0.00E+00	0.00E+00	0.00E+00
	4	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	0.22	2.16E-07	4.57E-14	4.18E-12
	5	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	0.00	0.00E+00	0.00E+00	0.00E+00
	6	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.17**	**1.66E-07**	**2.46E-14**	**2.25E-12**
	7	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	0.00	0.00E+00	0.00E+00	0.00E+00
	8	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	0.24	1.65E-06	3.88E-13	3.55E-11
	9	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00	0.00E+00	0.00E+00	0.00E+00
	10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00	0.00E+00	0.00E+00	0.00E+00
	11	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00	0.00E+00	0.00E+00	0.00E+00
3	1	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	2.36	1.64E-07	6.91E-14	6.33E-12
	2	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	7.59	3.68E-06	1.55E-12	1.42E-10
	3	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	0.00	0.00E+00	0.00E+00	0.00E+00
	4	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	13.41	1.31E-05	5.53E-12	5.06E-10
	5	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	9.43	5.77E-06	2.44E-12	2.23E-10
	6	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	**18.89**	**2.54E-05**	**1.07E-11**	**9.83E-10**
	7	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	8.07	4.38E-06	1.85E-12	1.69E-10
	8	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	24.17	4.21E-05	1.78E-11	1.63E-09
	9	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00	0.00E+00	0.00E+00	0.00E+00
	10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00	0.00E+00	0.00E+00	0.00E+00
	11	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00	0.00E+00	0.00E+00	0.00E+00
4	1	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	2.00	2.14E-08	9.03E-15	8.27E-13
	2	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	7.43	2.63E-07	1.11E-13	1.02E-11
	3	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	0.00	0.00E+00	0.00E+00	0.00E+00
	4	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	12.21	1.38E-06	5.83E-13	5.34E-11
	5	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	8.83	5.51E-07	2.33E-13	2.13E-11
	6	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	**13.39**	**2.64E-06**	**1.11E-12**	**1.02E-10**
	7	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	5.00	3.38E-07	1.43E-13	1.31E-11
	8	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	16.00	5.04E-06	2.13E-12	1.95E-10
	9	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00	0.00E+00	0.00E+00	0.00E+00
	10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00	0.00E+00	0.00E+00	0.00E+00
	11	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00	0.00E+00	0.00E+00	0.00E+00

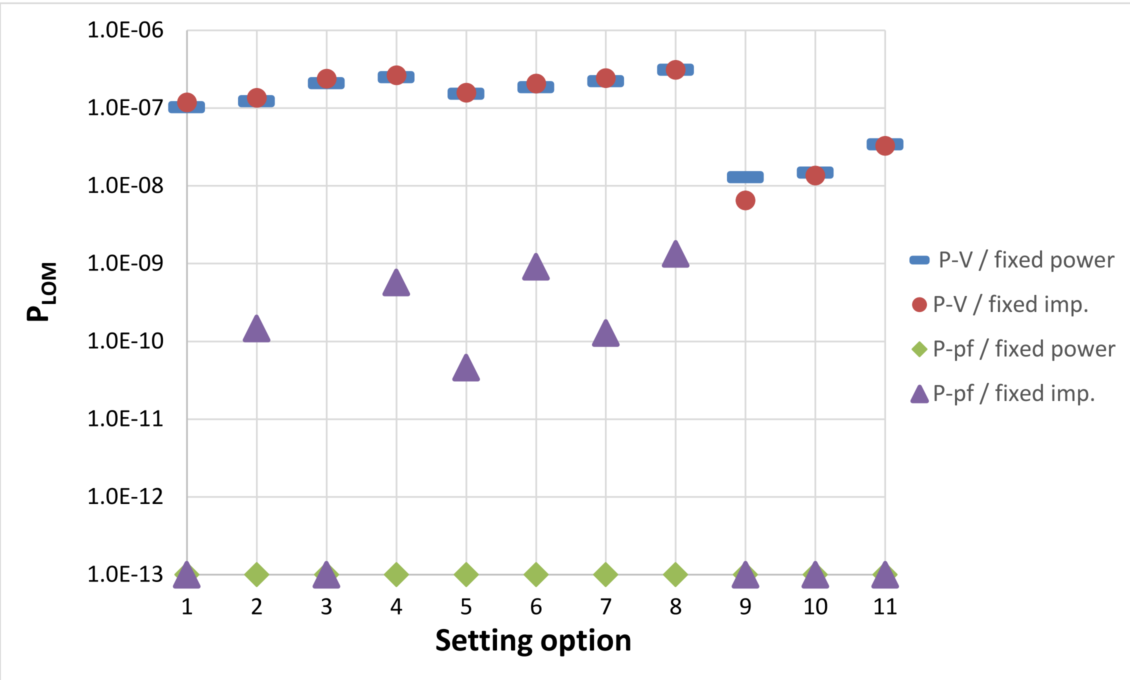
Table 13. Continued…

Load Case	Setting Option	Fixed power load				Fixed impedance load			
		T_{NDZavr} [min]	$N_{LOM,1DG}$	$P_{LOM,1DG}$	P_{LOM}	T_{NDZavr} [min]	$N_{LOM,1DG}$	$P_{LOM,1DG}$	P_{LOM}
5	1	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	2.00	9.94E-08	4.20E-14	3.85E-12
	2	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	3.98	2.15E-06	9.07E-13	8.30E-11
	3	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	0.00	0.00E+00	0.00E+00	0.00E+00
	4	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	7.66	8.45E-06	3.57E-12	3.27E-10
	5	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	5.39	3.68E-06	1.55E-12	1.42E-10
	6	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	**11.41**	**1.85E-05**	**7.81E-12**	**7.15E-10**
	7	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	4.14	2.42E-06	1.02E-12	9.37E-11
	8	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	13.59	3.10E-05	1.31E-11	1.20E-09
	9	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00	0.00E+00	0.00E+00	0.00E+00
	10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00	0.00E+00	0.00E+00	0.00E+00
	11	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00	0.00E+00	0.00E+00	0.00E+00
6	1	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	4.00	3.29E-09	1.39E-15	1.27E-13
	2	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	5.78	9.12E-08	3.86E-14	3.53E-12
	3	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	0.00	0.00E+00	0.00E+00	0.00E+00
	4	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	12.35	3.32E-07	1.40E-13	1.28E-11
	5	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	7.80	1.31E-07	5.56E-14	5.09E-12
	6	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	**15.42**	**6.57E-07**	**2.78E-13**	**2.54E-11**
	7	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	6.44	8.88E-08	3.75E-14	3.43E-12
	8	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	19.15	1.26E-06	5.33E-13	4.88E-11
	9	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00	0.00E+00	0.00E+00	0.00E+00
	10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00	0.00E+00	0.00E+00	0.00E+00
	11	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00	0.00E+00	0.00E+00	0.00E+00
7	1	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	0.00	0.00E+00	0.00E+00	0.00E+00
	2	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	0.00	0.00E+00	0.00E+00	0.00E+00
	3	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	0.00	0.00E+00	0.00E+00	0.00E+00
	4	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	0.00	0.00E+00	0.00E+00	0.00E+00
	5	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	0.00	0.00E+00	0.00E+00	0.00E+00
	6	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	0.00	0.00E+00	0.00E+00	0.00E+00
	7	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	0.00	0.00E+00	0.00E+00	0.00E+00
	8	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	0.00	0.00E+00	0.00E+00	0.00E+00
	9	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00	0.00E+00	0.00E+00	0.00E+00
	10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00	0.00E+00	0.00E+00	0.00E+00
	11	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00	0.00E+00	0.00E+00	0.00E+00
8	1	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	0.00	0.00E+00	0.00E+00	0.00E+00
	2	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	0.12	1.69E-06	1.56E-13	1.43E-11
	3	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	0.00	0.00E+00	0.00E+00	0.00E+00
	4	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	0.19	9.34E-06	1.72E-12	1.57E-10
	5	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	0.15	3.62E-06	4.37E-13	4.00E-11
	6	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.26**	**1.60E-05**	**4.28E-12**	**3.92E-10**
	7	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	0.13	2.08E-06	2.15E-13	1.97E-11
	8	**0.00E+00**	**0.00E+00**	**0.00E+00**	**0.00E+00**	0.32	3.28E-05	1.12E-11	1.03E-09
	9	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00	0.00E+00	0.00E+00	0.00E+00
	10	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00	0.00E+00	0.00E+00	0.00E+00
	11	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00	0.00E+00	0.00E+00	0.00E+00

D.3. Result figures

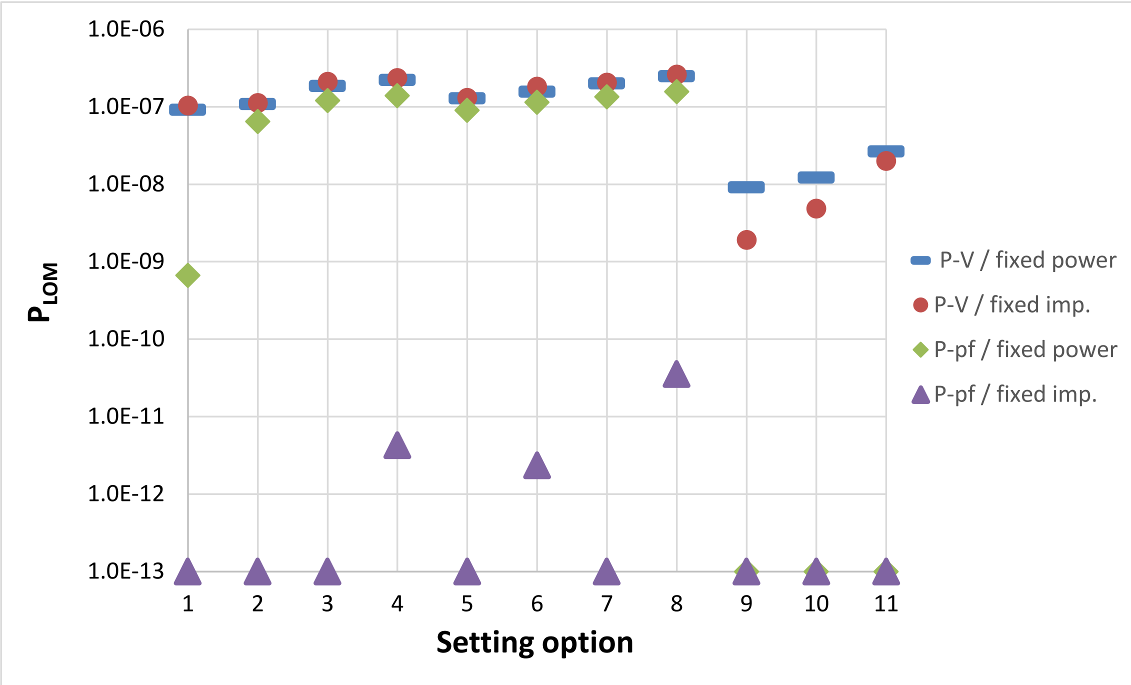


a) ROCOF enabled only

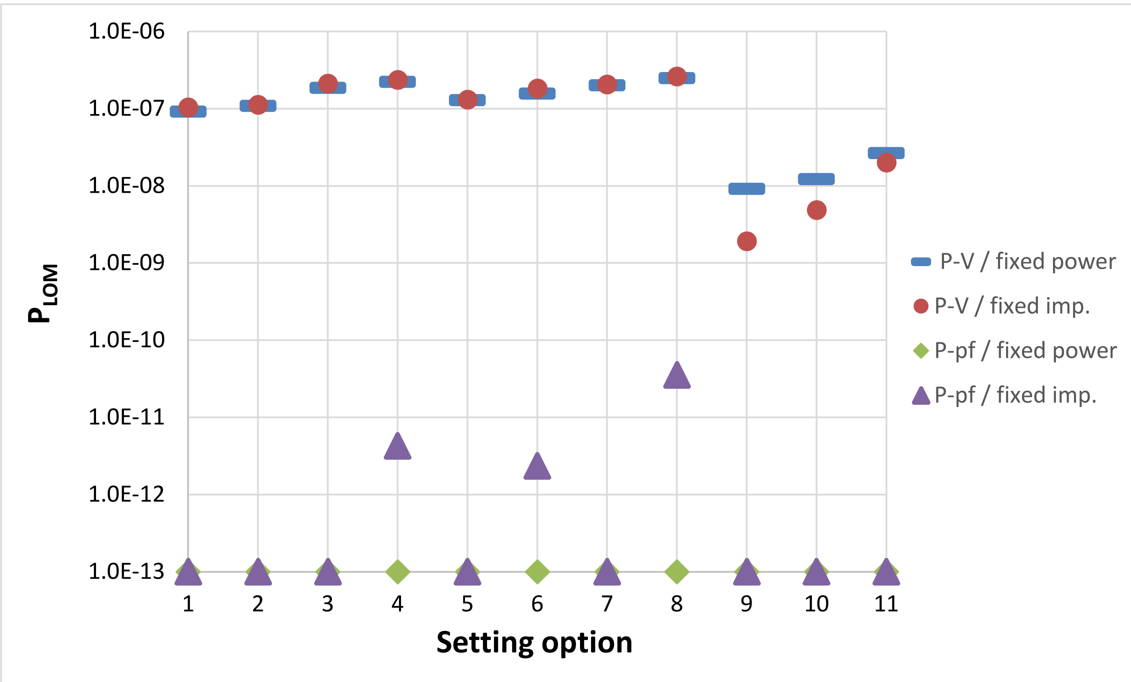


b) Full G59/2 interface protection enabled

Figure 25. Probability of undetected islanding operation – Load Case 1

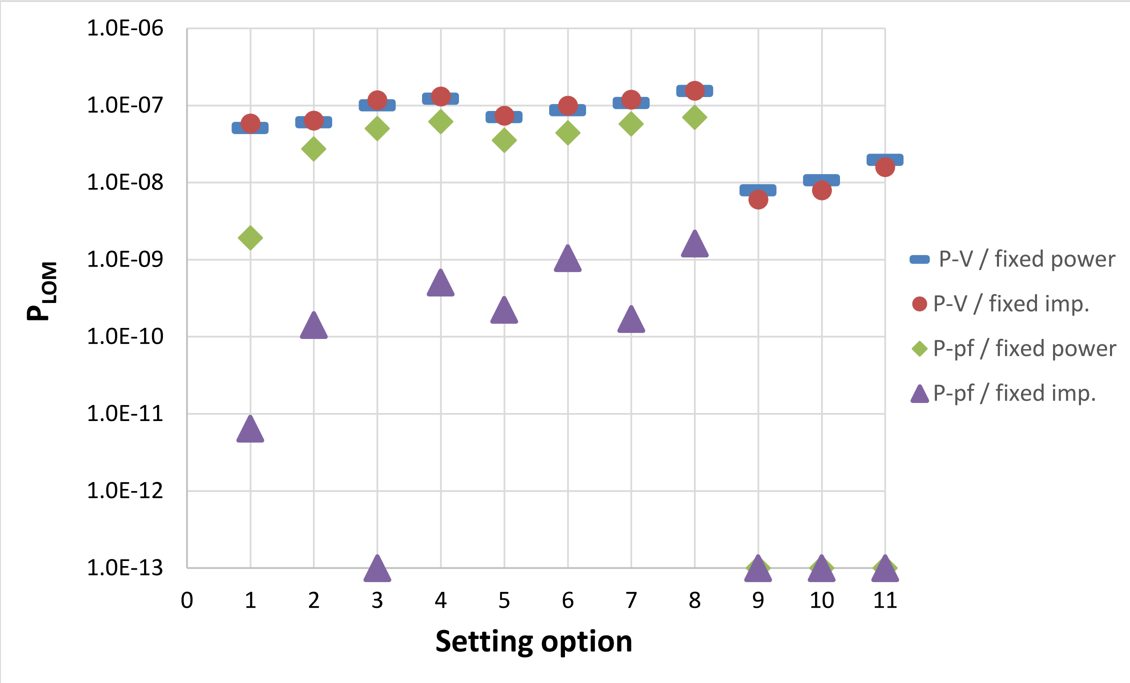


a) ROCOF enabled only

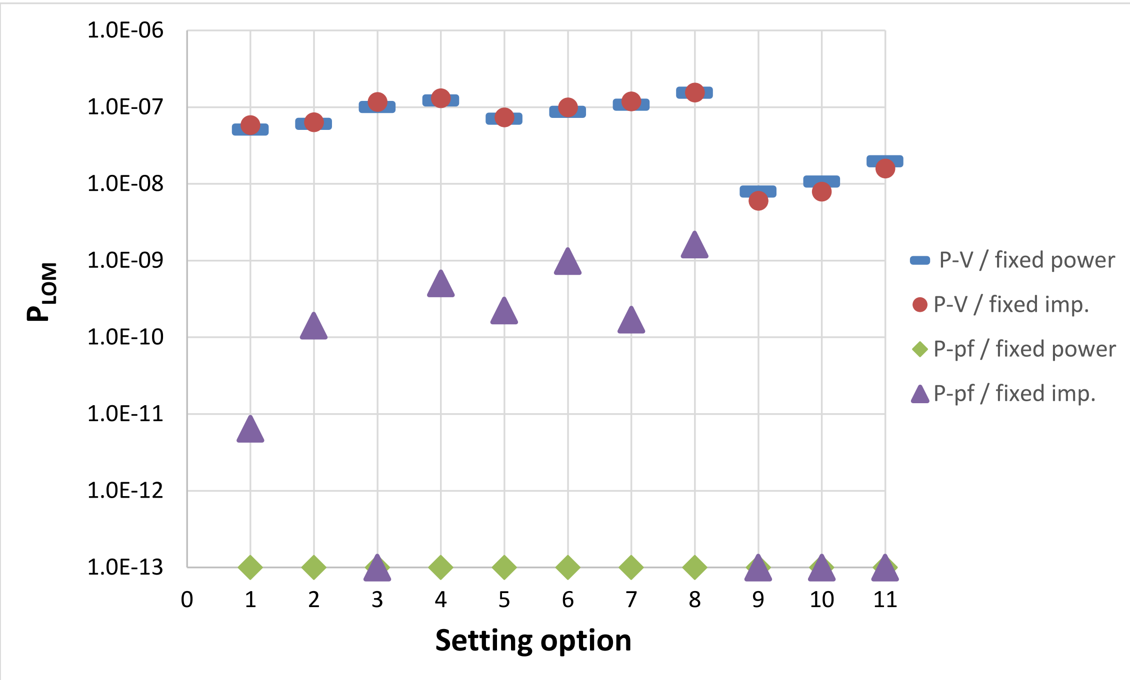


b) Full G59/2 interface protection enabled

Figure 26. Probability of undetected islanding operation – Load Case 2

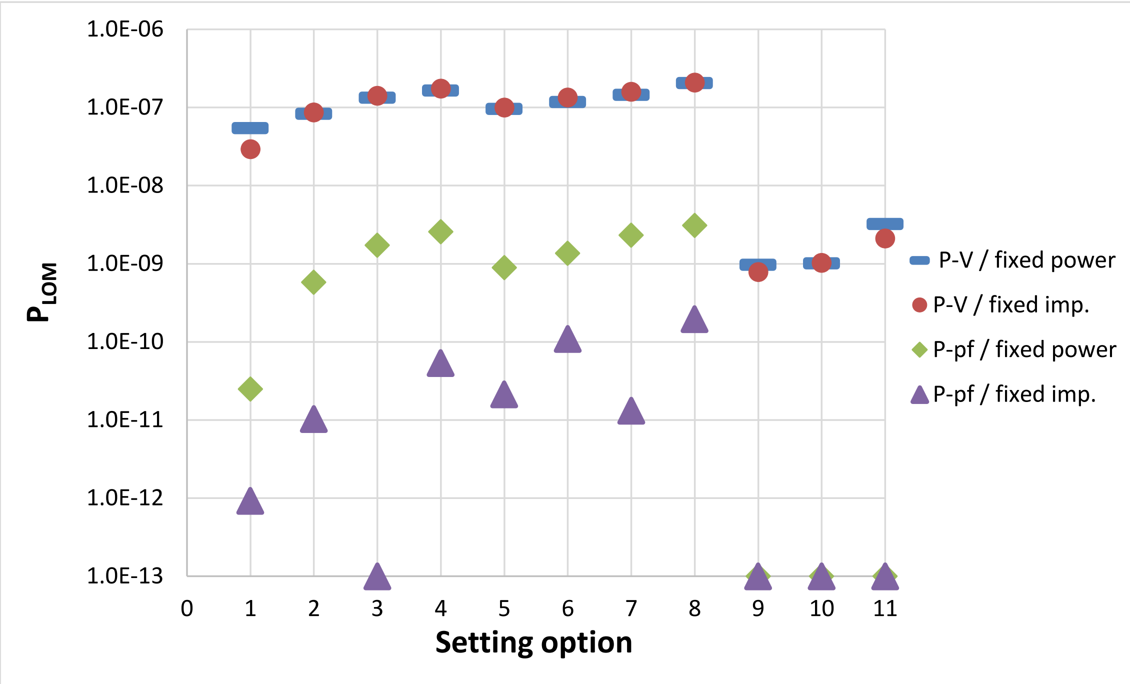


a) ROCOF enabled only

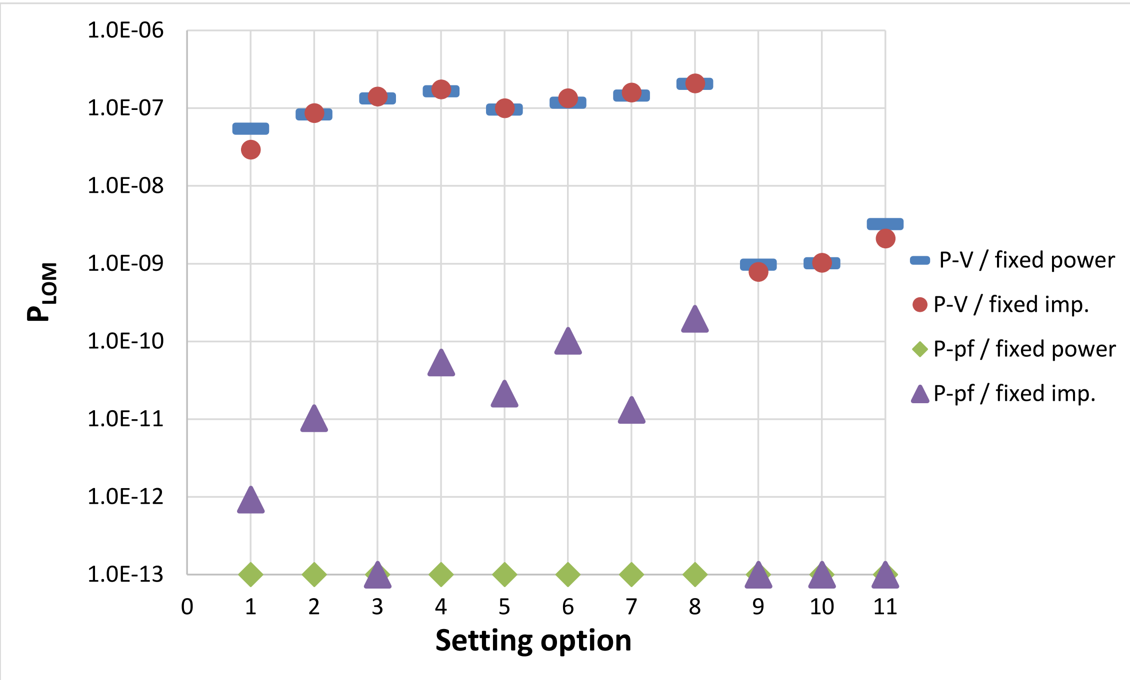


b) Full G59/2 interface protection enabled

Figure 27. Probability of undetected islanding operation – Load Case 3

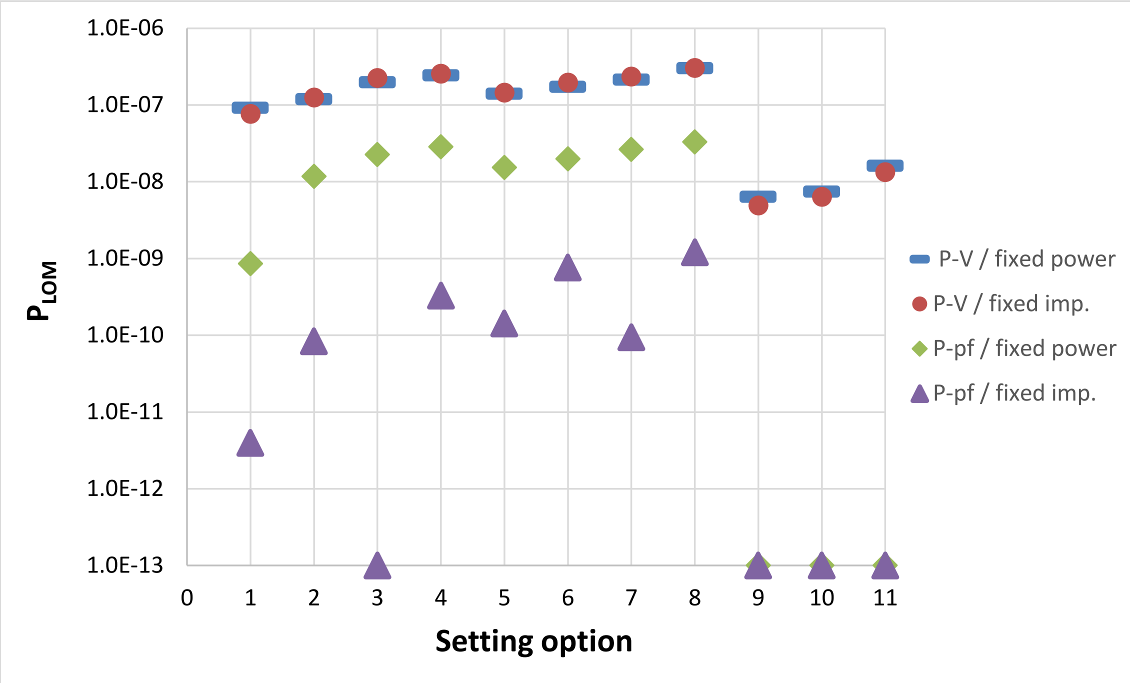


a) ROCOF enabled only

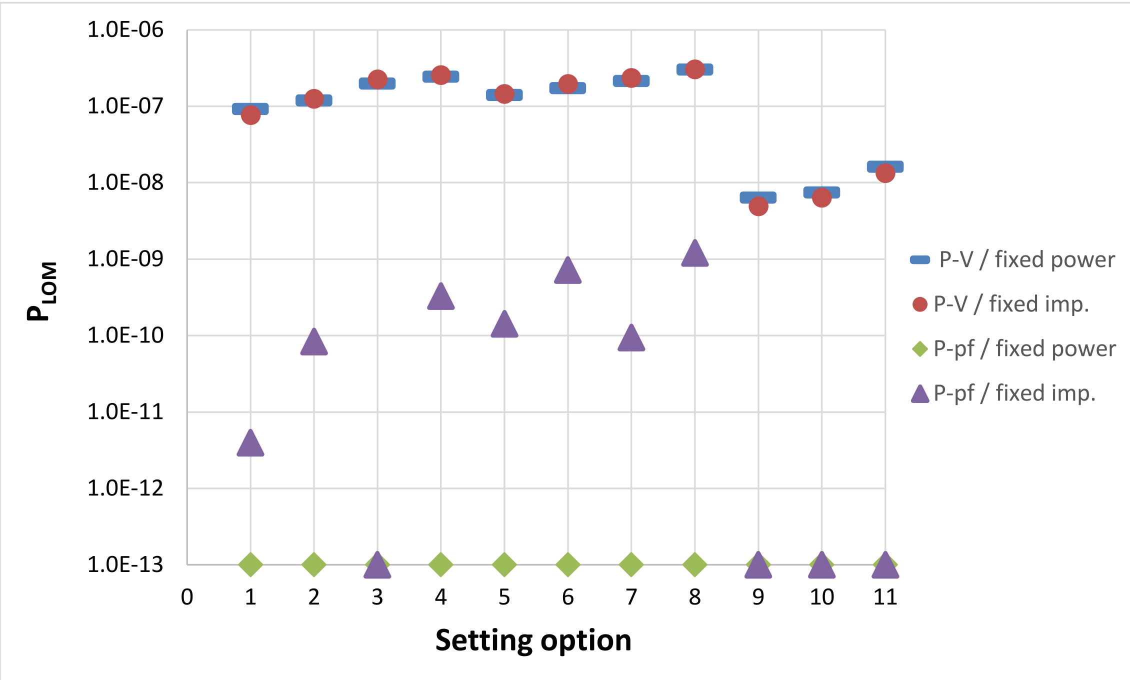


b) Full G59/2 interface protection enabled

Figure 28. Probability of undetected islanding operation – Load Case 4

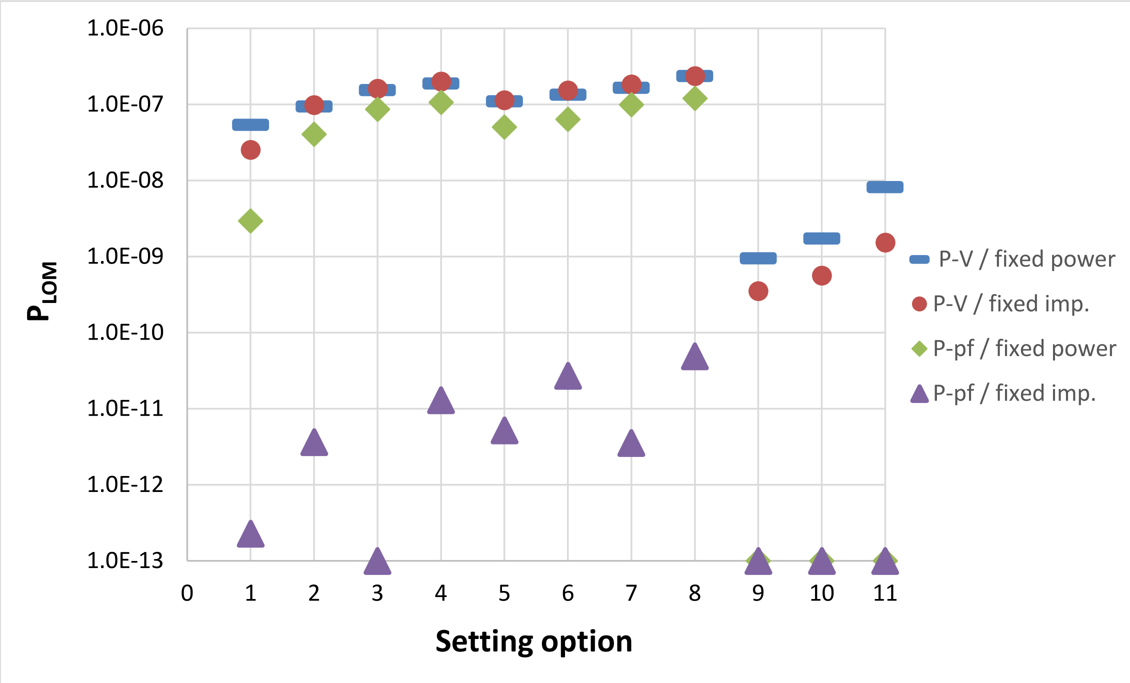


a) ROCOF enabled only

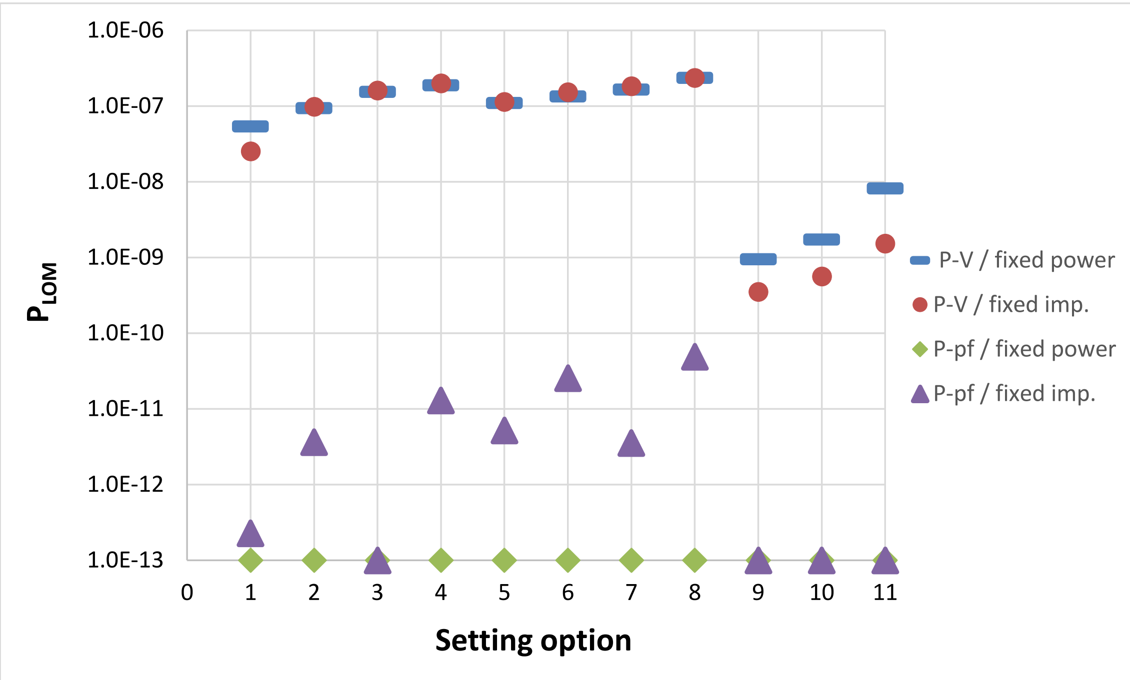


b) Full G59/2 interface protection enabled

Figure 29. Probability of undetected islanding operation – Load Case 5

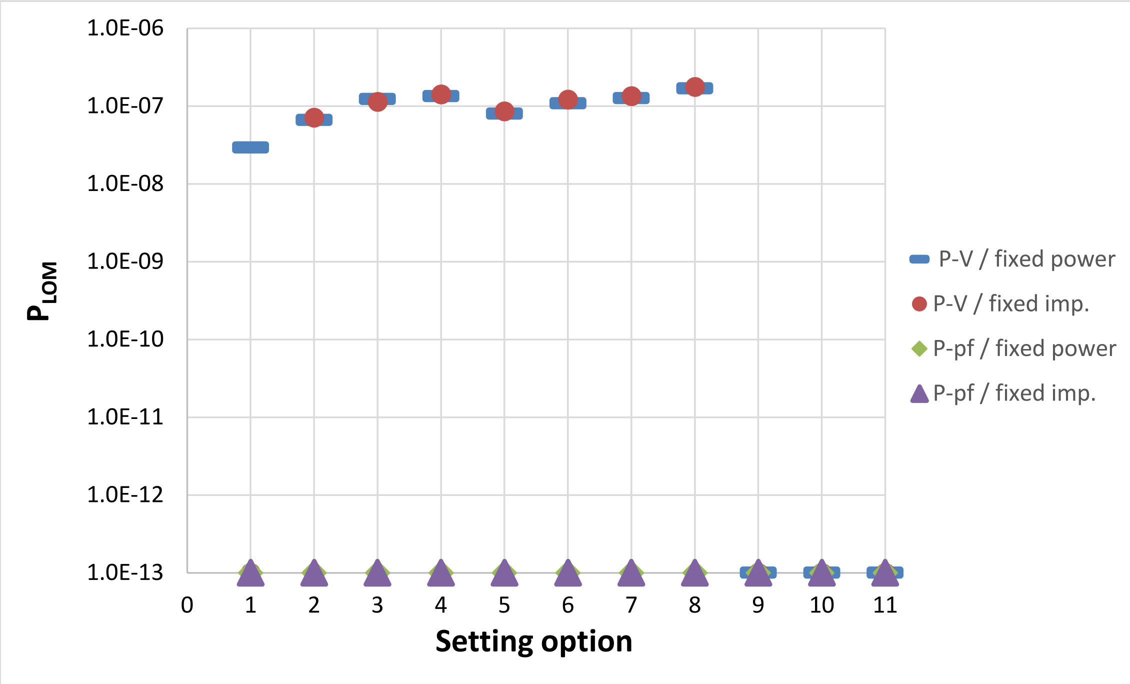


a) ROCOF enabled only

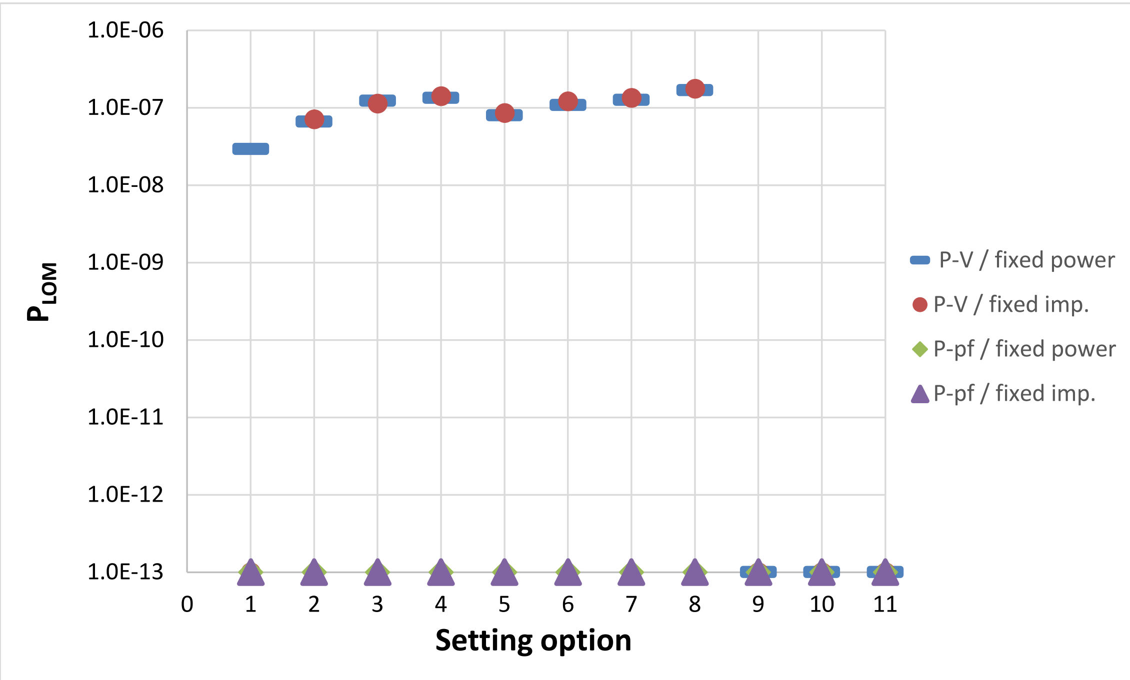


b) Full G59/2 interface protection enabled

Figure 30. Probability of undetected islanding operation – Load Case 6

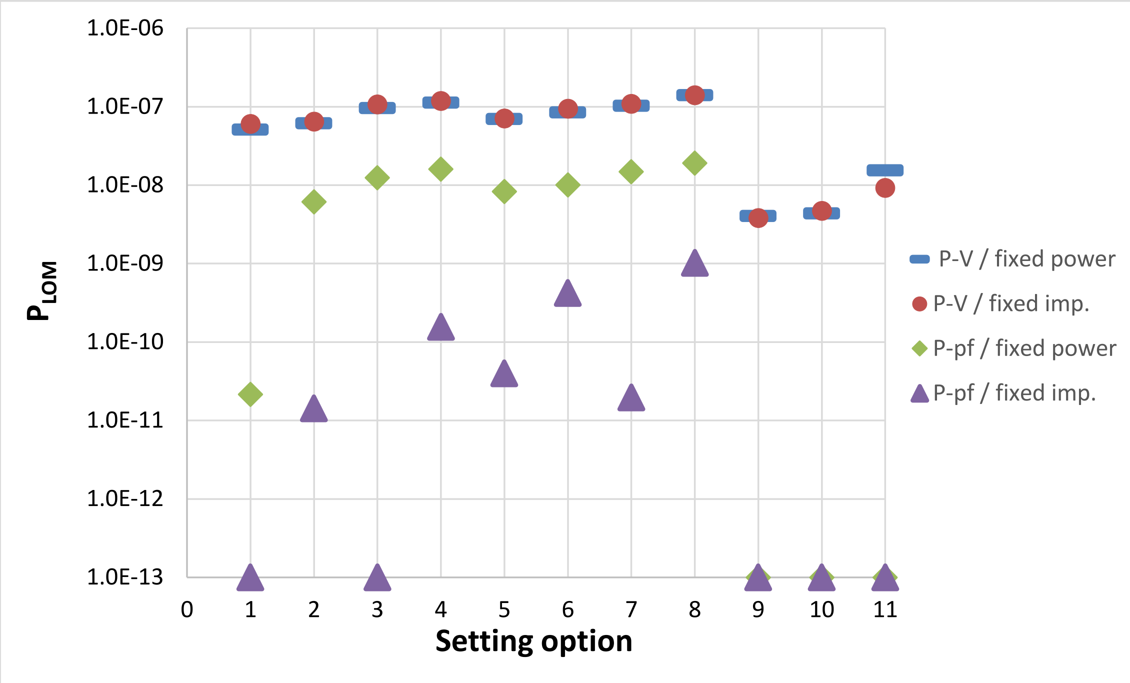


a) ROCOF enabled only

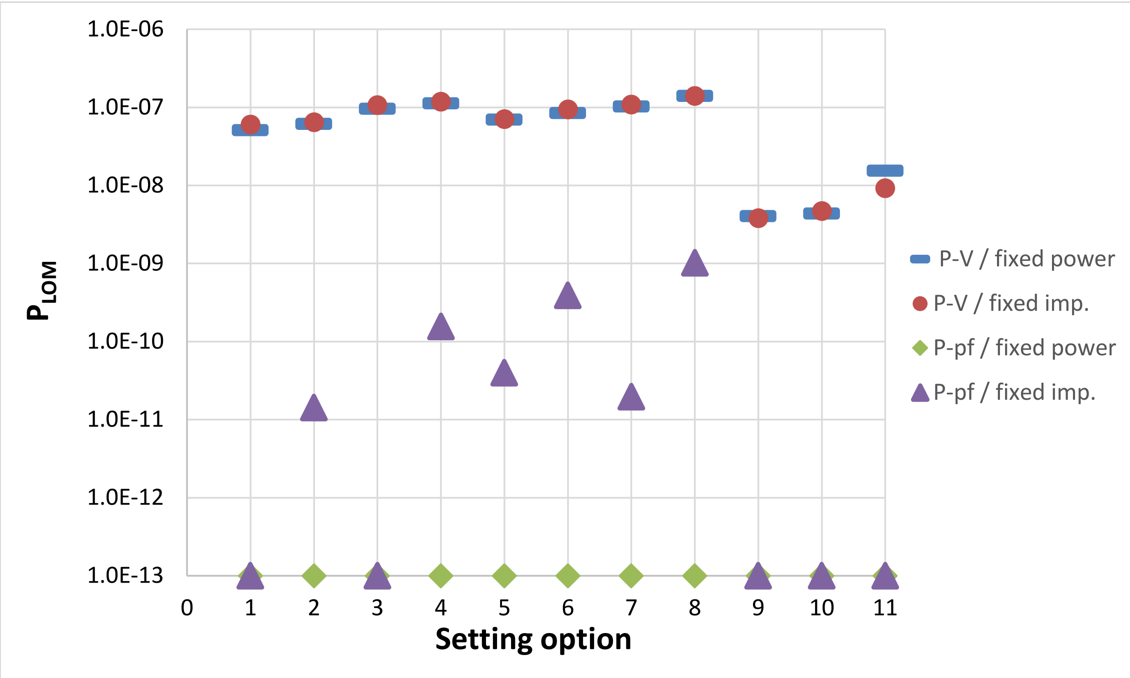


b) Full G59/2 interface protection enabled

Figure 31. Probability of undetected islanding operation – Load Case 7



a) ROCOF enabled only



b) Full G59/2 interface protection enabled

Figure 32. Probability of undetected islanding operation – Load Case 8