Interaction of FRT requirement and LOM protection with different technologies and solutions

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1. Introduction

The rapidly increasing amount of DG has raised concerns related to unintentional islanding. Unintentional islanding is prohibited due to the associated safety hazards which are:

1) Unsynchronized reclosing which may damage network components and DG units
2) Failed reclosing of a distribution feeder due to DG back feeding
3) Customer devices may be damaged due to poor power quality in the islanded circuit
4) Lines that are thought to be de-energized can be energized by DG. This is a safety risk for utility field personnel.

All DG units thus need to be equipped with some type of loss of mains (LOM) protection which ensures that unintentional islanding does not occur.

The operation speed requirement for LOM protection may vary from case to case. For instance, the utilization of fast reclosing, i.e. aforementioned reasons number 1 and 2, require rapid islanding detection times from LOM protection (typically from 0.2s to a couple of seconds). These requirements can be avoided by not using reclosing. However, this is highly undesirable from supply reliability point of view since the majority of faults are temporary in nature and can thus be cleared with the help of reclosings. For instance, in Finland about 90% of faults on overhead lines are temporary in nature and thus also clearable by automatic reclosing. One more reasonable option is to extend the open time of the circuit breaker during fast reclosing to provide enough time for LOM protection to operate correctly.

Very sensitive LOM protection settings, however, also have disadvantages. This stems from the fact that faults in the transmission network can launch huge amounts of adverse tripping of DG units which was, for instance, witnessed during the UCTE disturbance in the 4th of November 2006. Because of this risk, system operators have issued grid codes that define how long generating units have to be able to stay connected and support the system stability during various kinds of disturbances. These fault ride through (FRT) requirements were originally meant only for large wind parks connected to HV grids. However, the rapid growth of DG has led these requirements to diffuse to MV and LV levels as well.

It is generally known that the objectives of LOM protection are of somewhat controversial with the objectives of FRT requirements. However, it appears that no papers have studied the relation of LOM protection performance and FRT requirements thoroughly with simulations. This report aims to fill this gap by providing extensive simulations which show how exactly the grid code requirements affect the performance of LOM protection. The studies are performed in a unique simulation environment consisting of two different types of real time simulators and a real LOM relay.

2. Non-detection zone of LOM protection

The non-detection zone (NDZ) is a suitable approach for assessing the performance of different LOM protection algorithms. NDZs can be represented in a load parameter space [1], [2] or in a power mismatch (ΔP, ΔQ) space [3], [4]. Power mismatch space is suitable for the assessment of passive LOM detection methods, whereas, for the assessment of active LOM detection schemes, it is advisable to utilize load parameter space [1]. For more information concerning the NDZ concept, refer to [1] and [2].

The behaviour of voltage magnitude and frequency in an islanded circuit are largely dependent not only on the characteristics of the DG unit(s) in the island, but also on the characteristics of the islanded load(s). The loads used in islanding detection tests are usually modelled as parallel RLC circuits with a quality factor (Q_f) ranging from 1.0 to 2.5. A quality factor value of 2.5 is typically utilized in North American standards even though it is considerably higher than what would be expected for a typical parallel RLC load. However, there are plans to reduce the Q_f of islanding test load from 2.5 to 1.0. [5] The quality factor, which defines the relative energy storage and dissipation of an RLC circuit, is defined in IEEE-929-2000 standard for a parallel RLC circuit in equation 1 [1], [5], [6].

$$Q_f = \omega_0 RC = \frac{R}{\omega_0 L} = R\sqrt{\frac{L}{C}} \quad (1)$$

Where $\omega_0 = 2\pi f_0 = 1/\sqrt{LC}$ refers to angular resonant frequency of the load. IEEE 929-2000 standard is mostly concerned with small scale photovoltaic based DG units with rated capacity of 10kW or less, although it also contains some guidelines for systems up to 500kW as well. As mentioned, the Q_f value 2.5 is considerably higher than what would be expected for a typical parallel RLC load. Moreover, it is even more unlikely that a very large amount of parallel RLC loads lumped to one large MV level load model would have a quality factor as high as 2.5. Because of this, a Q_f value higher than 1.0 for the utilized lumped parallel RLC load was not utilized in the simulation studies of this report.

3. Simulation environment

The simulation studies presented here were conducted using a unique real time environment consisting of two types of real time simulators. The dSPACE is a well proven tool for modelling control systems and power electronics, whereas, the RTDS provides very accurate real time electromagnetic transient simulation for power systems. This environment, which is depicted in Fig. 1, also enables the connection of real external devices to be connected to function as a part of the simulation. More information on the simulation environment can be found from [7].

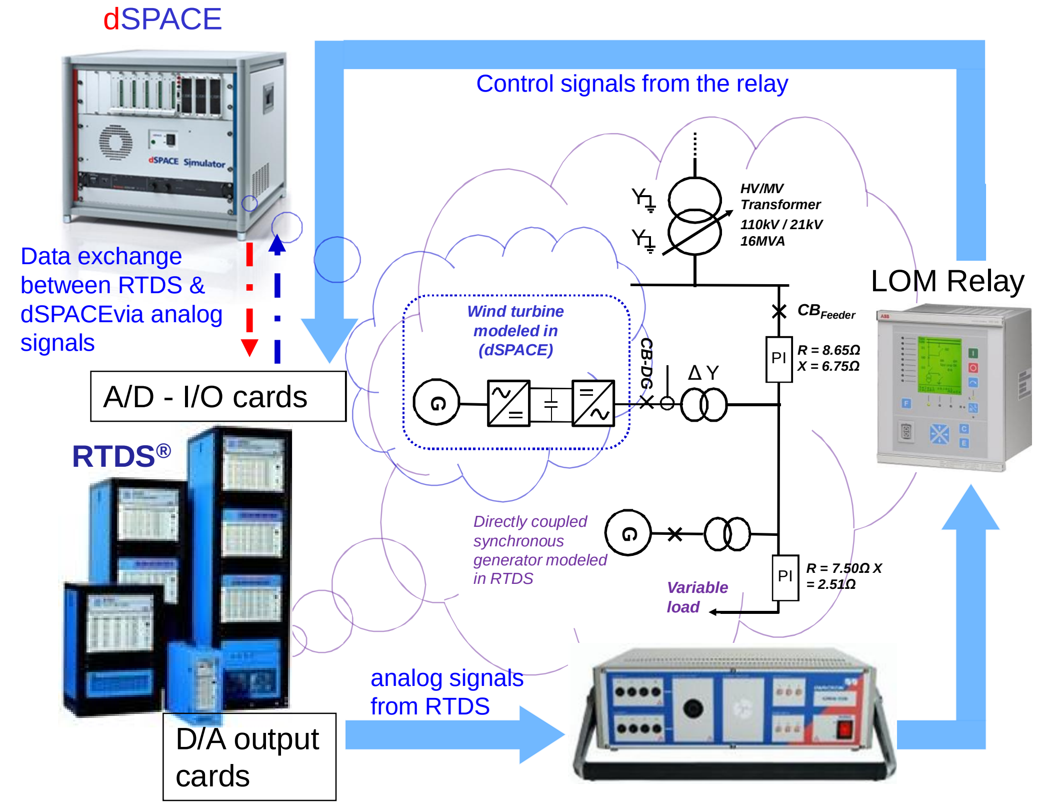

Fig. 1. The simulation environment

The RTDS, which consists of a number of processor cards, and I/O cards, was used for running the power system modelled with the help of a dedicated program called RSCAD. A real LOM relay was set to control the DG unit circuit breaker in the power system model. The voltage signals from the connection point of the DG were first given as analogue output signals to a Omicron CMS156 amplifier, which amplified the signals to proper scale for the use of the LOM relay. The LOM relay then sent its control decisions concerning the DG unit circuit breaker back to the RTDS as digital signals via copper wires.

3.1. Typical LOM relay settings

The utilized LOM protection functions in the studies of this report were undervoltage-, overvoltage, underfrequency and overfrequency protection. The LOM protection settings that were utilized for simulating the NDZs in Figs. 4 - 6, which are shown in table I, were not taken from any specific standard but they are very close to many European national recommendations [8].

Table I. – The utilized LOM protection settings

Protection function	Threshold	delay
Voltage	0.8 x Un & 1.15 x Un	0.2 s
Frequency	49 Hz & 51 Hz	0.2 s

3.2. FRT compliant LOM relay settings

Low voltage ride through (LVRT) requirement is mostly related to loosening the undervoltage protection (UVP) threshold of LOM protection. However, certain other methods, as for instance rate of change of voltage, which are based on detecting islanding with the help of change in voltage, may also need to be loosened to allow the LVRT. It is noteworthy that this issue is also related to communication based LOM protection methods, because remote methods often have a local LOM protection method for back up purposes. Thus, without coordination, the local back up protection may cause unwanted tripping during voltage dips. On the other hand, applying such back up protection settings that will enable the FRT will naturally degrade the performance of back up protection. One option to avoid this problem is to utilize continuous supervision of the communication channel instead of back up protection and immediately disconnect the protected DG unit whenever a malfunction in the communication channel is detected. However, as this kind of approach also causes unwanted tripping of DG, it would be wiser to only switch to the utilization of local back up protection once a malfunction in the communication channel is detected. This would ensure reliable and FRT compatible LOM protection.

The blue line in Fig. 2 illustrates the shape of FRT curve (for generating units in the range of 0.5MW to 100 MW) required by the Finnish transmission system operator Fingrid. Generating units need to be able to ride through faults in which the voltage does not drop below the blue curve in the figure, which represents the HV connection point voltage in per unit scale. The red line in Fig. 2 represents the two step approximation of the FRT curve which was utilized in the LOM relay.

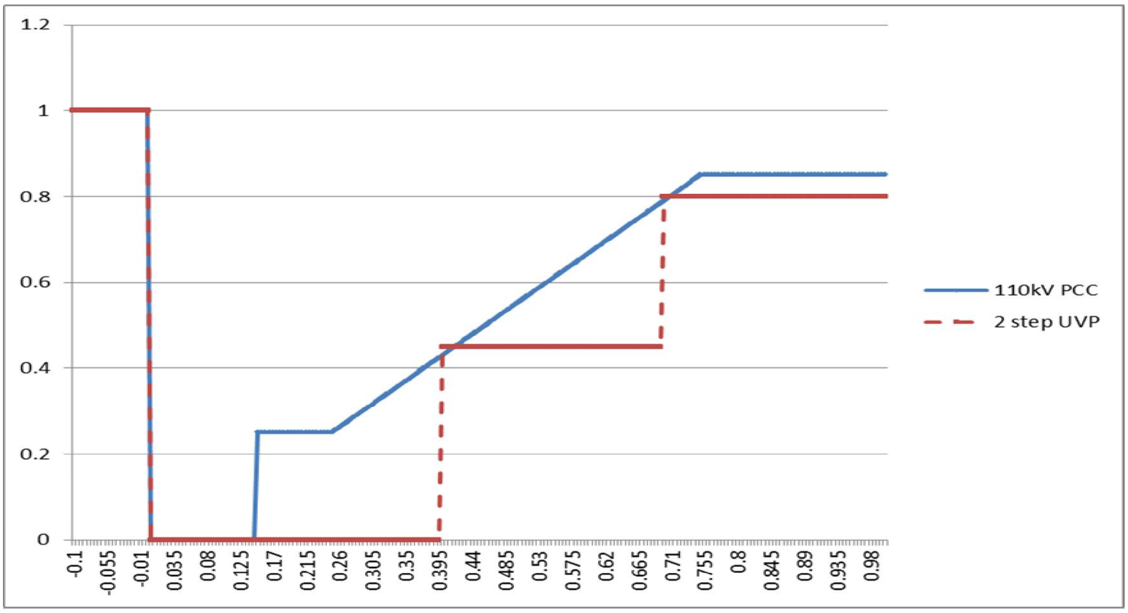

Fig. 2. The FRT requirement curve of Fingrid (blue line) and the utilized FRT compatible LOM protection UVP settings (red line)

The UVP settings had to be very simplified as shown in the figure because of the limited amount of configurable steps in the utilized protection relay. Relay manufacturers should take the FRT requirements into account in the UVP function blocks and design a user friendly way for making the UVP settings compatible with utility grid codes. The FRT compatible relay settings are also shown in table II. However, modern grid codes require generating units not only to be able to ride through faults but also to be able to support the voltages by feeding reactive power during grid faults [9, 10]. This issue will be taken into account in the simulation studies presented in chapter 5.

Table II. – The FRT compatible LOM protection settings

Protection function	Threshold	delay
Overvoltage	1.15 x Un	0.2 s
Undervoltage low stage	0.8 x Un	0.7 s
Undervoltage high stage	0.45 x Un	0.34 s
Frequency	49 Hz & 51 Hz	0.2 s

4. The simulation models

A simple distribution network model, which is shown in Fig. 3, was modelled with the help of RSCAD for performing these studies. The model consists of voltage source representing the main grid, a 110kV/21kV rated HV/MV transformer, one medium voltage distribution feeder which is represented by two π-line representations and a variable load at the tail part of the distribution feeder. All the above described components were simulated by the RTDS, whereas, the in-detail modelled full converter connected wind turbine (FCWT) was simulated by the dSPACE as shown in Fig. 2. This 500kVA rated DG unit is presented in detail in [7]. The synchronization to the grid voltage is carried out using synchronous reference frame phase locked loop (SRF-PLL) [11].

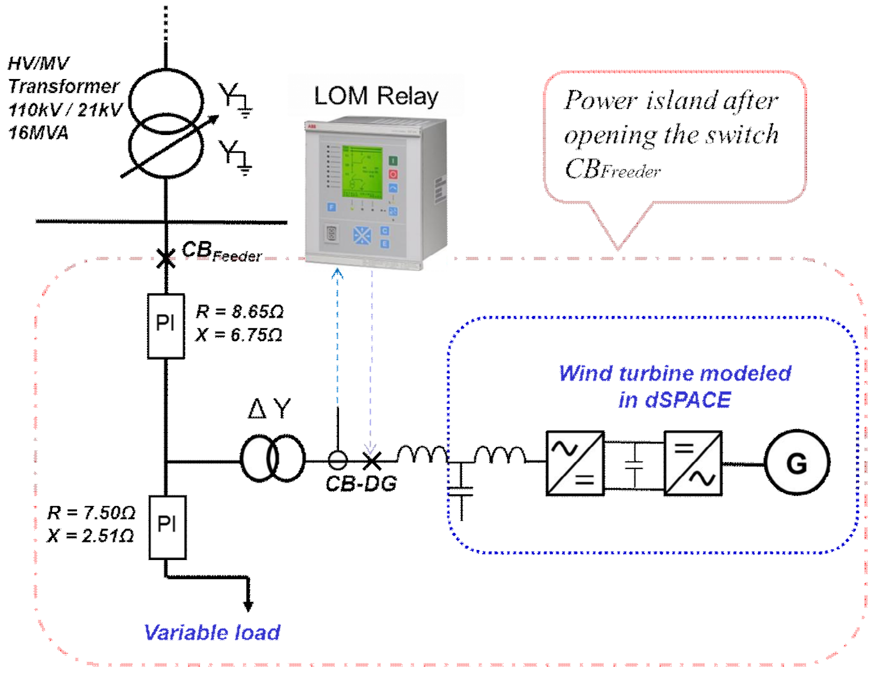

Fig. 3. The utilized simulation model

The power imbalance on the feeder was varied in small steps by varying the demand of the controllable constant impedance type load connected to the tail part of the feeder. For each combination of power imbalance, the CB_{Feeder} switch was opened after the output power of the DG unit had stabilized. The resulting power island was then maintained only by the DG until the LOM relay operated. In each case, the active and reactive power imbalance, the operation time of the LOM relay as well as certain other parameters were captured. The NDZs for the studied cases, which will be presented in the following chapter, were determined based on this stored data.

5. Simulation studies

This chapter which presents the simulated NDZs is divided into four subchapters. The first subchapter illustrates the effect of utilized synchronization method and the quality factor of the load on the performance of LOM protection. The second subchapter studies how exactly the performance of LOM protection is degraded when UVP function is set to allow the LVRT. The third subchapter demonstrates how reactive power support of DG affects the performance of LOM protection. Finally, the fourth subchapter examines how the addition of ROCOF function can enhance the situation. The quality factor was kept at 1.0 in all the simulation studies presented here except for the NDZ presented in Fig 6.

5.1. NDZ of a typical LOM protection

The LOM relay was configured according to the settings shown in table I in the studies of this subchapter. In the first simulated NDZ, the utilized synchronization method of the grid side converter (GSC) was a simple zero crossing based PLL (see [12] for more details). Fig. 4 shows the resulting NDZ. The pink coloured area marked with the sign “NDZ 1.5s” in Fig. 4 represents the set of power imbalance combinations where LOM protection failed to isolate the DG unit within 1.5s from the beginning of the islanding. The other layers marked with the signs “NDZ 1.0s”, “NDZ 0.7s”, “NDZ 0.5s” and “NDZ 0.3s” respectively refer to relay operation times 1.0s, 0.7s, 0.5s and 0.3s. This means that the smaller the size of NDZ is, the better the performance of LOM protection is. This multi-layer NDZ format is more suitable for showing the effect of the FRT compatible LOM protection settings as it will be seen from the later results of this report. The quality factor of the load was kept at 1.0 in the simulations.

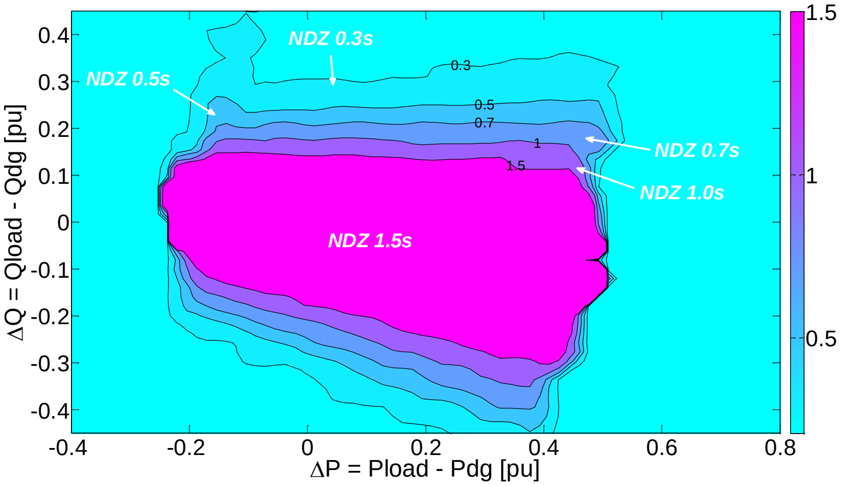

Fig. 4. The NDZ of LOM protection when the utilized synchronization method of the GSC was a PLL based on zero crossings. Q_f was 1.0.

In all the rest of the following simulations, the utilized synchronization method of the GSC was the SRF-PLL [11]. The resulting NDZ, which is shown in Fig. 5, is considerably smaller than the one in Fig 4. The comparison between Figs. 4 and 5 thus clearly illustrates that the importance of the utilized synchronization method of the grid side converter should not be underestimated.

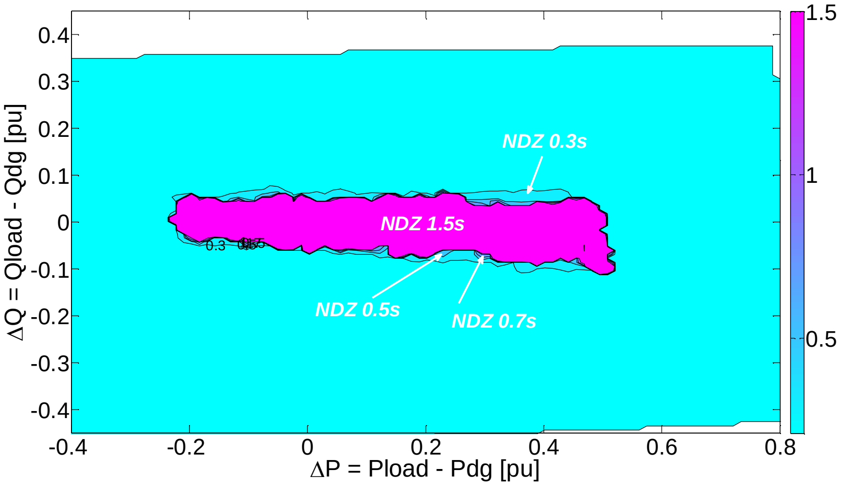

Fig. 5. The NDZ of LOM protection when the utilized synchronization method of the GSC was the SRF-PLL.

The quality factor of the parallel RLC load was now changed from 1.0 to 0.1 and the previous simulations were repeated. Fig. 5 shows the resulting NDZ. By comparing Figs. 5 and 6 it can be clearly seen that the size of the NDZ reduces significantly as the quality factor of the parallel RLC load is reduced to 0.1. However, the reduction in the size of the NDZ is only seen in the ΔQ direction and no significant change is seen ΔP axis direction.

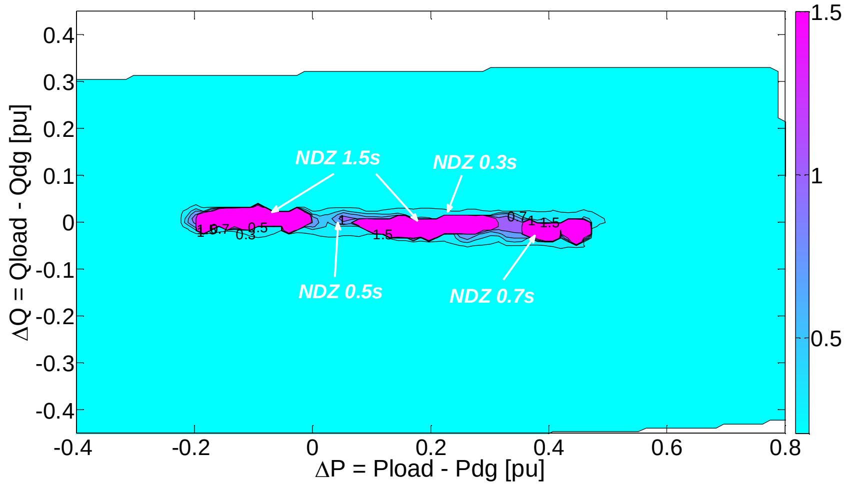

Fig. 6. The effect of reducing Q_f to 0.1.

5.2. NDZ of FRT compliant LOM protection

In the following case, the UVP function of the LOM relay was set to allow the FRT by utilizing the settings presented in table II. Fig. 7 represents the resulting NDZ. It can be seen from the figure that the NDZ now extends considerably further in the positive ΔP axis direction than what it did with the original settings (Fig. 5). It is noteworthy that UVP function trip region was not reached in the simulated NDZ, that is, the NDZ would extend even further towards the positive ΔP axis direction than what Fig. 7 shows. Note that the scaling in Fig. 7 is very different from the scaling in earlier figures. The quality factor was kept at 1.0.

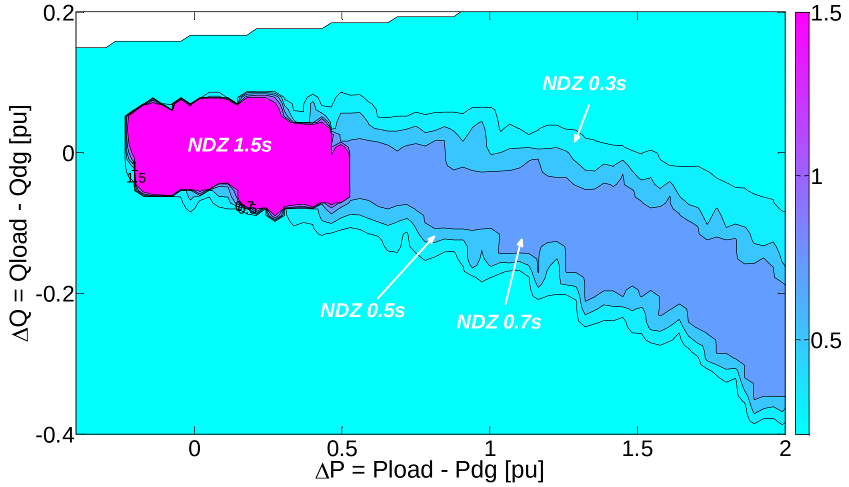

Fig. 7. NDZ of a FRT compatible LOM protection. Q_f was 1.0.

5.3. The effect of reactive power support of DG units

As already mentioned, modern grid codes usually also require generating units to be capable of supporting the power system during voltage dips by feeding reactive power into the grid. In the following case, a voltage droop with a 5 percent deadband was added to the grid side converter control system. The droop was adjusted so that the DG unit gave maximum available reactive power output at 50 percent voltage deviation. Fig. 8 shows the resulting NDZ. As the figure illustrates, the NDZ area now covered surprisingly large reactive power imbalances. This result shows that the performance of LOM protection is dangerously degraded when DG units are required to both be able to ride through faults and to provide voltage support by feeding reactive power.

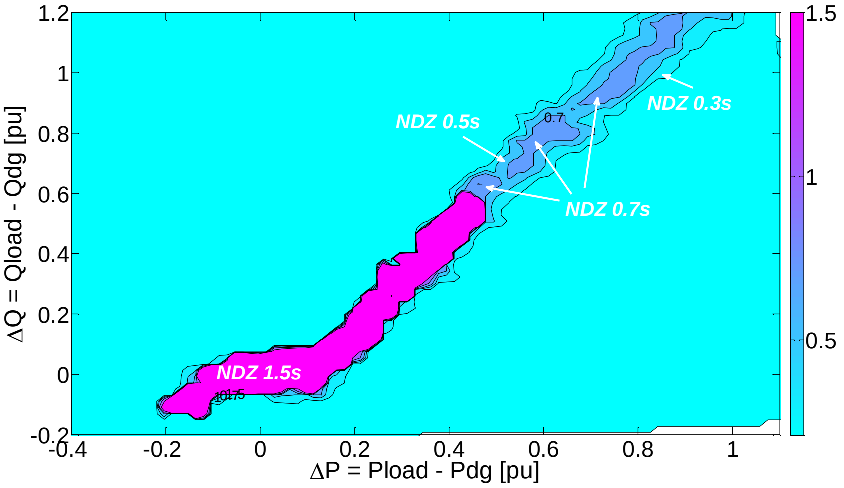

Fig. 8. The NDZ when a voltage droop control (5% deadband) was added to the GSC control system. Q_f was 1.0.

5.4. The effect adding ROCOF function

The rate of change of frequency (ROCOF) is one of the most utilized LOM protection methods. In the following case, the ROCOF function was added to the relay and its threshold was set to 1Hz/s with a 0.2s operate delay time. Fig 9 shows the resulting NDZ. The comparison between Figs. 8 and 9 shows that the addition of ROCOF reduces the size of the NDZ considerably from its ΔQ boundaries. However, the ROCOF is not able to reduce the size of the NDZ in the ΔP direction as expected.

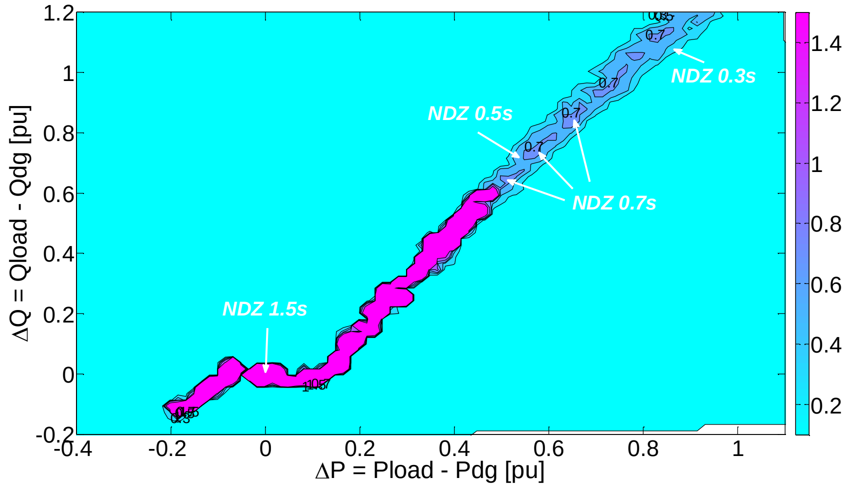

Fig. 9. The NDZ when the GSC was operated in voltage droop mode and the ROCOF function was set to 1Hz/s. Q_f was 1.0.

6. Conclusion

This report studied the effect of FRT requirements on loss of mains protection. The studies were based on a large number of simulations conducted in a unique real time simulation environment including a real LOM relay. It was observed that when LOM protection has to be set to allow DG units to ride through faults, the performance of UVP function is significantly degraded as expected. In fact, in these studies, the NDZ region extended to further than 2 per unit in real power imbalance. Another observation was that the reactive power support which is required in many modern grid codes has a significant effect on the performance of LOM protection. Problematic situations for LOM protection may exist with surprisingly large reactive power imbalance points when the studied DG unit configured to support the system during voltage dips by feeding reactive power. It was also observed that the utilized synchronization method of the GSC may have a significant effect on the performance of LOM protection.

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