Non-detection zone of LOM protection for converter connected wind turbines

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Introduction

The growth of distributed generation capacity brings upon many potential benefits but also raises new challenges. Among these challenges, unintentional islanding is considered to be among the most difficult issues. Islanding refers to situation where a network section including both customer loads and DG becomes isolated from the main grid. Unintentional islanding is forbidden because it raises safety hazards for utility personnel and may cause damage to DG units as well as to network components. All DG units thus need to be equipped with a loss of mains (LOM) protection scheme which ensures that unintentional islanding does not occur. Moreover, it is also important for the utilization of intentional islanding that the transition to islanding is rapidly detected so that the DG units in the islanded circuit can switch their control modes in order to sustain the frequency and voltages in the island.

A large number of various LOM detection methods have been presented in the literature [1-4]. Many of these are methods are claimed to show high performance. It is thus important that the performance of these methods can be assessed in an objective way. The determination of the non-detection zone (NDZs) of LOM detection algorithms is a suitable approach for this. NDZs can be represented in a load parameter space [1, 2] or in a power mismatch (ΔP, ΔQ) space [5, 6]. 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 [2]. The authors [5] presented studies in which the NDZ of voltage magnitude and frequency based LOM protection for a circuit which included a converter coupled DG unit. Similar studies with the exception that the protected DG unit was a directly coupled synchronous generator were presented by the authors [6]. However, there seems to be no studies concerning the NDZ in a case where the islanded circuit contains both directly as well as converter coupled DG units in the literature. This study aims to fill this gap.

Loss of mains protection

Most of the LOM protection methods are based on detecting the changes in some system quantities such as voltage and frequency. These changes, which usually take place when islanding occurs, are mainly caused by the imbalance between the production and consumption of real- and reactive power in the island. There is, however, a risk that this imbalance is so small that the transition to island mode does not cause any of the quantities measured by a LOM relay to drift out of the preset limits. In cases like this, LOM protection fails to detect islanding. This blind area of LOM protection in the surroundings of the production- consumption equilibrium is called the NDZ. [5, 6] The grey area in Fig. 1 illustrates the conceptual shape of the NDZ for traditional overvoltage- (OVP) / undervoltage (UVP) and overfrequency- (OFP) / underfrequency based LOM protection (UFP) in power mismatch space. As the left side of the figure illustrates, reactive power imbalance (ΔQ) is mainly related to UVP/ OVP limits and active power imbalance (ΔP) mainly to UFP/ OFP limits, when the islanded network is maintained by a directly coupled synchronous generator [6]. However, the boundaries formed by the protection functions in the NDZ twist approximately 90 degrees in relation to the active- and reactive power axes when the protected DG unit is constant power controlled converter coupled generating unit as the right side of fig 1 illustrates. [5].

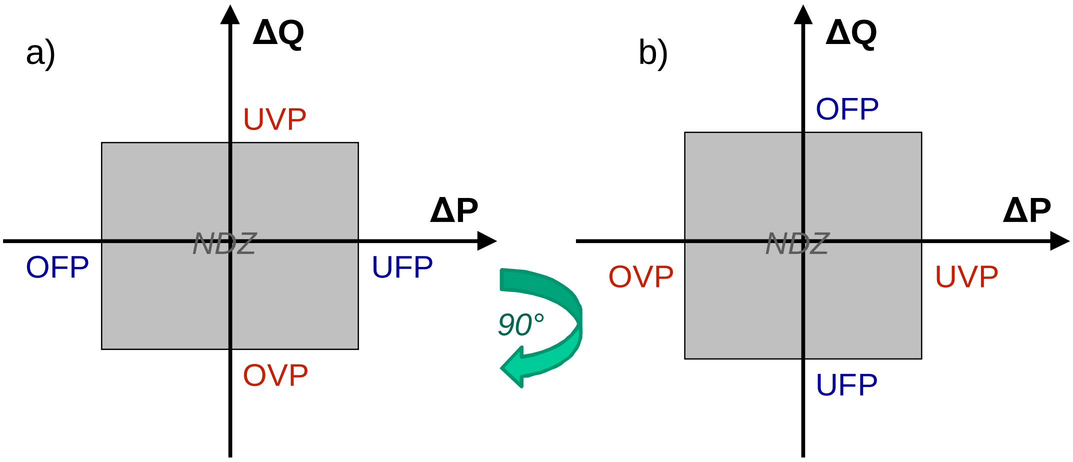

Fig. 1. Non-detection zone for voltage and frequency based LOM protection when the protected DG unit is a) directly coupled synchronous generator b) constant power controlled converter coupled generating unit

Categorization of LOM detection methods

LOM detection methods can be divided into four groups. These are communication based methods, local passive-, local active-, and hybrid methods. A short introduction to these methods is given in the following.

Passive methods are based on locally measuring certain system quantities, such as voltage and frequency. The idea behind these methods is that changes in the measured quantities usually occur during the transition to islanding. Passive methods are the most utilized ones due to their low cost and applicability to all DG units. However, most of these methods have a fairly large NDZ. [3,4]

Active LOM protection schemes are based on constantly injecting small perturbations into the network and measuring the response of the system. The idea behind this is that the system quantities can only be manipulated when islanding occurs. [4] Some active detection schemes can even detect balanced islanding, but they tend to provide slower detection because changing the system quantities takes time [3].

Hybrid methods attempt to combine the advantages of passive and active methods. This is done by activating the chosen active method only when the chosen passive method suspects islanding. This approach reduces the power quality problems caused by the active method remarkably since the active method is, most of the time, not activated. However, the utilization of two sequential methods usually results to longer detection time [3].

The idea in the communication based LOM protection schemes is to signal all the downstream DG units whenever the opening of an upstream switch causes the connection to the main grid to be lost. These schemes are immune to the NDZ problem because they are not based on local measurements. Communication based methods are superior to the other LOM detection methods from the technical point of view but they are also generally more costly and vulnerable to communication failures. [4]

Simulation environment

The studies were performed using a unique real time simulation environment consisting of two types of real time simulators, namely the dSPACE and the RTDS®. 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. 2, 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].

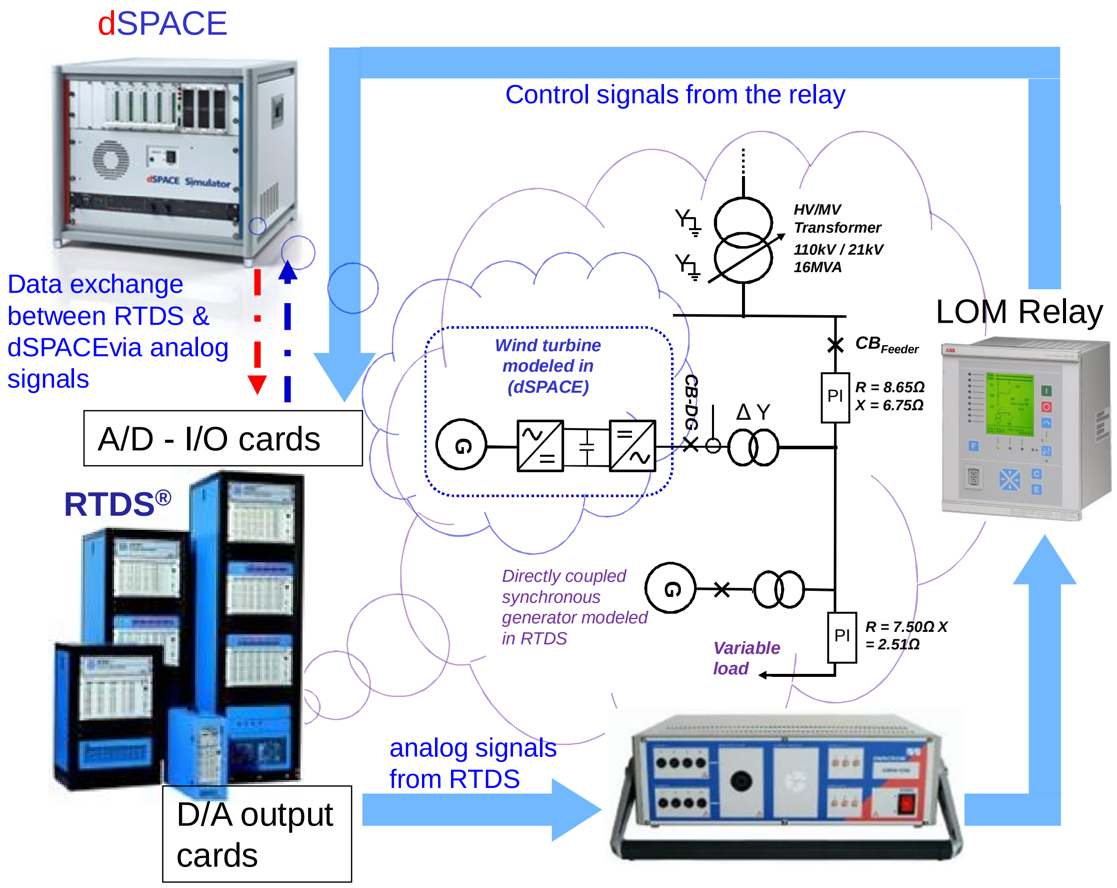

Fig. 2. The utilized simulation environment

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 analog 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. The utilized LOM protection settings, 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 relay protection setings

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

A full power converter connected wind turbine (FCWT) was modelled with the help of Matlab that was equipped with Simulink and Real Time Workshop. This model was then compiled for the use of the dSPACE simulator. The connection between the two real time simulators was established via analog signals as shown in Fig. 2.

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.

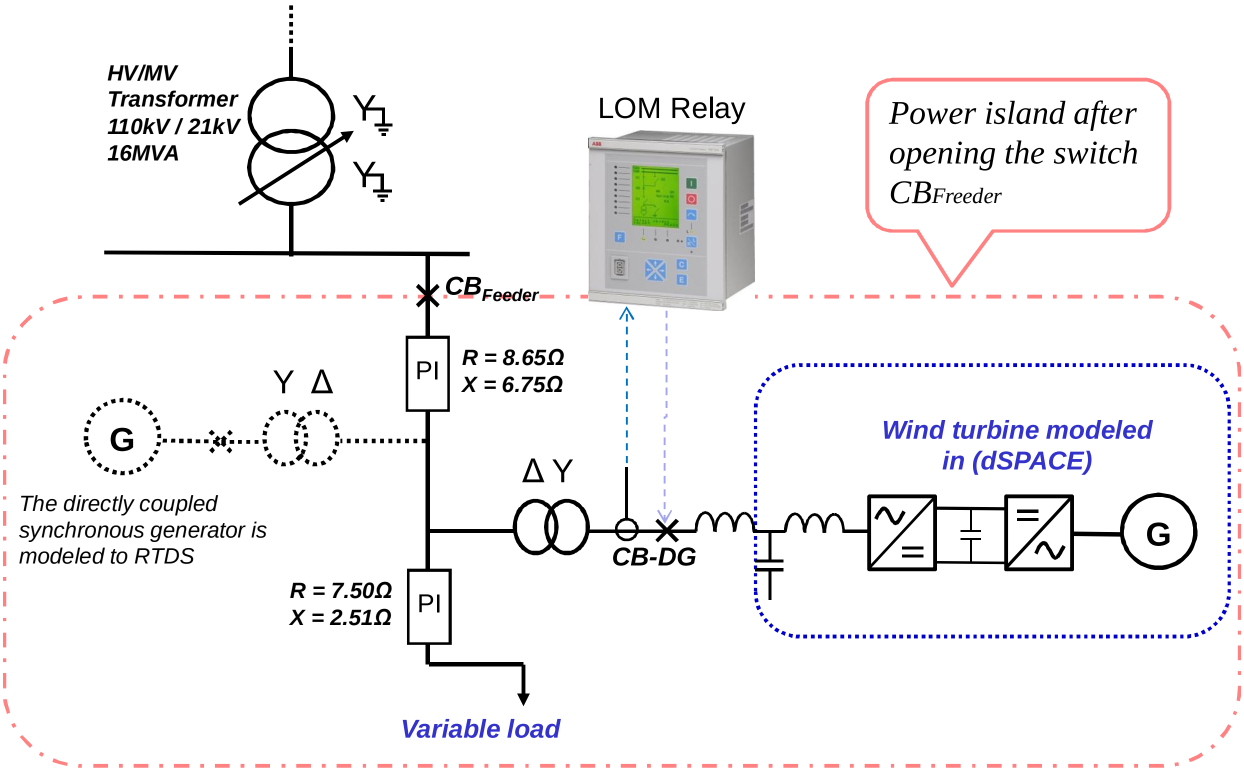

Fig. 3. The utilized simulation model

Additionally, a directly coupled 1.6MVA rated hydro power driven synchronous generator (SG) was connected to the mid-section of the feeder via a 0.66kV/21kV step up transformer. All the above described components were simulated by the RTDS, whereas, the in-detail modelled FCWT was simulated by the dSPACE as shown in Fig. 3. This 500kVA rated DG unit is presented in detail in [7].

The reactive power control of the SG model was realized using a cascade control, where a control loop determined the set point of the automatic voltage regulator with the aim of maintaining the reactive power output at a target value. Certain simplifications, namely the omission of the turbine controller modeling and the assumption of constant torque were made in the models. These measures are justified since hydro power plants have relatively high inertial mass which makes them respond to changes slowly, whereas, LOM protection studies are dealing with short timeframes only. The omission of turbine controller is justified because DG units are typically not attending to frequency control.

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.

Simulation results

This chapter presents the simulated NDZs. The first two simulation cases aimed to verify the phenomenon presented in Fig 1. The third simulation study examines the effect of mixed type of DG units on the NDZ. Finally, the last simulation case studies the effect of adding a voltage droop in the grid side control system of the FCWT.

The effect of DG type on the NDZ

The purpose of the first simulation study was to verify the phenomenon presented in Fig 1. The results of this study can be seen from Figs. 4, which represents the NDZ of UVP/OVP and UFP/OFP based LOM protection in a case where the only DG unit was the directly coupled SG unit, and 5, which represents the NDZ of the same protection functions when the protected DG unit was the FCWT which was operated in constant reactive current mode [7]. The green colour in Figs. 4 - 7 represents the power imbalance area (in terms of ΔP and ΔQ) where the OVP function tripped within 0.5s, whereas the light blue area similarly represents the respective area for UFP function, dark blue colour for OFP function and orange colour for UVP function. The red area in the middle of these four areas represents the set of power imbalance combinations where none of the four functions detected the islanding within 0.5s. The axes in the figures are in per unit (pu) values, where the utilized base value in each case is the total generation on the feeder before the islanding. The base values were thus 1.35 MVA in Fig. 4, 0.48 MVA in figures 5 and 7, and 1.83 MVA in Fig. 6.

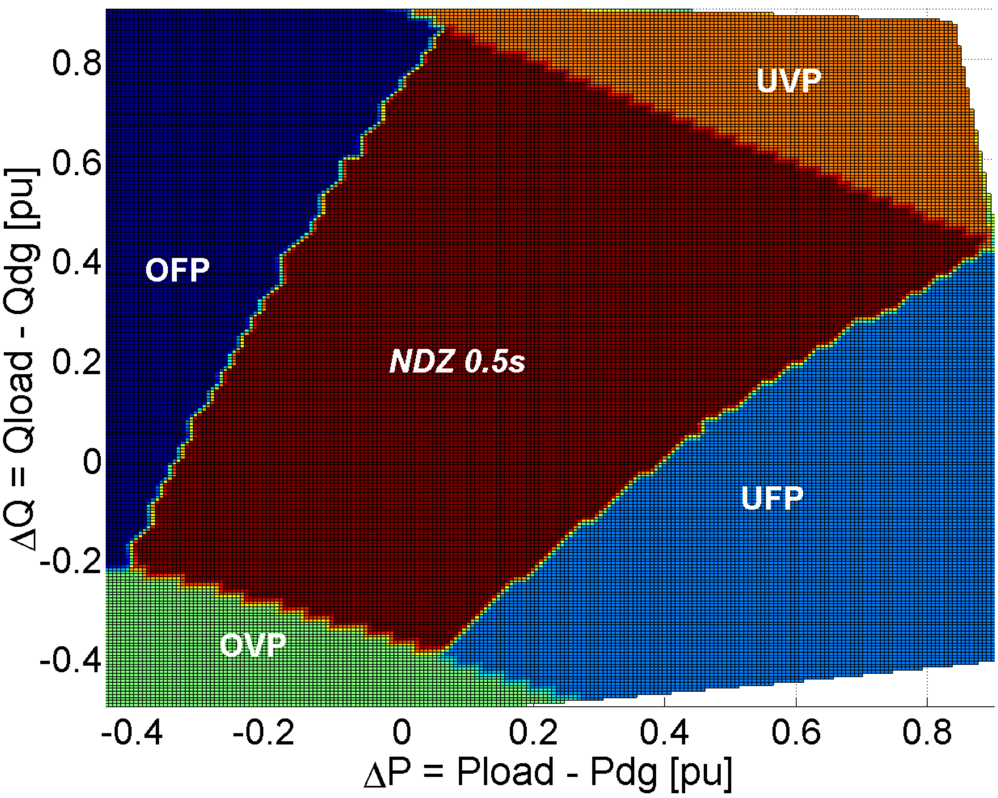

Fig. 4. The NDZ when the protected unit was the SG

By comparing Figs. 4 and 5, it can be seen that the NDZ as well as the four trip regions in Fig. 5 have twisted approximately 90 degrees in the clockwise direction in comparison to the ones in Fig. 4. This result is in line with the earlier studies in [5 and 6]. The clear twisting of the NDZ in Fig. 4 is caused by the voltage dependency of the utilized constant impedance load. This result is as well in line with the results in [6]

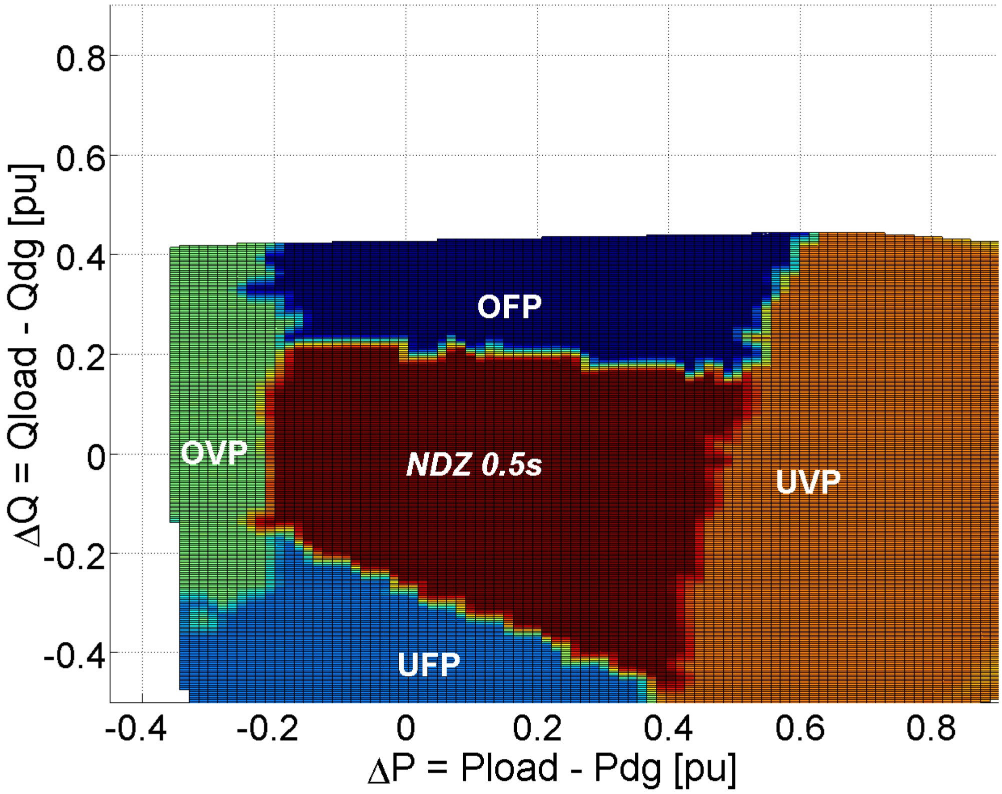

Fig. 5. The NDZ when the protected DG unit was the FCWT

The effect of mixed type of DG on the NDZ

In the following study, the FCWT and 1.6MW rated directly coupled SG were connected in parallel as presented in Fig. 3. The NDZ resulting from this study is shown in Fig. 6. By comparing Figs. 4 and 6, it can be seen the two NDZs have a similar type of shape and interestingly, the trip regions of the four protection functions in Fig. 6 are located very similarly as in Fig. 4. This means that the directly coupled SG seems to have dominated the relations between active- and reactive power imbalance with frequency and voltages.

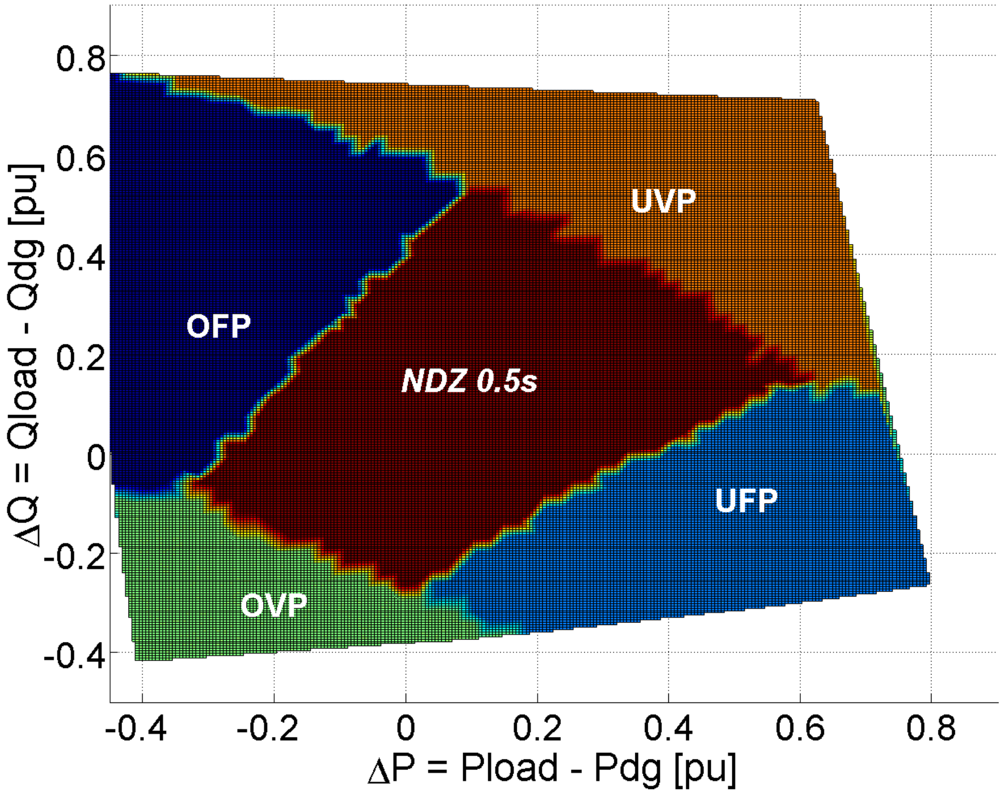

Fig. 6. The NDZ when both of the DG units were connected

This phenomenon can have implications on the functioning of certain active LOM detection schemes, since most of them assume that reactive power imbalance mainly determines frequency and active power mainly determines the voltages in an islanded network. Reactive power fluctuation method, for instance, is based on making small changes in its reactive output power based on the frequency response of the system it measures. However, reactive power doesn't necessarily affect frequency when the islanded circuit contains both converter connected DG and directly coupled SG as shown in Fig. 6. This scenario may thus lead to the malfunctioning of certain active methods.

It is noteworthy that the nominal power of the directly coupled SG was larger compared to the one of the FCWT. However, this kind of scenario is realistic since many of the converter connected DG units, such as photovoltaic and micro turbines, are small sized in comparison with directly coupled SGs.

The effect of voltage droop control of DG on the NDZ

In the following study, a voltage droop with a 5 percent deadband was added to the grid side converter control system. The droop was adjusted so that the FCWT gave maximum available reactive power output at 50 percent voltage deviation. The SG unit was disconnected and the simulations were repeated. Fig. 7, which represents the resulting NDZ, shows that the NDZ bends from both ends due to the droop, whereas, the deadband of the droop prevents the bending from the middle part of the NDZ. It is also interesting that the UVP trip region has enlarged to cover some of the power imbalance points which previously belonged to the UFP trip region. The bending of the NDZ in the right most side of Fig. 7 shows that the NDZ region can include surprising ΔP & ΔQ combinations depending on the utilized control mode of the protected DG unit.

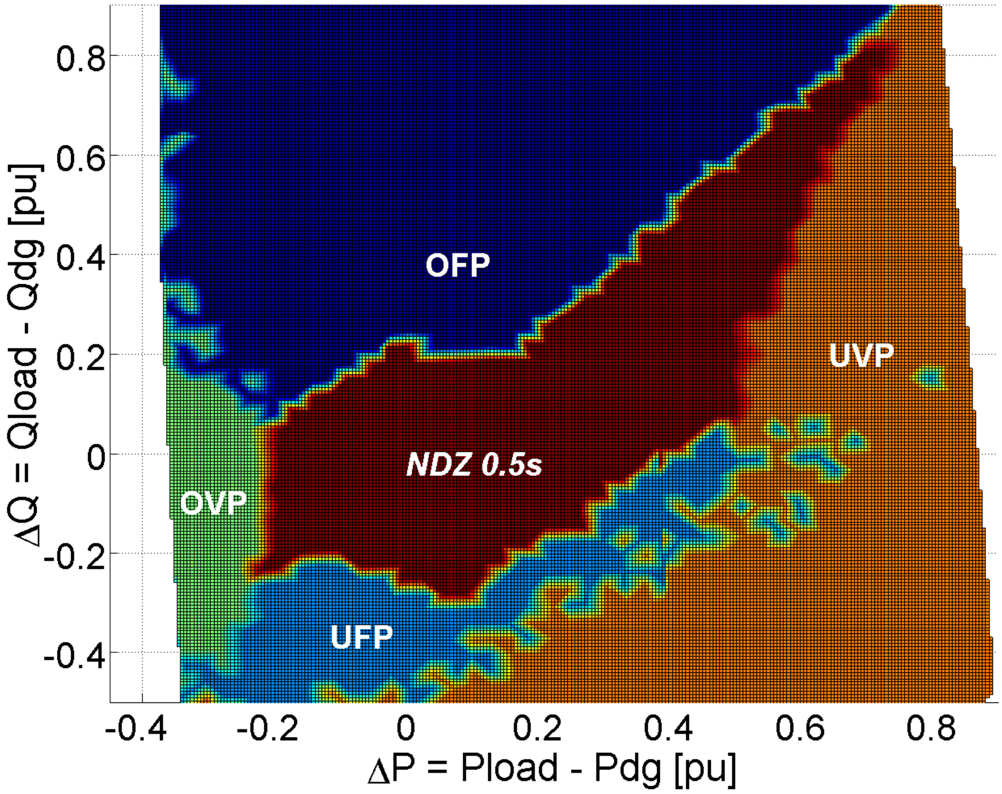

Fig. 7. The NDZ when the protected unit was the FCWT which was operated in voltage droop mode (5% deadband)

Discussion

The simulations indicate that the assumption between ΔP & voltages as well as ΔQ & frequency during islanding, which many active LOM detection schemes assume, is not always valid. It is problematic that even though this assumption may be valid at the time of installing a converter connected unit, it can later be invalidated once a synchronous generator is installed nearby.

It is noteworthy that albeit certain active LOM detection schemes may be considerably degraded in the presence of SGs, they may still function after the LOM protection of the SG unit has operated. This, however, causes an additional delay to the operation of the active scheme.

Conclusions

This report studied the effect of mixed type of DG on the NDZs of LOM protection. A directly coupled and a converter coupled DG unit were connected in parallel in order to study the combined effect on the NDZ. The simulations revealed a potential operational risk for certain active LOM detection methods. This risk should be taken into account in the design of these protection schemes. The simulations also revealed that the addition of voltage droop on grid side converter control system of the DG unit can extend the NDZ area to cover surprising power imbalance combinations.

References

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