New Multi-criteria-based Algorithm for Islanding Detection in Smart Grids

H. Laaksonen

Abstract—Islanding detection methods can be divided into communication-based and local detection-based methods. Proposed local passive detection methods have traditionally been dependent from the distributed generation unit type. A large non-detection zone near a power balance situation and unwanted distributed generation tripping due to other network events have also been major challenges with traditional, passive local islanding detection methods. In this paper, a new multi-criteria-based islanding detection algorithm is presented. This new islanding detection algorithm is able, based on local measurements, to detect very fast and selectively islanding situations in a perfect power balance without non-detection zone. The new multi-criteria algorithm measures the changing natural response of the network due to islanding based on voltage unbalance and voltage total harmonic distortion parameters as well as intelligently utilizes the available fault detection information. With the new islanding detection algorithm, no nuisance tripping is likely to occur due to other network events or disturbances and it is not dependent on the distributed generation unit type.

Index Terms--Distributed Generation, Islanding Detection, Loss-of-mains protection, Islanding, Smart Grids

I. INTRODUCTION

DISTRIBUTED energy resource (DER) units connected to the distribution networks have potential to reduce the demand for distribution and transmission network capacity, reduce losses and also increase the reliability of electricity supply to the customers. [1]

In general, protection-related and active management-related functionalities required in future smart grids to utilize the potential benefits of DER include for example: 1) Protection adaptivity to topology and earthing method changes, 2) Island operation capability and reliable islanding detection and 3) Utilization of distributed interconnection relays or intelligent electrical devices (IEDs) at MV/LV distribution substations or at medium voltage (MV)-connected distributed generation (DG) units for active network management, fault location calculation and power quality monitoring. In all the above-mentioned functionalities, communication plays major role. One way to realize active management and protection adaptivity in the future is the utilization of centralized functionalities within HV/MV substation computers (or station automation devices).

On the other hand, also the IEDs of distributed generation (DG) units should have enabling functionalities to support the active management of future distribution networks and support the realization of a vision from an environmentally friendly, energy efficient and reliable electricity distribution system i.e. Smart Grids.

Section II of the paper presents briefly the state of the art in islanding detection focusing especially on different local passive detection methods. Section III presents the proposed new multi-criteria algorithm for islanding detection. In Section IV the studied system and some example simulation results are presented. Conclusions are stated in Section V.

II. STATE OF THE ART IN ISLANDING DETECTION

In Fig. 1, one possible scheme for the future-proof DG interconnection IED functionality is presented. One essential functionality required from DG interconnection IEDs is reliable detection of islanding (also called loss-of-mains, LOM or anti-islanding protection).

Techniques proposed for islanding detection can be generally divided into two categories: communication-based and local detection-based (active and passive) methods [2]. Proposed local detection methods have traditionally been dependent from the DG type. Only communication-based islanding or LOM detection schemes can be generally applied for every type of DG units. Therefore, communication-based LOM schemes could provide the simplest and most reliable solution to detect islanding e.g. with transfer trip from MV feeder IED to DG interconnection IEDs after opening of the circuit breaker (CB) at the beginning of the same MV feeder where the DG units are connected. Two essential benefits of communication-based LOM protection are the lack of a non-detection zone (NDZ) near a power balance situation and the lack of unwanted DG trips due to other network events (nuisance tripping). These have been the major challenges with traditional, passive local islanding detection methods like frequency (f), rate-of-change-of-frequency (ROCOF / df/dt), vector shift (VS) / phase jump or voltage (U) based methods.

Traditional passive methods cannot guarantee a totally selective operation with other network events which may cause nuisance tripping of DGs like capacitor switching at HV/MV substation or connection of parallel transformer.

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Fig. 1. One possible scheme about future-proof DG interconnection IED functionalities for Smart Grids.

However, the communication-based LOM requires high-speed operation. This high-speed operation can be achieved e.g. by utilizing the IEC 61850 GOOSE message-based tripping signals [3] from MV feeder IEDs (communication e.g. through optical fibre or with wireless technologies such as WiMAX/LTE/HiperLAN) to DG interconnection IEDs. The main challenges of the communication-based transfer trip LOM schemes are availability and cost of high-speed communication as well as flexibility to network topology changes. The flexibility of the communication-based LOM schemes for network topology changes could be improved by pre-configuring the different IEC 61850 GOOSE signal-based transfer trip schemes and activating them after topology changes e.g. by command from substation computer. Also more flexible centralized, communication-based islanding detection schemes have been proposed based on the status checking of CBs in a certain area without a predetermined logic [4] where the islanding detection algorithm has been installed in a central controller, e.g. at station computer, which has connections to all IEDs with IEC 61850-based communication and utilizes also the transfer trip with GOOSE messages to disconnect DGs from the islanded part of the network. But, if centralized solutions like the one presented in [5] are not available and communication fails or is not high-speed enough or available at all (e.g. due to economic reasons in the near future) also reliable LOM method, based on local detection is still required in the future, but it has to overcome the major drawbacks of traditional LOM methods.

Active local methods have been in some cases questionable, because they introduce disturbances into distribution network which may become serious a problem when the number of DG units increases in the future. Passive methods are based on monitoring one or more system parameters locally and they make their trip decision without directly interacting with system operation. Traditional passive LOM methods work based on the assumption that in almost all circumstances a loss- of-mains will result in a measurable variation in voltage, frequency and/or power.

In the future, if the amount of DG units in distribution networks will increase, also the risk of power balance situations and hence the risk of possible operation in the NDZ of LOM protection will increase. Although the trend in future grid codes is to allow island operation, there still is a need to reliably detect the islanding situation to make correct operations e.g. change the setting group of DG interconnection IED or change the control principles and parameters of DG unit. To enable and guarantee the stability after transition to island operation, islanding and the change of DG unit control parameters or principles must be performed very fast, for instance, in less than 100 ms. Therefore, also a very rapid islanding detection is required.

Based on the above, it can be concluded that a reliable, local measurements-based islanding detection algorithm without the NDZ and nuisance tripping of the DG units is still needed. The new islanding detection algorithm must also be such that it can adapt or be adapted to the interconnection of different types of DG units. If traditional passive LOM methods based on local measurements, like ROCOF / $\frac{df}{dt}$, are still used in the future, significant improvements are required to their performance in terms of operation speed and selectivity (e.g. islanding detection in 75-100 ms). For example the detection of islanding situation with a trip time of 150 ms may be required to be able to disconnect the DG units during auto-reclosing open time (e.g. 200-400 ms). Therefore, to minimize their NDZ, more sensitive settings could be applied, but it also increases the risk of nuisance tripping of the DG units. However, no matter how sensitive settings are applied, traditional passive methods cannot detect islanding near a power balance very fast (e.g. in 75-100 ms), because they are based on parameters which measure dynamic changes such as frequency and $\frac{df}{dt}$. Therefore, other parameters need to be utilized which are also independent from the DG unit type and applied control principles.

A. Different Used and Proposed Passive Islanding Detection Methods

ROCOF is the most commonly employed LOM detection technique. However, the security of ROCOF relays based on this technique is continually being questioned, as it is sensitive to network disturbances, leading to nuisance tripping. The operating performance of a ROCOF relay is closely related to the power unbalance in the formed island at the moment of
islanding. The higher the setting, the larger the power unbalance required to operate the relay. Many factors affect the actual power unbalance, including load type, power factor and the inertia of the DG. [6], [7]

Three variations of the passive methods based on the local measurements were tested in [8] i.e. LOM based on locally delayed voltage angle signal (method 1), angle calculated from the local value of $df/dt$ (method 2) and, LOM based on frequency extrapolation (method 3). One main finding from the test results of the LOM methods 1, 2 and 3 was that these algorithms improved the sensitivity and stability of the LOM protection and the NDZ of LOM detection was reduced from +/-10% to +/-5%. [8]

Voltage unbalance (VU) has also been suggested for LOM detection as one parameter in [9], [10], because as the distribution networks generally include single-phase loads, it is highly possible that after islanding voltage unbalance will occur due to the change in network condition, i.e. transition from stiff to weak grid, and therefore it is likely that a change in the voltage unbalance could be utilized to LOM detection. [11]

VU has also been suggested in [12] as part of the hybrid LOM method which employs both the active and passive detection techniques. The active technique is implemented only when the islanding is suspected by the passive technique. For example, in [12] the islanding detection technique uses the positive feedback as the active technique and VU as the passive technique.

Change in the amount and configuration of load might result in different harmonic currents in the network, especially when the system has converter-based DGs [9]. One approach to detect islanding is to monitor the change of total harmonic distortion (THD) of the terminal voltage at the DG before and after the island is formed [13]. In this method, for example the DG unit converter controller can monitor the THD of the terminal voltage and shuts down the converter if the THD exceeds a threshold. [11], [14]

The principle of utilizing voltage THD is that in normal operation the distribution network acts as a stiff voltage source, maintaining a low distortion voltage on the DG unit terminals. When islanding occurs, an increase in $\Delta U_{THD}$ is expected, because the network system harmonic impedance changes after islanding. Therefore, also network frequency response changes and, as a result, current harmonics in the network will cause increased levels of voltage harmonics in the network voltage. On the other hand, non-linear loads within the island, particularly distribution step-down transformers [15], will be excited by the output current of the DG unit. The voltage response of the non-linear loads to the current excitation can be highly distorted. Voltage THD-based LOM method has been pointed out to have the advantage that it does not have a NDZ when the local load matches the converter output power. However, it suffers from the same problem as the ROCOF and phase jump/vector shift method i.e. it is difficult to set a voltage THD trip threshold that provides good islanding protection. [2]

In reference [10], multi-criteria LOM detection method based on voltage unbalance, one phase current THD and voltage magnitude has been proposed. It is stated in [10] that each of these three monitoring parameters can be used alone for detecting islanding operation. However, none of them guarantees that it, in any kind of network conditions, would be able to detect islanding and not to mal-operate for normal load variations. So, the multi-criteria decision approach is required for a reliable islanding detection. [10]

Also in [16], the utilization of current THD in island detection together with ROCOF function is discussed. However, based on simulation studies, the use of the current THD proved to be an improper parameter for LOM detection in particular cases with converter-based DG units with good filters, non-detection zone for current THD may exist. The current THD also depends on the current magnitude, and when for example the production of photovoltaic panels or wind turbines rapidly changes, also the current THD changes. So setting a detection limit for current THD-based LOM algorithm might be impossible when satisfactory selective LOM detection is needed to be ensured.

In recent years, also the passive and hybrid LOM detection methods based on the utilization of the wavelet transform has been suggested in [17], [18], [19]. Based on a family of basic functions, wavelets can be formulated to describe signals in a localized time and frequency format. [17] In [19], it is stated that the proposed wavelet transform-based scheme operates on the PCC voltage measurement and is able to detect the islanding condition within 2.5 cycles with a reduced number of nuisance tripping due to transient disturbances and effective islanding detection near zero power unbalance condition. [19]

III. NEW MULTI-CRITERIA-BASED ALGORITHM FOR ISLANDING DETECTION IN DISTRIBUTION NETWORKS

In this paper, new multi-criteria algorithm for islanding detection is proposed based on multiple PSCAD simulations with different kind of generators (converter interfaced, directly connected SG) in different kind of networks (different short circuit ratio, $R/X$-ratio of feeders, cable or overhead, isolated or compensated, partially compensated). Target has been that the developed algorithm does not have a NDZ, is selective and fast, is not dependent from DG type and will not cause nuisance tripping due to other events or disturbances in the utility grid. The idea was that the new multi-criteria algorithm could minimize the NDZ by relying on parameters which are based on the changing natural response of the MV grid due to islanding. These parameters were identified to be change in voltage unbalance $AVU$ and change in voltage THD of all phase voltages $\Delta U_{THD,sa}$ $\Delta U_{THD,sb}$ $\Delta U_{THD,sc}$, and the proposed multi-criteria LOM detection method is based on simultaneous usage of these parameters (see Fig. 2). In Fig. 2, change in the voltage THD is calculated from 15 harmonics, but alternatively also a smaller, e.g. 11, or larger, e.g. 25, number of harmonics could be used.

Voltage THD is quite a sensitive criterion, and therefore many network disturbances will be noticed. Nuisance tripping due to faults could be avoided with sufficiently long time delays. Then momentary false islanding detections would be
able to disappear. But if a very fast LOM detection is required, this is not possible. The use of the change-of-voltage THD has the further advantage, because it does not have a NDZ when the local load matches the DG output power, that is, in a power balance situation. Islanding can be detected by monitoring the change of THD of the DG terminal voltage before and after the island is formed. The monitoring is based on a predetermined threshold value, which means that the change-of-voltage THD, \( \Delta U_{THD} \), is used as the decisive criterion. It is required that the change can be seen in all phase components (A, B and C) of the signal.

Another criterion in the present paper to detect LOM is the voltage unbalance. The voltage unbalance criterion is advantageous because it provides quickly an indication of the islanding situation, but is immune to many of the network disturbances. The use of the voltage unbalance also as a change parameter instead of a voltage unbalance threshold value is advantageous, as the setting of a fixed threshold is difficult in varying network structures.

In the proposed new multi-criteria LOM algorithm, the implementation of the fault detection functionality, i.e. fault detection based on the change in residual voltage (\( \Delta U_0 \)) or change in positive sequence voltage (\( \Delta U_+ \)), in connection with the multi-criteria islanding detection method, provides even further advantage to the reliability of the islanding detection (see Fig. 2). “Healthy island” in Fig. 2 means that there were no fault before “islanding detection” and correspondingly “faulty island” means that the fault was on the same feeder where the islanding had been detected after MV feeder circuit-breaker opening due to that fault. Just in case if a fault causes simultaneous false “islanding detection”, islanding detection block is reset (Fig. 2) By utilizing fault detection information, the reliability of the fast islanding detection can be even further improved to ensure a selective operation and to avoid nuisance tripping due to faults or due to fault clearances on other MV feeders or in upstream network.

IV. STUDY SYSTEM AND SIMULATION RESULTS

In this section, the simulation model and some example simulation results are presented and discussed.

A. Simulation Model of the Study System

In Fig. 3, a study network for PSCAD simulation studies used in the development of new multi-criteria-based islanding detection algorithm is presented. Cable parameters used in simulations are shown in Table I.

Load mainly consisted of passive constant impedance load, and a small part of the load was constant power load. For instance a few small 1-phase loads were used to introduce a “realistic” amount of voltage unbalance to the distribution network (Fig. 3). Multiple different islanding simulations near the perfect power balance situation will be minimized.

In case of a fault on the same feeder where islanding detection was initiated, islanding detection block is reset (Fig. 2). By utilizing fault detection information, the reliability of the fast islanding detection can be even further improved to ensure a selective operation and to avoid nuisance tripping due to faults or due to fault clearances on other MV feeders or in upstream network.
configurations as well as with different line types were simulated. To minimize the possibility of an incorrect islanding detection, also different events which should not lead to the tripping of DG unit were simulated (Fig. 3 and table III).

### Table I

<table>
<thead>
<tr>
<th>Line type</th>
<th>R (Ω/km)</th>
<th>X (Ω/km)</th>
<th>R/X</th>
</tr>
</thead>
<tbody>
<tr>
<td>AHXMK-W 240</td>
<td>0.15</td>
<td>0.11</td>
<td>1.36</td>
</tr>
<tr>
<td>AXMK 4x185S</td>
<td>0.164</td>
<td>0.0817</td>
<td>2.01</td>
</tr>
<tr>
<td>At 132</td>
<td>0.218</td>
<td>0.344</td>
<td>0.63</td>
</tr>
<tr>
<td>Pigeon</td>
<td>0.337</td>
<td>0.354</td>
<td>0.95</td>
</tr>
<tr>
<td>AHMCMK 120</td>
<td>0.254</td>
<td>0.107</td>
<td>2.37</td>
</tr>
</tbody>
</table>

**B. Simulation Results**

The change in the frequency response of the MV network due to islanding greatly affects the relative change in the voltage THD after islanding. As an example the frequency responses in connection point of MV network connected DG unit (Fig. 3) during normal (utility grid connected) and island operation from a few cases are presented in Fig. 4. Some details about these cases are provided in table II.

**Table II**

<table>
<thead>
<tr>
<th>Case</th>
<th>MV feeder type / total length of the feeder / topology</th>
<th>Fault level / R/X-ratio of 110 source</th>
<th>Earthing method / Nominal power of HV/MV main transformer(s)</th>
<th>DG type / Inertia constant</th>
</tr>
</thead>
<tbody>
<tr>
<td>1a</td>
<td>Pigeon / 35 km (overhead line) / radial</td>
<td>800 MVA / 0.3</td>
<td>Isolated / Two 10 MVA</td>
<td>Converter conn. DG / -</td>
</tr>
<tr>
<td>1b</td>
<td>AHMCMK / 35 km (cable) / radial</td>
<td>1000 MVA / 0.2</td>
<td>Compensated (decentralized comp.) / Two 10 MVA</td>
<td>Converter conn. DG / -</td>
</tr>
<tr>
<td>1aSG</td>
<td>Pigeon / 35 km (overhead line) / radial</td>
<td>800 MVA / 0.3</td>
<td>Isolated / Two 10 MVA</td>
<td>Directly conn. SG / 0.6 s</td>
</tr>
</tbody>
</table>

*With converter-based energy storage unit connected (Fig. 3)

**Table III**

<table>
<thead>
<tr>
<th>Event</th>
<th>Time(s)</th>
<th>Event / Disturbance Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>i</td>
<td>1.4</td>
<td>Sudden load increase at the beginning of the feeder, passive balanced load</td>
</tr>
<tr>
<td>ii</td>
<td>1.6</td>
<td>Sudden load increase near the connection point of the MV feeder DG unit, passive balanced load</td>
</tr>
<tr>
<td>iii</td>
<td>1.8</td>
<td>Operation of on-load tap changer at HV/MV substation</td>
</tr>
<tr>
<td>iv</td>
<td>2.3</td>
<td>Capacitor switching at HV/MV substation, 0.4 MVAr</td>
</tr>
<tr>
<td>v</td>
<td>2.6</td>
<td>Disconnection of parallel transformer at HV/MV substation</td>
</tr>
<tr>
<td>vi</td>
<td>3.0 - 3.15</td>
<td>1-phase-to-earth (A-G) fault 150 ms at the end of adjacent MV feeder (fault resistance $R_f = 750 \Omega$)</td>
</tr>
<tr>
<td>vii</td>
<td>3.45 - 3.6</td>
<td>1-phase-to-earth (B-G) fault 150 ms at the beginning of adjacent MV feeder (fault resistance $R_f = 100 \Omega$)</td>
</tr>
<tr>
<td>viii</td>
<td>3.9 - 4.05</td>
<td>1-phase-to-earth (A-G) fault 150 ms in the middle of the same MV feeder (fault resistance $R_f = 1000 \Omega$)</td>
</tr>
<tr>
<td>ix</td>
<td>4.35 - 4.5</td>
<td>2-phase (A-B) fault 150 ms in the middle of adjacent MV feeder (fault resistance $R_f = 5 \Omega$)</td>
</tr>
<tr>
<td>x</td>
<td>4.8 - 4.95</td>
<td>3-phase (A-B-C) fault 150 ms at the beg.of adjacent MV feeder (fault resistance $R_f = 1 \Omega$)</td>
</tr>
<tr>
<td>xi</td>
<td>5.3 - 5.45</td>
<td>3-phase 30 % voltage dip in HV network</td>
</tr>
</tbody>
</table>

From Fig. 5, it can be seen how the frequency behaves during islanding and other network disturbances in simulation case 1a. Islanding in a near power balance situation cannot be detected rapidly only based on the frequency, no matter how sensitive settings are used. On the other hand, if very sensitive
settings were used for rapid islanding detection, the possibility for nuisance tripping would also have been increased substantially.

In Fig. 6, voltage unbalance values during the simulation sequence are presented. From Fig. 6 it can be seen that the voltage unbalance alone is not a fully sufficient criterion for island detection, because for example 2-phase faults at adjacent feeders would lead to an unwanted tripping of DG units. From Fig. 6, it can also be seen how the structure of directly connected synchronous generators (damping windings) will compensate the voltage unbalance to some extent (case 1aSG).

In Fig. 7, the voltage THD (%) values including harmonics up to the 15th harmonic from phases A, B and C during the simulation sequence are shown. It can be seen from Fig. 7 that if changes in multiple harmonics \( (\Delta U_{THD}) \) from all phase voltages A, B and C are used alone, i.e. without \( \Delta VU \) criteria, for high-speed islanding detection, there is a risk that for example capacitor switching at HV/MV substation (at t=2.3 s) or a clearance of faults on adjacent feeders could cause nuisance tripping. If only multiple harmonics from one phase voltage, e.g. A, were used for islanding detection, the number of nuisance tripping would be even further increased. Therefore, it is preferred to utilize multiple harmonics from all phase voltages as part of the islanding detection.

Due to the above reasons, the use of a change parameter in the voltage THD \( (\Delta U_{THD}) \) values from all phases together with a change parameter of the voltage unbalance \( (\Delta VU) \) for islanding detection tremendously improves the selectivity and reduces the nuisance tripping of islanding detection.

By the utilization of fault detection information, the selective operation of the islanding detection algorithm can be even further ensured and improved. In case of a 150-ms 2-phase (A-B) fault in the middle of an adjacent MV feeder (fault resistance \( R_f = 5 \text{ ohm} \)) (4.35-4.5 s), the islanding detection can be securely prevented by applying fault detection based on, for instance, change in the positive sequence voltage \( (\Delta U+) \) or undervoltage of one phase-to-earth voltage.

On the other hand, when the high-speed detection of islanding is required, it is possible also by the intelligent utilization of fault detection information to avoid false island detection after the fault clearances on other feeders. For example, after the clearance of a 3-phase fault on the other feeder (4.8-4.95 s), the fault detection status can be taken into
account with the islanding detection to prevent false detection when a very fast LOM protection e.g. in 80 ms is needed.

The developed multi-criteria algorithm is based on measurements from the MV network side, but it could be applied also on the LV network. Although in some cases, for instance in case 1a without a diode load, $\Delta U_{THD}$ in the LV network side at the connection point of the MV network connected DG unit may not be that large (Fig. 8) when compared to MV network side measurements (Fig. 7). In addition, based on simulation results with diode load connected in cases with 35 km AHMCMMK cable, it was found out that on LV side islanding detection also at the end of MV feeder should be based only on voltage unbalance values (Fig. 3). With other MV feeder line types this challenge with voltage THD level change in LV side at the end of MV feeder did not exist.

earth-faults or clearance of earth-faults will not necessarily lead to nuisance tripping in the LV network side (Fig. 11) similarly as in the MV network side (Fig. 7). In Fig. 12, the effect of the diode load to voltage THD values during normal operation from case 1a with diode load (Fig. 3 and table II) is shown as a comparison to values presented in Fig. 8 and 11. Due to the diode load, the change value $\Delta U_{THD}$ will be in case 1a with diode load smaller on the LV side than on the MV side at the end of the MV feeder. This is one thing which has to be taken into account when start values for the new multi-criteria-based islanding detection algorithm are determined.

It should be also noticed that the fault detection information ($U_0$) from the MV network earth-faults cannot be utilized in the LV network because MV earth-faults cannot be seen in the LV network voltages (Fig. 9 and 10). One possibility is to send $U_0$ detection to LV network side DER units with high-speed communication e.g. from corresponding MV/LV distribution substations. On the other hand, from the rapid islanding detection point of view, based on the behavior of $U_{THD}$ values from all phases, earth-fault indication is not necessarily even required in the LV network side because...
V. CONCLUSIONS

In this paper new multi-criteria-based islanding detection algorithm based on multiple PSCAD simulations with different kind of generators in different kind of networks has been presented. This new islanding detection algorithm is able, based on local measurements, to detect very fast and selectively islanding situations in a perfect power balance without a non-detection zone. The new multi-criteria algorithm measures the changing natural response of the network due to islanding based on a change in the voltage THD of all the phase components $ΔU_{THD15a}$, $ΔU_{THD15b}$, $ΔU_{THD15c}$ and a change in the voltage unbalance $ΔVU$ as well as utilizes intelligently the available fault detection information which ensures a rapid and reliable islanding detection. With the new islanding detection algorithm no nuisance tripping is likely to occur due to other network events or disturbances and it is not dependent on the DG unit type.

Before future real-life measurements, based on simulations, the initial start values for the proposed new multi-criteria-based islanding detection algorithm, applicable in all studied cases, could be as follows: $ΔU_{THD15a}$, $ΔU_{THD15b}$, $ΔU_{THD15c}$: 0.5%, $ΔVU$: 0.5%, $ΔU_{Ic}$: 1% and $ΔU_{Ia}$: -8%. However, in general it should be noted that when the proposed multi-criteria algorithm is used for islanding detection in cases with very long cable MV feeders even smaller $ΔU_{THD15}$ start values for MV side measurements may be required. In addition, with directly connected generators $ΔVU$ start values should be a bit lower than with converter connected DGs.

VI. REFERENCES


VII. BIOGRAPHY

H. Laaksonen was born in Vaasa, Finland, on November 22, 1977. He received his MSc degree (2004) in Electrical Power Engineering from Tampere University of Technology and PhD degree (2011) in Electrical Engineering from University of Vaasa. His fields of interest are protection of Smart Grids, integration and active management of distributed energy resources in smart distribution networks and development of new functionalities and algorithms for future Smart Grid concepts (e.g. microgrids).