FUTURE-PROOF ISLANDING DETECTION SCHEMES IN SUNDOM SMART GRID

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ABSTRACT

Future resilient distribution grids need new, standard-based, agile management and protection architectures which can intelligently utilize flexible, distributed energy resources for local and system-wide technical services. For example, future-proof islanding detection methods can be realized and utilization of flexible energy resources can be maximized by taking into account fault location, power balance situation, prioritization issues and intentional island operation status as part of the islanding detection scheme. In this paper future-proof, grid code compatible islanding detection schemes will be determined for both medium- and low-voltage network connected distributed generation units during both grid-connected and islanded (nested microgrid) operation of Sundom Smart Grid. Also significant issues, like network status dependency, distributed generation unit type, fault-ride-through capability and fault behavior as well as high-speed wireless 5G communication and routable GOOSE, having impact on future islanding detection schemes will be presented and discussed.

INTRODUCTION

The major challenges with distributed generation (DG) traditional passive islanding detection methods like frequency (*f*), rate-of-change-of-frequency (ROCOF), voltage (*U*) or voltage vector shift (VVS) have been non-detection zone (NDZ) near a power balance situation and maloperation due to other network events like, for example, utility grid / parallel MV feeder faults or utility grid frequency fluctuations. In the future, for example the use of *f*, *U* and ROCOF for defining DG units' fault-ride-through (FRT) requirements in the new grid codes will increase and also in European ENTSO-E grid code Requirements for Generators (RfG) it has been stated that islanding detection should not be based only on network operator's switchgear position signals (Fig. 1a).

Based on above, combined islanding detection schemes (Fig. 1) are needed in the future. With combined scheme maloperation due to other network events can be avoided, NDZ can be minimized, prioritization issues with DG unit grid code requirements can be avoided and ENTSO-E RfG requirement (not only circuit breaker, CB, status position detection) can be fulfilled. Active network management (ANM) functionality at MV level could also be used to control the reactive power unbalance Q_{unb} continuously in order to ensure islanding detection of the passive method (like VVS with sensitive settings) in the combined scheme without NDZ (Fig. 1).

In this paper, combined islanding detection schemes (Fig. 2) for both MV and LV network connected DG units will be further studied and developed. The focus in this paper is on such scheme (Fig. 2) which utilizes reactive power unbalance control based Q_{flow} & U -management based ANM scheme. Q_{flow} & U -scheme is able to fulfill multiple targets simultaneously (not only islanding detection without NDZ). The purpose is also, as part of the combined islanding detection scheme, that the fault location could be taken intelligently into account by fault detection/direction information from primary and secondary substations so that depending on the fault location, DG units inside faulted network section will be disconnected (faulty island) and DG units outside faulted section would not be unnecessarily disconnected (Fig. 2). The DG units outside the faulted section could then be used for improving local or system-wide grid resiliency through FRT, P/f- or Q/U -control or intentional island operation depending on the fault location, power balance situation etc. before fault, prioritization as well as allowance of intended island operation (Fig. 2). Realization of future-proof and grid code compatible schemes requires studies regarding dependencies between protection, islanding detection and active network management (ANM) functionalities. [1], [2], [3]

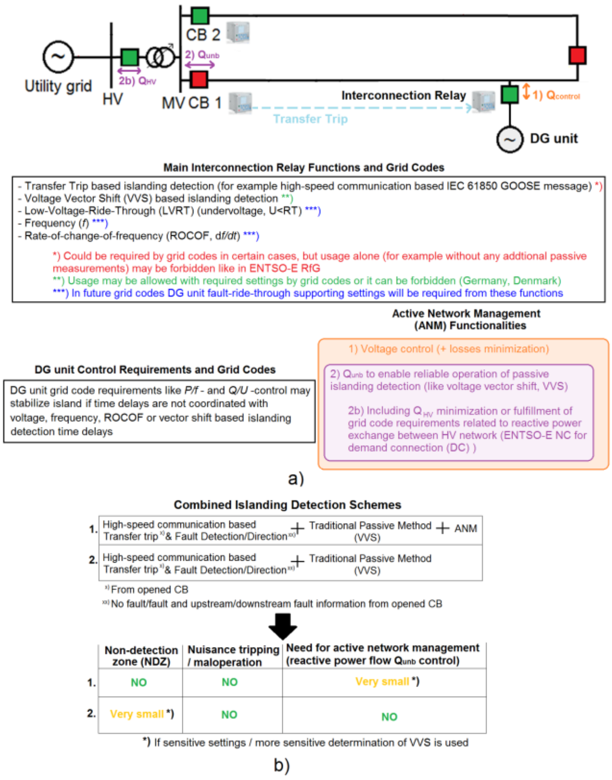

Figure 1. a) Grid code requirements and future islanding detection schemes and b) Future-proof, grid code compatible combined islanding detection schemes.

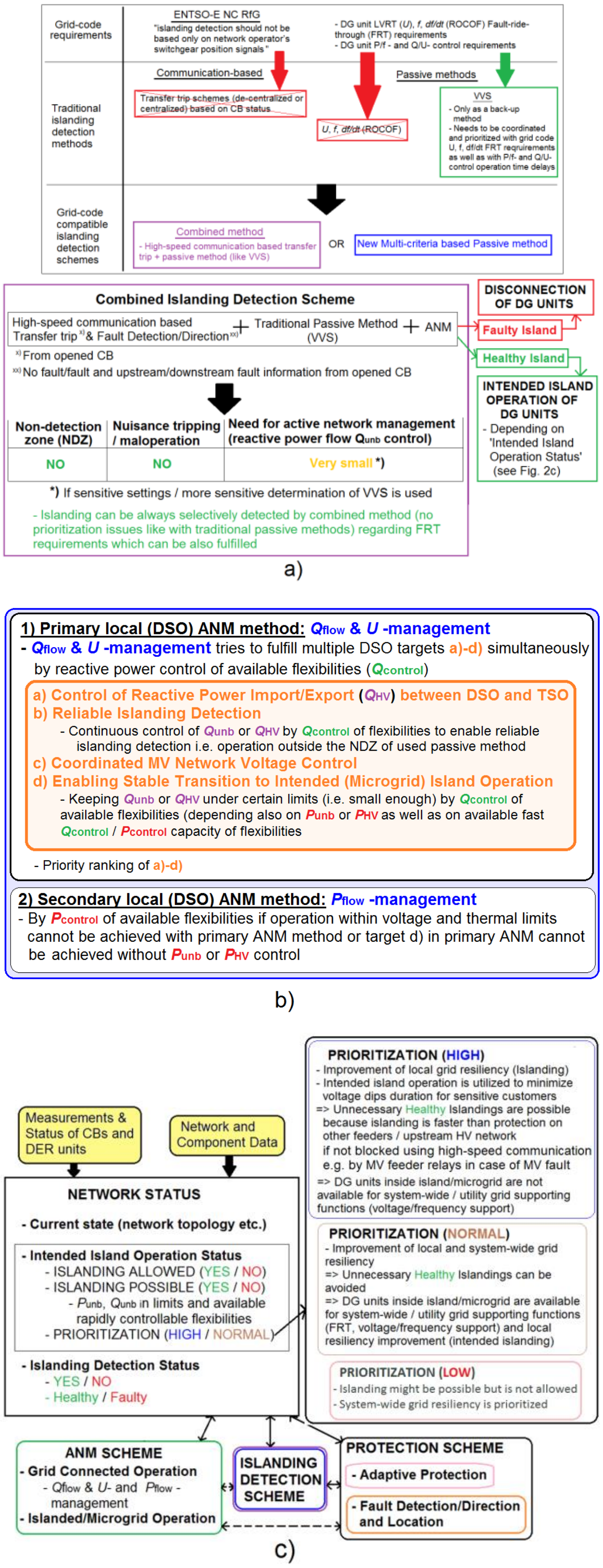

Figure 2. a) Proposed future-proof, grid code compatible combined islanding detection scheme, b) grid code compatible ANM scheme able to fulfill multiple targets simultaneously [4] and c) Dependencies between network status, future-proof protection, islanding detection and ANM functionalities as well as issues related to intended islanding (microgrid operation) prioritization.

ISSUES RELATED TO FUTURE ISLANDING DETECTION SCHEMES

Network Status Dependency

In the future, need for network status dependent, adaptive islanding detection schemes (Fig. 2c) increases. Islanding detection scheme must adapt to changes in network state like, for example, to changes in network topology (e.g. grid-connected / islanded), changes in DG unit state and output, changes in prioritization (Fig. 2c) or faults. In addition, future-proof, network status dependent islanding detection scheme provides important input for other related functionalities (Fig. 2c). Due to this network status dependency, traditional, local (standalone) islanding detection schemes may become incompatible because they always behave in a predetermined way without network status knowledge.

Network status for future-proof islanding detection schemes can be determined by HV/MV primary or MV/LV secondary substation protection and control unit devices or by SCADA/DMS systems. In the future, one potential alternative is some HV/MV or MV/LV substation protection and control (or FlexZone) unit functionalities like network status monitoring, forecasts, ANM schemes etc. could be located in cloud servers. [4] However, the islanding detection itself, utilizing this network status information, could be realized either centrally by HV/MV or MV/LV substation protection and control units or decentrally within DG interconnection IEDs, like in [5], or within inverter-based DG unit (or distributed energy resource, DER unit) control systems. In case of decentralized islanding detection the network status related information (islanding allowed or possible (Fig. 2c) should be communicated, for example, to the DER interconnection IED when required to ensure correct operation i.e. decentralized scheme will be in reality combination of decentralized and centralized information. Correspondingly after islanding detection DER interconnection should communicate healthy/faulty island information to upper level control/management system (i.e. HV/MV or MV/LV substation protection and control unit or SCADA/DMS).

DG Unit Type, FRT Capability and Fault Behavior

In addition to network status dependency, adaptive future-proof islanding detection schemes as well as protection and control schemes need to take into account different fault behavior and FRT capability of different type of DG units (e.g. directly connected synchronous generator or converter/inverter connected generating unit) and their grid code requirements. For example, different active / hybrid (passive + active) islanding detection schemes used and proposed for inverter-based DG units may not be fully compatible with different local or system-wide grid resiliency improving grid code requirements. Usually their effect e.g. on stability of microgrid after transition to intentional island operation has not been fully considered. Also potential use of additional *Q/f* -droop on directly connected synchronous generator based DG units has been studied and proposed in [6] in order to enable stable islanding or to even further ensure reliable islanding detection and disconnection of

DG units. Another potential possibility to enable stable transition to intended island (microgrid) operation could be adaptation of DG unit voltage and frequency FRT requirements, for example, based on intended island operation status (Fig. 2c). This means that if intended island operation is allowed and possible, then extended (when compared to grid code requirements) voltage and frequency FRT requirements and settings could be activated. Especially inverter/converter connected DER units are potentially capable of riding through from larger voltage and frequency oscillations/deviations over short-period than what the grid codes require today. Longer voltage FRT (low-voltage-ride-through, LVRT) requirement of DG units could also possibly support use of LVRT curve compatible protection schemes [1], [7].

Islanding Detection During Islanded Operation of Nested Microgrids

Future intended island operation of nested microgrids (e.g. MV microgrid including multiple MV and/or LV microgrids) will create a need for islanding detection also during this islanded operation. In general, during islanded operation only CB status change and high-speed transfer trip based islanding detection could be enough if only CB status position based detection is allowed. However, if it is not allowed, then it could be feasible to utilize similar combined islanding detection scheme also during islanded microgrid operation (Fig. 1, Fig. 2).

On the other hand, there may be differences in the dynamic behavior of the islanded network (microgrid) when compared to grid-connected operation. Therefore, it is not obvious that the same combined islanding detection scheme is also valid during islanded microgrid operation. For example, if traditional synchronous generator (SG) based generating units, are be connected in microgrid, then it could be expected that islanding can be detected even more rapidly with same e.g. VVS settings as in grid-connected mode due to more sensitive dynamics during islanded operation. However, if island operated network is formed purely by inverter connected DER units which are controlled very rapidly in a “grid-forming” way (in terms of frequency and voltage) to ensure stability in every situation during islanded operation, then islanding detection with VVS based combined scheme may become challenging because VVS detection is based on the changing voltage angle / frequency unless very sensitive settings are used. Therefore, multi-criteria (voltage total harmonic distortion U_{THD} & voltage unbalance VU) based islanding detection scheme [5] could be another potential option if DER units in the islanded MV+MV nested microgrid are not controlled to compensate voltage unbalance. But if they are, then combined (transfer trip + U_{THD}) could be one possibility for islanding detection of islanded nested microgrids.

Utilization of 5G and R-GOOSE

In the future, wide use of high-speed e.g. fibre optic or more cost-efficient wireless 5G communication could enable reliable, low-latency, real-time technological solutions for ANM, protection and islanding detection of smart grids with higher amount of DER units and measurements. If combined islanding detection scheme (Fig. 1 and 2) is used as primary islanding detection method and fibre optic is used primarily for transfer trip then wireless 5G could provide very good back-up method for transfer trip in combined islanding detection scheme and possibility to avoid such prioritization issues described in [3] with passive only islanding detection methods. On the other hand, in the future combined islanding detection scheme with cost-efficient wireless 5G based transfer trip could be used as primary method and new multi-criteria based passive method (Fig. 2a) [5] as a back-up. Also regarding islanding detection scheme (Fig. 2c), for example, potential prioritization (HIGH) challenges with unnecessary healthy islanding due to faults on other/parallel MV feeders could be avoided with utilization of high-speed (5G or fibre optic) communication based interlocking from faulty MV feeder after directional protection start/pick-up i.e. before the parallel MV feeder protection operates.

As part of combined scheme (Fig. 1 and 2) GOOSE message based transfer trip could be used. Traditionally GOOSE was specified for local applications over local area network (LAN), i.e. within substation, power plant or industrial sites. IEC technical report (TR) TR 61850-90-5:2012 extends the application of GOOSE from LAN to wide area network (WAN), either using tunneling or allowing GOOSE to multicast over IP networks using IGMPv3 protocol [8]. In IEC TR 61850-90-5 RS control blocks are used to control routable sampled value (R-SV) data and RG control blocks are used to control routable GOOSE (R-GOOSE) state information [8]. R-SV data can be used for the synchrophasor (phasors calculated with reference to Global Time Reference, GPS, clock) communication and potentially also as part of different future islanding detection and protection schemes. R-GOOSE data is event driven i.e. the messages are transmitted at higher rate only in case of an event and they could be suitable for high-speed (5G or fiber optic) communication based transfer trip as part of combined islanding detection scheme. In the combined scheme use of locally measured VVS as passive method (Fig. 1 and 2) instead of comparison of R-SV based (e.g. positive sequence angle, U_{1_angle} or change of it i.e. $\Delta U_{1\_\mathrm{angle}}$) values from different points could be still preferred today because local VVS is immune to measurement inaccuracies and lost or erroneous data packages.

SUNDOM SMART GRID

Sundom Smart Grid (SSG) in Vaasa, Finland (Fig. 3) is a smart grid pilot of ABB Oy, Vaasan Sähkö (local DSO), Elisa (previously Anvia) and University of Vaasa (http://ses.jrc.ec.europa.eu/sundom-smart-grid-ssg). Until recently, new grid automation solutions have been installed in SSG to enable more accurate earth-fault detection and localization in compensated mixed (overhead, OH-line & cable) distribution grids. Today SSG serves as Finnish Innovation Cell in a 3-year ERA-Net Smart Grids Plus project called DeCAS (Demonstration of coordinated ancillary services covering different voltage levels and the integration in future markets) [9] which started 2016 (Fig. 3). In SSG IEEE 1588 time-synchronized, IEC 61850-9-2 SV based, measurement data from multiple points is collected and stored in servers (Fig. 3) to enable research and development of future ANM, protection and islanding detection functionalities (Fig. 2). [4]

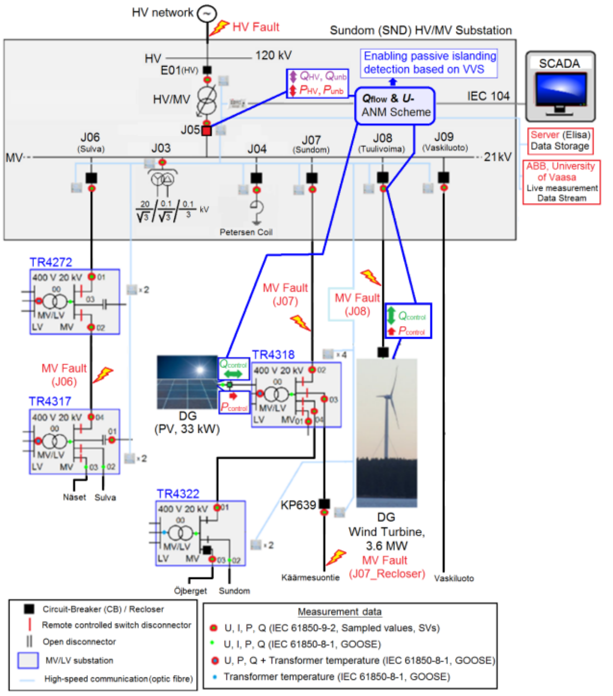

Figure 3. Sundom Smart Grid in which ANM and islanding detection schemes presented in Fig. 2 will be investigated including fault locations considered in islanding detection example cases.

ISLANDING DETECTION CASES IN SUNDOM SMART GRID

Grid-Connected Operation of SSG

In Fig. 4 primary and back-up islanding detection schemes which will be studied and developed in SSG during normal grid-connected operation are presented (see also Fig. 2). Regarding VVS based back-up scheme in Fig. 4a) it should be noted that maloperations are possible due to utility grid frequency fluctuations as well as prioritization issues with grid code requirements as presented in [3].

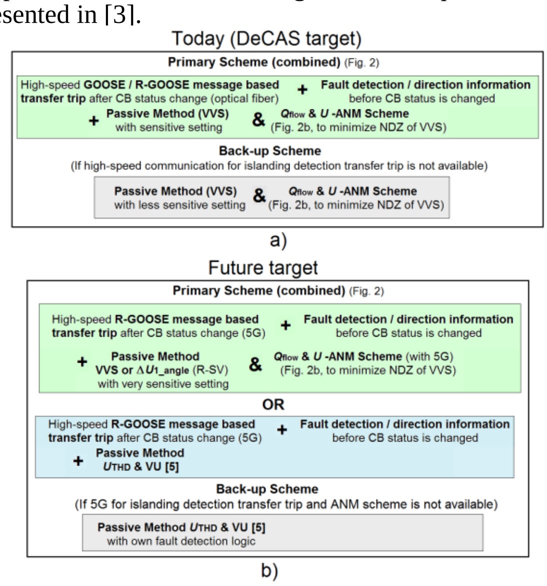

Figure 4. Future-proof primary and back-up islanding detection schemes which will be studied and developed in SSG a) today in DeCAS-project and b) in the future during grid-connected operation.

In VVS based back-up scheme integrated undervoltage blocking is needed [2], [3], but when VVS is used as part of primary combined scheme blocking is not used. However, in this paper high-speed communication based primary islanding detection and protection schemes are considered. Utilized islanding detection scheme (Fig. 4) should be coordinated with used protection scheme during normal grid-connected operation as well as with DER unit *P/f* and *Q/U* -control grid code requirements (Fig. 1 and 2). In addition, both islanding detection and protection (e.g. in [1] and [10]) schemes during normal operation should be compatible with DER unit voltage and frequency FRT requirements which are set by grid codes or which enable stable transition to islanded operation (like extended FRT requirements). In Fig. 5-7 MV and LV network primary islanding detection scheme operation/detection principles in some example cases are presented.

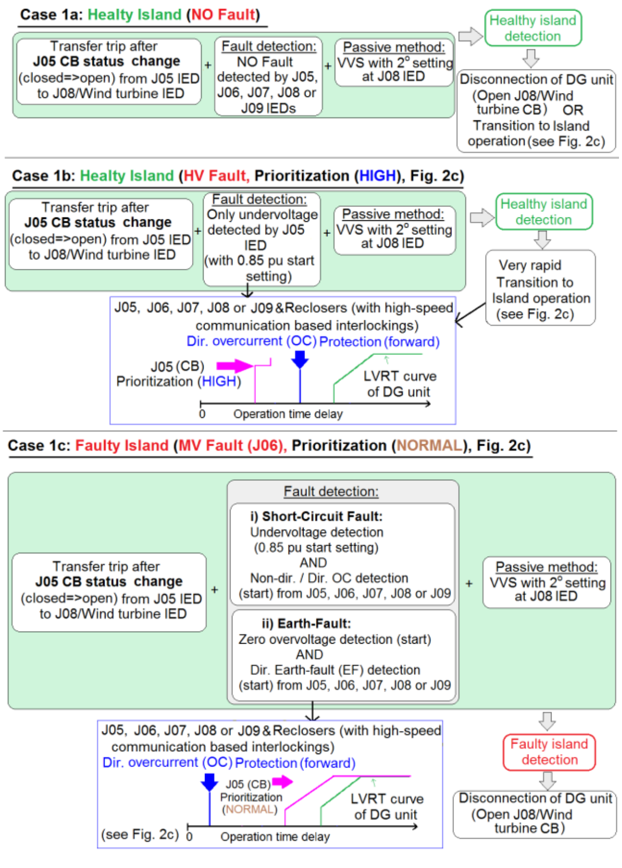

Figure 5. MV network DG unit primary islanding detection scheme example cases 1a)-c) during grid-connected operation of SSG (Fig. 3).

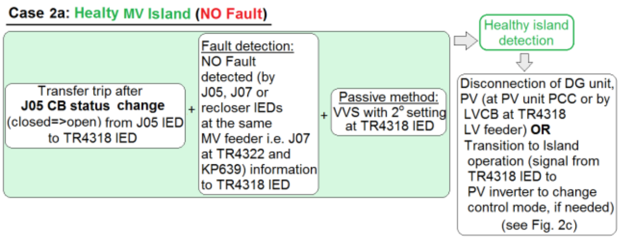

Figure 6. LV network DG unit primary islanding detection scheme example case 2a (healthy MV island, NO fault) during grid-connected operation of SSG (Fig. 3).

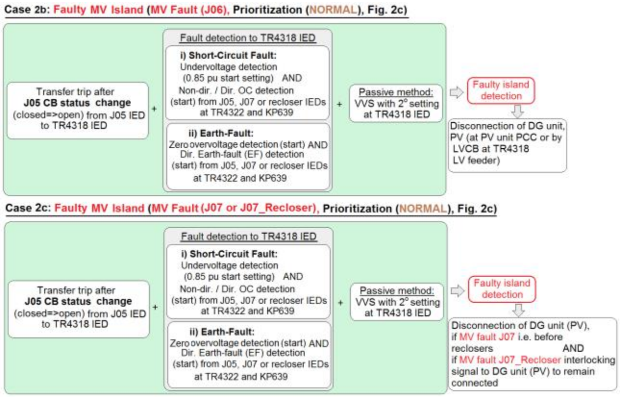

Figure 7. LV network DG unit primary islanding detection scheme example cases (faulty MV island cases 2b and 2c) during grid-connected operation of SSG (Fig. 3).

From Fig. 5-7 it can be seen that simultaneous utilization of fault detection information with MV or LV network connected DG unit islanding detection makes the combined scheme more complicated. However, it is needed to disconnect DG units inside faulted network section correctly (faulty island) and to prevent unnecessary disconnection of DG units outside faulted section. The fault detection logic, either centralized or decentralized, requires information from multiple locations as well as from other network status related issues. Therefore, centralized islanding detection logic at HV/MV and MV/LV substation protection and control unit level utilizing high-speed communication (5G and R-GOOSE in the future) would be very potential way to realize these future schemes which also have dependencies with protection and ANM functionalities.

Islanded Operation of SSG

Intended island operation of nested microgrids creates need to detect islanding also during islanded operation. In Fig. 8 potential islanding detection scheme during islanded (nested microgrid) operation is shown.

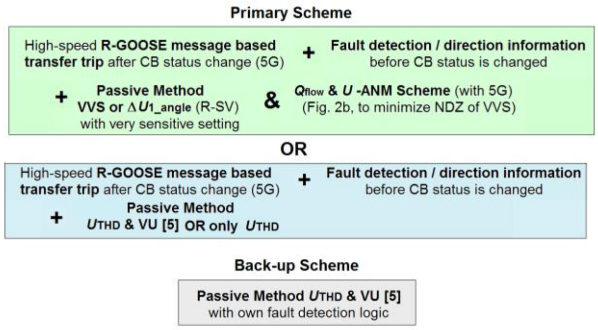

Figure 8. Potential islanding detection scheme during islanded nested microgrid operation.

In general, islanding detection logic and settings during island operation of nested (e.g. MV+MV) microgrid must take into account the DER unit control principles regarding, for example, grid-forming control methods (e.g. change to grid-forming control based potentially on CB status change AND +/- 0.1 Hz frequency deviation). In addition, protection scheme during island operation (e.g. [7]) needs to be also compatible with DER unit FRT (U, f) requirements/capability as well as with DER unit fault behavior (i.e. fault current feeding ability / principles).

In Fig. 9 LV network DG unit (PV) primary islanding detection scheme operation/detection principles during islanded operation of SSG (CB J05 open, Fig. 3) in one example case (healthy LV islanding after MV fault) is presented. Here LV network islanding with PV is considered possible and allowed unlike previously in grid-connected operation of SSG.

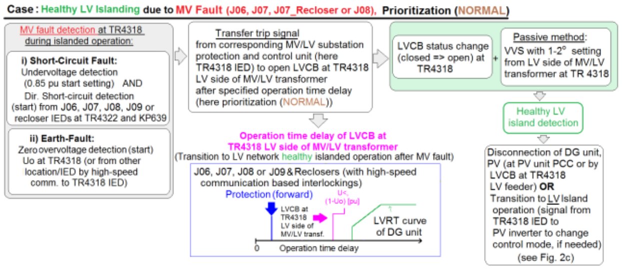

Figure 9. LV network DG unit (PV) primary islanding detection scheme example case (healthy LV islanding after MV fault) during islanded operation of SSG (Fig. 3).

Testing and further development of above presented future-proof islanding detection schemes during grid-connected and islanded operation of SSG (Fig. 5-7 and 9) will be first done with PSCAD / Matlab simulations. After that they will be verified with real-time simulator and at last possibly piloted in SSG islanding detection field tests.

Acknowledgments

This work was supported by DeCAS project (http://www.decas-project.eu/), which has received funding from the joint EU program initiative ERA-Net Smart Grids Plus (http://www.eranet-smartgridsplus.eu/).

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