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ADVANCED ISLANDING DETECTION IN GRID INTERACTIVE MICROGRIDS

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ABSTRACT

In the future active network management and protection solutions have to enable utilization of intended island operation as well as active control and utilization flexibilities during normal and islanded operation of grid interactive microgrids. In this paper, combined islanding detection schemes for both MV and LV network connected distributed generation units during normal grid-connected operation are studied. Utilization of active network management functionality at MV level enables to control the reactive power unbalance continuously in order to ensure reliable islanding detection without non-detection zone. Combined scheme also prevents maloperations due to other disturbances.

INTRODUCTION

In the future, active utilization of controllable, flexible, distributed energy resources, DER, like distributed generation, energy storages, controllable loads/demand response, intelligent charging of electric vehicles will be in key role to enable more resilient power system. In addition, new cost-efficient, reliable, standardized and redundant solutions for future resilient power system must utilize possibilities of advanced ICT technologies (like wireless 5G and cloud servers with smart big data-analytics) and have cyber-security integrated in all solutions.

Electricity distribution network areas with DER, i.e. FlexZones [1] or nested, grid interactive microgrids could be seen as resilient power system building-blocks. Intelligent and coordinated use of microgrids' flexibilities between distribution and transmission system operators (DSOs and TSOs) for different technical services enables realization of improved local and system-wide grid resiliency in the future during normal grid interactive operation mode. During transmission or distribution network downtimes due to storms, natural disasters or external attacks (physical or cyber) microgrid with flexibilities can still continue electricity supply to customers in islanded operation mode.

Grid-code compatible, combined islanding detection schemes (e.g. high-speed communication based transfer trip through optical fibre / wireless 5G, like IEC 61850-based GOOSE or routable R-GOOSE message & fault detection/direction + voltage vector shift, VVS) (Fig. 1) are needed in the future. With resilient combined scheme maloperation due to other network events can be avoided, non-detection zone (NDZ) can be minimized, prioritization issues with DG unit grid code requirements can be avoided and ENTSO-E RfG requirement (not only status position detection) can be fulfilled. Utilization of active network management

(ANM) functionality at MV level enables 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). Realization of future-proof and grid code compatible schemes requires studies regarding dependencies between protection, islanding detection and ANM functionalities. [1]-[7]
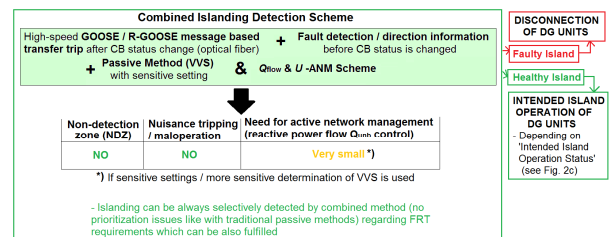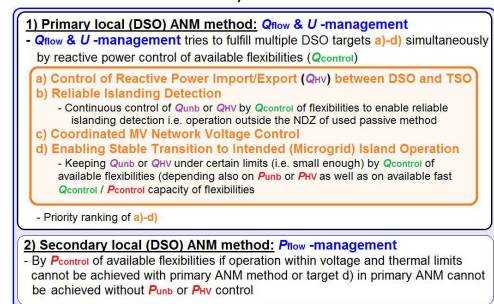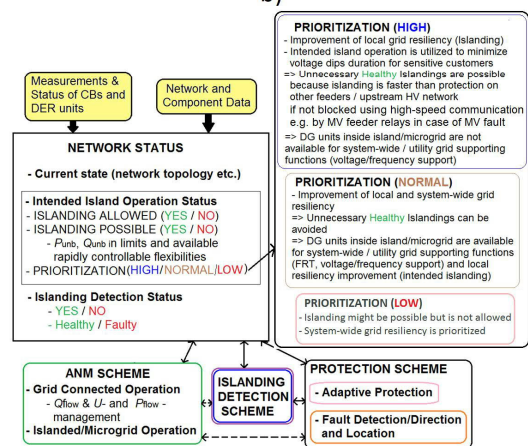
Figure 1. a) Combined islanding detection scheme, b) grid code compatible ANM scheme able to fulfill multiple targets simultaneously (see Fig. 2) and c) Dependencies between network status, protection, islanding detection & ANM functionalities and issues related to intended islanding operation prioritization.

In this paper, combined islanding detection schemes (Fig. 1) for both MV and LV network connected DG units during grid-connected operation are studied by PSCAD simulations with model from Sundom Smart

Grid (SSG) which is a local smart grid pilot in Vaasa, Finland (Fig. 2). The focus is on such scheme (Fig. 1) which, in addition to other simultaneous Q_{flow} & U -management targets (Fig. 1), utilizes reactive power unbalance control based Q_{flow} & U -management ANM scheme to ensure reliable islanding detection. 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. 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. 1). 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. 1).

Today there are two DG units connected to SSG (Fig. 2). One full-power-converter based wind turbine (3.6 MW) connected to MV network with own MV feeder J08 (Fig. 2) and another LV network connected inverter based PV unit (33 kW) at MV/LV substation TR4318 (Fig. 2).
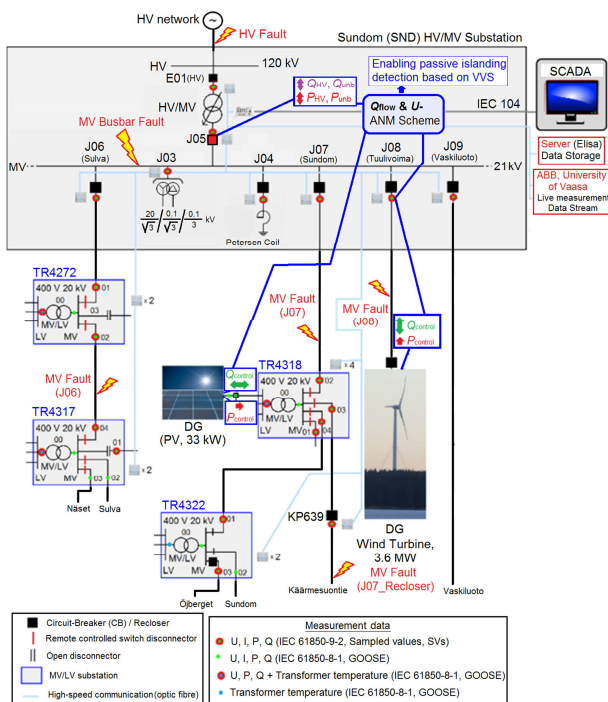

Figure 2. Sundom Smart Grid (SSG) in which ANM and islanding detection presented in Fig. 1 will be studied.

Islanding detection (Fig. 1a) is one of the multiple targets of the studied and developed ANM scheme (Fig. 1b). The ANM scheme target limits which need to be fulfilled can be studied in two different cases (Fig. 3). In case 1 Fingrid's (Finnish TSO) 'reactive power window' (which is requirement today) is used to set the limits for reactive power exchange between distribution network and transmission network at SSG HV/MV substation (Fig. 3a). The ENTSO-E NC for demand connection (DC) [8] (future requirement) is used to set these same limits in case 2 (Fig. 3b).
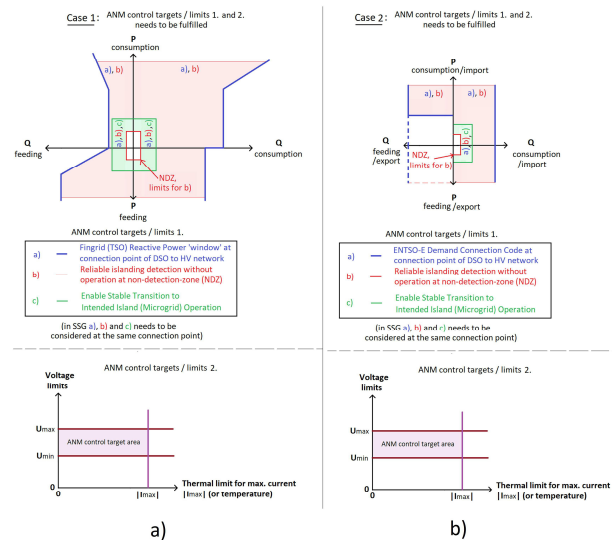

Figure 3. a) In case 1 Fingrid's 'reactive power window' and b) in case 2 ENTSO-E NC for demand connection (DC) [8] is used to set the limits for reactive power exchange between distribution network and transmission network at SSG HV/MV substation (Fig. 2) as part of the studied ANM scheme (Fig. 1b).

SIMULATION CASES AND RESULTS

In the following PSCAD simulation results from islanding detection simulations in SSG (Fig. 2) during grid-connected operation are presented. The simulation studies purpose for this paper was to focus on the development of primary combined islanding detection schemes [5] shown in Fig. 1 (i.e. high-speed communication based transfer trip & fault detection/direction + 1°-2° VVS). From combined islanding detection (Fig. 1) operation speed point of view it matters to some extent (communication latency) in which point VVS detection is made (see Fig. 2). Islanding can be detected most rapidly if VVS is detected at the connection point of the DG unit. Also from back-up islanding detection scheme point of view, local VVS and fault detection [5] at connection point is beneficial. However, fault detection information from the opened CB (which sends islanding detection transfer trip signal) should include also healthy or faulty island detection information (Fig. 1) [5]. Many different islanding detection scenarios were simulated with and without fault before islanding (fault locations are shown in Fig. 2). In following some chosen cases are presented. In all simulations MV islanding occurs at $t = 3.6$ s by opening of CB J05 (Fig. 2).

Healthy islanding detection simulations without fault

Fig. 4 shows MV and LV network primary islanding detection schemes for wind turbine and PV unit (Fig. 2) during grid-connected operation of SSG in healthy islanding detection cases without fault. In Fig. 5 and 6 frequency, positive sequence voltage (U_1) and VVS seen by the primary islanding detection scheme of MV network DG unit (wind turbine) and LV network DG unit (PV) during grid-connected operation of SSG (Fig. 2) in different healthy islanding detection cases without fault (see Fig. 4) are presented. In Fig. 5 six different cases are shown in which wind turbine control mode is

not changed after islanding at $t = 3.6$ s and active power unbalance also is not zero before islanding. Respectively, in Fig. 6 four different cases are presented from cases where active power unbalance is nearly zero before islanding and wind turbine control mode is changed after islanding when VVS value is more than 1 or 2 degrees.
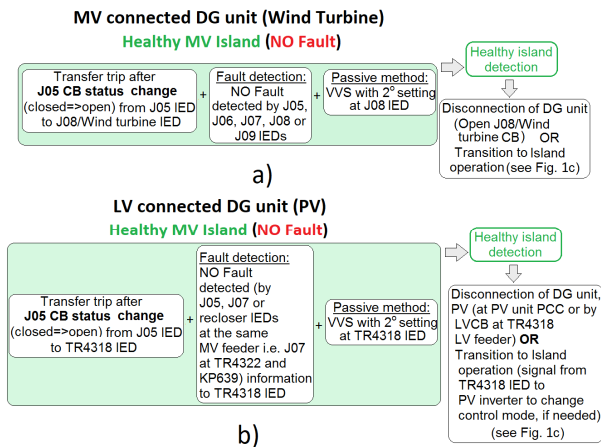

Figure 4. a) MV network DG unit (wind turbine) and b) LV network DG unit (PV) primary islanding detection scheme during grid-connected operation of SSG (Fig. 2) in healthy islanding detection cases without fault.
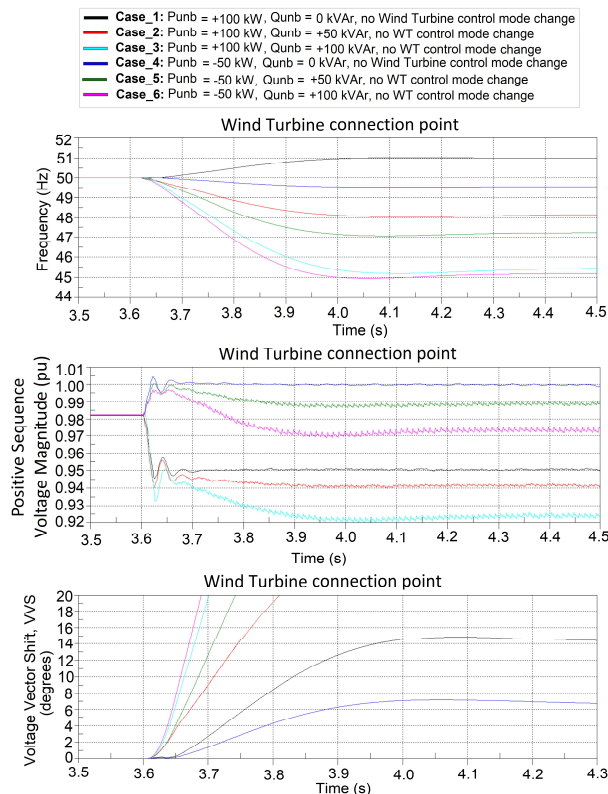

Figure 5. Frequency, positive sequence voltage and VVS of MV network DG unit (wind turbine) during grid-connected operation of SSG (Fig. 2) in 6 different healthy islanding detection cases without fault (see Fig. 4), without wind turbine control mode change and islanding at $t = 3.6$ s.

From simulation results (Fig. 5) it can be seen that fast, in less than 100 ms, islanding detection can be achieved with proposed combined scheme (Fig. 1) and 2° VVS setting in all cases except in case 4.
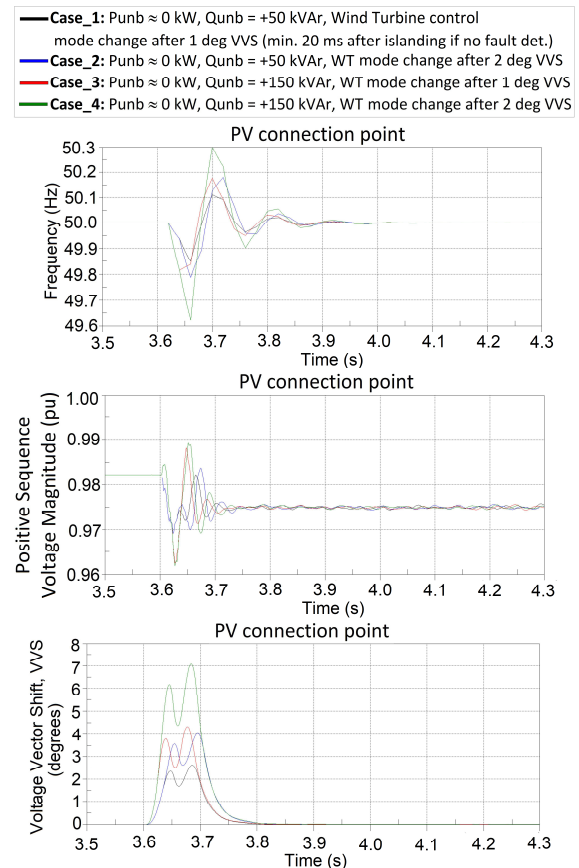

Figure 6. Frequency, positive sequence voltage and VVS of LV network DG unit (PV) during grid-connected operation of SSG (Fig. 2) in 4 different healthy islanding detection cases without fault (see Fig. 4), with wind turbine control mode change and islanding at $t = 3.6$ s.

Fig. 6 shows that MV network connected wind turbine control mode should be changed after islanding when VVS value is more than 2 degrees in order to enable the operation of LV network DG unit (PV) combined islanding detection scheme with 2° VVS setting in all cases.

SSG with parallel MV feeder fault - No faulty islanding

In Fig. 7 MV network primary islanding detection schemes for wind turbine (Fig. 2) with NORMAL prioritization during grid-connected operation of SSG in faulty islanding detection cases with MV fault at parallel (J06) or same (J08) MV feeder are presented.

When there is MV fault at parallel MV feeder (J06 in Fig. 7), no faulty islanding by opening of J05 CB should happen. Preventing blocking signal should be sent from J06 IED to J05. In general, in both MV fault related cases in Fig. 7 HIGH prioritization (Fig. 1c) should be only possible in case of upstream faults i.e. no directional over-current (DOC) starting/detection simultaneously. Fig. 8 and 9 present the simulation results from cases with MV fault at the parallel (J06) MV feeder i.e. no faulty islanding. Fig. 9 shows positive and negative sequence current magnitudes and angle differences seen in different points by respective IEDs (J05, J06, J07 and J08) during 3- or 2-phase fault at the parallel (J06) MV feeder.
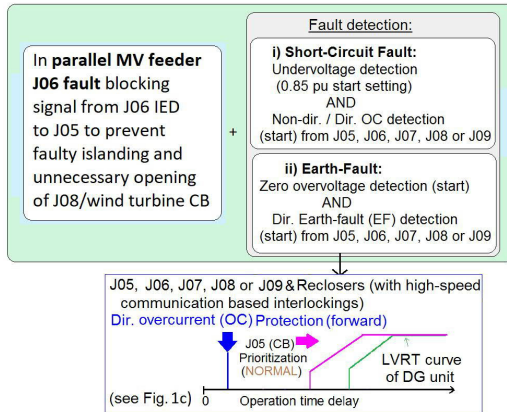
Figure 7. MV network DG unit (wind turbine) primary islanding detection scheme during grid-connected operation of SSG (Fig. 2) in faulty islanding detection cases with MV fault (NORMAL prioritization) at parallel (J06) MV feeder.
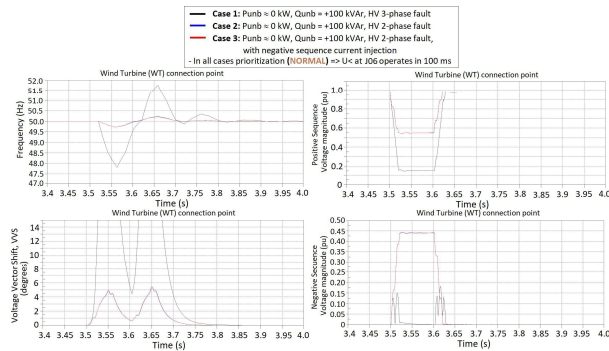

Figure 8. Frequency, positive sequence voltage and VVS of MV network DG unit (wind turbine) primary islanding detection scheme during grid-connected operation of SSG (Fig. 2) in 3 different cases with parallel (J06) MV feeder fault (NORMAL prioritization) 100 ms before islanding at t = 3.6 s (see Fig. 7).
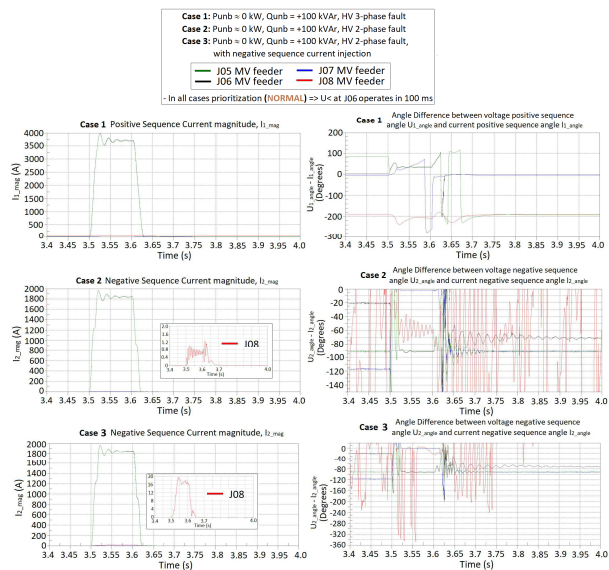

Figure 9. Positive and negative sequence current magnitudes (I_{1_mag} and I_{2_mag}) as well as U_{1_angle}-I_{1_angle} and U_{2_angle}-I_{2_angle} during grid-connected operation of SSG (Fig. 2) in 2 different no faulty islanding detection cases with MV fault (NORMAL prioritization) at the parallel (J06) MV feeder 100 ms before islanding at t = 3.6 s (see Fig. 7).

From Fig. 9 simulation results it can be seen how wind turbine negative sequence current injection during 2-phase fault affects on the angle seen by MV feeder J08 IED.

CONCLUSIONS

This paper presented successful simulations of combined islanding detection schemes for both MV and LV network connected DG units during grid-connected operation. Islanding detection is one of the multiple targets of the studied ANM scheme and Fig. 10 shows the initial ANM scheme control limits in SSG based on the islanding detection simulations.
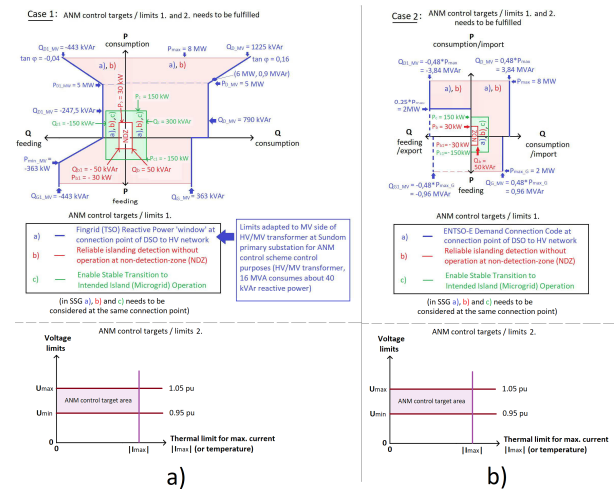

Figure 10. Accurate studied ANM scheme (Fig. 1b) control limits in SSG (Fig. 2) for a) case 1 Fingrid's 'reactive power window' and b) case 2 ENTSO-E NC for demand connection (DC) [8] (see Fig. 3).

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