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Combined islanding detection scheme utilising active network management for future resilient distribution networks

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Abstract: Needed new cost-efficient, reliable, standardised and redundant solutions for future resilient smart grids must utilise possibilities of advanced ICT technologies (such as wireless fifth generation and cloud servers with smart big data analytics) and have cyber-security integrated into all solutions. In this study, resilient, future-proof, grid-code compatible combined islanding detection scheme for medium-voltage (MV) and low-voltage network-connected distributed generation units during grid-connected operation is simulated. The utilisation of active network management functionality at the MV level enables to control the reactive power unbalance continuously in order to ensure reliable islanding detection without a non-detection zone. The combined scheme also prevents maloperations due to other disturbances.

1 Introduction

In the future, active utilisation of controllable, flexible, distributed energy resources (i.e. flexibilities such as distributed generation (DG), energy storages, controllable loads/demand response, intelligent charging of electric vehicles) will be in key role to enable more resilient power system. Electricity distribution network areas with flexibilities, i.e. FlexZones [1] or nested 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 the realisation of improved local and system-wide grid resiliency in the future during grid-connected 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. However, this also creates needs for future network management and protection methods and solutions which have to be adapted and developed in order to enable utilisation of intended island operation as well as active control and utilisation flexibilities during grid-connected and islanded operation modes [2–5].

Already today and also in the future, the use of frequency (f), voltage (U) and rate-of-change-of-frequency for defining DG units' fault-ride-through (FRT) requirements in the new gridcodes are on the rise. In addition, in European ENTSO-E grid-code requirements for generators (RfG) [6], it has been stated that islanding detection should not be based only on the network operator's switchgear position signals. Therefore, combined islanding detection schemes [e.g. high-speed communication-based transfer trip through optical fibre/wireless fifth generation (5G) such as IEC, 61850-based GOOSE or routable R-GOOSE message and 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 minimised, prioritisation issues with DG unit grid-code requirements can be avoided and ENTSO-E RfG requirement (not only status position detection) can be fulfilled. Utilisation of active network management (ANM) functionality at medium-voltage (MV) level enables to control the reactive power unbalance Q_{unb} continuously in order to ensure islanding detection of the passive method (such as VVS with sensitive settings) in the combined scheme without NDZ (Fig. 1). Realisation of future-proof and grid-code compatible schemes requires studies regarding dependencies between protection, islanding detection and ANM functionalities [1, 5–13].

In this paper, combined islanding detection schemes (Fig. 1) for both MV and low-voltage (LV) network-connected DG units during grid-connected operation are studied by power systems computer-aided design (PSCAD) simulations with a model from Sundom smart grid (SSG), which is a local smart grid pilot in Vaasa, Finland. The focus is on such scheme (Fig. 1) which, in addition to other simultaneous Q_{flow} and U -management targets (Fig. 1), utilises reactive power unbalance control-based Q_{flow} and 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 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. 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, prioritisation as well as allowance of intended island operation (Fig. 1).

2 SSG and studied ANM scheme

SSG in Vaasa, Finland (Fig. 2) is a smart grid pilot of ABB Oy, Vaasan Sähkö (local DSO), Elisa (telecommunication company, previously Anvia) and University of Vaasa. SSG serves as Finnish Innovation Cell (IC) in demonstration of coordinated ancillary services (DeCAS covering different voltage levels and the integration in future markets) project. IC Finland concentrates on research and development of (i) future ANM scheme (Fig. 1*b*) and (ii) related technical flexibility service market structures as well as on the development of (iii) future-proof islanding detection functionalities (Fig. 1*a*). In SSG IEEE 1588 time-synchronised, more accurate IEC 61850-9-2 sampled values and less accurate GOOSE values based, measurement data from multiple points is collected and stored in servers (Fig. 2) to enable research and development of ANM (Fig. 1*b*), protection and islanding detection functionalities (Fig. 1*a*) [10]. 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

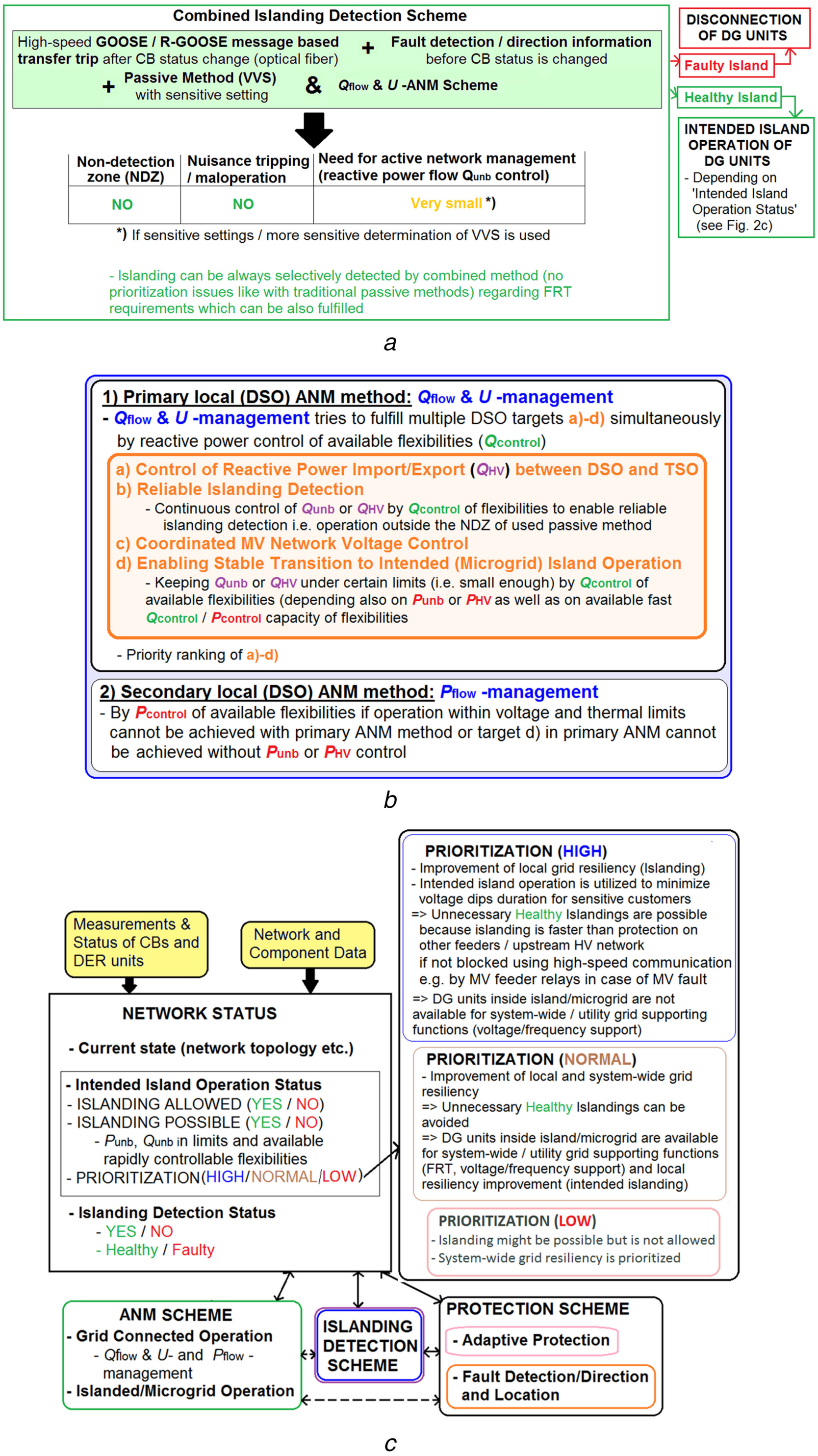


Fig. 1 *Combined islanding detection schemes*

(a) Combined islanding detection scheme, ***(b)*** Grid-code compatible ANM scheme able to fulfil multiple targets simultaneously, ***(c)*** Dependencies between network status, protection, islanding detection and ANM functionalities and issues related to intended islanding (microgrid operation) prioritisation

unit (33 kW) at MV/LV substation TR4318 (Fig. 2). Islanding detection (Fig. 1*a*) is one of the multiple targets of the studied and developed ANM scheme (Fig. 1*b*). 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 a requirement today) is used to set the limits for reactive power exchange between distribution network and transmission network at SSG HV/MV substation (Fig. 3*a*). The ENTSO-E network code for demand connection (DC) [14] (future requirement) is used to set these same limits in case 2 (Fig. 3*b*).

Fig. 4 presents DeCAS target schematics of IC Finland (SSG) regarding ANM scheme (Fig. 1*b*) mapped to smart grid architecture model (i.e. SGAM that shows the different layers of interoperability.). In Fig. 5, also the developed web interface (Fig. 4) in the DeCAS project for IC Finland GOOSE values based measurement data real-time (RT) viewing, storing and downloading developed by Jubic (https://www.jubic.fi/en/) is presented.

Fig. 6 shows that based on real-life GOOSE measurements from SSG (Figs. 2 and 5), operation in active (P) and reactive (Q) power balance (i.e. in NDZ of most passive islanding detection methods) is possible in the studied substation.

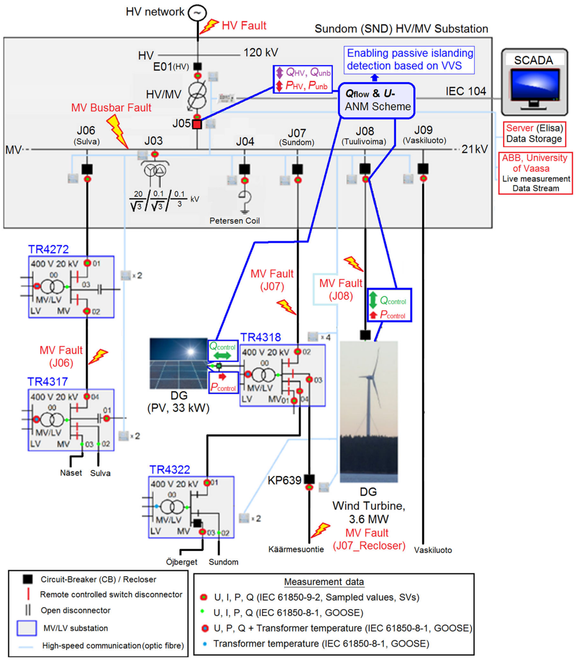


Fig. 2 *SSG in which ANM and islanding detection presented in Fig. 1 will be studied*

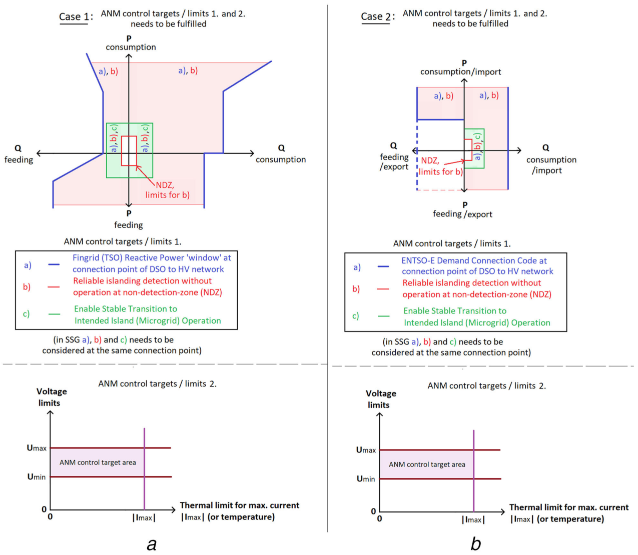


Fig. 3 *ANM scheme target limits*

(a) In case 1, Fingrid's 'reactive power window', ***(b)*** In case 2 ENTSO-E NC for DC [14] 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. 1*b*)

3 Simulation study cases and results

In this section, 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 primarily combined islanding detection schemes [10] shown in Fig. 1 (i.e. high-speed communication-based transfer trip and fault detection/direction + VVS).

The fault detection logic, either centralised or decentralised, requires information from multiple locations as well as from other network status related issues. Therefore, in the future, for example, centralised islanding detection logic at HV/MV and MV/LV substation protection and control unit level utilising high-speed communication (cost-efficient, low-latency wireless 5G and R-GOOSE in the future) would be very potential way to realise these future schemes which have dependencies with protection and ANM functionalities (Fig. 1) [10]. Utilised islanding detection

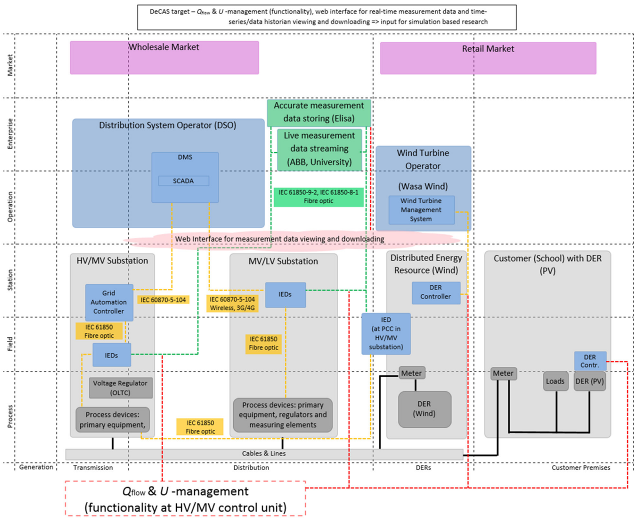


Fig. 4 *DeCAS target of IC Finland (SSG) regarding ANM scheme (Fig. 1b) mapped to SGAM [15]*

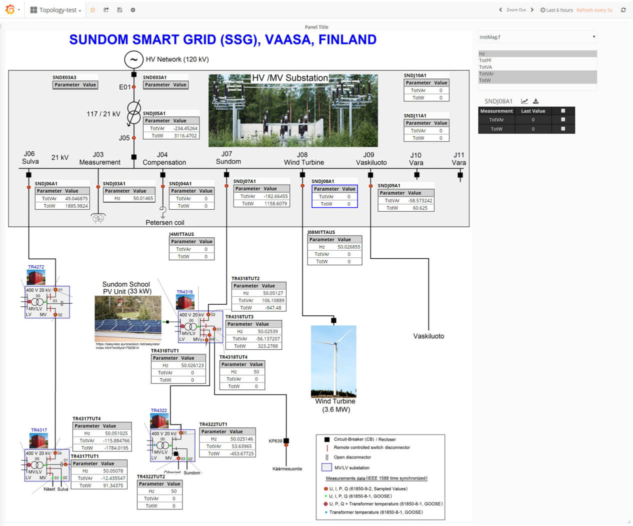


Fig. 5 *Developed web interface (Fig. 4) in the DeCAS project for IC Finland GOOSE values based measurement data RT viewing, storing and downloading*

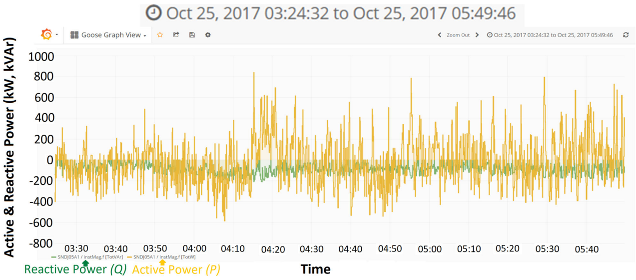


Fig. 6 *Measured (Fig. 5) active and reactive power flows through CB J05 at Sundom HV/MV substation (Fig. 2)*

scheme should be coordinated with used protection scheme during normal grid-connected operation as well as with distributed energy resourced (DER) unit *P*/*f* and *Q*/*U*-control grid-code requirements as stated in [10]. In addition, both islanding detection and protection (e.g. in [4, 16, 17]) schemes during normal operation should be compatible with DER unit voltage and frequency FRT requirements which are set by gridcodes or which enable the stable transition to islanded operation (such as extended FRT requirements).

In general, 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

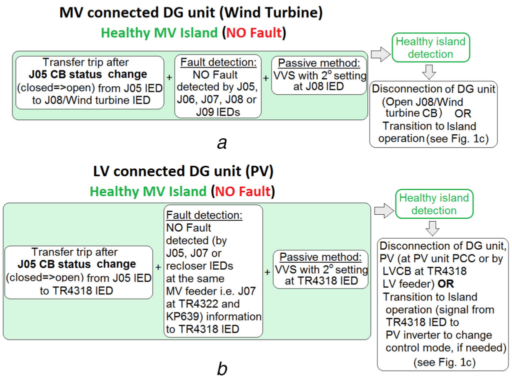


Fig. 7 *MV and LV network primary islanding detection schemes*
(a) MV network DG unit (wind turbine), ***(b)*** LV network DG unit (PV) primary islanding detection scheme during grid-connected operation of SSG (Fig. 2) in healthy islanding detection cases without fault

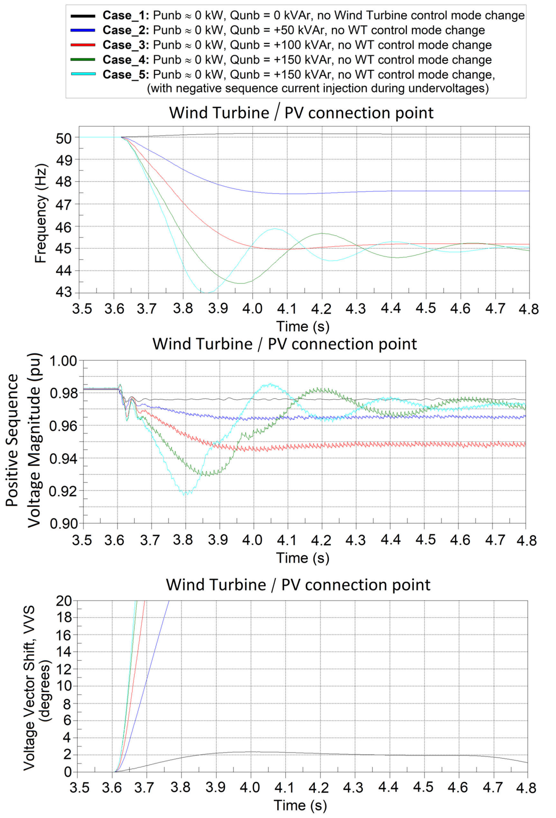


Fig. 8 *Frequency, positive sequence voltage and VVS of MV network DG unit (wind turbine) and LV network DG unit (PV) primary islanding detection scheme during grid-connected operation of SSG (Fig. 2) in five different healthy islanding detection cases without fault (see Fig. 7), islanding at $t = 3.6$ s*

(see Fig. 2). Islanding can be detected most rapidly if VVS is detected at the connection point of the DG unit. Also from a back-up islanding detection scheme point of view, local VVS and fault detection [10] at connection point is beneficial. However, fault detection information from the opened circuit breaker (CB) (which sends an islanding detection transfer trip signal) should include also healthy or faulty island detection information (Fig. 1) [10]. Many different islanding detection scenarios were simulated with and without fault before islanding (fault locations are shown in Fig. 2). In the following, some chosen healthy and faulty islanding detection cases are presented. In all simulations MV islanding occurs at $t = 3.6$ s by the opening of CB J05 (Fig. 2).

3.1 SSG healthy islanding detection simulations without fault

In Fig. 7, 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 are presented. Fig. 8 shows frequency, positive sequence voltage ($U1$) 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 five different healthy islanding detection cases without fault (see Fig. 7).

From simulation results (Fig. 8), it can be seen that rapid enough (<100 ms) islanding detection can be achieved with the proposed combined scheme (Fig. 1) in all cases, except in case 1 near active and reactive power unbalances.

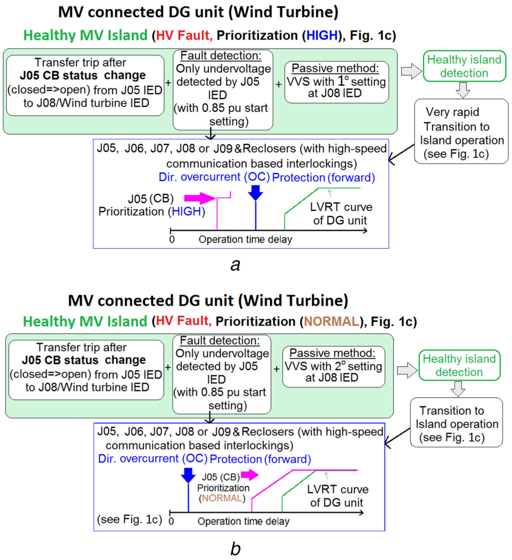


Fig. 9 *MV network DG unit (wind turbine) primary islanding detection scheme with*
(a) HIGH prioritisation, ***(b)*** NORMAL prioritisation (Fig. 1*c*) during grid-connected operation of SSG (Fig. 2) in healthy islanding detection case with HV fault

3.2 SSG healthy islanding detection simulations with HV fault

In Fig. 9, MV network primary islanding detection schemes for a wind turbine (Fig. 2) with HIGH or NORMAL prioritisation during grid-connected operation of SSG in healthy islanding detection cases with HV fault are shown. Figs. 10 and 11 present the simulation results from cases with HIGH prioritisation.

In Fig. 9, cases of wind turbine control mode (from grid-connected to islanded control mode) are changed after healthy islanding detection (and 2° VVS) with J05 fault detection (U<) and no fault detection (DOC) from J06, J07, J08, J09 and reclosers (islanding prioritised HIGH or NORMAL). In these cases with HIGH prioritisation (Figs. 10 and 11) islanding happens rapidly in 50 ms after detected undervoltage due to three-phase HV fault (cases 1 and 4). However, VVS setting 2° would not be enough in two-phase HV fault cases 2, 3 and 5 for fast islanding detection (Fig. 10). To enable islanding detection in these cases with HIGH

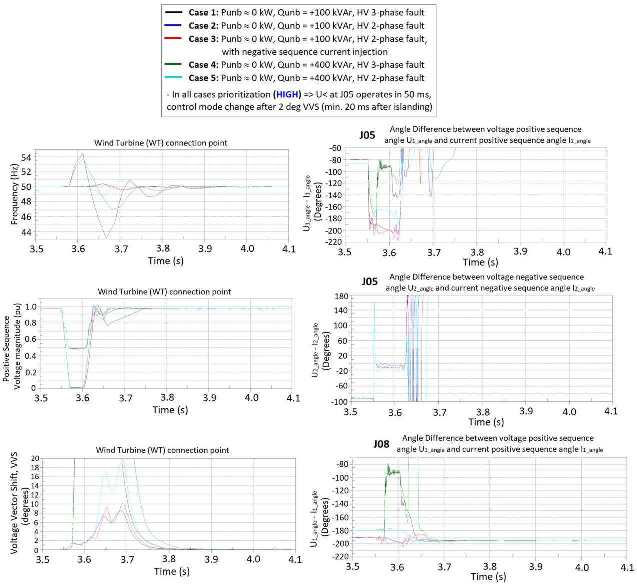


Fig. 10 *Frequency, positive sequence voltage and VVS of MV network DG unit (wind turbine) primary islanding detection scheme and* $U_{1\_angle}-I_{1\_angle}$ *(J05),* $U_{2\_angle}-I_{2\_angle}$ *(J05) and* $U_{1\_angle}-I_{1\_angle}$ *(J08) with HIGH prioritisation during grid-connected operation of SSG (Fig. 2) in five different healthy islanding detection cases with HV fault 50 ms before islanding at t = 3.6 s (see Fig. 9)*

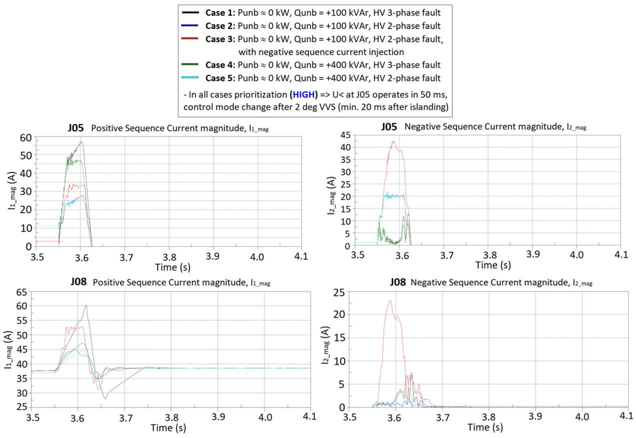


Fig. 11 *Positive and negative sequence current magnitudes (I1_mag and I2_mag) at J05 and J08 with HIGH prioritisation during grid-connected operation of SSG (Fig. 2) in five different healthy islanding detection cases with HV fault 50 ms before islanding at t = 3.6 s (see Fig. 9)*

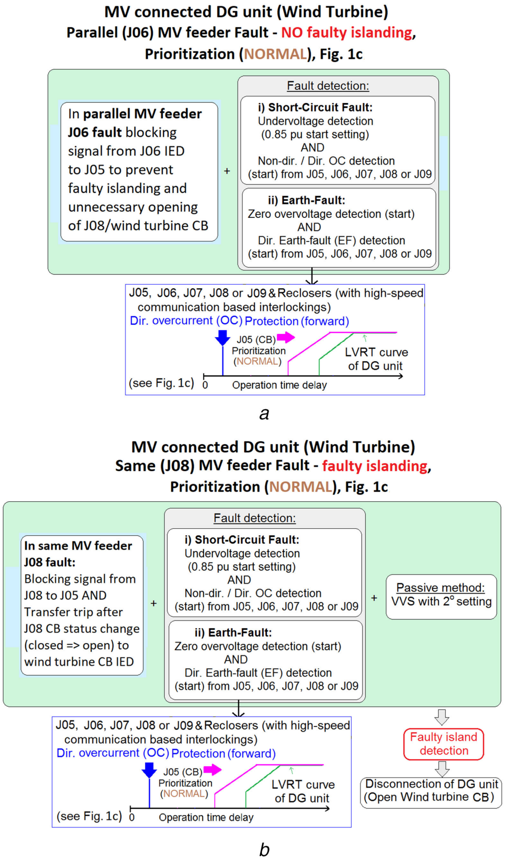
prioritisation even more sensitive (e.g. 1°) setting should be used (Fig. 9). Fault direction can be detected in all HV fault cases based on positive and negative sequence current magnitudes and angle differences (Figs. 10 and 11).

3.3 SSG faulty islanding detection simulations with MV fault

In Fig. 12, MV network primary islanding detection schemes for a wind turbine (Fig. 2) with NORMAL prioritisation 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. 12*a*), no faulty islanding by the 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. 12 HIGH prioritisation should be only possible in case of upstream faults, i.e. no directional over-current (DOC) starting/detection simultaneously.

In MV fault at the same (J08) MV feeder (Fig. 12*b*), MV feeder protection J08 should operate and wind turbine control mode should not be changed (faulty islanding detection). In MV fault at the same (J08) MV feeder DG unit connection point CB disconnects the wind turbine by operating in 70 ms after faulty islanding detection. Figs. 13 and 14 present the simulation results from cases with MV fault at the same (J08) MV feeder.



a

b

Fig. 12 *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 prioritisation) at*
(a) Parallel (J06), ***(b)*** Same (J08) MV feeder

In Fig. 14, positive and negative sequence current magnitudes and angle differences seen in different points by respective IEDs (J05, J06, J07 and J08) during three- or two-phase faults at the same (J08) MV feeder in which wind turbine (Fig. 2) is connected to are shown. To prevent unnecessary operation of J05, blocking signal should be sent from J08 IED to J05 IED.

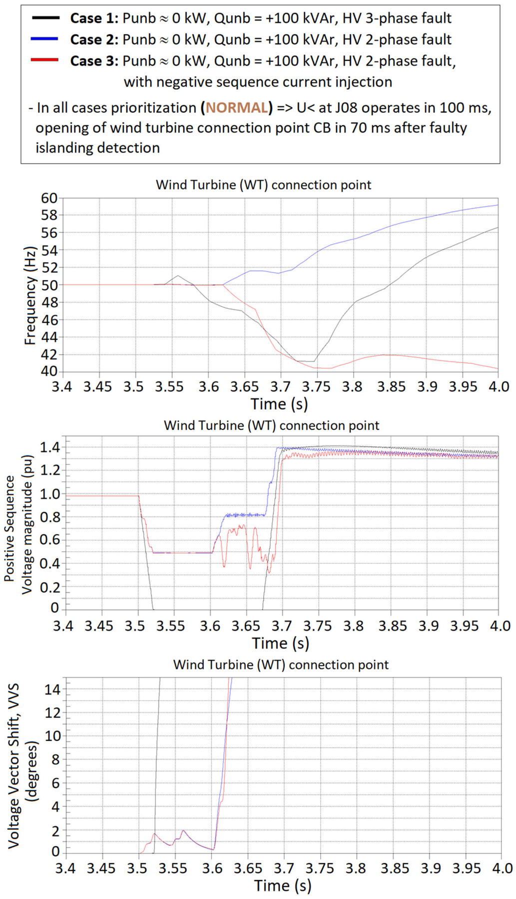


Fig. 13 *Frequency, positive sequence voltage and VVS of MV network DG unit (wind turbine) primary islanding detection scheme during grid-connected operation of SSG (Fig. 2) in three different faulty islanding detection cases with MV fault (NORMAL prioritisation) at the same (J08) MV feeder 100 ms before islanding at t = 3.6 s (see Fig. 12)*

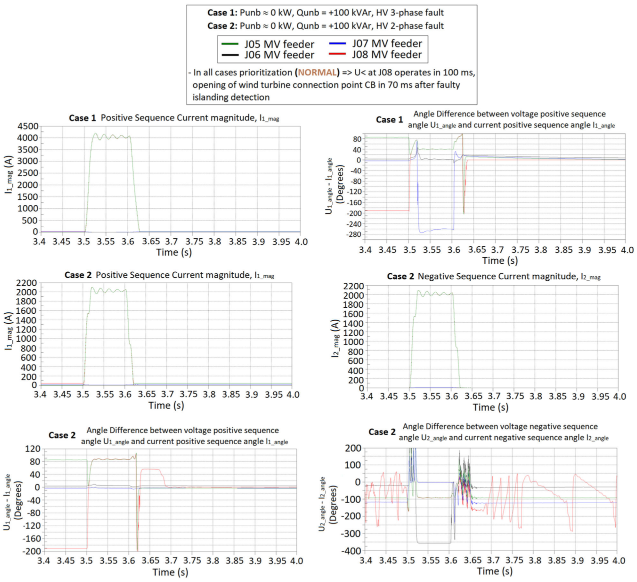


Fig. 14 *Positive and negative sequence current magnitudes (I_{1_mag} and I_{2_mag}) as well as $U_{1\_angle}-I_{1\_angle}$ and $U_{2\_angle}-I_{2\_angle}$ during grid-connected operation of SSG (Fig. 2) in two different faulty islanding detection cases with MV fault (NORMAL prioritisation) at the same (J08) MV feeder 100 ms before islanding at t = 3.6 s (see Fig. 12)*

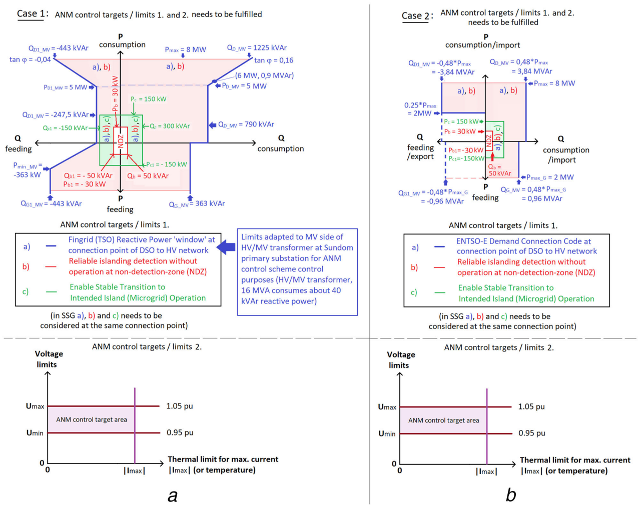


Fig. 15 *Accurate studied ANM scheme (Fig. 1b) control limits in SSG (Fig. 2) for*

(a) Case 1 Fingrid's 'reactive power window', ***(b)*** Case 2 ENTSO-E NC for DC [14] (see also Fig. 3)

4 Conclusions

In this paper, combined islanding detection schemes for both MV and LV network-connected DG units during the grid-connected operation were successfully simulated. Islanding detection is one of the multiple targets of the studied ANM scheme and Fig. 15 shows the initial ANM scheme control limits in SSG based on the islanding detection simulations.

In the future, the target is that the combined islanding detection scheme simulated in this paper with PSCAD is further verified with OPAL-RT RT simulator at the University of Vaasa and field tests at SSG.

5 Acknowledgments

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