RELIABLE ISLANDING DETECTION WITH ACTIVE MV NETWORK MANAGEMENT

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ABSTRACT

Active management of distribution networks and different controllable resources will play a key role in future Smart Grids. This paper proposes that centralized active network management functionalities at MV level could also include an algorithm which in real time confirms reliable islanding detection with local measurements based passive method. The proposed algorithm continuously ensures that there is such reactive power unbalance, so that the operation point remains constantly outside the non-detection zone of the used passive islanding detection method. The effect of recent grid code requirements on the proposed scheme, like the P/f -droop control of DG units, has been also considered.

INTRODUCTION

In the future it is likely that different active network management functionalities, like voltage control, island operation coordination, minimization of losses, etc. will be realized through centralized solutions at primary (HV/MV) and secondary (MV/LV) substations [1], [2].

Traditionally active network management and adaptive protection functionalities have been developed and operated independently [3]. However, in the future increasing attention should be paid to understand the level of active network management and protection functions coupling to be able to create future-proof solutions for the Smart Grids [4].

One of the key protection functionalities in the Smart Grids will be reliable detection of islanding. Although the trend in new grid codes is to require fault-ride-through (FRT) capability from distributed generation (DG) units and possibly also allow island operation, there is still a need to reliably detect the islanding situation to make the correct operations, e.g. change the setting group of DG interconnection IED or change the control principles and parameters of DG unit.

In the forthcoming ENTSO-E network code (NC) for generators (RfG) [5], it has been stated that islanding detection should not be based only on the network operator's switchgear position signals. Moreover, if high-speed communication is used as a primary islanding detection method, the passive local islanding detection method is still needed as a back-up.

Non-detection zone (NDZ) near power balance situation and unwanted DG trips due to other network events (nuisance tripping) have been the major challenges with traditional, passive local islanding detection methods like frequency (*f*), *df/dt*, vector shift (*VS*) or voltage (*U*).

If the number of DG units in distribution networks increases, as is expected in the future, the risk of power balance situations will also increase. Therefore, the risk of possible operation in the NDZ of the traditional passive islanding detection methods will increase, too. In addition, the use of *f*, *U* and rate-of-change-of-frequency (ROCOF) for defining the DG unit FRT requirements in the new grid codes (as in [5]) to enable utility grid stability supporting functionalities from DG units, will increase.

Recent and forthcoming grid code requirements, such as the active power/frequency (*P/f*) regulation of all DG units during over-frequency, and larger DG units during both over- and under-frequency [5], [10] will make DG units connected to MV and LV networks control their active power after islanding. This means that frequency deviations are instantly corrected and islanding cannot be detected with the traditional, passive islanding detection methods. Therefore, the use of the traditional parameters for reliable and selective islanding detection may become even more difficult in the future than it is today.

Due to the above-mentioned reasons in [7] and [8] a new, future-proof, passive islanding detection algorithm and scheme has been proposed, which is able to detect very fast and selectively islanding situations in a perfect power balance without NDZ, and is also applicable to different type of DG units.

However, this paper proposes that centralized active network management functionalities (CANM) at the MV level, like voltage control or losses minimization, could in the future include an algorithm which in real time confirms the operation of reliable islanding detection, even based on passive methods like voltage phase angle-based methods as proposed e.g. in [9]. The proposed algorithm continuously ensures that there is such reactive power unbalance so that the operation point remains constantly outside the NDZ of the used islanding detection method.

In the following, some of the new grid code requirements, which may have an effect on islanding detection with traditional passive methods and the proposed scheme, are briefly presented. After that, a more detailed description of the proposed scheme is presented with additional functionalities, like adaptive detection of islanding, adaptive auto-reclosing open-time settings, and the minimization of the DNO reactive power costs. Finally, example simulation results are presented followed by discussion and conclusions.

NEW GRID CODE REQUIREMENTS

In the future, ENTSO-E NC RfG [5] will provide a legal framework for DG units (> 0.8 kW) grid code requirements in Europe, but it will not replace local national grid codes. ENTSO-E NC RfG [5] divides the requirements for four type/size of DG units (power generating modules) i.e. Type A (DG units > 0.8 kW connected to voltage levels below 110 kV) and B, C and D, which have different maximum capacity thresholds for the five different synchronous areas.

Frequency

In NC RfG [5] for DG units (Type A and larger), it has been stated that with regard to frequency ranges, a DG unit shall be capable of staying connected to the network and operating within the frequency ranges (some difference between synchronous areas) and time periods specified in Fig. 1.

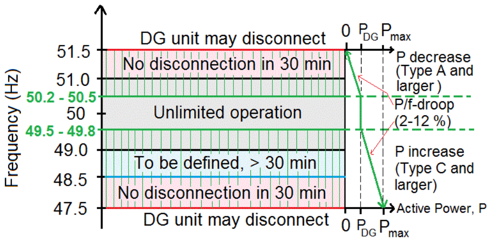


Figure 1. Frequency FRT (Nordic area) and support requirements for DG units (Type A and larger). [5]

Frequency support – Active power control

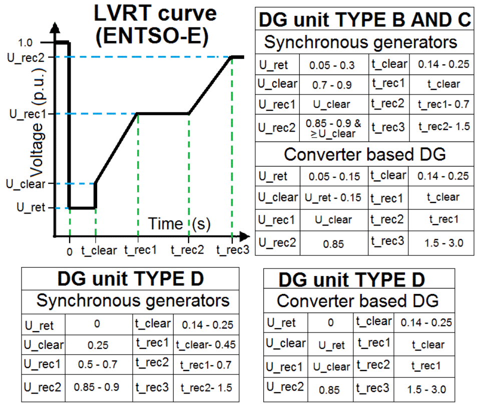
In NC RfG [5] it is also stated that the DG unit (Type A and larger) shall be capable of reducing active power during over-frequencies (*P/f* -droop) starting from a point between 50.2 Hz and 50.5 Hz with a droop in a range of 2–12% (Fig. 1). In [10], similar requirements for the active power response of DG units to over-frequencies has been set as in [5]. The range of intentional delay is 0-2 seconds and the default setting is 0 s.

ROCOF/*df/dt*

In NC RfG [5], it is stated for DG units (Type A and larger) that with regard to the ROCOF or *df/dt* withstanding capability, a DG unit shall be capable of staying connected to the network and operating at rates of change of frequency up to a value defined by the TSO. Possible ROCOF-based passive islanding detection should be coordinated with required ROCOF withstand capability [5], which may also be coordinated or prioritized with the voltage FRT curve. In [10], the required ROCOF withstand capability has been set up to 2.5 Hz/s.

Voltage

In NC RfG [5] for Type B and larger DG units it has been stated that with regard to FRT capability of DG units, each TSO should define a voltage-against-time-profile (low-voltage-ride-through, LVRT, curve) as shown in Fig. 2. [5]



DG unit TYPE B AND C			
Synchronous generators			
U_ret	0.05 - 0.3	t_clear	0.14 - 0.25
U_clear	0.7 - 0.9	t_rec1	t_clear
U_rec1	U_clear	t_rec2	t_rec1- 0.7
U_rec2	0.85 - 0.9 & ≥U_clear	t_rec3	t_rec2- 1.5
Converter based DG			
U_ret	0.05 - 0.15	t_clear	0.14 - 0.25
U_clear	U_ret - 0.15	t_rec1	t_clear
U_rec1	U_clear	t_rec2	t_rec1
U_rec2	0.85	t_rec3	1.5 - 3.0

DG unit TYPE D			
Synchronous generators			
U_ret	0	t_clear	0.14 - 0.25
U_clear	0.25	t_rec1	t_clear- 0.45
U_rec1	0.5 - 0.7	t_rec2	t_rec1- 0.7
U_rec2	0.85 - 0.9	t_rec3	t_rec2- 1.5

DG unit TYPE D			
Converter based DG			
U_ret	0	t_clear	0.14 - 0.25
U_clear	U_ret	t_rec1	t_clear
U_rec1	U_clear	t_rec2	t_rec1
U_rec2	0.85	t_rec3	1.5 - 3.0

Figure 2. Voltage FRT requirements for DG units (Type B and larger). [5]

Reactive power exchange and control between distribution and transmission networks

In ENTSO-E NC for demand connection (DC) [6] it has been stated that all transmission connected distribution networks shall fulfill the requirements related to reactive power exchange and control. These include requirements like 1) the actual reactive power range specified by the DSO shall not be wider than 0.9 power factor of the larger of their maximum import capability, 2) DSOs shall have the capability at the connection point to not export reactive power (at nominal voltage) at an active power flow of less than 25% of the maximum import capability, and 3) TSO shall have the right to require DSOs to actively control the exchange of reactive power at the connection point as part of a wider common concept for the management of reactive power capabilities for the benefit of the entire network. [6]

PROPOSED ACTIVE NETWORK MANAGEMENT SCHEME

In Fig. 3, the proposed CANM scheme is presented. In the future, as part of CANM functionalities such as voltage control or losses minimization (Fig. 3) at the MV level, an algorithm could be included which confirms the operation of reliable islanding detection in real time, even with passive methods.

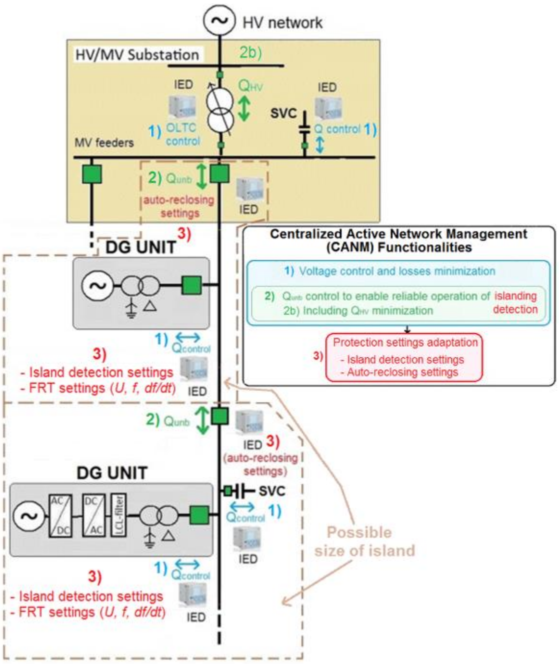


Figure 3. Integration of a new algorithm as part of future active MV network management functionalities to continuously ensure reliable islanding detection even with traditional passive methods.

The proposed algorithm ensures that a larger reactive power unbalance Q_{unb} constantly exists than the lowest level/stage of reactive power unbalance required (for example ± 100–150 kVAr at the beginning of the corresponding MV feeder) and that the operation point remains constantly outside the NDZ of the used islanding detection method. Naturally, control of active power unbalance P_{unb} in an MV network to ensure reliable islanding could also be used. However, based on the simulations, the active management of reactive power unbalance and +/- reactive (Q) power control to enable reliable islanding detection was seen as a better option. It may also be easier to integrate additional functionalities, like adaptive detection of islanding, adaptive auto-reclosing open-time settings and the minimization of the DNO reactive power costs (Fig. 3) with the reactive power Q_{unb} control-based scheme.

The power unbalance P_{unb} and Q_{unb} monitoring can be performed either centrally based on MV feeder measurements or independently by each MV feeder IED. When, for example, an MV feeder IED measures that the reactive power unbalance Q_{unb} changes from one stage to another, it sends a signal to CANM functions at the MV level for the registering of the change and the required actions (Fig. 4). For instance, three levels (high, medium, low) for Q_{unb} level could be used.

Minimization of losses and reactive power costs of DSO

From the simultaneous network losses minimization point of view, the algorithm integrated within the centralized voltage control and losses minimization functionality, which enables the reliable islanding detection of DG units (Fig. 3), must be such that the voltage level will always stay within allowable limits at each point of the MV network by 1) minimizing the reactive power flow in the MV network by feeding/absorbing reactive power as close as possible to the point with voltage level violation, and 2) if this is not enough from a reliable islanding detection point of view, e.g. reactive power unbalance Q_{unb} at the beginning of MV feeder, it must be ensured by increasing reactive power feeding/absorbing as close as possible to the MV feeder CB (i.e. to minimize reactive power flow in the MV feeder).

Increased cabling of overhead lines in Nordic countries, for example, will create a need to compensate for the reactive power produced by long MV cable feeders to reduce losses, to prevent an increase in voltage, and to reduce reactive power costs from feeding reactive power to the HV network. On the other hand, as stated before the ENTSO-E NC for demand connection includes requirements to control reactive power import/export between the distribution and transmission network at HV/MV primary substations.

Therefore, in order to minimize the total reactive power feeding/absorbing of the HV/MV substation from HV network Q_{HV}, the algorithm which ensures reliable islanding detection by introducing reactive power unbalance Q_{unb} at the beginning of each MV feeder should be just that the “direction” of the reactive power flow varies between MV feeders. Simultaneously, naturally voltage level must be maintained in each MV feeder at an acceptable level. In cases where in HV network connection point, $\mathrm{CP}_{\mathrm{HV}}$, both Q_{HV} and P_{HV} are close to zero and intended island operation is not allowed, such a scheme should be implemented in which IED at $\mathrm{CP}_{\mathrm{HV}}$ will sent a signal after the opening of CB to the MV feeder IEDs to open corresponding CBs to enable the correct operation of passive islanding detection methods.

If multiple protection zones are used in the same MV feeder, the power flow i.e. power unbalance through each CB, should be taken into account in the centralized algorithm (Fig. 3). A change of network topology e.g. from radial to meshed, could also in some cases lead to reduced network losses, but before possible change it should be checked that the condition from a reliable islanding detection point of view can also be fulfilled after the topology change.

Adaptive islanding detection settings

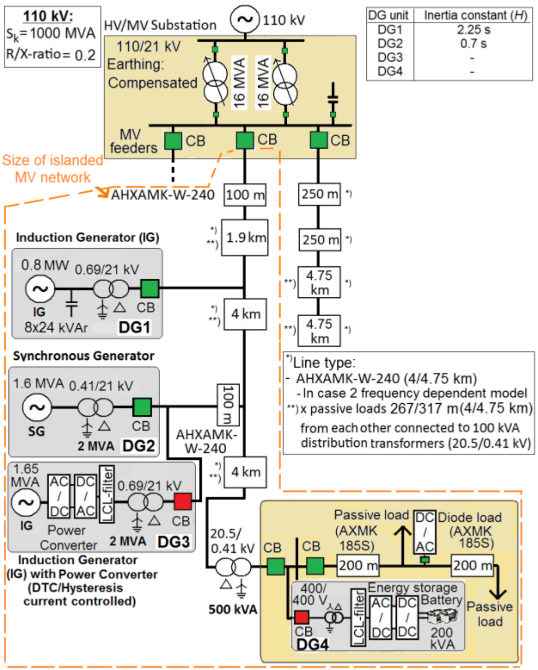
In general, it could also be possible to include features as part of CANM schemes which ensure the operation of passive islanding detection so that the islanding detection settings in the DG unit IED are updated in real time, depending (Fig. 3) on the power unbalance P_{unb} and Q_{unb} at the beginning of the MV feeder or at the closest MV feeder CB/recloser if multiple protection zones are utilized at the same feeder. However, if under-voltage, frequency or df/dt is used for islanding detection, the time delay settings of these functions must first be coordinated with corresponding grid code FRT requirements. Similarly, it is important to coordinate e.g. islanding detection intentional operation time delay settings (to avoid nuisance tripping) and auto-reclosing open-time settings so that their selective operation can be always ensured (Fig. 3).

Adaptive auto-reclosing open-time settings

To guarantee reliable and selective operation of islanding detection, fast auto-reclosing open time must be longer than the operation time of islanding detection, and it can also be adaptive in a similar way to islanding detection, i.e. dependent on the active (P_{unb}) and/or reactive power (Q_{unb}) flow through the corresponding MV feeder CB (Fig. 3). The variation possibility of fast auto-reclosing time could be e.g. between 150–600 ms and when the power flow, i.e. the power unbalance is small, the fast auto-reclosing open time is longer. This adaptive functionality could easily be added to MV feeder IEDs or alternatively it could also be centrally coordinated by the grid automation controller, for example.

SIMULATION EXAMPLES

In Fig. 4, a study network for the PSCAD simulation studies is presented. More details about the simulation model can be found from [7]-[9]. The purpose of the simulation examples is to show how the proposed algorithm could ensure reliable passive islanding detection by actively controlling the reactive power unbalance Q_{unb} through connection point CB, as well as to study the effect of P/f droop control of the LV network-connected DG units during over-frequency situations on the proposed scheme.



Line type	R (Ω/km)	X (Ω/km)	R/X
AHXAMK-W 240	0.15	0.11	1.36

Figure 4. Studied MV network.

Effect of reactive power unbalance Q_{unb} level

In the following, the effect of reactive power unbalance Q_{unb} level before islanding on frequency, voltage and passive islanding detection based on change in a voltage positive sequence phase angle (ΔU_{+_angle}) is presented (Fig. 5). The initial setting for ΔU_{+_angle} based passive islanding detection could be 10 degrees with 200 ms time delay and under-voltage blocking, for example. In this case (Fig. 5) there was only a synchronous generator (P_{DG2} = 1350 kW, Q_{DG2} = 275 kVAr) and induction generator (P_{DG1} = 800 kW, Q_{DG1} = -132 kVAr). The increase in the Q_{unb} level was performed by decreasing the reactive power output of the synchronous generator (DG 2 in Fig. 4).

From Fig. 5 it can be seen how the speed of islanding detection based on ΔU_{+_angle} decreases while the Q_{unb} level is increased (Fig. 5c). Simultaneously, when frequency (Fig. 5a) and voltage (Fig. 5b) values remain within the grid code FRT limits [5], the passive islanding detection based on ΔU_{+_angle} could be performed in less than 400 ms (including time delay 200 ms) in cases D and E with Q_{unb} levels -157 kVAr and -210 kVAr, respectively. However, the main challenge in using ΔU_{+_angle} and other voltage phase angle-based islanding detection schemes for passive islanding detection is the sensitivity to mal-operation during frequency fluctuations in the utility grid. In addition, these fluctuations cannot be blocked in a similar manner as under-voltage situations.

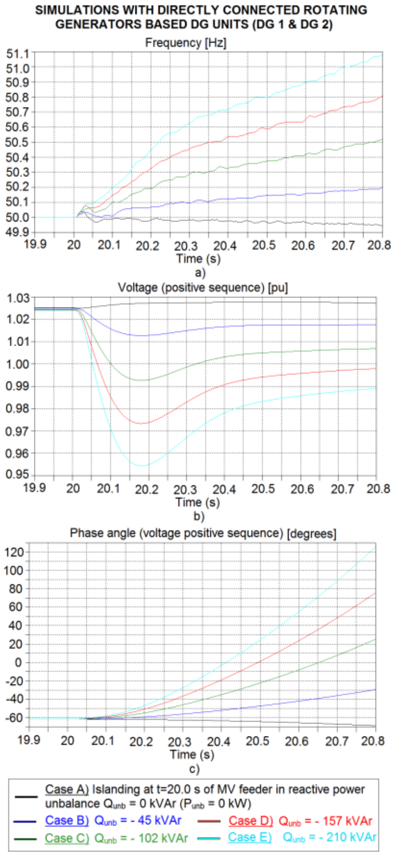


Figure 5. The effect of Q_{unb} level on a) frequency, b) positive sequence voltage U_+ and c) U_{+_angle}.

Effect of P/f -droop control of LV network-connected DG units during over-frequency

In the following, the effect of P/f -droop control of LV network-connected DG units, which will be required by grid codes like [5] from all DG units, is presented. In the simulations, the effect of P/f -droop control of LV network-connected DG units during over-frequency situations is simulated between 50.3 and 51.5 Hz by linearly increasing the LV load on some of the MV/LV transformers. It was also assumed that in the simulations the intentional time delay of the P/f -droop control of the LV network-connected DG unit is 0 seconds as also proposed in [10]. In Fig. 6 the simulation results with DG 1 and DG 2 (Fig. 4) are shown, and in Fig. 7 results with converter-connected DG units DG 3 and DG 4 (Fig. 4) are presented.

Fig. 6a shows how P/f -droop control restricts the frequency increase in both P_{unb} (Case_P2a) and Q_{unb} (Case_Q2a) situations. Over a longer (a few seconds) time scale it can be also seen that, unlike the Q_{unb} situation after islanding, in P_{unb} the frequency and voltage (Fig. 6a and 6b) may remain for many seconds in the FRT limits set by the grid codes. However, from a fast (less than 400 ms) islanding detection point of view, no significant differences exist either due to P/f -droop control or due to islanding in active (P_{unb}) or reactive (Q_{unb}) power unbalance (Fig. 6).

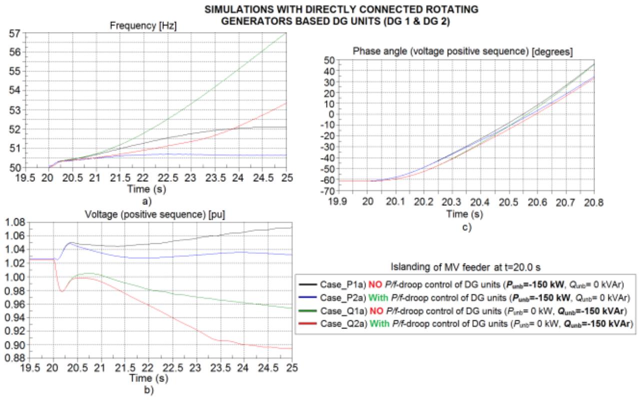


Figure 6. The effect of *P/f* -droop control of DG units during over-frequency on a) frequency, b) positive sequence voltage U_+ and c) U_{+_angle}.

From Fig. 7 we can see that with converter-connected DG units, active power unbalance P_{unb} before islanding (Case_P1a) in Fig. 7) will not necessarily lead to islanding detection based on passive islanding methods like frequency (Fig. 7a) or ROCOF. However, this is also dependent on the control scheme and dynamics of the converters. Here it should also be noted that when the simulations with DG 3 and DG 4 (Fig. 4 and 7) were done, the system had no inertia to constrain the dynamics.

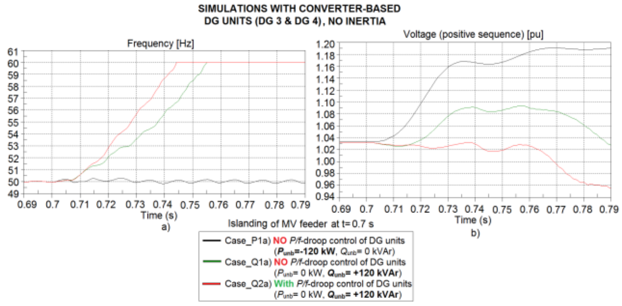


Figure 7. The effect of *P/f* -droop control of DG units during over-frequency on a) frequency and b) positive sequence voltage U_+.

Nevertheless, based on the simulation results of Fig. 7, it is recommended that the Q_{unb} (Case_Q1a and Case_Q2a) level instead of P_{unb} (Case_P1a) level is controlled to ensure reliable islanding detection with passive methods. From Fig. 7 we can also see that in Case_Q2a, *P/f* droop control of LV network-connected DG units (*P/f* droop control was not applied on DG units DG 3 and DG 4 in the simulations) did not affect negatively on the ability to detect islanding with passive methods like frequency (Fig. 7a) or ROCOF.

CONCLUSIONS

In this paper it is proposed that CANM functionalities, like voltage control or losses minimization, at the MV level could include an add-on scheme in the future, which confirms the reliable operation of the passive islanding detection method in real time and also has additional possible functionalities, like adaptive islanding detection, adaptive auto-reclosing open-time settings and the minimization of the DNO reactive power costs. The proposed scheme continuously controls the reactive power unbalance Q_{unb} so that the operation point remains constantly outside the NDZ of the used islanding detection method. In this paper, special attention was given to the passive islanding detection method, which is based on change in voltage positive sequence phase angle (ΔU_{+_angle}).

The proposed scheme has been simulated with different DG unit configurations as well as by taking the effect of recent grid code requirements into account, especially *P/f* droop control of DG units. In addition, the possibility of controlling active power unbalance P_{unb} instead of Q_{unb} was simulated. In general, the simulation results showed the Q_{unb}-based approach to be more advantageousness.

Although the operation outside the NDZ of ΔU_{+_angle}-based islanding detection method could be avoided by the proposed CANM and the Q_{unb} control-based scheme, the main challenge of ΔU_{+_angle} (and other voltage phase angle-based islanding detection schemes) for passive islanding detection still remains. It is very sensitive to mal-operation during utility grid frequency fluctuations which cannot be blocked in a similar manner as under-voltage situations. Therefore, in addition to fast communication-based islanding detection schemes, the multi-criteria based passive islanding detection method without NDZ proposed in [7] still seems to be one promising option for fast and selective islanding detection in future distribution networks.

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