FLEXZONE CONCEPT TO ENABLE RESILIENT DISTRIBUTION GRIDS – POSSIBILITIES IN SUNDOM SMART GRID

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ABSTRACT

In the future active distribution network management will be in key role to enable future resilient distribution grids. It includes for example solutions for distribution automation and control of flexible energy resources (flexibilities). Distribution grid zones with flexibilities can be seen as resilient distribution grid building-blocks. In this paper flexibilities based FlexZone concept is proposed. FlexZone concept can create basis for coordinated use of flexibilities between distribution and transmission system operators and realization of improved local and system-wide grid resiliency. In the end, also possibilities to apply FlexZone concept in Sundom Smart Grid for the development of active network management and protection applications will be presented.

INTRODUCTION

Due to increased amount of non-synchronous, inertialess, distribution grid connected renewable generation traditional, HV grid connected, large synchronous generators are shut-down and their technical/ancillary services are not available anymore. Therefore, in the future transmission system operators (TSOs) may have challenges in maintaining overall system security (frequency control) and voltage support in the high-voltage (HV) grid. Simultaneously, also due to distributed generation (DG) units, distribution system operators (DSOs) will have challenges in managing voltage levels, stability as well as congestion in distribution grids.

In the future, DSOs role might also include, for example, utilization of momentary intended island/microgrid operation by controlling flexibilities in order to continue supply e.g. in case of upstream grid disturbances. Flexibilities can consist of active (*P*) and reactive (*Q*) power control of flexible resources like controllable DG units, energy storages (ESs), controllable loads and electric vehicles (EVs) which are connected in DSOs grids. Potentially these distribution grid connected flexibilities can provide different local (DSO) and system-wide (TSO) technical/ancillary flexibility services (Fig. 1). However, potentially the use of, for example, active power flexibility for TSO purposes will have mutual impact in corresponding DSOs grid (and vice versa) and simultaneously the same flexibilities cannot be used for different TSO and DSO purposes. Therefore in the future, transparent coordination and cooperation between TSOs and DSOs becomes increasingly important. This will include, for example, data management and exchange related to grid/flexibilities data, control schemes, protection settings etc.

The local and system-wide technical flexibility services (Fig. 1) can be required by the grid codes and regulations or they can be offered by technical service / flexibility markets. In Europe, different forthcoming ENTSO-E grid codes try to ensure many aspects related to future TSO-DSO interaction and provision of technical services from DG units. In the future, also marketplace for both TSOs and DSOs will be needed like, for example, one central data hub in TSOs control area, to enable all parties with flexibility to participate into different markets (retail and local/system-wide flexibility service markets).

- Frequency control participation / Frequency support service via control of active power *P* **(System-wide service)**
- Voltage control participation / Voltage support service via control of reactive power *Q* and/or active power *P*, depending on the voltage level (MV or LV) **(Local / System-wide service)**
- Balancing power supply service **(Local / System-wide Service)**
- Islanding / Microgrid operation of part of the network **(Local Service)**
- Blackstart support service **(System-wide Service)**
- Controlled (reactive *Q*) power unbalance to enable reliable islanding detection **(Local Service)**
- Reactive Power Control in HV PCC according to grid codes **(System-wide Service)** or
- Reactive Power Control in HV PCC to minimize DSOs reactive power costs **(Local Service)**
- Availability to be used for intertripping / tranfer trip (disconnection) **(Local / System-wide Service)**
- Network losses minimization / Network loss compensation service **(Local Service)**

Figure 1. Potential applications utilizing flexibilities for local (DSO) or system-wide (TSO) technical services.

Local and system-wide grid resiliency

The control of flexibilities connected in distribution grids and increased amount of accurate/time-synchronized, real-time measurements from medium-voltage (MV) and low-voltage (LV) distribution grids will create basis for local (DSO, MV&LV grid) and system-wide (TSO, HV grid) grid resiliency improvement. Use of flexibilities and real-time measurements in active network management (ANM) functionalities will play a key role in enabling local distribution grid resiliency and technical services (like congestion management, voltage control, automatic restoration and island operation coordination/microgrid management). Simultaneously also costly network infrastructure upgrades can be avoided, network hosting capacity can be increased and supply interruptions can be minimized. Accurate real-time measurements and the utilization of fast and cost-efficient communication technologies (optical fibre, 4G/5G, broadband PLC) and standardization (IEC 61850, CIM, DDS) will enable the real-time response of the flexibilities as well as improved state-estimation. Accurate state-estimation is an important input for different ANM functionalities in distribution grids as well as for potential future big data based enhanced monitoring / predictive protection solutions.

Flexibilities connected in DSOs grid can be also used to provide system-wide technical (TSO) services and to enhance system-wide grid resiliency, for example, through frequency control support/participation, with *Q* control in DSOs connection point to HV grid and by fault-ride-through (FRT) capability of DG units and storages. Wide-area protection and control solutions, which need accurate real-time measurements from HV/MV substations, can be also used increasingly in the future to support the system-wide resiliency.

General features of flexibilities

The active power *P* related available flexibilities from ESs, loads and wind turbines and photovoltaic (PV) based

DG units are varying in time. However, converter-based flexibilities may be able to provide reactive power *Q* related services even when active power *P* production/consumption is zero. In general, ESs will have very important role to enable different local and system-wide flexibility services (Fig. 1). For example battery energy storage (BES) at MV/LV substation could provide multiple local flexibility services (e.g. voltage control and congestion management by *P* and *Q* control, compensation of *Q* produced by MV cables, enabling LV microgrid operation) as well as frequency control related system-wide services (under-/over-frequency based active power *P* control). Also prioritized (multiple stages with different operation time delays) active power *P* related load control / demand response (DR) by relays/smart meters will have an important role in normal situation and especially in emergency situations regarding frequency control participation and intentional islanding/microgrid operation (under-frequency based load shedding) as part of system-wide/local flexibility services.
In general, existing and forthcoming DG unit grid code FRT requirements have been made mainly from HV grid (TSO) stability point of view and less attention has been paid on potential conflicts with recent islanding detection and protection schemes used in DSOs grids. For example, operation time delays of different active power/frequency (*P/f*) and reactive power/voltage (*Q/U*) -control related flexibility services provided by flexibilities needs to be selective with islanding detection settings. Also status of certain DG unit with LVRT & HVRT requirement and island operation capability may have an effect on protection settings in DSOs grid. In addition, there is a clear need to define measured frequency in a standardized, fast and accurate way by all different flexibilities to be able to achieve desired response and to avoid unwanted effects on local/system-wide stability.

FLEXZONE CONCEPT

In the future distribution grid zones with flexibilities i.e. FlexZones could be seen as building-blocks of resilient distribution grid. FlexZone could be also called as an active cell, zone with DER (distributed energy resources) or local energy community. Also, for example, one utility grid connected MV or LV microgrid could create one FlexZone (Fig. 2). FlexZone approach could also create basis to implement new business and market models for flexibilities (flexibility service markets). As illustrated in Fig. 2 there can be different level of FlexZones and higher level FlexZone can consist of multiple lower level FlexZones.
The flexibilities (other than on-load-tap-changers, OLTCs) could be seen mainly as controllable *P* and *Q* of the DER units in that particular FlexZone. In order to calculate available controllable *P* & *Q* of one particular DER unit, the nominal *P* & *Q*, operational characteristics (*Q* capability and dependence on *P* value) and circuit-breaker (CB) status of that DER unit must be also known. Real-time information about available flexibilities and flexibility forecasts of different FlexZones (e.g. for FlexZone 1 in Fig. 2 data about $P_{Flex\_Z1\_DG}$, $P_{Flex\_Z1\_ES}$, $P_{Flex\_Z1\_load}$, $Q_{Flex\_Z1\_DG}$, $Q_{Flex\_Z1\_ES}$, $Q_{Flex\_Z1\_load}$ is needed), forecasted DSO flexibility needs and information sharing between DSOs, TSOs and aggregators becomes essential. All flexible resources at different FlexZone levels may not be available for every possible local (DSO) or system-wide (TSO) flexibility service (Fig. 1). In order to avoid possible conflict of interest between different schemes and DSO/TSO needs cooperation and transparency in flexibilities/services prioritization as well as further studies and demonstrations will be needed.

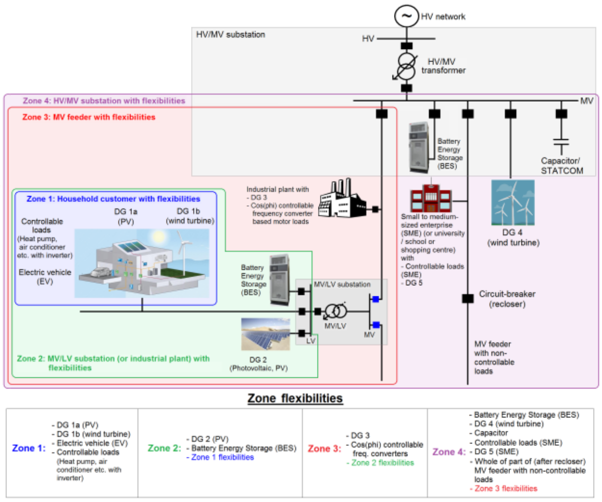

Figure 2. Different level of FlexZones with possible flexibilities.

Functionalities which potentially could utilize these available flexibilities to technical services (Fig. 1) also need status of other CBs and OLTCs and accurate measurement data (voltages, currents, temperatures) from the network for state estimation and topology verification purposes as well as for detection of possible limit (voltage, thermal) violations.

Functionalities of FlexZone Units (FZUs)

In the future different local (DSO) ANM functionalities could be realized by (de)centralized, hierarchical and coordinated management solutions at HV/MV, MV/LV substations with management units called FlexZone units (FZUs).
These HV/MV and MV/LV FZUs could be all-in-one solutions for realizing better local grid resiliency. FZUs could include, in addition to different ANM functionalities, also other 'centralized' functionalities like protection/fault indication & fault location, islanding detection & logic, status monitoring, predictive protection, available flexibilities, flexibility forecasts and historian from flexibilities control/use (Fig. 3). MV/LV FZU would be responsible for FlexZone 2 (Fig. 2) functionalities and HV/MV FZU for FlexZone 4 and 3 (Fig. 2) functionalities. Naturally, the needed logics and details of different protection and ANM functionalities at different levels (at HV/MV and MV/LV FZUs) would need to be a bit different. However, coordinated operation and interoperability of FZUs in different levels needs to be ensured in all situations.
In the future, one alternative could be that some of the less critical / high-speed communication dependent DSO FZU functionalities (Fig. 3) like, for example, monitoring or

predictive protection related big data solutions, flexibility forecasts, some ANM schemes etc. would be alternatively located in cloud servers. This approach could enable more flexible and scalable solutions when only most communication and time-critical protection and islanding detection applications would remain at actual HV/MV or MV/LV FZUs. In order to realize these different FZU functionalities (Fig. 3), service business focused approach could be also increasingly interesting for the DSOs in the future instead of the traditional product focused approach.

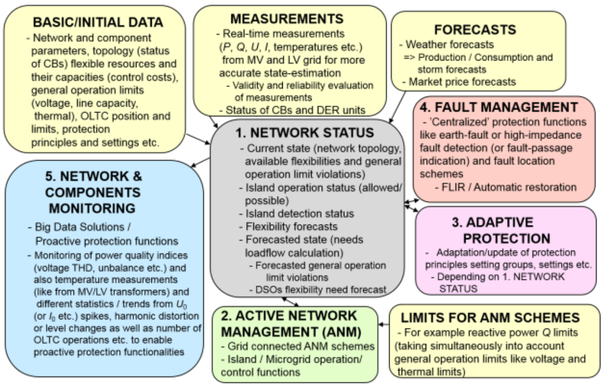

Figure 3. Possible main protection and control functionalities of HV/MV and MV/LV FlexZone units.

Communication – Reliable and standard based

Communication reliability and cyber security will play more and more important role in the future grid protection and management solutions and, for example, potential short data packet loss should not cause false operation of FZU functionalities (Fig. 3). In possible cloud server based applications role of redundant back-up schemes, like hot-standby or hot-hot schemes, becomes also significant. In Europe the Working Group of European mandate M/490 has provided an universal Smart Grid Architecture Model (SGAM) that shows the different layers of interoperability. SGAM can be also used to develop the requirements and information models for the data exchange between the different flexibilities and DSOs and provides potential framework for the interoperability between different parties. The IEC 61850 and the common information model (CIM) based standards are seen as the primary sets of standards. Also relationship between these standards is described in the new IEC reference architecture.

DER unit interconnection relay/IED or inverter will have an important role in enabling flexibilities participation to different local (DSO) ANM schemes and microgrid/island operation management. One key standard related to DG unit control is IEC 61850-7-420 which also covers microgrids to some extent. Most recent edition of IEC 61850-7-420:2015 will include a generic DER interface model as well as a system view. The system view will include information about the nominal available active and reactive power, the currently available active and reactive power as well as set points or other control mechanisms. By using this kind of system view, it is possible to enable the participation of clusters with many DER units in a standardized way into local DSOs ANM schemes. Also IEC 61850-90-7:2012 models are expected to be included in the latest edition of IEC 61850-7-420:2015 and, for example, in [1] it has been shown how the DER capabilities could be described based on these standards. Regarding system level information exchange as well as retail and technical flexibility market based data exchange, CIM based standards (like 61970/61968, 62746, 62325) are expected to play major role.

Proposed FlexZone concept, FZUs and their functionalities as well as interoperability of FZUs with other DSO systems like DMS/SCADA in network control center (NCC) should be also based on SGAM / IEC reference information exchange architecture and on above described recent, future-proof standards like IEC 61850 and CIM.

SUNDOM SMART GRID

Sundom Smart Grid, SSG, in Vaasa (Finland) is a smart grid pilot of ABB Oy, Vaasan Sähkö (local DSO), Anvia (telecommunication/IT company) and University of Vaasa. SSG pilot has been funded by TEKES Innovative Cities program.

Present status

Presently in SSG, (Fig. 4) new grid automation solutions have been installed to enable more accurate earth-fault detection and localization in compensated mixed (overhead, OH-line & cable) distribution grids in order to increase electricity supply reliability. In addition, IEEE 1588 time-synchronized, IEC 61850-9-2 sampled value (SV) based, measurement data from multiple points is collected and stored in servers (Fig. 4) to enable research and development of future FZU functionalities (Fig. 3).

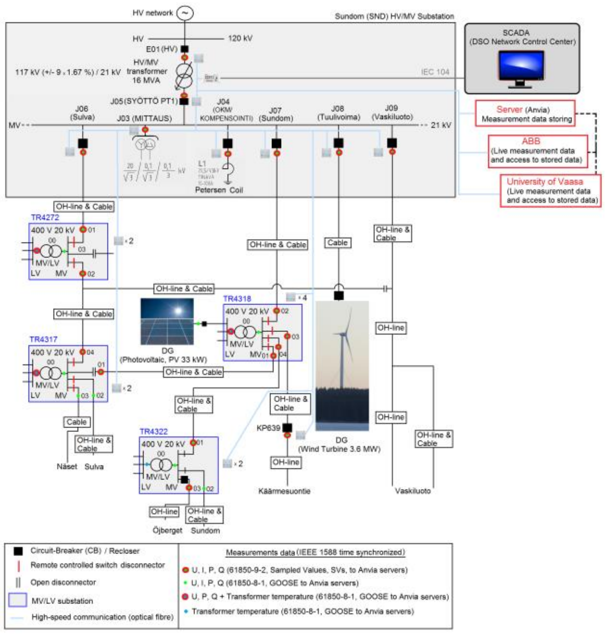

Figure 4. Sundom Smart Grid single line diagram (SLD) and data measurement points.

In [2] more detailed description about SSG communication solutions and in [3] information about installed and tested new earth-fault detection (fault passage indication, FPI) solutions at MV/LV substations can be found.

From the FlexZone concept point of view and due to small amount of flexible resources in LV network (only one PV unit at MV/LV substation TR4318 in Fig. 4) at the moment, SSG could be initially seen as a single Zone i.e. Zone 4 (Fig. 2). In the next stage, as part of 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), accurate real-time measurement data of SSG pilot will be used to improved network state estimation as an input for the development of new, future-proof and grid code compatible ANM, islanding detection and distribution network protection schemes (Fig. 3). Special focus in the DeCAS project, in cooperation with University of Vaasa, will be on R&D of

1) Different new passive [4] or centralized/decentralized combined [5] islanding detection schemes (transfer trip with high-speed communication based on status change of CB(s) + measured time-synchronized parameters) and
2) Local (DSO) ANM scheme for HV/MV FZU which can fulfill multiple Zone 4 targets [6], [7] simultaneously during grid connected operation (Fig. 5) as well as study
3) Possible future retail and technical flexibility (ancillary) service market structures in Europe especially related to proposed ANM scheme (Fig. 5) and considering coupling/potential challenges between local (DSO) needs and system-wide (TSO) needs as well as taking into account ENTSO-E recommendations, new and forthcoming grid codes etc.

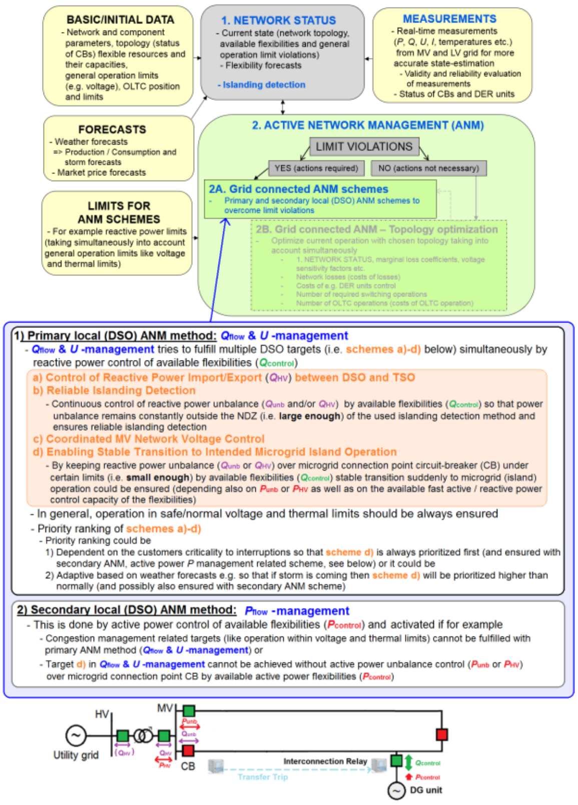

Figure 5. Future-proof, grid code compatible ANM scheme for HV/MV FZU which can fulfill multiple Zone 4 targets simultaneously.

In addition, coupling and potential mutual effects 1) between ANM schemes / targets of different level of FlexZones (e.g. Zone 2 and 4) and 2) between local (DSO) and system-wide (TSO) flexibility service schemes will be studied. Studies are expected to show, for example, a) what is the effect of Zone 2 ANM methods on Zone 4 ANM methods and vice versa, b) what is the effect of local (DSO) Zone 4 ANM methods (i.e. Q_{flow} & U and P_{flow} -management, Fig. 5) on available system-wide (TSO) flexibilities/flexibility forecasts (from that particular DSO network) and c) how possible system-wide (TSO) flexibility services like P/f -control may affect on local (DSO) level for example on congestion management (voltage and thermal limits) and on available local (DSO) flexibilities for primary and secondary local ANM schemes. Different scenarios related to above issues will be studied by simulations with larger amount of different available flexibilities connected in MV and LV network than today (Fig. 4).

Future possibilities

In addition to simulations versatile investments in different new flexibilities and future technologies (Fig. 6) in forthcoming projects would support the development and real-life testing of simultaneous behavior / interoperability / mutual interaction of flexibilities, communication solutions, FZU functionalities and future technology concepts. New FZU functionalities (Fig. 3) could be, for example, first verified with real-time simulator in the forthcoming Smart Grid Lab at University of Vaasa and then piloted in the SSG.

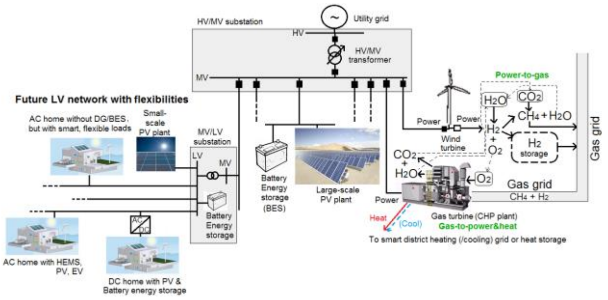

Figure 6. Sundom Smart Grid vision with different type of flexibilities.

REFERENCES

[1] P. Tumino, C. Tschendel, G. Bianco and G. Di Lembo, 2014, "IEC 61850 profile for the energy regulation interface – A proposal of communication between the distributor system operator and the full controllable plant", *CIRED Workshop 2014*, Rome, Italy

[2] A. Monot, J. Valtari, M. Wahler, 2016, "Real-time Research Lab In The Sundom Smart Grid Pilot", *CIRED 2016*, Helsinki, Finland

[3] J. Altonen, A. Wahlroos, 2016, "Performance of modern fault passage indicator concept in compensated MV-networks", *CIRED 2016 Workshop*, Helsinki, Finland

[4] H. Laaksonen, 2014, "Enhanced Multi-Criteria-Based Passive Islanding Detection Scheme", *IREE journal*, vol. 9, 1162-1170.

[5] H. Laaksonen, 2016, "Grid code compatible islanding detection schemes using traditional passive methods", *DPSP 2016*, Edinburgh, Scotland, UK

[6] H. Laaksonen, 2014, "Reliable Islanding Detection with Active MV Network Management", *CIRED 2014 Workshop*, Rome, Italy

[7] H. Laaksonen, 2014, "Securing Passive Islanding Detection and Enabling Stable Islanding with Q/f -droop Control of DG Unit", *IREE journal*, vol. 9, 592-602.