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Theme 1: Integrating New Flexibility Tools and Principles for Planning

Flexible control and management methods for future distribution networks

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Abstract: The realisation of future flexibility services for distribution and transmission system operators (DSOs and TSOs), e.g. through different flexibility market platforms, requires new compatible control principles for flexibilities as well as flexible and adaptive distribution network management methods which will act as enablers of the evolution. This study first briefly describes the potential three-stage evolution path towards fully flexible and digitalised electricity distribution networks. In addition, the proposed study presents flexible and adaptive management schemes for distribution network connected flexibilities improved utilisation for local and system-wide services. The target of these new adaptive control and management methods is to maximise also the availability of all low voltage network connected flexibilities for different DSO and TSO needs during the evolution.

1 Introduction

In the future, active (*P*) and reactive powers (*Q*) control potential of distribution network medium and low voltage (MV and LV) connected flexible energy resources needs to be utilised increasingly to the provision of different local and system-wide flexibility services for distribution and transmission system operators (DSOs and TSOs). These flexible energy resources, i.e. flexibilities can consist of distributed generation, energy storages (ESs), demand response or electric vehicles (EVs). Flexibility services for DSOs and TSOs can be related, for example, to (i) frequency control and balancing, (ii) congestion management, (iii) voltage control, (iv) security of supply/islanded operation, (v) reactive power flow control between voltage levels or (vi) network losses minimisation. In addition, different options are also possible for the realisation of the flexibility services like (i) technical, (ii) tariff, (iii) market, (iv) connection agreement or (v) rule code-based solutions [1–5].

Increased cooperation between DSOs and TSOs will be increasingly important in order to maximise the whole system benefits of flexibilities utilisation and future flexibility markets must enable the highest collaborative value of the flexibilities. However, today participation of these distribution network-connected resources may be restricted due to local network limitations. Therefore, flexibilities participation in the provision of flexibility services must be enabled by new management schemes, regulation, market structures and business models as well as distribution and transmission network operation and planning principles, which are based on active utilisation of flexibilities [1–5].

The realisation of future flexibility services for DSOs and TSO, e.g. through future flexibility platforms, requires new compatible control principles for flexibilities as well as flexible and adaptive distribution network management methods. At first, this paper briefly describes the potential three-stage evolution path towards fully flexible and digitalised electricity distribution networks. During the evolution different kind of LV network connected customer flexibilities large-scale utilisation enabling new management and market schemes are needed and each evolution stage is affected by the level of development regarding different issues (Section 2) [1–5].

After that, the paper presents flexible and adaptive management schemes for distribution network connected flexibilities improved utilisation for local and system-wide services. The target of these new adaptive control and management methods is to maximise also the availability of all LV network connected flexibilities for different DSO and TSO needs. The proposed new voltage, frequency and time (month, season) dependent *P* and *Q* management methods consist of compatible adaptive

- reactive power/voltage (*QU*) droop, active power/frequency (*Pf*) droop and active power/voltage (*PU*) droop on flexibilities (like PVs and battery ESs),
- EVs charging principles,
- on-load-tap-changer (OLTC) control principles,
- Reactive power window (RPW) limits (i.e. reactive power flow between DSO and TSO networks) and
- Customer connection point power factor cos(φ) control principles.

2 Evolution towards future flexible electricity distribution networks

Achievement of future visions [4] and evolution to flexible and fully digitalised electricity distribution system (Fig. 1) can be roughly divided into three stages (Table 1). During the evolution of different kinds of LV network connected customer flexibilities large-scale utilisation enabling new management and market schemes are needed. New technical adaptive management schemes can increase the availability of flexibilities for local and system-wide flexibility services and new market schemes are needed for the utilisation of flexibility services from DER.

The new management and market structures (incl. flexibility markets for LV network connected small-scale customers/prosumers) have to be compatible in all evolution stages and act as an enabler of the evolution in addition to needed new regulation development as well as flexibilities utilisation based operation and planning principles. Complexity with different needs increases during the evolution and future digitalised protection/control/management devices must support that needed flexibility (e.g. by software updates) and simultaneously also the role of cybersecurity increases substantially. Evolution stages can be seen as dependent on different issues and level of their existence/deployment (Table 1).

3 Future adaptive control and management methods

Future adaptive management methods and compatible flexibility market structures must enable the highest collaborative value of

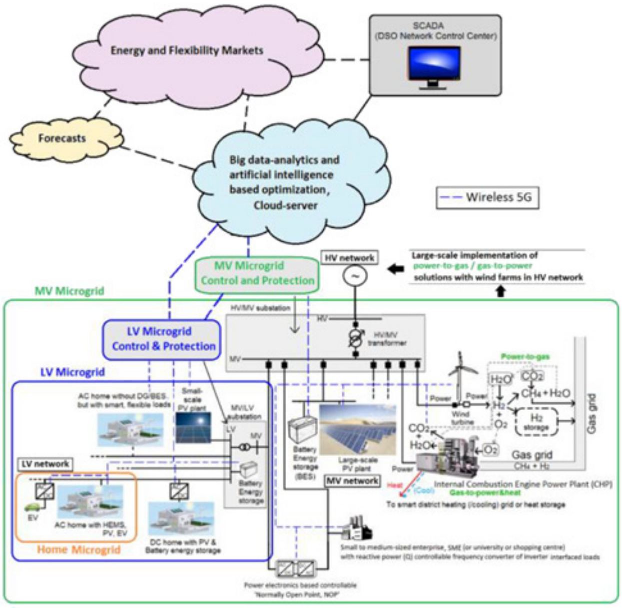

Fig. 1 *Future flexible and digitalised distribution networks*

Table 1 Potential three-stage evolution path towards fully flexible and digitalised electricity distribution networks

Development stage/level of	Stage 1 (today/ short term)	Stage 2 (short-/ mid-term)	Stage 3 (mid-/ long-term)
(i) controllable flexibilities	–/**+**	++/**+++**	**+++**
(ii) accurate monitoring of distribution network	–	**+**	++
(iii) TSO/(iv) DSO flexibility needs	**+**/–	++/**+**	**+++**/++
(v) required DSO–TSO coordination	–	**+**	++
(vi) coupling between different energy sectors	–	**+**	++
(vii) new market and management schemes	–/**+**	++	**+++**
(viii) regulation development related to flexibilities utilisation	–	++	**+++**
(ix) advanced ICT-based protection and control solutions	–	**+**	++
(x) resiliency	**+**	++	**+++**

–, very low/low; **+**, small/medium, ++, medium/high, **+++**, high/very high.

the flexibilities. In this regard, the location of flexibilities is highly relevant and it affects, for example, in most feasible use cases and potential restrictions in the utilisation of DSO network connected flexibilities. For example in the work of Laaksonen *et al.* [5], (1) utilisation of DSO network connected reactive power control resources located close to high-voltage (HV)/MV substation to support HV network (TSO) reactive power needs could be more feasible than utilisation of reactive power resources located far away from HV network connection point i.e. deep in MV or LV network and (ii) utilisation of reactive power resources deep in MV or LV (DSO) network in providing local technical services i.e. voltage control through their reactive power control is more feasible than their utilisation to provide services for HV network (TSO) needs. Therefore, forecasted and real-time knowledge about local need and availability of flexibilities (active P and reactive Q power) at each voltage/zone level [2] is one key input for active utilisation of flexibilities in the operation and planning of future DSO and TSO networks.

In the following, the flexible and adaptive technical management solutions for distribution network connected flexibilities improved utilisation for local and system-wide services are proposed (Fig. 2). The target of these new adaptive control and management methods is to maximise the availability of all LV network

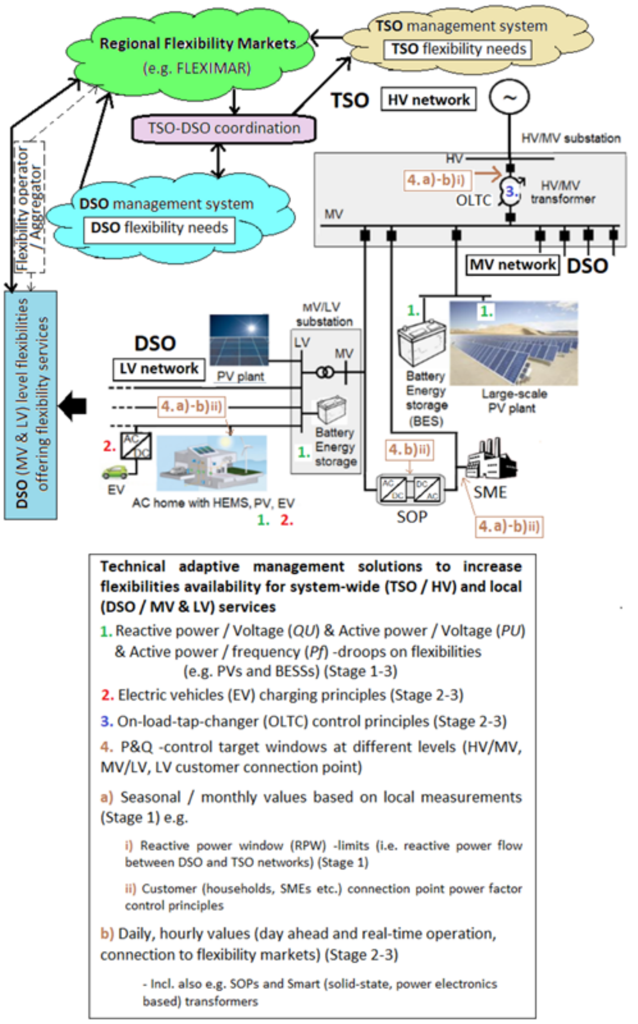

Fig. 2 *Technical adaptive management solutions to increase flexibilities availability for flexible services in the future (see Table 1)*

connected flexibilities for different DSO and TSO needs during the evolution (Table 1). These proposed adaptive technical management solutions can be seen as 'flexibility services' and they should be also compensated by TSOs and DSOs in the future.

The main principles and settings proposed in Fig. 2 are today/in Stage 1 (Table 1) decentralised/local and could be in near future used without or with minimum communication. However, in the future/Stages 2–3 (Table 1) increased use of real-time measurements from MV and LV network with some centralised active network management (ANM) functions and active participation in different markets and marketplaces will require also increased utilisation of reliable, cost-efficient, low-latency communication. In the future, when more real-time measurements will become available for accurate state estimation and related ANM functions, also the setting values of OLTCs and DER unit local *QU*- and *PU*-droops could be more frequently adapted. This means that short (time of day) forecasts and locational aspects would be increasingly considered with some centralised multi-objective ANM functionality. Adaptive and flexible *QU*-, *PU*- and *Pf*-droop functions could enable local operation optimisation at the DSO level by updating the dead-zone values and activation limits of droop functions in a (i) seasonal/monthly/weekly/daily manner (Stagees 1–2) and (ii) more real-time manner (Stages 2–3).

3.1 *Adaptive* QU, Pf *and* PU *droops*

3.1.1 Adaptive QU-droops: In order to, for example, avoid larger reactive power consumption of PV units in Stage 1 (Fig. 2)

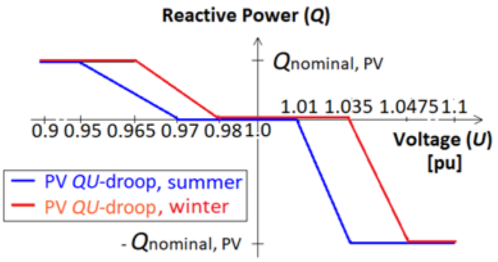

Fig. 3 *Seasonal adaptive QU-droops (Stage 1, Fig. 2 and Table 1)*

during very high-load situations, less sensitive seasonal *QU*-droops could be used with PVs during the wintertime and more sensitive droops during low-loads/summer-time (Fig. 3). More sensitive *QU*-droops of PVs' during summertime mean that they have smaller dead zones in order to also compensate for more reactive power produced by MV cables during very low loads.

In addition, *QU*-droop seasonal settings should also be dependent on the location of the DER unit in the DSO network, i.e. dependent on the (electrical) distance of DER unit from HV/MV substation with OLTC (or from MV/LV substation if there is also OLTC-based voltage-level control).

3.1.2 Adaptive Pf *droops:* Also, *Pf* droops of DER units should have adaptive seasonal settings in order to enable participation of DER (e.g. PV) on frequency control. The *Pf* droop with a smaller dead zone could be used on PVs during summertime when there is typically less inertia in the power system. However, it was found out in the work of Laaksonen *et al.* [5] that *Pf*- and *PU*-droop control mutual effects during over-frequency support participation might need additional logic (*PU* blocking) in the control system. Otherwise, active power curtailed PV (PV 2) cannot participate in frequency control effectively.

3.1.3 Frequency adaptive PU-droops: For example, if a large PV unit with BESS is connected in weak LV network and (electrical) distance to MV/LV substation is long then BESS participation to frequency control can be limited during under-frequency events or simultaneous unwanted PV active power curtailment may be required in order to maintain voltages between allowed limits at the connection point, e.g. between 0.95 and 1.05 pu. However, this is not feasible from the whole system perspective if the frequency deviation is large. Therefore, 'frequency adaptive *PU* droops' with PVs and BESSs could be utilised when, e.g. the following conditions prevail:

(i) Frequency is ≥±0.2–0.5 Hz and
(ii) Voltage is between over-voltage limits 1.05–1.15 pu or under-voltage limits 0.85–0.95 pu.

These 'frequency adaptive *PU*-droops' could also simultaneously enable larger demand response based load disconnection participation in frequency control near PV and BESS connection point if a momentary violation of voltage limits locally is not considered too critical during severe frequency deviations.

3.2 Adaptive EV charging

Traditional (Stage 1) adaptive EV charging is typically local current measurement based adaptation at LV network connection point, i.e. charging current is restricted in order to prevent violation of customer connection point maximum allowed current limit. However, this approach does not consider the real-time state of the network, e.g. regarding allowed voltage limits. Therefore, it may unnecessarily also limit the participation possibility of EVs to the provision of flexibility services, e.g. through flexibility markets. In the near future (Stage 2, Table 1), more advanced adaptive EV charging methods which take also into account local voltage level and EV state-of-charge level could be applied.

3.3 Adaptive OLTC control

Adaptive seasonal (summer and winter) OLTC setting values could be utilised in Stage 1 (Table 1, Fig. 2) to (i) avoid voltage limit violations in the distribution network (MV and LV) due to DER (PV and demand response) participation on frequency control, (ii) reduce the need for MV and LV network voltage control during the normal operation and (iii) enable maximum PV hosting capacity in distribution networks [5, 6].

OLTC setting during very high-load (winter season) could be for example 20.3 kV and during very-low load (summer season) 20.0 kV with dead-zone ±0.3 kV in both cases. In addition to PV hosting capacity increase, the *Q* produced by MV cables is dependent on voltage and therefore lower OLTC setting is more suitable during summertime. It is worth noticing that if the OLTC set-value is changed, then also *QU*-droop settings of DER units should be adapted (Section 3.1). More developed adaptive OLTC control schemes could be further applied in Stages 2–3 (Table 1, Fig. 2).

3.4 Adaptive P and Q -control window

In order to improve the coordinated provision of flexibility services by flexible active and reactive power resources located at different voltage levels, different type of *P* and *Q* – control target windows at different levels/connection points (HV/MV, MV/LV, LV customer connection point) – could be applied in the future in different Stages 1–3 (Table 1, Fig. 2).

3.4.1 Seasonal/monthly values (stage 1): In this Stage 1, adaptive (i) RPW limits could be applied between HV (TSO) and MV (DSO) networks so that seasonal flexibility needs of TSO networks and DSO networks are considered and (ii) customer connection point (household, SME, school etc.; Fig. 2) power factor cos(φ) settings, e.g. cos(φ) = 1 (winter) and cos(φ) = 0.95_{ind} (summer) could be applied at customer connection points.

3.4.2 Daily/hourly values (stages 2–3): In the next Stages 2–3 more specific, daily and hourly *P*- and *Q*-control target windows for different connection points (HV/MV, MV/LV, customer connection point, power-electronic based normally open points, i.e. soft-open points including also potential smart power electronic transformers at HV/MV or MV/LV substations, Fig. 2). These could enable more optimised real-time operation of the TSO and DSO networks by utilising flexible services from different type and size of resources through flexible markets and consideration of potential DSO network constraints, for example, related to voltage limits.

4 Conclusions

In this paper, the potential three-stage evolution path towards fully flexible and digitalised electricity distribution networks was presented. The paper also proposed different flexible and adaptive management schemes for distribution network connected flexibilities so that the availability of all LV network connected flexibilities for different DSO and TSO needs during the evolution could be maximised.

5 Acknowledgments

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