24th International Conference & Exhibition on Electricity Distribution (CIRED)

12-15 June 2017

Session 5: Planning of power distribution systems

Control and automation functions at the TSO and DSO interface – impact on network planning

ISSN 2515-0855
doi: 10.1049/oap-cired.2017.0975
www.ietdl.org

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Abstract: This paper presents the activities of the CIGRE/CIRED C6.25/B5 joint working group (JWG), focusing on the control and automation systems for the future electric networks. This JWG is mainly focused to evaluate the level of automation and control necessary to better manage distribution networks with large penetrations of distributed energy resources, as seen from both the TSO and DSO perspectives.

1 Introduction

The electric power system is undergoing a rapid transformation towards both centralised and decentralised generation and controls – with a significant amount of all newly interconnected resources being integrated at the distribution network level. Most of these distributed resources are difficult to predict, observe and control [1]. Nonetheless, these distributed resources could provide system services when coordinated and managed in an intelligent manner. Furthermore, demand response resources – such as electric vehicles, heat pumps and distribution connected energy storage – could provide significant benefits in terms of system flexibility.

Closer interaction between transmission system operators (TSOs) and distribution system operators (DSOs) is essential to realise the optimal and reliable utilisation of distributed resources as well as secured and economic operation of the overall power system. This requires improved observability and controllability of the distribution grids through the establishment of automation and communication services between TSO and DSO. It is also important that the DSOs implement new communication and control solutions with the prosumers/flexible consumers as well as with the market players to carry out flexibility and congestion management and to deliver ancillary services to the grid [2]. Additionally, the communications and data exchange will need to support and facilitate the necessary network planning functions. The joint working group (JWG) worked on providing an evaluation of the changing (a) operational, (b) market and (c) planning functions related to the TSO and DSO interface.

2 TSO/DSO functions

In the following, the most common functions at the interface between TSO and DSO connection are described with particular reference to the results of the survey performed by JWG C6.25/B5 [3]. Functions are grouped into three clusters that represent typical activities that involve TSO and DSO at the interface between the two relevant systems.

2.1 Operational functions

2.1.1 Short-term forecasting: Forecasting of distributed generation and consumption is expected to enhance distribution network operation significantly [4, 5]. Forecasting tools using information gathered from advanced metering and monitoring interfaces (wind speed, temperature etc.) will be used to predict network conditions, power flows and resource availability, thereby providing close to real-time information concerning the state of the grid and resources. The TSO needs aggregated short-term forecasts of active and reactive power at well-defined interfaces for congestion management, maintenance management and look-ahead optimal power flow, particularly with high shares of RES spread in the distribution system. Reserve management and generator redispatch can be improved by the exchange of information at the TSO/DSO interface. Additionally, information on new and planned DG connections, if not already known by the TSO, may be valuable. In certain areas of activities, such as planned outages, major network expansion and reconfiguration, a mutual exchange of relevant forecast schedules between TSO and DSO is recommended.

2.1.2 Network state observability: Real-time information on load and generation in the distribution system may also be used by the TSO as input for computing the system voltage stability margin and for strategically smoothing frequency transients [6]. Conventionally, the stability margin is determined by TSOs from available supervisory control and data acquisition (SCADA)/ energy management system (EMS) data. However, additional and more precise information from DSOs can improve the accuracy of calculation [7–9]. Increasingly, stability margin estimation is based on PMU measurements [10]. In the rare cases where DSOs have phasor measurement unit (PMUs) (e.g. in the context of system protection), sharing this data with the TSO may be particularly valuable.

2.1.3 Load shedding: In critical system states, the DSO must implement generation or load shedding as requested by the TSO. Reducing implementation times of such emergency active power management and increasing the related degree of automation is crucial for future power systems, especially for those with high degrees of distribution-level generation [11].

2.2 Market services

2.2.1 Reactive power ancillary services: Voltage and reactive power control becomes more complex with increasing penetration of distributed energy resources. As it is a local problem, voltage has to be managed by the DSOs within the control area such that it will not create imbalances in the neighbouring distribution and the upper transmission grids. The TSO should be restrained from directly controlling the local units as this could lead to further grid constraints that can impact the system as a whole [12]. Apart from the dedicated reactive power supply units of the TSOs, the strategy to measure the available capacity of reactive power in the distribution grid and the ratio of the active and reactive power at the TSO–DSO interfacing nodes could be agreed between the two parties in order to support the secure operation of the power system with voltage control reserves [13]. The TSO can utilise the reactive power reserves in the distribution grids by sending appropriate set-points of voltage, power factor or reactive power schedule to the probable interconnection points of the TSO–DSO. The DSOs can apply TSO's voltage control requirements/set-points by suitably managing and controlling the tap settings of transformers and voltage regulators, the flow of reactive power in the distribution grids, and also the reactive power injection for DER. In future also, converter-based active loads might have possibilities for reactive power control.

2.2.2 Demand flexibility: In general, the assessment of flexibility needs allows the TSOs and DSOs to enter into contractual agreements with power production units/prosumers to exploit the reserves and demand-side participation from generation and consumption units, respectively, to relieve grid congestion and to estimate system reserve [14]. This in turn allows both TSOs and DSOs to schedule operational set-points of grid assets, perform effective network reconfigurations for reducing energy losses, relieving power congestions and improve continuity.

2.2.3 Ancillary (replacement) reserves: TSO and DSO will need to find ways to facilitate participation of DER and third parties (e.g. aggregators) within the framework of the market structure. In particular, the ability to activate DER participation in the reserve market strongly depends on the market schema and rules implemented in different countries and the role of the DSO (active or only 'informed'). Different possible schema of interactions among DER and DSO are reported in the next section in accordance to market framework (Figs. 1 and 2).

2.3 Network planning aspects

As is the case with operational function, short-term forecasts of active and reactive power at well-defined interfaces may be helpful to the TSO. Combining forecasting data with short- and long-term prognosis tools, along with relevant information from the TSO, will provide DSOs the ability to more effectively plan the system operations in order to minimise losses, mitigate voltage issues, and coordinate maintenance. Furthermore, this capability will enable DSOs to more effectively optimise their network operations, utilise flexibilities from grid assets and relieve network congestions [15].

Impacts of DER on long-term planning of HV networks are examined in the recent Cigre technical brochure C1.29 on 'Planning Criteria for Future Transmission Network in the Presence of a Greater Variability of Power Exchange with Distribution Systems' [16].

In general, recommended areas of DSO/TSO coordination for medium- to long-term planning are distance protection coordination, network expansion and management of short-circuit levels, and reactive power planning. Reactive power planning solutions, in particular, may in turn be affected by operational TSO/DSO agreements. The key potential in TSO/DSO interaction is to achieve improved levels of overall cost–benefit. Regulations as found in [13, 17] support this process.

3 Advanced distribution automation for enabling/improving emerging TSO/DSO functionalities

The level of benefit that advanced distribution automation (ADA) are expected to provide operational, planning and market functions are summarised in Fig. 1. As shown, short-term forecasting of demand and generation is expected to be the most beneficial to all TSO/DSO functions. Improved situational awareness through the application of advanced monitoring (AMI etc.) and state estimation at the distribution level will improve the overall system observability. However, the main benefit to the TSO/DSO interface will be through more accurate short-term forecasts of net active and reactive power at defined interfaces. Topology recognition, through SCADA systems and advanced distribution management systems (ADMS), can be used to improve distribution state estimations as well as provide information on the connected DER during normal conditions and during reconfigured system states. Additionally, the resulting enhanced system observability can enable flexibility in real-time operation of the active network management.

The ability to schedule and/or dispatch DG active power production and demand participation is necessary to enable the majority of the operational and market functionalities. It is also expected to have an indirect relationship with operational planning. Dispatching the reactive capabilities of DER may enhance the DSOs ability to provide reactive power reserves to the TSO. However, this potential is highly dependent upon the specific distribution network and system constraints as well as resource capabilities. Volt/var optimisation (VVO) is already used

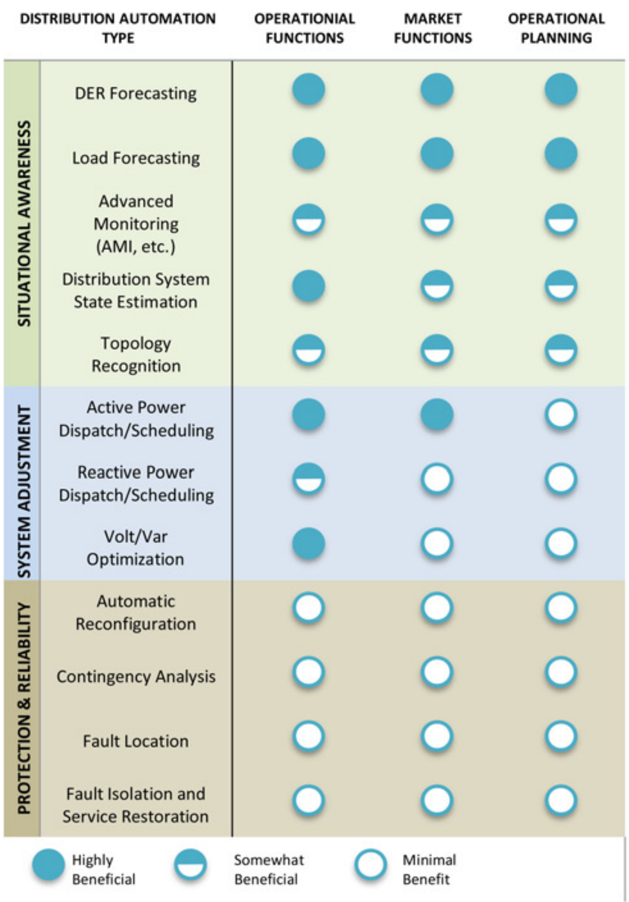

Fig. 1 *ADA for emerging TSO/DSO functionalities*

in many distribution networks to reduce consumption during emergencies or peak demand periods. It can also support the operational functions at the TSO/DSO interface.

Many ADA applications – such as contingency analysis and fault location, isolation and service restoration (FLISR) – will improve overall system reliability, but are expected to have an indirect or minor influence on the TSO/DSO functionalities. Automatic reconfiguration of distribution networks to optimise system performance and losses is also expected to have a minor influence on the TSO/DSO functionalities and can be easily accounted for within system forecasts.

4 Classification of possible schemes for access to DER in DSO system

The higher the DER penetration, the more important the involvement of distribution level DER in providing manual and in the future increasingly also automatic frequency restoration reserve. A variety of schemes are possible for ensuring suitable information flows between all relevant actors (Figs. 2–5). Physical flow of information (sending of set-points) must be distinguished from contractual and informative enablers. Grey arrows refer to possible flows of information related to dispatching DER. Coloured arrows indicate a direct control and monitoring connection; lightly coloured arrows mean connections only utilised in the event of an emergency, e.g. for congestion management.

In Fig. 2 scheme, the TSO has a direct communication connection to significant DER in the DSO system [18]. A typical sizing limit is 5 MW (Ireland, US, Italy). If large amounts of distribution-level DER are to be managed, dedicated renewable control centres may be an option (Fig. 3).

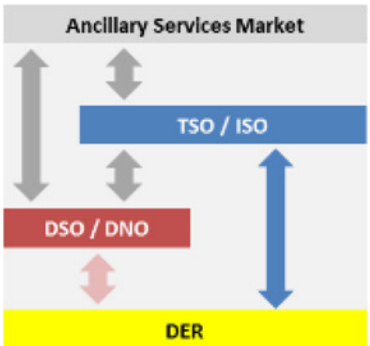

Fig. 2 *Scheme for physical access to DER in DSO systems with direct communication between TSO and DER*

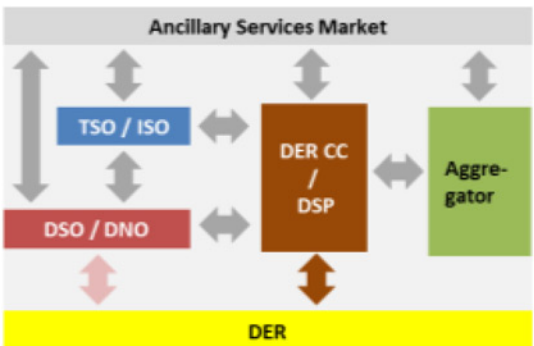

Fig. 3 *Scheme for physical access to DER in DSO systems with aggregators and DER control centre*

The smaller the amount of regulating capacity reached per communication connection, the more important are considerations of efficiency. To integrate generators and storages in the scale of up to 100 kW to several MW into the procurement of frequency restoration reserve, in many cases aggregators are involved. Communication of actors can in principle occur directly, or via the ancillary services market platform. DSOs/DNOs may or may not have an own connection for emergency measures. Generally, there is a trend to involve even smaller units in reserve types requiring short activation times. If large amounts of these diverse small resources are available, a certain non-availability of the communication connections can be compensated for as long as rescheduling can be carried out by the aggregator sufficiently fast. This is usually the idea behind concept in Fig. 4 (Germany).

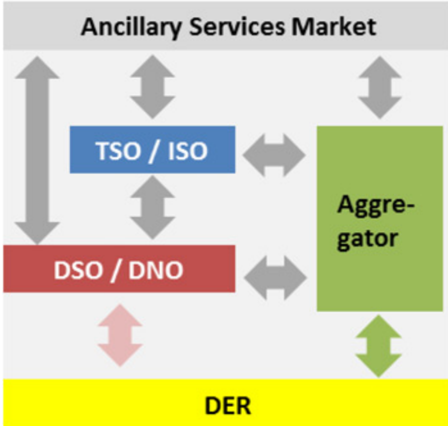

Fig. 4 *Scheme for physical access to DER in DSO systems with aggregator directly communicating with DER*

However, to date, there is less communication between the participants than sketched. Future schemes might add situation-dependent information flows. The scheme in Fig. 5 is characterised by the DSO making available his communication infrastructure to interested market participants, most notably aggregators. At the same time, the DSO maintains the possibility of emergency override. While this design has the charm of using available, frequently high speed, reliable infrastructure and thus may be quite efficient with respect to the utilised amount of communication infrastructure, it must be carefully investigated for compatibility with the relevant regulatory framework. Also, not all DSOs are prepared to take on roles as sketched in Fig. 5.

Summarising, in addition to providing tertiary frequency regulation in the future more and more generators and energy storage devices could also provide a band for f/P control (secondary frequency regulation) so as to guarantee a band of power to restore the nominal value of frequency after a transient.

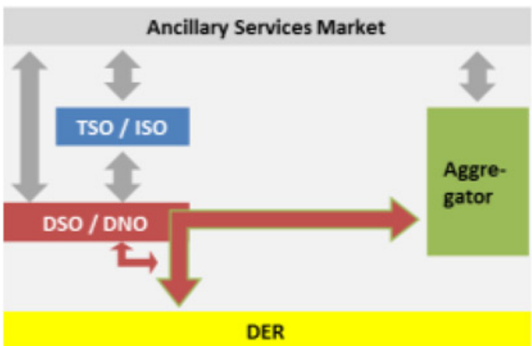

Fig. 5 *Scheme for physical access to with aggregator using fast DSO communication link to DER*

CIRED, Open Access Proc. J., 2017, Vol. 2017, Iss. 1, pp. 2188–2191

In future also, real-time activation of small local generation plants or active loads could be based on droop controls with local measurements of voltage or frequency, which could help in providing primary frequency control or eliminated voltage limit congestions, depending on the control variable [19].

5 Conclusion

This paper has presented an overview of the activities of CIRED/ CIGRE C6.25 /B5 Joint Working Group (WG), focusing on the planning and optimisation of active distribution systems.

The JWG CIGRE C6.25/B5/CIRED is working towards a technical brochure, which will draw together the international perspectives and experiences when dealing with the control and automation systems for electricity distribution networks of the future.

Results coming from the on-going survey are showing that DSOs among the world are conducting different tests to move from a 'blind' exercise of the network to a more and more monitored and control one.

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