INTEGRATION AND AGGREGATION OF DISTRIBUTED ENERGY RESOURCES – OPERATING APPROACHES, STANDARDS AND GUIDELINES

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ABSTRACT

This paper addresses the large scale integration of distributed energy resources (DER), including distributed generation based on renewable energy resources, electric storage systems, and demand response in distribution systems. This integration has a direct impact on the planning and operation of electric distribution systems and at the higher level, of the transmission systems. The deployment of DER also impacts the transmission system operator in its generation dispatch role, since local generation reduces the power dispatched by large central generation plants. The solutions discussed in the paper include standards for the interconnection of individual DER, standards for the aggregation of DER within microgrids and guidelines for the aggregation of DER under DER management systems (DERMS).

INTRODUCTION

DER deployment trends – USA

Over 30 GW of new distributed solar photovoltaic is expected in the U.S. by the end of 2023. California is projected to have over 18 GW of distributed solar photovoltaic (PV) by 2023, which is nearly 40 percent of its projected peak demand for the same period. New Jersey, Massachusetts, and New York are projected to each have between 3.5 and 4 GW of distributed solar PV by 2023. In Canada, Ontario has already installed just over two GW of DER and no less than 500 MW are expected in the coming years.

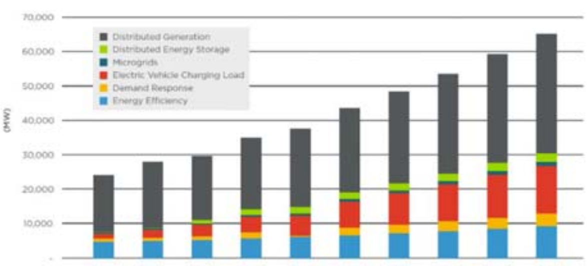

Fig. 1. USA annual installed DER power capacity additions by DER Technology, 2015-2024 (Source: Navigant report).

DER Types and Features

DER are local energy resources that include power generation from fossil fuels, renewables (solar, wind and alternative fuels), electricity storage and controlled loads (demand response).

DER from renewable resources (wind, solar) is variable and intermittent, and as such typically operates at maximum power point tracking (MPPT) for economic reasons and is non dispatchable (however, curtailment is possible). Storage operates in two modes, as generator (discharging) or load (charging). It is helpful for balancing variability and storing/retrieving excess power from renewables.

Flexibility Services

There is a need to enable DER so that it can offer flexibility services to the grid. Basic DER services are energy, power, and reactive power. Ancillary services include voltage and reactive power support, balancing variability and intermittency, ramping and frequency regulation, and short-term frequency support. Other services include reliability and resilience.

Integration and Grid Management

The large-scale integration of DER will have a direct impact on the planning and operation of distribution systems, and at the higher level, of the transmission system. This level of integration of distributed energy resources (DER) will modify how distribution and transmission systems interact with each other. Transmission planners and operators may not have complete visibility and control of these resources, but as growth increases and they as they provide a growing portion of the energy consumed, their contributions must be considered in system planning and operation, forecasting, and modeling. The lack of visibility into DER prevents using aggregations to inject power as a system resource. However, despite the lack of visibility, aggregated DER is being used for demand response in some jurisdictions (the PJM system).

The integration and aggregation of DER creates the need for operating approaches, guidelines and standards for Distributed Energy Resources Management Systems (DERMS).

DER MANAGEMENT SYSTEMS (DERMS)

Context of DER deployment

DERMS is relatively a new concept. Its objectives and functionalities mainly consist of effectively organizing, managing, optimizing and controlling DER resources for maximum grid operational flexibility and economic benefits, and enhanced grid operation reliability through the aggregation of DERs at the substation level, feeder level, by generation types, capacities, response rates or other characteristics.

DER management options

The problem of a large-scale integration can be addressed at the level of individual DER or aggregated DER.

Individual DER level. For individual DER the approach to integration involves developing and implementing more demanding and stringent standards and grid codes for interconnecting DER at the distribution level, taking advantage of the support DER can provide to the grid. New requirements have been developed, including standards such as IEEE Std 1547^{TM}-2018 and utility grid codes.

Aggregation in managed systems – microgrid/VPP. At a higher level, a large scale integration can be addressed by aggregating DER to facilitate the integration and management of a larger scale deployment at the distribution level. Options include Virtual Power Plants (VPP) and microgrids, connected to distribution systems. New standards developed for microgrid control systems include IEEE Std 2030.7^{TM}, functional specification of microgrid controllers.

Aggregation to provide services – DERMS. Alternatively, DER can be aggregated using a DER Management Systems (DERMS). This independent system is designed to aggregate services that can be offered by individual DER, including energy and capacity, and reactive power. New working groups have been set-up to develop this approach, including IEEE P2030.11, functional specification for DERMS.

There is a present need for guidance on DER, aggregated DER, and DERMS. This begins with a commonly accepted definition for DERMS and the aggregation of DER, defining a minimum number of functions for a basic DERMS (similar to core functions for microgrids); and defining the interactions between DERMS (as an aggregate net generator) and transmission/ distribution operations.

Microgrid features

With DER aggregated into microgrids, security of the load supply can be provided beyond the parameters associated with the DSO, including islanded operation in the event of the loss of the distribution feeder, for increased reliability and resilience.

The microgrid concept can also be used to design advanced network schemes for the best exploitation of distributed generation and energy storage, with the inclusion of electric vehicle loads, and solve hosting capacity, flexibility, and investment deferment, Fig. 2.

DERMS for aggregated DER – features

The purpose of the DERMS is to aggregate and dispatch multiple DER, coordinate their operation in the distribution grid and optimize their output. With the increased deployment and penetration of Distributed Energy Resources (DER), aggregation of DER is an effective approach to integrate DER into the planning and operation of distribution and transmission systems.

DERMS must have an implementation framework, if for no other reason than to define the monitoring of DER and the physical signals that are sent from/to the DSO/TSO. DERMS needs to be implemented in some hardware and resides in a well-defined location, with the aggregator or the DSO, either as an add-on or as an integral part of the DMS. DERMS may have multiple components but is an entity in itself.

DERMS is different from microgrid energy management systems in that it relates to the management of large numbers of DER (mostly solar and storage) deployed throughout the distribution network, and does not have boundaries or capabilities for planned islanding; it is the control of aggregations of DER as an entity.

DERMS – basic functions

For the aggregation of a large number of DER using a DERMS, benefits and impacts include services that can be provided to a range of stakeholders including distribution system operators (DSO), with a direct link of the DERMS to Distribution Management Systems (DMS), and transmission system operators (TSO) and Energy Management Systems (EMS). These services include energy and capacity and ancillary services.

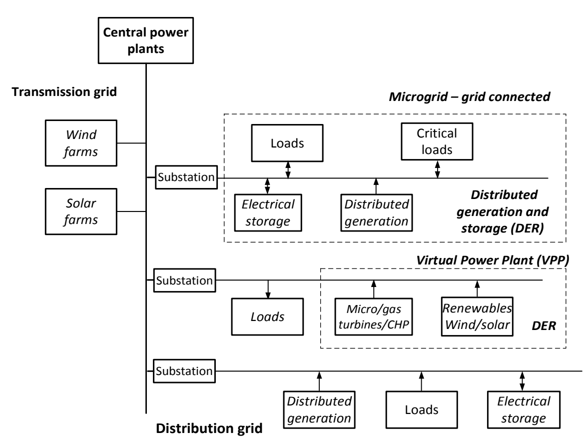

Fig. 2. DER integration – transmission and distribution grid.

DERMS interaction – transmission level

The value from DERMS will be realized early on by transmission planning, later operations.

DERMS fills a gap for Bulk Power System (BPS) reliability under the fundamental concepts of the North American Electric Reliability Corporation (NERC):

Adequacy. This is defined as the ability of the electric system to supply the aggregate electric power and energy requirements of the electricity consumers at all times, taking into account scheduled and reasonably expected unscheduled outages of system components.

Operating reliability. This is defined as the ability of the electric system to withstand sudden disturbances such as electric short circuits or unanticipated loss of system components.

DERMS at a minimum will provide a level of visibility into how the distribution system performs. This will provide the transmission planner with details on how to construct models (e.g. equivalent models most likely due to number of buses) which is based on the performance of feeders. This aligns with requirements for system models and assessments (e.g., steady state and stability studies) in NERC Reliability Standard TPL-001-4, Transmission System Planning Performance Requirements.

DERMS could provide forecasts for time periods that can be used in transmission operations. This would help with normal and abnormal operations of the power system and help maintain reliability in the bulk power system (BPS). At some point distribution resources need to perform for BPS reliability. However, as an initial step the distribution system resource performance monitoring and situational awareness that is the missing link that operators need for BPS reliability.

The main issues that concern (NERC) are:

DERMS generates useful information required by NERC. This information is not necessarily in the form required by NERC. Addressing the specific needs of NERC is important in North America, as well as transmission system operators (TSO) internationally. Visibility and situational awareness of DER impacts on the transmission system operations merits serious attention.

Information generated by the DERMS. This information is for the specific needs of the aggregation done by the DERMS and to establish the power and ancillary services to be rendered to the DSO and possibly the TSO; this information may be proprietary to the DERMS operator, and more generally to the DSO; the manner in which this information could be shared remains to be decided in the industry.

DERMS OPERATING APPROACHES

DERMS requirements

DERMS should effectively manage, optimize and control the DER dispersed along distribution feeder circuits in order to maximize the economic benefits of DER, enhance grid operation reliability, and minimize possible negative impacts on the grid operation, transmission and distribution.

Group structures and aggregation policies are characteristics of DERMS. DER can be physically dispersed anywhere on the distribution grid, Fig. 2. They have diversified characteristics in terms of energy sources (solar, wind, biogas, hydro, fuel cell, battery storage), generation types (inverter-based or rotational machine-based), physical locations in the feeder circuits or feeder sections, power capacities, dynamic response performance to voltage and frequency changes, controls (local or remote), connection statuses, and many other features.

DERMS aggregates or groups DER based on their features or specific characteristics in order to effectively manage and optimize the services rendered to the DSO. Aggregated DER based on their specific characteristics or features may be organized as Virtual Power Plants (VPP).

DERMS operational rules

DERMS bases dispatch signals on energy availabilities and the demands at different levels, e.g., substation, feeder and feeder sections, considering network constraints in distribution grid operations Before committing to a schedule, DERMS should verify that it will not adversely impact overall grid operation reliability. The TSO, in turn, may accept or reject the schedule, or offer an alternative. Once accepted, however, a schedule becomes a commitment and must be followed or incur penalties.

DER generation forecasting

DER impacts generation dispatch by transmission system operator, since local generation reduces the power dispatched by large central generation plants.

The optimization in scheduling aggregated DER is based on the available energy resources. However, a large portion of the DER may be from renewable energy, e.g., wind and solar resources, which are intermittent and may not be fully dispatchable in response to a signal at a given point in time. Therefore, it is necessary to have a good forecast of the available aggregated generation. The generation forecast can either be an independent module to provide the forecasts to a DMS or be an application in DERMS.

Impacts of DERMS on DMS

DERMS may help DMS reduce the uncertainties caused by the dispersed DER that may not follow a unified or coordinated operational pattern. With a DERMS, the DMS can get the real-time generation values of aggregated DER, as well as their schedules for look-ahead time intervals. This can be very effective in enabling the DMS to make predictive operation, control and management.

DER STANDARDS AND GUIDELINES

Individual DER – IEEE Std 1547™

New grid codes and standards are required for high levels of DER integrated into the grid. For individual DER, the standard for interconnection has been updated recently and is now published as IEEE Std 1547™-2018, Interconnection and Interoperability of Distributed Energy Resources with Associated Electric Power Systems Interfaces.

The updated interconnection requirements include (a) low voltage ride-through, the DER remaining connected in the event of a fault on the distribution feeder; (b) low frequency ride-through, in the event of the contingency on the distribution and/or transmission system; (c) voltage and frequency support and regulation.

IEEE Std IEEE 1547™ deals with individual DER, not aggregations of DER or microgrids. Existing standards for individual DER do not however allow for the visibility and control necessary to maintain reliable operations. New standards must include aggregation of DER, either in the form of microgrids or as VPP, or using dedicated DER management systems (DERMS).

DER within microgrids – IEEE Std 2030.7™

A new standard, IEEE Std 2030.7™ functional specification of microgrid controllers has been developed and approved by the IEEE SA (2017). It defines the core functions for the microgrid control system are shown in Fig. 3. Two core functions are defined: (a) transition function, defining transitions from grid connected to islanded modes; (b) dispatch function, specifying the operation of the microgrid assets in grid connected and islanded modes, under steady state and during transitions.

The dispatch function, or energy management function, dispatches assets to meet specified performance criteria, including asset utilization and power exchange with and the ancillary services provided to the grid in grid connected mode. In this mode, the dispatch function acts as a management function for the DER within the microgrid.

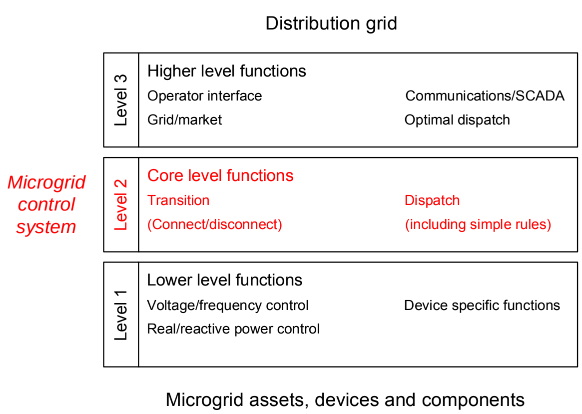

Fig. 3. IEEE Std 2030.7™ – microgrid core functions.

DERMS functional specification – IEEE P2030.11

A working group to write a guide to develop a functional specification for distributed energy resource management systems (DERMS) was approved by the IEEE Standards Association in March 2018 and is expected to complete its work in 2020. The creation of the working group recognizes the need to define and formalize the functions of a DERMS and to address the interactions between aggregated DER and distribution and transmission networks.

This document will provide a guide for the development of DERMS. It will include guiding principles for the application and deployment of DERMS and DERMS control systems, will address the basic functional requirements and propose a set of core functions.

Preliminary work has defined the core functions, as shown in Fig. 4. The functions associated with the DERMS control system (Level 2) are the following:

Aggregation. Function include DER (a) grouping; (b) registration; (c) capability/discovery; (d) real and reactive power output estimation and monitoring; (e) generation forecasting; (f) visualization of operation and capacity; (g) modeling; (h) translation.

Monitoring (real time). Functions include (a) measuring and measurement validation; (b) alarms.

Operation (real time). Functions include (a) asset and real and reactive power dispatching, ancillary services provision, including voltage and frequency control/support.; (b) asset scheduling; (c) capacity forecasting (hr ahead, day ahead); (d) asset control and optimization of operation; (e) analysis and evaluation.

The DERMS functional specification approach can be extended to Virtual Power Plant (VPP) control systems.

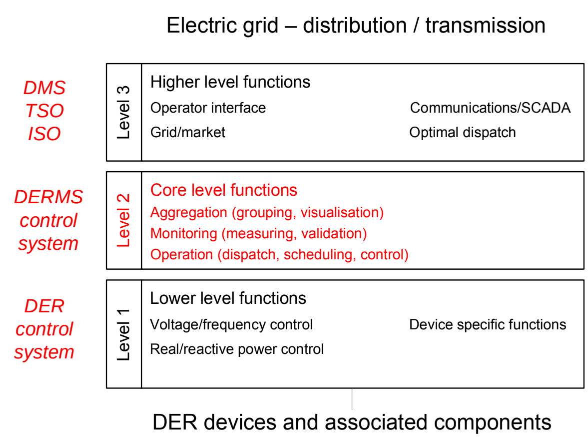

Fig. 4. IEEE P2030.11 – DERMS core functions.

DERMS users – aggregators

Standard IEEE P2030.11 will assist utilities, vendors, consultants, aggregators, and other users (independent DER owners and operators) to specify and configure DERMS. It will inform distribution, transmission and independent system operators of basic approaches to integrate aggregated DER in grid planning and operation; help integrate DERMS in Distribution Management Systems (DMS) and Transmission Energy Management Systems (EMS); and facilitate the development and deployment of DER integrated into the DMS.

Aggregators and their justification for the use of a DERMS include:

Grid operators (DSO/TSO). The DERMS uses include: (a) managing the grid in the presence of DER; (b) meeting the need for DER visibility, monitoring and assessment of DER operating capabilities to facilitate integration into the distribution system operation

Independent Power Producers (generators) and power retailers. Uses include: (a) managing by means of aggregation a large portfolio of DER, including renewable energy resources and storage; (b) participating in energy markets and developing new business models

Pure aggregators. Uses are mostly for the creation and management of a portfolio of DER and renewable assets to offer power and energy capabilities and ancillary services to the DSO, TSO and other grid operators.

DERMS services – distribution/transmission

A DERMS can provide the listed services at the following levels:

Distribution level services. These include: (a) capacity/power and energy; (b) voltage support and reactive power; (c) support to enhance operational reliability; (d) contribution to resiliency.

Bulk transmission (TSO, DSO and balancing authority) level services. These include: (a) energy; (b) capacity; (c) frequency regulation; (d) frequency response; (e) voltage support and reactive power; (f) synchronous / non-synchronous reserve; (g) ramping services; (h) black start.

CONCLUSIONS

DERs are a significant energy resource interconnected to the grid. In order to offer flexibility services to the grid, they need to be aggregated and controlled so as to be dispatchable as a group to provide services that meet the requirements of transmission and distribution operators. No longer can DER be considered as individual devices interconnected to the grid. In order to deliver flexibility services, DER must be integrated and managed as part of transmission and distribution systems.

The integration and aggregation of DER creates the need for operating approaches, standards for Distributed Energy Resources Management System (DERMS). These operating approaches show a progression from simple DER interconnection, often invisible to grid operators, to aggregations of DER, organized in microgrids or aggregated by utilities or independent operators that can be managed by grid operators, contribute to the bulk power system operation and participate in electricity markets. Utilities/regulators need to be involved in defining DER interconnection/integration requirements.

DERMS is a key building block for DSO/TSO interactions involving DER management and operation. It is recognized as a tool for the management of DER for TSO/DSO coordination. It provides situational awareness of the status of DER and is a candidate technology solution to execute operations commands between Transmission and Distribution Operators.

Acknowledgments

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