Integration of Utility Distributed Energy Resource Management System and Aggregators for Evolving Distribution System Operators

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***Abstract*—With the rapid integration of distributed energy resources (DERs), distribution utilities are faced with new and unprecedented issues. New challenges introduced by high penetration of DERs range from poor observability to overload and reverse power flow problems, under-/over-voltages, maloperation of legacy protection systems, and requirements for new planning procedures. Distribution utility personnel are not adequately trained, and legacy control centers are not properly equipped to cope with these issues. Fortunately, distribution energy resource management systems (DERMSs) are emerging software technologies aimed to provide distribution system operators (DSOs) with a specialized set of tools to enable them to overcome the issues caused by DERs and to maximize the benefits of the presence of high penetration of these novel resources. However, as DERMS technology is still emerging, its definition is vague and can refer to very different levels of software hierarchies, spanning from decentralized virtual power plants to DER aggregators and fully centralized enterprise systems (called utility DERMS). Although they are all frequently simply called DERMS, these software technologies have different sets of tools and aim to provide different services to different stakeholders. This paper explores how these different software technologies can complement each other, and how they can provide significant benefits to DSOs in enabling them to successfully manage evolving distribution networks with high penetration of DERs when they are integrated together into the control centers of distribution utilities.**

***Index Terms*—Distributed generation, distributed energy resource (DER), aggregator, distributed energy resource management system (DERMS), non-wire alternatives.**

I. Introduction

WITH the rapidly increasing penetration of distributed energy resources (DERs) worldwide, distribution networks are evolving towards complex and dynamically changing systems [1]-[3]. The term DER itself relates to active resources connected to distribution networks and can include distributed generators (DGs) such as solar photovoltaic (PV) and wind generators, various types of energy storage systems such as electric batteries or flywheels, as well as electric vehicles (EVs) and their charging stations [4], [5]. Massive integration of DERs is introducing a high level of complexity in traditionally passive distribution networks, including their observability, management, control, and protection [6], [7].

Poorly planned and stochastic integration of DERs have been introducing challenges that are felt all over the distribution network. First, distribution network operators (DNOs) are facing increasing amounts of overloads on their feeders, over-/under-voltages at the DER buses, and protection coordination and sensitivity issues due to the dynamic and often unpredictable behavior of DERs [7]-[11]. Second, end-customers, including behind-the-meter DERs, now having an ability to produce more energy than they need, are becoming eager to trade with their excess energy and enter the electricity markets, but are often too small and do not possess economic leverage to gain significant attention and benefits from their services.

These changes are accompanied with the restructuring of the traditional players in the electric power system area. Two of the most important changes are as follows. First, the traditional DNOs are required to rapidly evolve into much more active operators, termed distribution system operators (DSOs), that would be able to manage, protect, and control emerging distribution networks in near real time. Second, traditionally passive loads are rapidly evolving into much more dynamic "prosumers", that can both consume and produce electric power, and even trade with the excess energy. Finally, groups of prosumers and other behind-the-meter DERs

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are increasingly starting to aggregate into DER groups, virtual power plants (VPPs), and DER communities, and consequently offer their services at the aggregated level, where they can present a considerable asset for balancing authorities and other market participants [7], [10]-[15].

Nonetheless, such a core transition of traditionally passive distribution networks cannot be successfully performed without the accompanying modernization of control centers and the development of highly intelligent software systems to enable real-time observability, control, aggregation, and protection of increasingly complex distribution networks with huge numbers of DERs dispersed throughout the distribution network. Thus, emerging software solutions that are aimed to enable proper management and control of distribution networks with high penetration of DERs, called distributed energy resource management systems (DERMSs), come into play [7], [10], [11], [15].

Ideally, a DERMS solution should provide a wide range of tools, which would benefit both DSOs and end-customers. Nonetheless, because these technologies are still very novel, the definition of a DERMS is vague and can often refer to very different DER management solutions, spanning from VPPs to demand response (DR) providers and DER aggregators, and to centralized enterprise systems, called utility DERMS or grid DERMS. Further, DERMS should be considered as a logical entity rather than as a physical platform. DERMS functionalities can reside in other enterprise platforms such as the advanced distribution management system (ADMS). This paper uses the term utility DERMS for simplicity, but it might refer to having the functionality of controlling DER in the applications such as volt/var optimization (VVO) and peak load management in ADMS or DMS solutions used by utilities in North America. The confusion among the key stakeholders arises because even though all these solutions and grouped functionalities are frequently simply called DERMS, they have different sets of tools and aim to provide different services to different stakeholders. Two examples – both often called DERMS – are DER aggregators and utility DERMS. Although the aim of both might seem similar – to manage and control DERs, these two solutions differ widely in their nature and responsibilities [11], [15]. This poor understanding of the available technologies and their functionalities often leads to distribution utilities being reluctant in implementing DERMS, which consequently defers DER integration, or even worse, leads to serious issues caused by high penetration of DERs, but without a proper tool for controlling and managing such an evolving environment.

Thus, the main motivation of this paper is to fill this gap and clarify the confusion when using the term DERMS, through clearly distinguishing between the structure and authority of different DER management software solutions and explaining their different roles and responsibilities. Further, it is our aim to present how the two solutions on the opposite ends of this spectrum, i.e., a DER aggregator and a utility DERMS, can complement each other when deployed together and offer a comprehensive set of tools for optimally managing all DERs, from small-scale, behind-the-meter, to large-scale DERs connected to the middle-voltage network. Finally, we will present our vision how this integration enables both the DSOs and end-customers to overcome the challenges imposed by high penetration of DERs, and further, how this can enable them to reap the highest possible benefits from DERs and their services.

For DSOs, addition of DERMS to their control centers becomes inevitable with the ever-increasing penetration of DERs to properly observe, manage, control, and protect their corresponding grids; while for the end-customers, it enables them to properly offer their services to DSOs and balancing parties, and help in dynamically managing the emerging grids. To further validate our points and to showcase where the power system community and industry currently stands with DERMS, at the end of the paper, we present several real-life use cases from ongoing projects from Schneider Electric and the National Renewable Energy Laboratory (NREL), where the integration of various DER management software solutions has already been tested in the real-life environment.

Thus, the contributions of this paper are as follows.

1) The logical concept of DERMS, including all levels of hierarchy, is clearly introduced in this paper.

2) The inevitable need for the emerging distribution network control centers to implement DERMS is elaborated in detail and the benefits of integrated centralized DER management solutions, i.e., utility DERMS, and decentralized ones, i.e., DER aggregators, are comprehensively presented.

3) The proposed claims are validated on the most recent, real-life projects, where these benefits have been already proven.

Taken together, we hope that this effort will lead to better understanding of DERMS concept within academia and industry, and that it will contribute to faster implementation of DERMS into distribution network control centers globally.

The rest of this paper is organized as follows. Section II presents the challenges imposed by high penetration of DERs to distribution networks. Section III introduces and discusses the utility DERMS and DER aggregator concepts and reveals the authors' view of their complementary natures. Section IV presents several use cases from ongoing projects that describes the progression of different DERMS solutions all the way up to the integration of utility DERMS and DER aggregators to provide optimal benefits to DSOs and end-customers. Section V concludes the paper.

II. Challenges Imposed by High Penetration of DERs to Distribution Networks

DERs introduce several different categories of challenges to the traditionally passive distribution networks. First, the addition of high penetration of DERs into the existing distribution networks, if poorly planned, can infer instability, congestion, and other technical issues. Moreover, the addition of DERs can require huge investments by the utilities to build new or strengthen the existing distribution network assets. Furthermore, DGs and energy storage technologies, when managed improperly, can cause over-voltages on the existing feeders, and can considerably increase the voltages at their points of interconnection (POIs) as well as at the neighboring locations. Moreover, because of the intermittent nature of the renewable DERs, in periods of low demand but high production of these resources (e.g., high solar irradiation or wind power), a new phenomenon of reverse power flow can occur. Consequently, this issue could inaccurately trigger the reaction of protective devices, as well as cause voltage problems and unpredicted variations along the feeders [11], [15]. Finally, it is very hard to accurately predict the behavior of renewable DGs using the traditional forecasting methods; thus, if left unmanaged in real time, this added uncertainty could cause issues in the operation planning and management of emerging distribution networks.

On the other hand, at the low-voltage side, where most of the end-customers are located, ever-increasing penetration of rooftop PVs, energy storages for households, as well as the massive integration of EVs are significantly transforming the state of traditionally passive, low-voltage parts of distribution networks, and driving the need for systematic and intelligent management.

Thus, distribution utilities and especially operators and grid engineers, must adapt to the emerging conditions by learning and adopting new technologies for planning and managing evolving distribution networks with high penetration of DERs. Traditional practices and procedures that are used for managing passive distribution networks, are already outdated and inapplicable to these emerging conditions. However, DERMS can successfully cope with DER-imposed challenges and secure the systematic and intelligent management of a wide range of different DERs. Further, DERMS technologies strive to turn the potentially dangerous behavior of DERs into operational and monetary benefits for utilities, as well as end-customers [15]-[18]. But there are different levels to the DERMS hierarchy, which aim to provide different services regarding DER management, while targeting different DERs relative to their sizes and connection point locations (on a medium- or low-voltage distribution network).

Our goal is to show how the integration of two of these solutions, located on the opposite ends of the hierarchical spectrum, namely utility DERMS and DER aggregators, can work in coherence. By complementing each other, they can provide a required set of tools for the integration and active management of all types of DERs, regardless of their technology, size, or connection point location.

III. Different DER Management Solutions and Their Complementary Natures

This section introduces a DERMS concept and presents the nature and characteristics of utility DERMS and DER aggregators and the benefits of their integration to DSOs.

A. DERMS and Its Usage

As the DERMS concept is novel and still emerging, the term DERMS itself is still vague and may refer to different solutions. Generally speaking, the term DERMS corresponds to a software solution for managing high penetration of DERs. However, because of its novelty, DERMS is often used to describe various different levels of software solutions aimed for managing DERs.

On the one hand, there are decentralized software packages that aim to aggregate behind-the-meter DERs such as air-conditioning or heating devices, rooftop PVs, small-scale batteries, or EVs, with the main goal to provide a better awareness of these small-scale but very dispersed assets and to provide their services in an aggregated and much more useful manner, e.g., by entering the electricity market or by providing DR and energy-efficiency programs, among others [15]-[19]. On the other hand, there are fully centralized enterprise systems that aim to provide services to the DSOs, to enable them to swiftly overcome the challenges that DERs impose on the distribution networks and their assets. These services range from providing situational awareness to manual/automatic DER control, constraint resolution, and advanced optimization applications for the efficient management of medium- to large-scale DERs and DER groups consisting of numerous small-scale units, with the objectives to provide operational and monetary benefits to the grid operators and engineers in the control room and to grid planners that are responsible for the network upgrades and the addition of new resources [11], [15].

Both utility DERMS and DER aggregators are frequently called DERMS, but these two solutions differ widely in their nature and responsibilities considering the existing real-world solutions applied in North America and worldwide. One is a centralized enterprise system, which is completely grid-aware, whereas the other is usually implemented as a decentralized solution that is unaware or partially aware of the grid conditions and limitations and is concerned only with DERs and their internal conditions and responsibilities.

But these two solutions also complement each other in securing a full spectrum of services essential for today's DSOs, who are responsible for ensuring the safe, reliable, and optimal management of an ever-increasing penetration of DERs [15].

B. Roles and Responsibilities of DER Management Solutions

The main role of DER aggregators is to provide the aggregation of small-scale DERs into DER groups, and consequently to enable their services using the aggregated DER power. The added value provided by DER aggregators includes enabling the participation of small-scale DERs in the electricity markets, the engagement of DERs and prosumers in energy-saving and energy-efficiency programs, the provision of DR and load shedding services, as well as other mostly customer-related services. However, because of their structure that is generally adopted nowadays, DER aggregators are either not aware or only partially aware of the grid model and its conditions and technical boundaries, so they cannot guarantee not causing technical constraint violations such as congestions, voltage violations, or protection issues. Thus, to enable the safe use of the services offered by DER aggregators, DSOs must have observability of the real-time conditions in the grid, as well as the ability to validate – and modify, if necessary – the schedules of DER aggregators to avoid constraint violations on the grid assets.

This is where a utility DERMS comes into play. Utility DERMS solutions are intelligent, grid-aware software packages that enable the full awareness, control, and optimal management of medium- to large-scale DERs and DER groups (consisting of behind-the-meter DERs), with the goal of using all these resources to achieve system-wide benefits without violating grid constraints. Further, utility DERMS solutions use all available resources to solve existing violations or predicted constraint violations and keep the system in a stable and optimal state in real time. Therefore, for large- and medium-scale DERs, whose impact on the grid conditions can be significant, a grid-aware utility DERMS is a natural solution for their management and control [11], [15].

Even though both solutions are concerned with DER management, utility DERMS and DER aggregators are vastly different software packages, and thus they should not be referred to by the same term. Referring to both solutions as DERMS leads to confusion, even among parties interested in deploying DERMS (i.e., electric utilities), and thus it should be abandoned. From the standpoint of DSO, utility DERMS and DER aggregators should be understood as different levels in a hierarchy: DER aggregators mainly communicate with behind-the-meter units and use them in an aggregated fashion to provide various services regarding customer engagement and operations. Besides, utility DERMS uses DER aggregators, among other resources such as individual medium- to large-scale DERs, various types of DER groups, VPPs, microgrids, and traditional resources such as switches and capacitors, to provide DSOs with a complete awareness as well as effortless, real-time, look-ahead constraint management and the optimal coordination and management of DERs, DER groups, and other system-wide operations. Therefore, if properly integrated, a DER aggregator and utility DERMS can complement each other and provide a full spectrum of DER services regarding both customer-related and grid-related operations, which is regardless of the sizes and locations of DERs.

C. Integration of Utility DERMS and DER Aggregators: an Ideal Case

Even though both a DER aggregator and a utility DERMS can be used as a stand-alone solution and can successfully provide numerous benefits, their values are tremendously increased when they are integrated and used together. When they are properly integrated and set to work coherently, these two solutions can cover a full spectrum of DER management services and can open a new world of possibilities for DSOs to use DERs as valuable resources in performing a broad set of required operations, both grid-related and customer-related [15], [19].

Through (near) real-time communications and data exchange with a utility DERMS, DER aggregators highly enhance DSOs' awareness of and ability to manage behind-the-meter DERs, especially in customer-related operations such as participation in electricity market and DR or energy-efficiency schemes. Nonetheless, through its advanced applications such as hosting capacity, real-time and look-ahead constraint management, volt/var/watt optimization, demand flexibility, load and DER forecast, and through sophisticated integration with DER aggregators, utility DERMS enables DSOs with an ability to successfully manage and optimize their emerging distribution systems with high penetration of different DERs, which are dispersed throughout the grid (from behind-the-meter to large-scale DERs connected to the medium-voltage distribution network) [19].

Further, DER aggregators, if integrated with a utility DERMS, would be able to provide a much better quality of their services because all their scheduled programs could be validated by a utility DERMS, therefore ensuring that none of the technical constraints are ever violated. Hence, this integration would ultimately lead DSOs to a much-needed transformation into a new era of future distribution systems with high penetration of DERs.

Near real-time communication in this context is envisioned through supervisory control and data acquisition (SCADA) and internet protocols, but can also be performed through custom-made application programing interfaces (APIs). Using custom-made APIs is a current practice, as in many cases, a utility DERMS of the specific vendor on one side, and a DER aggregator on the other side, do not support the same protocols. Hopefully, this practice will soon change, as the standardization of the communication protocols is currently taking place, and for example, the IEEE 2030.5 protocol is a very promising solution that could be useful on both ends.

The information exchanged through this communication often consists of advanced metering infrastructure (AMI) measurements that an aggregator collects for behind-the-meter resources, as well as forecasted production of small-scale DERs controlled by DER aggregators and their operation schedules. These data are then used in near real-time applications of the utility DERMS, i.e., state estimation, to improve situation awareness, as well as in constraint management and grid optimization for near real-time and forecasted periods. Thus, not only the observability of the grid conditions in near real-time is significantly improved, but also the predictions of the constraint violations can be performed with more accuracy and consequently they can be managed proactively.

IV. Real-life Use Cases for Utility DERMS and DER Aggregators

This section presents several real-life use cases that demonstrate the progression of different DERMS solutions all the way up to the integration of utility DERMS and DER aggregators to provide benefits to DSOs and end-customers. The following examples have already been tested or are currently being tested in industrial and academic projects, using commercially available or prototype utility DERMS and DER aggregator solutions.

A. Distribution Voltage Management and Peak Load Reduction Through Utility DERMS

This use case demonstrates a utility DERMS that directly controls residential DERs that are owned by the utility. These DERs are aggregated and controlled as a VPP to provide peak demand reduction while enforcing the voltage regulation. This utility DERMS is a software prototype developed by NREL [20] (originally referred as real-time optimal power flow) by using a feedback-based real-time optimization algorithm [21], [22].

A distribution feeder, located in Colorado within the service territory of an electric utility in North America, is used as the simulation test system in this study. There are 1137 residential loads modeled, of which 163 loads represent all-electric homes. These all-electric homes are assumed to have residential rooftop PV and battery energy storage system (BESS) installed on their premises that participate in the VPP and voltage regulation controls through the utility DERMS. The experiments are conducted in the ADMS testbed [14], [23], [24]. The testbed was developed by NREL and the U. S. Department of Energy's (DOE's) Office of Electricity for vendor-neutral evaluation of distribution management strategies and through that, to help accelerate ADMS deployments among DSOs. The testbed uses multi-timescale simulation platforms of distribution system models, interfaced with physical hardware to represent real-world and hypothetical future system conditions. The testbed also has a communication interface that allows ADMS and other utility management systems such as DERMS to interface with the testbed using industry-standard protocols. NREL works with utility, industry, and other research groups, to identify and evaluate ADMS applications that are important for grid modernization. The simulations for this use case are conducted on the ADMS testbed using the data from a representative peak load day on January 27, 2018.

Figure 1 shows the results from utility DERMS use case, including substation power, total BESS power output, and average BESS state of charge (SOC).

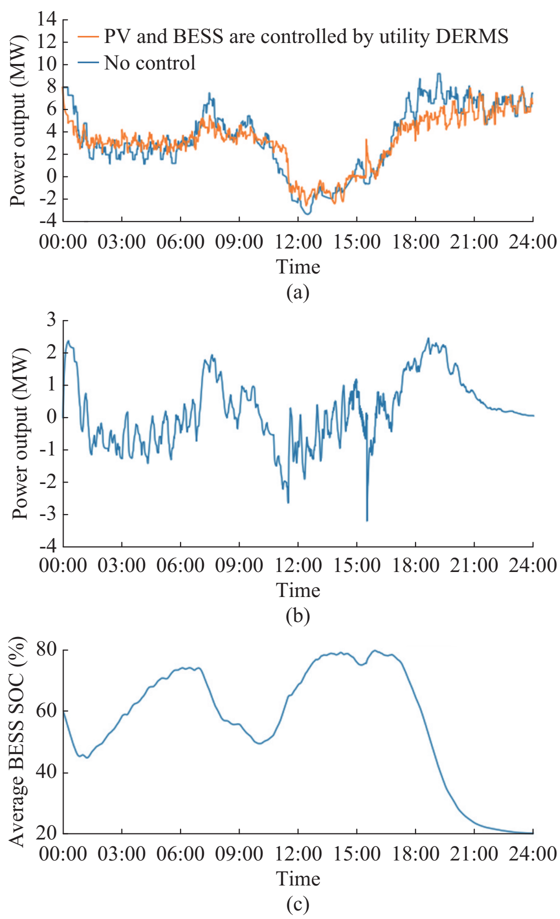

Fig. 1. Results from utility DERMS use case. (a) Substation power output. (b) Total BESS power output when BESSs are controlled by utility DERMS. (c) Average BESS SOC when BESSs are controlled by utility DERMS.

High load consumptions are observed during 07:00-08:00 and 17:00-23:00 for the baseline (no control) scenario. With BESSs controlled by the utility DERMS, they discharge power to offset the high load consumptions during these periods and recoup the energy by charging in other periods. Voltage regulation is implemented simultaneously by controlling the reactive power output of PV inverters.

Figure 2 shows the results of the system voltages and the active and reactive power outputs of PV inverters when PVs are controlled by the utility DERMS.

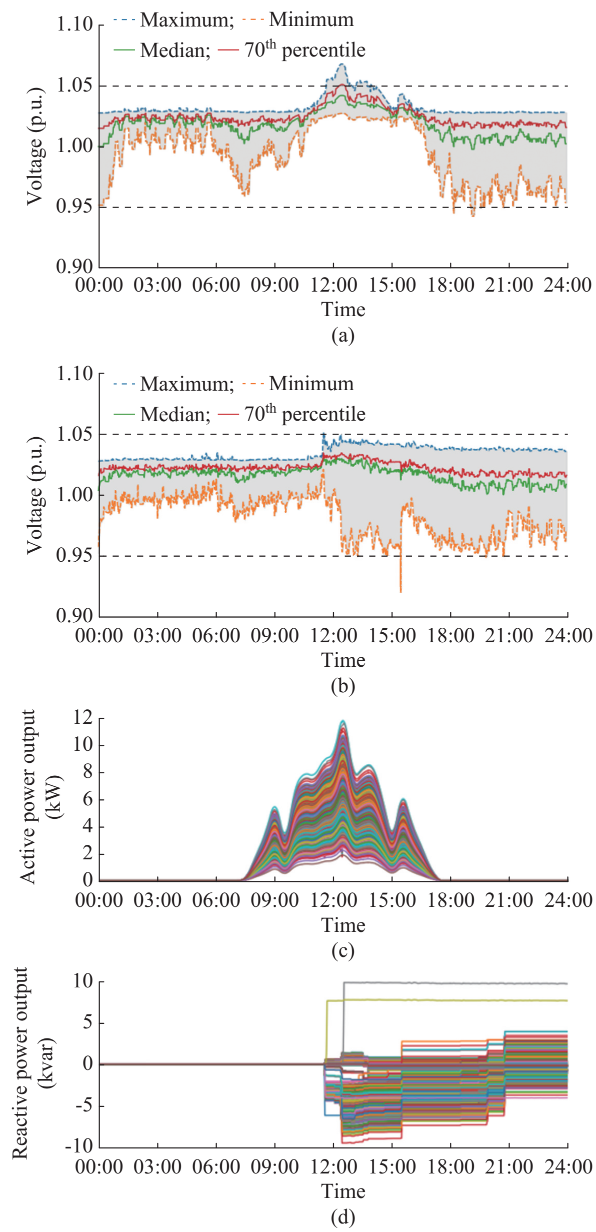

Fig. 2. Results of system voltages and active and reactive power outputs of PV inverters. (a) System voltages for no control scenario. (b) System voltages when PVs are controlled by utility DERMS. (c) Active power outputs of PV inverters. (d) Reactive power outputs of PV inverters.

Reactive power support provided by PV inverters is used to mitigate over-voltage without causing PV curtailment. The negative PV reactive power indicates reactive power absorption.

B. Improved Monitoring and Control in Emerging Distribution Networks with Large Amounts of Dispersed DERs

Utility DERMS provides accurate situation awareness of real-time conditions in the grid to the operator, including voltages, current and power flows, and congestions, through SCADA and AMI systems [13]. Moreover, through sophisticated load and DER forecast algorithms, accurate predictions of future grid conditions are estimated by utility DERMS systems; however, with the emergence of high penetration of behind-the-meter DERs and flexible loads, which are frequently not connected to SCADA or AMI systems, their conditions have traditionally been estimated using state estimation or other advanced applications [13], [15]. Besides, DER aggregators enable near real-time measurements of small-scale DERs that are not connected to SCADA or AMI as well as accurate forecasted behavior of DER groups comprising these small DERs. With these data being constantly imported from DER aggregators, a utility DERMS increases the accuracy of the real-time situational awareness and expands it to the grid-edge devices [13], [15].

This use case describes a study of the ability of DER aggregator and ADMS (with utility DERMS functionalities) coordination to achieve situation awareness and voltage regulation in the presence of very high penetration of DERs, using the NREL ADMS testbed [14], [24], [25].

When high PV generation is present, the voltage regulation is a major issue. This use case also demonstrates the ability of the real-time optimal power flow [20] introduced in Section IV-A to coordinate with an ADMS to enforce the voltage regulation in the distribution feeders. Specifically, the ADMS reduces the bus voltages to mitigate the voltage rise and the DER aggregator dispatches the PV smart inverters to further resolve the voltage issues.

This study models a set of four distribution feeders supplied by a 30 MVA, 110 kV/13.2 kV substation transformer in OpenDSS. The model is developed based on the data from a North American electric utility. The topology of this model is shown in Fig. 3. The feeders, located in Colorado, serve nearly 6000 customers and have more than 13000 buses. The substation transformer is equipped with a load tap changer (LTC). Additionally, there are 13 switched capacitor banks with a total rating of 15.6 Mvar available for voltage regulation and reactive power management. More than 3000 distributed PV systems are added to the model with a total rating of 24 MW (about 200% relative to the minimum load) to simulate a scenario with high PV penetration.

The experiments for two scenarios are carried out, as described in [25], for 4 hours of simulation time to study the coordinated operation of the ADMS and DER aggregator in accomplishing the voltage regulation. In the first scenario, referred to as the baseline, the controls of the ADMS and DER aggregator are turned off. The legacy devices (LTC and capacitor banks) follow their local controller responses and the PV smart inverters inject power at unity power factor. The bus voltages from this scenario are shown in Fig. 4(a). It is evident that many buses experience over-voltage issues, i.e., voltages above the upper voltage limit of American National Standards Institute (ANSI) (1.05 p.u.) during the simulated period.

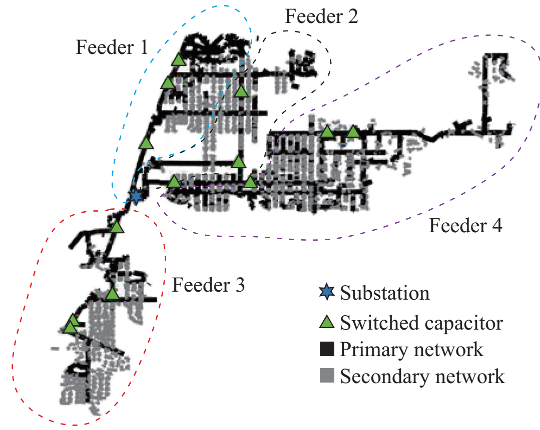

Fig. 3. Topology of studied model.

In the second scenario, referred to as the virtual reality (VR)-enabled scenario, the VVO of ADMS is enabled with the voltage regulation (customer voltage improvement) as the control objective. This study uses the ADMS developed by Schneider Electric [26]. The ADMS runs advanced model-based optimization using the VVO application to issue optimal set-points to the legacy devices, i.e., the LTC and capacitor banks. Since the scenario with high PV penetration in this use case considers residential rooftop PV systems only, they (PVs) are all assumed to be controlled by the DER aggregator and not by the ADMS. The VVO of ADMS is configured to run every 5 min to issue the set-points to the legacy devices on the slow timescale. Further, the real-time optimal power flow algorithm [27] is used to implement the DER aggregator. The DER aggregator commands are configured to run every 5 s to enforce the bus voltages to be within the limits using the reactive power compensation from the small-scale PV smart inverters and the active power curtailment, if needed.

The results from the second scenario are shown in Fig. 4(b)-(e). As observed in Fig. 4(b), the ADMS reduces the LTC voltage regulation set-point to 119 V from the default LTC local controller set-point of 124 V during the initial few minutes of the simulation. As a result, the LTC tap position is lowered to −5. Consequently, the bus voltages are reduced and reasonably confined to the ANSI voltage band from 0.95 p.u. to 1.05 p.u, as shown in Fig. 4(d). Thus, the voltage regulation is ensured despite the presence of high PV generation. The total PV power outputs in both the scenarios are compared in Fig. 4(e). As the PV inverters are not oversized, the DER aggregator curtails the PV active power to allow reactive power absorption to regulate the voltage within operating limits. It is observed that approximately 9 kvar reactive power is absorbed by the PV smart inverters at around 10:00.

C. Utilizing DERs to Mitigate Real-time Constraint Violations After Restoration of a De-energized Island

Another related use case currently being tested by using the utility DERMS of Schneider Electric investigates how to optimally use DERs to mitigate constraint violations after the restoration of a de-energized island [15].

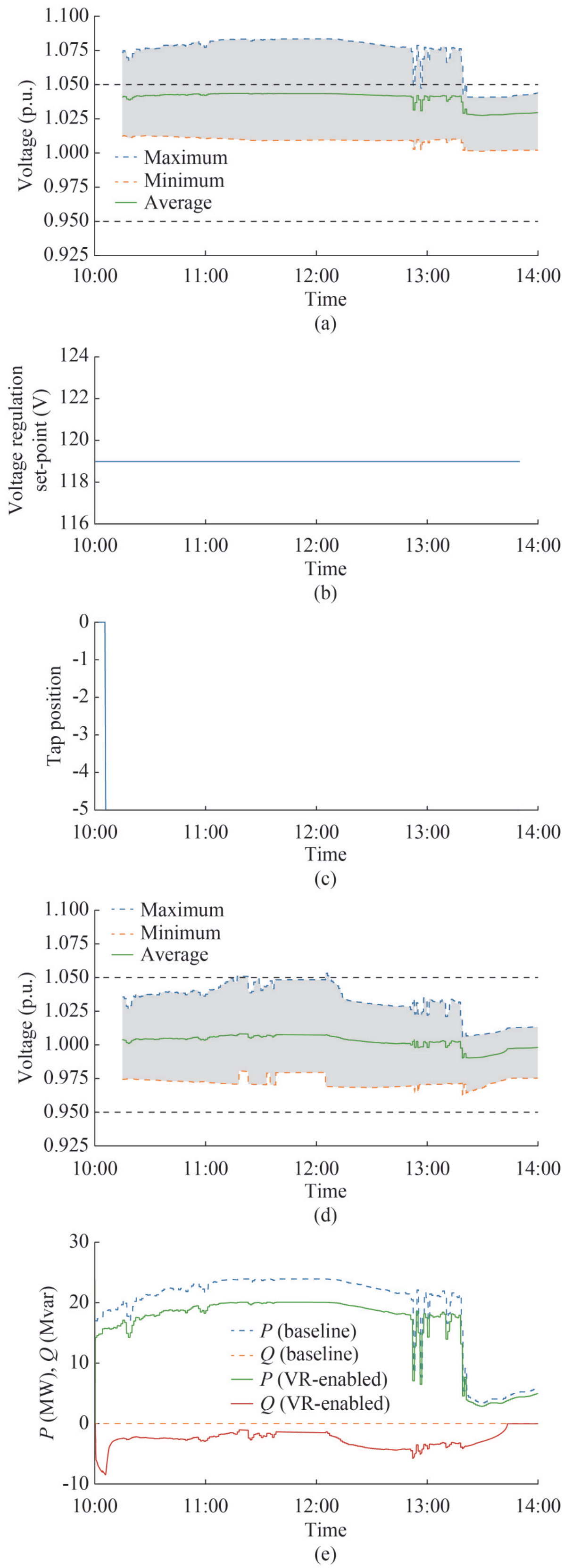

Fig. 4. Results from voltage regulation use case. (a) Bus voltages in baseline scenario. (b) LTC voltage regulation set-points. (c) LTC tap positions. (d) Bus voltages in VR-enabled scenario. (e) Total PV power outputs.

In a simulated environment, during the restoration of a de-energized island after a fault isolation, an overload is detected at the beginning of the feeder, and an overload alarm appears in the utility DERMS. It triggers a real-time constraint management application; and the application, among its resources for constraint resolution, detects a DER group managed by a DER aggregator consisting of batteries and solar PVs. The application computes the result that this DER group can provide enough flexibility to mitigate the overload condition. The command is consequently sent to the DER aggregator to increase the production of the resources in one of the DER groups managed by it. Finally, the DER aggregator dispatches the commands among its individual DER assets to increase production and alleviate congestion. Through the real-time measurements, the utility DERMS confirms that the overload issue is successfully mitigated, and the alarm disappears, informing the operator that the violation is successfully solved.

D. Participation of DERs in Electricity Markets Without Violating Technical Constraints

In accordance with their integration with a day-ahead electricity market, DER aggregators determine schedules for their DER groups. We propose that, to validate these schedules against technical constraints, DER aggregators send these schedules to the utility DERMS. These schedules are considered within the look-ahead constraint management application of DERMS, which determines if some of the schedules would violate the technical constraints. Therefore, for these DER groups, modified schedules as well as the maximum export and import limits are calculated within the DERMS and sent back to the DER aggregators, along with the positive validations for the rest of the schedules that do not violate any constraint. The DER aggregators accordingly modify the schedules for critical DER groups, and it is finally ensured that all the new schedules are valid and safe to be implemented when the time comes. The integration of the utility DERMS and DER aggregators is essential to effectively aggregate DERs to provide bulk grid services [28].

A variation of this approach is a new grid control architecture, referred to as the federated architecture for secure and transactive distributed energy resource management solutions (FAST-DERMS) [29], which is shown in Fig. 5. It is currently under development and proposes a distribution utility DERMS, which consists of flexible resource schedulers (FRSs) and an FRS coordinator. Each FRS schedules DERs within a substation service area. The FRS can control some DERs, which may include a building (B) or microgrid (MG) directly and others through a DER aggregator. Yet others may be managed through a transactive market manager (TMM).

The FAST-DERMS project focuses on enabling scalable aggregation and near real-time management of utility-scale and small-scale DERs through grid-aware, reliability-constrained economic dispatch by the FRS. It aims to support reliable, resilient, and secure distribution and transmission network services. Further, the advancements on multiple fronts, including communication standards, controls that effectively handle load and DER uncertainties, transactive market structures that ensure the protection of customer autonomy, DER anomaly detection methods, and fail-safe DER operating modes, are being developed for the successful provision of transmission services by distribution-connected DERs. These controls will be demonstrated at NREL using the ADMS test-bed.

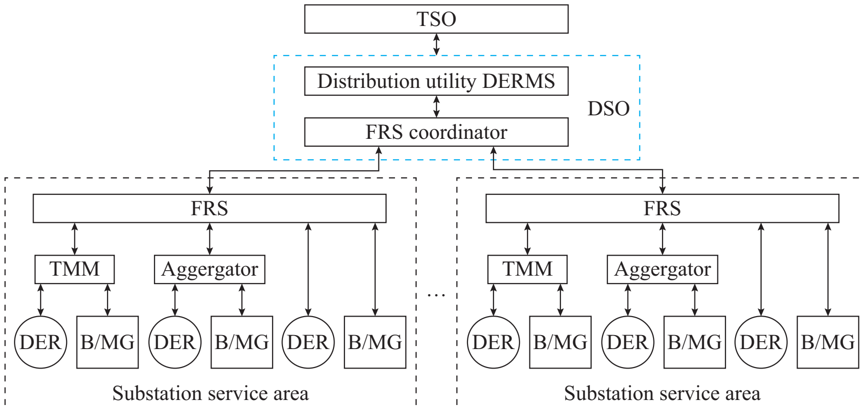

Fig. 5. Schematic of FAST-DERMS.

E. Discussion of Presented Use Cases

The presented use cases showcase the importance of DER management solutions to the emerging DSOs. First, the critically important awareness of the near real-time state of the highly dynamic conditions in emerging distribution networks is provided using DERMS and maximized by the integration of a utility DERMS and DER aggregators. Second, utility DERMS and DER aggregators provide DSOs with an ability to assist TSOs in their balancing needs and other important services, e.g., peak reduction, by intelligently using the flexibility of the available DERs and optimizing their output per the requests for aggregated power received from TSOs. Finally, to enable DERs to participate in the electricity markets, distribution utilities need to be sure that the technical constraints would not be violated by the (aggregated) DER schedules. As presented, this is also enabled through the integration of utility DERMS and DER aggregators, where the utility DERMS validates the schedules of DER groups against the technical limitations of distribution networks.

The aim of this paper with presenting these use cases has been to showcase the current state of the art in the development of DERMS industry. These are some of the latest examples from the real-life industrial use cases, and thus where the power system community and industry are currently standing with DERMS development is shown, especially with the integration of utility DERMS and DER aggregators. As presented, a lot has already been done, but to reach an ideal case that would provide effortless integration and management of the emerging distribution systems with high penetration of DERs, a much better understanding of different levels of DERMS solutions is needed, to use their full potential. We hope that this paper will contribute to this area and that it will help in better understanding how different hierarchical levels of DERMS solutions can work in coherence and contribute to an effortless DNO to DSO transformation and application in the emerging distribution network control centers.

V. Conclusion

With an ever-increasing penetration of DERs, driven by crucially important carbon reduction initiatives around the globe, traditionally passive distribution networks are rapidly evolving towards highly complex and dynamically changing systems. Such complex systems cannot be managed, controlled, or protected using legacy software solutions designed for traditional control centers; thus, control centers, along with the personnel of electric utilities, must evolve accordingly.

To enable such an evolvement, DERMS software solutions are emerging. DERMS software solutions are software packages aiming to provide DSOs, end-customers, and other stakeholders, with a set of tools that will enable them to cope with the challenges imposed by DERs. But the term DERMS is very broad and includes vastly different DER management solutions, aimed for different stakeholders and with different goals. On the one hand, mainly customer- and single-DER-related solutions, are decentralized software solutions called DER aggregators. On the other end, the fully grid-aware and centralized solutions, are so-called utility DERMS solutions.

In this paper, we explore the roles and responsibilities of these different DER management solutions and offer the view on how the optimal integration of a utility DERMS and DER aggregators leads to an ideal case for the future DSO, enabling a smooth shift towards emerging distribution networks with high penetration of DERs.

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