Overview of Evolving Distributed Energy Resource Grid Interconnection Standards

Preprint

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Evolution of Distributed Energy Resource Grid Interconnection Standards for Integrating Emerging Storage Technologies

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***Abstract*—Grid interconnection standards facilitate safe and reliable grid integration of distributed energy resources (DERs). Evolution of a standard for DERs is expected to capture and accommodate widely different characteristics of DER and minimize unique grid integration challenges. This makes development of a uniform grid interconnection standard for all types of DERs a challenging and an ever-evolving consideration. This paper presents a detailed timeline of evolution, from the early 2000s to 2018, of DER interconnection standards and the research that informed their development. This is followed by a review of the research topics being considered in the grid integration of Energy Storage Systems (ESSs) which are expected to have the most significant growth amongst all DER types. These help in highlighting the need for a new standard to accommodate the unique characteristics of ESSs, and where the existing DER interconnection standard frameworks may be leveraged.**

***Index Terms*— Energy Storage Systems, Distributed Energy Resource Integration, Interconnection Standards**

I. INTRODUCTION

Distributed Energy Resources (DERs) are defined as sources of electric power not directly connected to the bulk power system [1]. DERs by definition include generators capable of exporting active power to the electric power system [1]. Thus, generators such as solar photovoltaic (PV) and wind, fossil fuel-based generation technologies not directly connected to the bulk system, and energy storage systems (ESSs) such as batteries, can all be categorized as DERs. Each of these DERs has widely different characteristics and pose unique grid integration challenges. This diversity makes development of a uniform grid interconnection standard for all types of DERs a challenging and ever evolving consideration.

Interconnection of DERs and mitigation of grid impacts has been a global concern. Germany experienced a large amount of DER interconnection in their low voltage networks, which led to the development of BDEW (2009) and VDE 4105 (2012) for the medium and low voltage grids, respectively [2][3]. CEI 0-21, the Italian equivalent of VDE 4105, was published in 2011 and governs the connection of power generation and consumption plants [4]. Similarly, RD 1565 published in 2010 mandated dynamic grid support for all PV plants exceeding 2 MWs in Spain [5].

The first uniform power systems interconnection standard in the United States was the IEEE 1547-2003 [6]. IEEE 1547 has been a foundational document for interconnection of DERs. It was cited in the US Federal Energy Policy Act of 2005 and has since been adopted by a majority of states and used in the development of many state's own interconnection rules [7]. However, the penetration of DERs, particularly solar PV, increased significantly in most states in the years after this standard was developed. This increase prompted significant research on technologies to mitigate the potential adverse grid impacts. Technologies based on smart inverters, which are inverters capable of providing grid support functions (GSFs), dominated the bulk of this research [8][9]. These technological advancements resulted in a major revision to IEEE 1547 in 2018. This standard now addresses not only interconnection but also the interoperability of DERs with the area electric power system (EPS) and lays significant emphasis on mandatory grid support capabilities of inverter connected DERs.

PV penetration levels are certainly expected to increase further, but the total US energy storage deployments are also expected to increase much more rapidly from their current levels. The total US energy storage deployments are expected to reach 4 GW by 2023, which is 18 times higher than the total energy storage deployed in the US in 2017 [10]. A significant percentage of these deployments will be behind the meter which will pose substantial grid integration challenges. For instance, battery storage systems (BSSs) can act both as a load (during charging) and as a generator (during discharging), which might require network upgrades to accommodate the increased bi-directional power flow.

Thus, it is important to proactively design a new set of guidelines or a standard which considers the unique characteristics of ESSs and facilitates their reliable grid integration. One major ongoing effort in this direction is the development of IEEE 1547.9 for interconnection of energy storage DERs with the EPS. To better inform the development of such an ESS standard, this paper presents a detailed timeline of evolution of interconnection standards and the contemporary grid integration research which helped in their development in Section II. This is followed by a review of the current ESS grid integration research in section III, which highlights how a new energy storage standard can draw from the global DER integration research and what its key considerations should be.

II. Evolution of Interconnection Standards

Most state Public Utility Commissions (PUC) have developed state-specific grid-interconnection rules. Even though each state's rules may embody unique specifications, most tend to be based on IEEE 1547 [7]. To understand how state rules and grid integration research impacted the most recent revision of IEEE 1547, it is relevant to look at the state rules of California (CA) and Hawaii (HI), two states that experienced significant DER penetration in the years after IEEE 1547 was published. The state rule governing DER interconnections in CA is Rule 21 and its equivalent in HI is Rule 14H [11][12]. It is important to mention here that a state rule not only specifies the mandatory requirements for DERs but also provides guidelines to utilities on the interconnection approval steps to be followed to avoid adverse grid impacts. These steps are not included in IEEE 1547. This makes it even more important to consider their framework, as these state rules may also need revisions for facilitating safe ESS integration.

Figure 1 shows the three basic interconnection steps common to both of these state rules. To speed up the interconnection application approval process, the application is initially tested on a set of quick review screens. These screens estimate the DER's potential impact on the grid based on its capacity, existing DER penetration on the grid, and a few other characteristics. If the initial screen identifies a violation, a more detailed supplemental review is required. During supplemental review, power quality, voltage fluctuation, and safety and reliability metrics are evaluated. If any of these supplemental review screens identifies a violation, the application is sent for the interconnection study process, which involves running load flow, dynamic stability analysis, transient overvoltage, and short circuit and relay coordination studies on the feeder model. This screen determines if any grid upgrades are required before approving the interconnection.

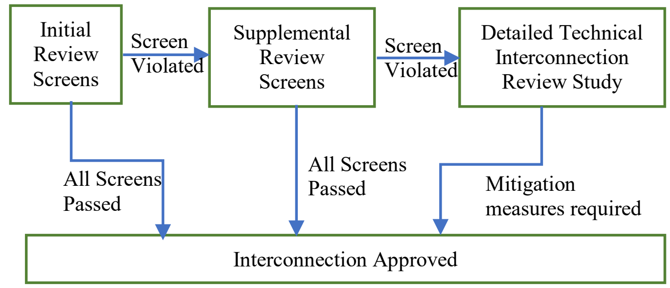

Figure 1. Interconnection approval steps in Rule 21 and Rule 14H

The similarities in these state rules are not limited to the application approval process alone. After IEEE 1547 and 1547.1, which provides the conformance test procedures for interconnecting DERs, were published the next major revision came out in 2018. During the intermediate years both state Rules 21 and 14H underwent similar revisions to manage increasing DER penetration. Figure 2 shows a timeline of evolution of state rules 21 and 14H.

IEEE 1547-2003 did not allow the interconnecting DER to actively regulate the grid parameters at the point of common coupling (PCC). This implied that any mitigation required would have to be through external upgrades. In 2011 the California Public Utilities Commission (CPUC) started looking at possibilities of using inverter connected DERs to mitigate their impacts by allowing active voltage regulation at the PCC. Later the same year the Electric Power Research Institute (EPRI) published a report on common smart inverter functions. These were created in collaboration with industry stakeholders and have undergone multiple revisions since then [8]. These smart inverter functions had the potential to alleviate DER

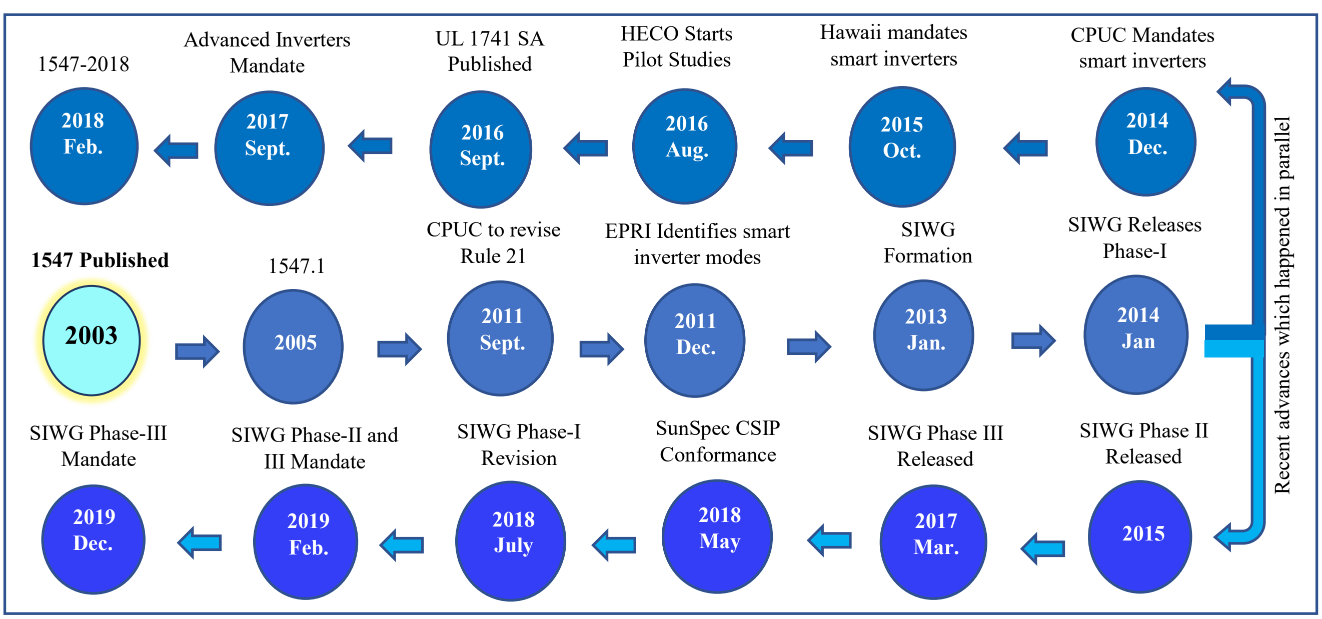

Figure 2. Timeline of evolution of interconnection standards and state rules

impacts locally, and the Smart Inverter Working Group (SIWG) was formed out of a collaboration between the CPUC and the California Energy Commission (CEC) in early 2013 to facilitate their rollout in CA. SIWG submitted its phase I recommendations to the CPUC in early 2014, which recommended that DERs be able to ride-through larger ranges of voltage and frequency fluctuations, have soft-reconnect capabilities after power outages, and actively regulate PCC voltage, such as volt-VAR control [13]. These recommendations were accepted by the CPUC, however, in the absence of an updated testing standard, the recommendations could not all be mandated the same year. However, all new installations were mandated to be smart inverters from 2014 in CA and from 2015 in Hawaii. In 2015 Hawaiian Electric also mandated ride-through capabilities.

Along with the required revision to the testing standards, the other major hurdle was identifying the communication requirements and standards for inverter connected DERs. The latter was the objective for SIWG's phase II recommendations [14]. Communication may be required between the utility and individual or facility DER operators and becomes critical in regions where DERs may have material impact on the power system. Smart Energy Profile 2.0/IEEE 2030.5 were the recommended default communication protocols. A key outcome was the development of the Common Smart Inverter Profile (CSIP), which provides a complete profile including a data model, messaging model, communication protocol, and security [15]. Meanwhile in 2016 the revised testing standard UL 1741 SA was published.

This was followed by the release of SIWG's phase III recommendations in 2017 [16]. It recommended the adoption of 8 advanced inverter functions: 1) Monitor key DER data, 2) DER disconnect and reconnect command, 3) Limit maximum active power mode, 4) Set active power mode, 5) Frequency watt mode, 6) Volt watt mode, 7) Dynamic reactive support, and 8) Scheduling power values and modes. Based on Resolution E4898 it was decided that functions 1,5,6 and 8 should be adopted 9 months after release of SunSpec Alliance Communication Protocol Certification Test Standard, whereas the remaining functions will be mandatory from December of 2019 [17]. The SunSpec CSIP was accepted in May of 2018, which implies that both Phase II recommendations on communication protocols and communication dependent functions of Phase III will be mandatory from February of 2019.

While these developments were taking place in CA, Hawaiian Electric (HECO) started pilot studies in collaboration with the National Renewable Energy Laboratory (NREL) in 2016 [9]. One of the key issues being addressed in these studies was the impact of operating the inverter connected DERs in reactive power priority mode. Until then all DERs were operated in real power priority mode, which meant that real power was never curtailed. This could be an issue when all DERs are operating at their peak capacity and have the highest potential for adverse grid impacts but are unable to provide reactive power support to the grid due to capacity constraints. This study found that reactive power priority mode provides significant grid support as shown in Fig. 3, where it can be seen that the volt-VAR VAR priority mode leads to lesser load voltages [9]. The average real power curtailment with volt-VAR VAR priority mode was only about 0.24% [18]. Consequently, reactive power priority was mandated in Rule 14H in early 2018 and in July of 2018 SIWG also revised Phase I to reactive power priority.

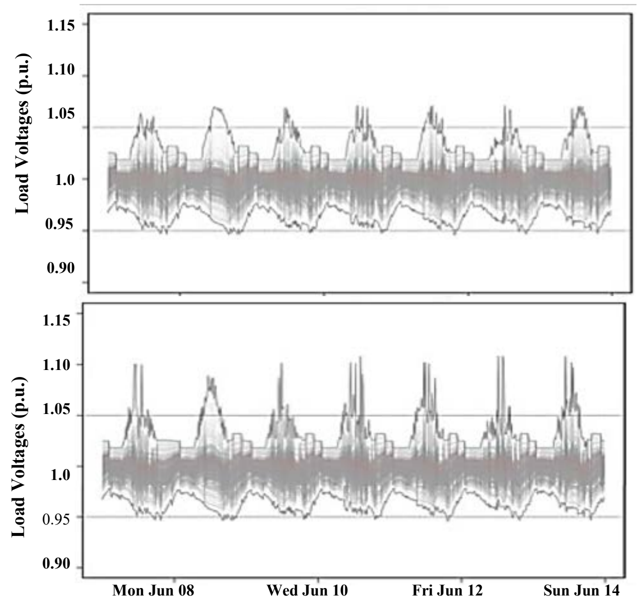

Figure 3. PV Systems in volt-VAR VAR priority mode (top) and volt-VAR watt priority mode (bottom) [9]

The impact of all these developments, grid integration research and the lessons learnt can be seen in the latest revision of IEEE 1547 as well. For instance, the latest version of this standard has introduced normal and abnormal operation performance categories for DERs [1]. The normal operation categories define the minimum capabilities required from DERs for voltage regulation and reactive power and includes GSFs such as Volt-Var and Volt-Watt. The abnormal performance categories on the other hand define the mandatory minimum ride-through requirements during voltage and frequency disturbances. This standard also requires DERs to support at least one of the eligible communication protocols, which include IEEE 2030.5, SunSpec Modbus and IEEE 1815 (DNP3). This discussion highlights that it is likely that the current ESS grid integration research will also influence the ESS standard development.

A similar interconnection standard evolution process can be seen in other parts of the world as well. Significant amount of work has been done in Europe and in Asia to update interconnection standards. These standard development efforts are often leveraged while developing new standards. For instance, the Central Electricity Authority (CEA) in India amended the CEA Technical standards for connectivity to the grid for the second time in 2016 [19]. This amendment contains guidelines on acceptable levels of voltage and current harmonics and uses the guidelines defined in IEEE 519 and

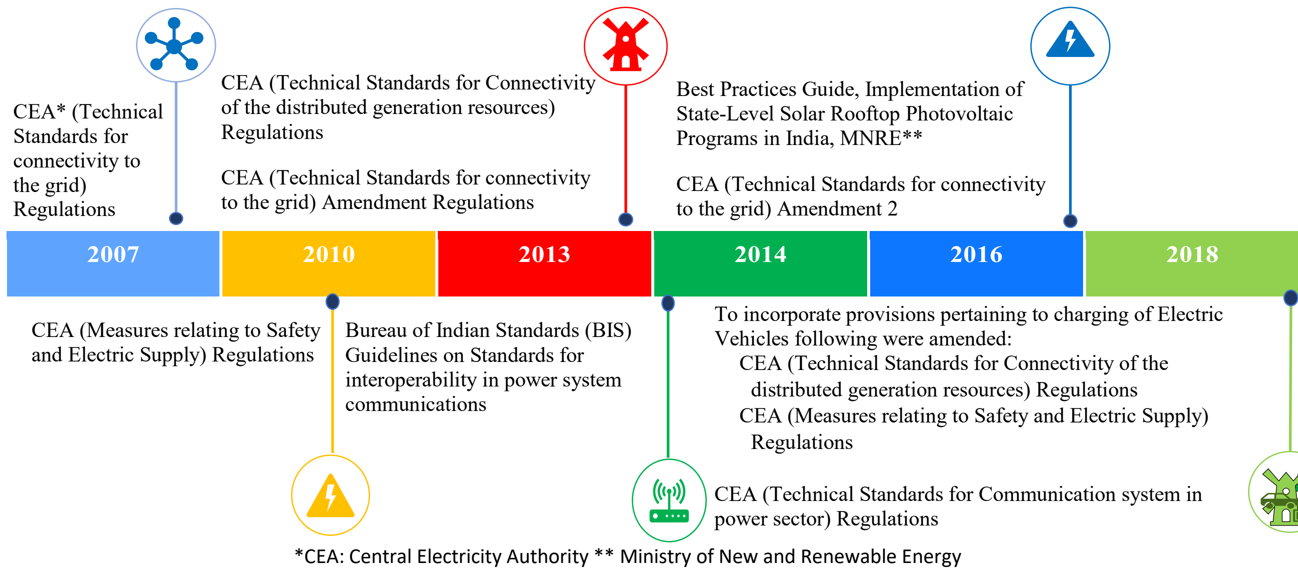

Figure 4. Timeline of evolution of interconnection standards in India

IEC 61000-4-30 standards for the methods of harmonic measurement and meter specifications respectively [20], [21]. IEC 61727 is a commonly used standard for PV systems in Europe which works along with IEEE 1547 and aims to unify interconnection standards used globally [22]. For micro generation EN 50438 is commonly used in Europe [23]. In New Zealand, the commonly used distribution interconnection standard is the AS/NZS 4777 which itself was recently revised [24]. Its latest draft covers inverter connected distributed generators connected to low voltage networks while the previous version only specified per phase power ratings [25].

The Government of India has established a renewable energy target of 175 GW by 2022, which translates to a wind and solar penetration level of 22% of India's projected electricity consumption [26]. The target includes 40 GW of rooftop solar, all of which would be at the distribution level. To manage their grid impact, CEA published the Technical Standards for Connectivity of the distributed generation resources in 2013, which were then revised in 2018 to incorporate provisions pertaining to charging of electric vehicles [27]. Similarly, communication was considered critical for interoperability in the power system, and the Bureau of Indian Standards (BIS) published communication guidelines in 2014. Subsequently in 2018, CEA published the technical standards for communication system in power sector [28]. A more comprehensive timeline of power system standards development in India is shown in Fig. 4.

III. Storage Technologies Standard Development

Energy storage systems consist of batteries, flywheels, pumped hydro, large-scale thermal storage, fuel cells and super capacitors (ultracapacitors). Even though IEEE 1547 is applicable to all DERs, energy storage systems present unique challenges and opportunities. For instance, battery storage systems (BSSs) can act both as a load (during charging) and as a generator (during discharging), which might require network upgrades to accommodate the increased bi-directional power flow. On the other hand, the significant advantage with BSSs is that their charging/discharging rates and times are controllable and therefore unlike PV systems, batteries are dispatchable.

These characteristics highlight the need for the development of a separate standard for ESSs, such as IEEE 1547.9, to standardize their unique grid support functionalities. This standard however should build upon the existing DER interconnection standards. Section II highlighted the significant impact grid integration research had on the development of IEEE 1547; thus, it is worthwhile to look at the use cases being developed in the ongoing ESS grid integration research.

A. Use cases for utility-scale ESSs

As the name suggests a utility-scale ESS is installed to provide support to a utility's distribution feeders. The capacity of these systems may range from few hundred kWh to MWh, depending on the intended use [29]. To maximize the revenue streams achievable from these ESSs, a significant amount of research is currently underway for development of potential use cases [30][31]. Some of these use cases that try to maximize the utilization of the dispatchability and controllability of ESSs are:

- Peak shaving: The ESS is charged during low load periods and discharged during the high load conditions to reduce the peak demand [30]. This service can avoid the use of more expensive generators, which are brought online only during peak load conditions.
- Renewable energy capacity firming: The ESS tries to smooth out the variable renewable generation in this use case [30]. ESS can be charged during the periods when renewable generation exceeds the load and discharged during low generation periods, effectively smoothing the variability.

- Voltage support: This use case is very similar to GSFs of inverter connected DERs. As the ESS is also inverter connected, it can absorb and inject reactive power based on the local voltage [30].
- Frequency Support: Similar to modes specified for DERs in IEEE 1547, the ESS system can also participate in low/high frequency ride through and frequency-watt functions. These functions help in regulating the system frequency. For instance, in the frequency-watt mode of operation, the ESS modifies its charging and discharging rates based on the specified frequency-watt curves to regulate the system frequency with the standard limits [31]. The ride through modes on the other hand provide support to the grid during an emergency provided the system frequency doesn't go beyond the must trip boundaries.
- Energy arbitrage: If the utility follows a time of use (TOU) tariff structure, the ESS can be charged during the low tariff periods and discharged during the higher tariff periods [30]. This is similar to the peak shaving function, except the control signal is based on tariffs instead of the system load.

B. Use cases for residential ESSs

Residential ESSs may be used alone or coupled with other DERs, typically PV systems. There could be several different use cases based on the way the ESS is being used, existing tariff structures, capacity and the capabilities of its inverter system.

- Backup: Here the residential ESS, typically a BSS, is used for providing backup power during an outage event. This use case may have minimal impact on the grid as outage events are infrequent and BSS only uses a small amount of current for trickle charging to counter the self-discharge rate. However, the potential of the BSS remains underutilized.
- Demand Charge Reduction: Some utilities now have a demand charge for residential customers. The customer's peak monthly demand is the maximum of all 15 or 30-minute average demands. A fixed amount is charged if the peak demand exceeds the values provided in the tariff. The ESS can help in reducing the demand charge by supplying the residential load demand whenever it reaches near the tariff limits.
- Energy arbitrage: Similar to the utility scale ESS use case, a residential ESS can also be charged during the low tariff periods and discharged during the high tariff periods to earn money, provided TOU tariff structure exists for the residential customers.

C. Using current DER interconnection standards for developing energy storage standards

The use cases described in the previous sections for utility-scale and residential ESSs are only some of the many possible options. For instance, the Modular Energy Storage Architecture - Energy Storage System (MESA-ESS) standard, one of the first standards dedicated exclusively to the communication requirements for ESSs, describes about 27 possible functions or modes an ESS may be operated in [31]. However, the use cases discussed here highlight the key requirements and capabilities of these systems. Most of these use cases require information about the existing grid parameters such as voltages, frequency, tariff structure, load demand, renewable generation among others. This requires a robust and standardized communication system. Secondly many of these use cases can overlap. For instance, a frequency event or an outage may occur while the ESS is providing reactive power support. To ensure proper interoperability a priority order is required. Most of these issues have already been addressed in the latest revision of IEEE 1547. It mentions the default communication protocols and also defines the priority order for the different DER modes of operation. For example, the voltage and frequency ride through requirements take precedence over all reactive power support modes.

Considering these points, the rationale for a new ESS standard, such as IEEE 1547.9, is to provide a standardized set of grid support functions that consider the unique characteristics of ESSs, building upon the reactive power support and disturbance ride-through GSFs already described in IEEE 1547-2018. Also, a performance category approach described in IEEE 1547-2018 can be adopted to allow different ESS types, such as lead-acid, lithium ion, sodium-sulfur, flow batteries, fuel cells etc. to be integrated based on their widely different capabilities [32]. This standard should also provide a priority order scheme that ensures grid reliability and resiliency by considering the criticality of each of these GSFs. Since communication is mandatory for the implementation of most of these functions, this standard should provide standard communication protocols including cyber security requirements. Additional technical specifications or requirements may have to be included to ensure safety and power quality if any ESS related grid reliability concerns are highlighted in the ongoing research. The state interconnection rules might need to be revised to include additional review screens if any such concerns arise, otherwise the interconnection approval process could still have the same 3 stages. Finally, a testing standard will have to be developed to ensure ESS conformance with each of the GSFs identified in the new standard.

IV. CONCLUSIONS

Grid integration of energy storage systems (ESSs) is expected to increase rapidly due to their projected fall in costs and ability to provide a range of grid services. A new standard that specifies grid support functions and technical specifications for ESSs while considering their unique characteristics is required to facilitate their grid integration, while ensuring grid reliability and resiliency. However, this new standard can build upon the existing interconnection standards to expedite the process. This paper presented a timeline of the evolution of grid interconnection standards and how this process was influenced by the contemporary challenges and renewable energy grid integration research. The review of ongoing ESS integration research presented here highlighted how the existing DER standard frameworks can be molded into a new ESS standard and where additional effort might be required.

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