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Exploring Customer Interoperability Pathways with the Utility and Grid Service Providers

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SUMMARY

The power grid is undergoing a transformative shift driven by decarbonization, decentralization, and digitization. This transition is leading to a more distributed, dynamic, and complex power grid, reliant on Information and Communication Technology (ICT) and automation. The traditional role of electricity customers is evolving from passive consumption to becoming proactive prosumers with diverse "wants and needs," including self-generation through renewable energy, enhanced resiliency using energy storage, and the adoption of electric vehicles and devices. However, their main objective remains the same: to reliably meet their electric energy demand. Meanwhile, the modern grid is undergoing significant changes, posing challenges to power system reliability and stability, including the retirement of large coal power plants in favor of cleaner energy sources and the ever-increasing integration of inverter-based renewable energy resources to accommodate the growing energy demand.

This paper explored three methods and their associated ICT for interfacing with customer smart devices: interface via OEM aggregator, local gateway device, and home energy management system (HEMS). Then these methods were compared and assessed based on a selected set of criteria: communication performance, cybersecurity resilience, scalability and flexibility, spectrum of grid support functions, and customer conform. By examining these approaches, we aim to provide insights into the most suitable solutions for integrating customer smart devices into the power grid and enhancing the overall grid functionality and customer satisfaction.

Device communications via aggregators is the most straightforward to implement, leveraging existing OEM and customer communications infrastructure to provide an array of grid-supporting functions. However, there may be performance and data access challenges associated with OEM aggregators to support the full range of use cases by a utility or a 3rd party grid service provider. Device communications via local gateways can potentially provide a more effective solution to these challenges. However, this approach comes with the trade-off of increased system complexity and higher costs associated with the installation and implementation of new devices. Assessing the cybersecurity implications of each approach

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presents significant differences. Device communications via HEMS enable the most optimal resource allocation for grid services while simultaneously considering a customer's desired comfort level. HEMS can take on the characteristics of either of the other two interoperability pathways, contingent on whether it is implemented in the cloud or locally within the building. The development of HEMS is primarily undertaken by smart home technology companies. This could potentially lead to challenges in coordinating with utility and grid service provider systems if the applications solely focus on addressing customer "wants and needs" without considering the broader integration and compatibility requirements of the utility and grid infrastructure.

Ultimately, the selection of the appropriate solution depends on several factors, such as desired use cases, required functionality, and the type of customer resources. This renders the decision flexible, allowing for adaptability based on specific needs and circumstances. The primary goal when choosing an interoperability pathway is to enhance overall grid attributes and customer satisfaction while fostering coordination between bottom-up and top-down power system features. This focus on improving both grid performance and customer experience contributes to a stronger and more adaptable power infrastructure.

KEYWORDS

Interoperability Pathways, DER Gateway, Aggregator, Building Energy Management System, Empowered Customer, Challenged Grid, Grid Support Functions

Introduction

The power grid is undergoing a transformative shift driven through decarbonization, decentralization, and digitization. The grid of the future will be more distributed and dynamic, reliant on optimization and automation, and exchange of data at all system levels to manage the complexity. In the new architecture, both a bottom-up as well as a top-down perspective is required to build-out a robust power system where "the wants and needs" or objectives of all stakeholders are met simultaneously with power security and fairness as the two key tenets.

Historically, customers have strictly been consumers of electricity and the only way to decrease bills was to consume less. Even in the current landscape of smart meters, customers typically only have access to their monthly usage, and there is often no choice as to who they buy this electricity from. However, the traditional role of electric customers as mere energy consumers is evolving, with the emergence of a more active and prominent role in shaping the future grid. This new type of customer, known as the prosumer, has emerged with diverse desires and goals. Prosumers can seek real-time insights into their energy usage, opt for sustainable self-produced electric power through rooftop solar, invest in battery energy storage for backup during grid outages, prioritize economic and timely Electric Vehicle (EV) charging, aim to reduce electric bills, view solar and energy storage as investments, and value comprehensive information and insights on their energy use.

On the other hand, the traditional role of the distribution operator is centred around ensuring a secure, reliable, and stable grid operation, while keeping costs low and efficiently allocating resources. However, the paradigm shift brought about by decarbonization, decentralization, and digitization is reshaping the grid and introducing new objectives, presenting both challenges and opportunities for distribution operators. Now, they must address the risks associated with integrating new Distributed Energy Resources (DERs) into their systems. Beyond risk mitigation, they are tasked with finding ways to seamlessly integrate DERs into the grid and harness their benefits and services. As the landscape evolves, 3rd party service providers, such as Independent Power Producers (IPPs) and aggregators, are expected to play a pivotal role. These 3rd party entities will aggregate various resources into their portfolios, offering support functions and creating new revenue streams.

To align with the objectives of emerging customers and the evolving grid, a novel architecture must be established to support a bottom-up approach to grid development. Essential to this new paradigm is the customer interoperability with the utility and grid service providers to efficiently optimize and foster value-sharing among the stakeholders. This paper explores three methods and their associated ICT for interfacing with customer smart devices: interface via aggregator, local gateway device, and HEMS. The assessment of each method is based on a selected set of criteria: communication performance, cybersecurity resilience, scalability and flexibility, spectrum of grid support functions, and customer conform.

The Role of the Emerging Customer in Empowering the Future Grid

This section outlines the primary use cases supported by integrating and interfacing the customer domain with grid operations and service provider domains. Fig. 1 lists an example of grid service functions focusing on customer domain, showcasing key elements of a bottom-up power system model. The diagram can be extended to all power system levels, however the focus of this paper is the intersection between the customer and grid domains.

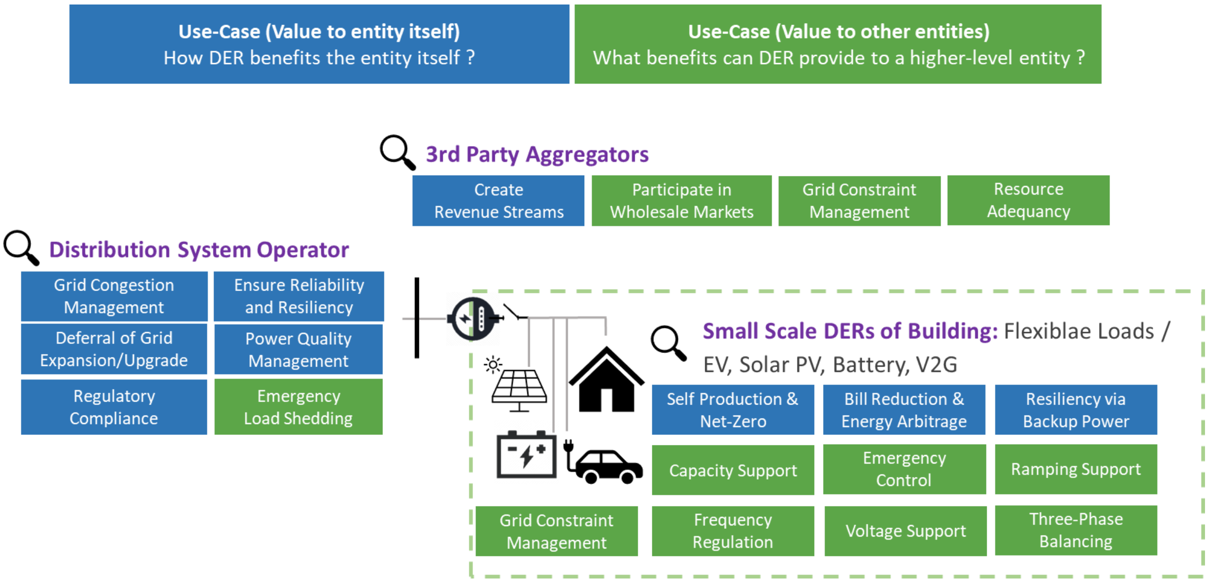

Figure 1: Example Customer Domain Grid Service Functions

In addition to economically and reliably meeting their electric demand with acceptable power quality, prosumers have the flexibility to make environmentally responsible choices, enhance resilience against power outages, and get financial compensation for providing grid support functions. On the other hand, the modern grid is undergoing significant changes, including the retirement of large coal power plants in favour of cleaner energy sources and an increasing adoption of inverter-based renewable energy resources. These trends lead to a grid with reduced inertia and limited controllability due to the decreasing availability of dispatchable resources.

It's important to note that all these changes are happening in a grid that was not originally designed for bidirectional power flow.

Hence, a symbiotic relationship between the empowered customer and the challenged grid becomes essential to establish a robust and dependable grid of the future. The emerging customer assumes an active role by offering a diverse range of grid services, helping to balance supply and demand across various power system levels and timeframes. As reflected in Fig. 2, interoperability is key to achieving seamless interaction between the customer and grid operations and 3rd party service providers. Interoperability is enabled by not only new technology, but also industry consensus through standardization and organizational processes. Secure interface with adequate performance is necessary to achieve interoperability, catering to the unique requirements of each use case. These requirements may vary significantly across different scenarios, necessitating a flexible and adaptable approach.

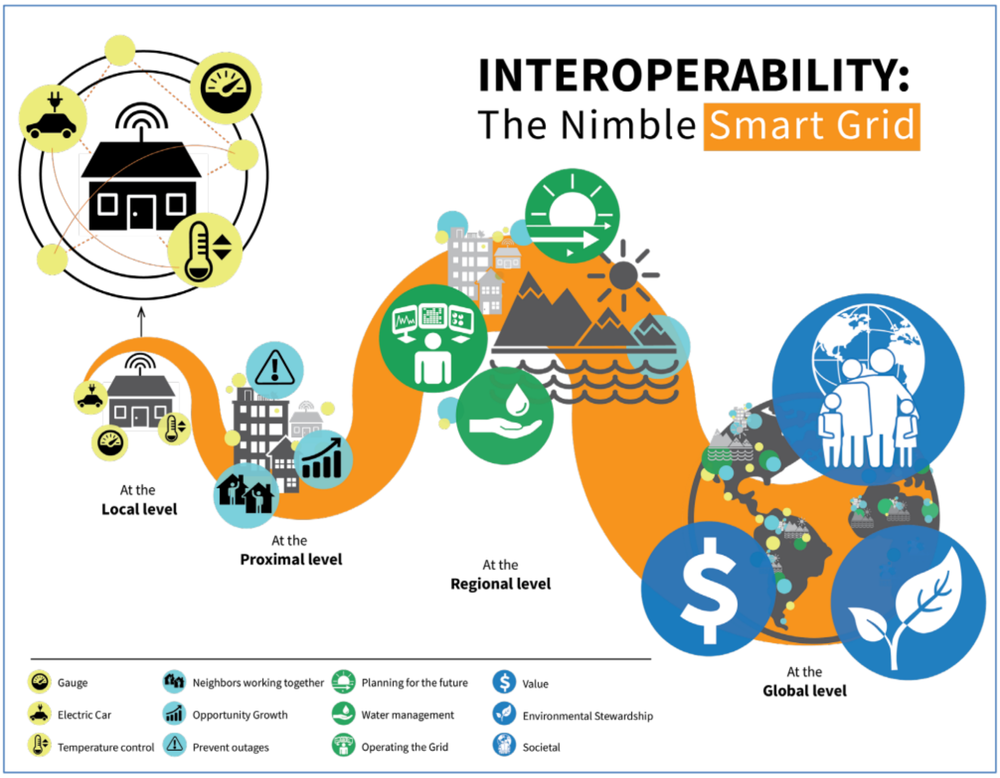

Figure 2: Illustration of how value accrues as interoperability flows from the local to the global level [12]

Customer Interoperability Pathways with The Utility and Service Providers

The current state of a typical utility and customer device interactions largely consists of disparate Demand Response (DR) programs and EV managed charging programs controlled directly or through price signals based on bulk power system market. These programs are commonly managed by utilities via OEM aggregators (e.g., Resideo [18] by Honeywell, Powerhub [16] by Tesla) or more recently by DER type specific management platforms (e.g., WeaveGrid [25] managed charging, Uplight [24] demand management, Leap [10] virtual power plant (VPP) aggregation). These systems and platforms often exist siloed from one another and lack visibility of the distribution operations. Applications of these programs are thus limited to simple use cases with limited capability such as peak load shaving or participation in capacity wholesale markets through a utility's commercial operations group.

The future state of utility and customer device interactions will require the use of a Distributed Energy Resources Management System (DERMS) to aggregate and optimize device capabilities [3][12]. DERMS rises from a grid operator need to manage high Distributed Energy Resource (DER) penetration at the distribution level. Visibility and control of DERs will thus become key to safe and reliable operation of the grid [23] as opposed to historically supplemental support.

Interoperability and cybersecurity will be of critical importance to this new operational structure. Different architectures for a utility and customer device interactions inherently support or challenge interoperability at different levels, impacting the flow of value shown in Fig. 2. Cybersecurity will be key to protecting this complex new communication network and a grid that is increasingly powered by distributed, customer-owned assets. Different architectures pose different performance, cybersecurity, scalability, flexibility, and cost considerations as the scope and quantity of information shared between the various actors and devices differs.

There are different methods of establishing interoperability between the customer domain and the other domains. Here we will describe the three methods and in the next section compare these methods based on a set of criteria.

Device communication via aggregators as shown in Fig. 3 is the natural evolution of current customer-device management programs. Device-level communication is provided via OEM aggregators relaying information between individual devices and a utility or a 3rd party service provider DERMS. Thereby, this interoperability pathway establishes a hierarchical control structure with information flowing bi-directionally between OEM aggregators, customer devices, and utility and grid service provider DERMS. Between the OEM and the DER type, proprietary communication protocols are typically used but standards-based communication protocols can also be utilized. Standard smart-grid protocols (e.g., IEEE 2030.5 [4], OpenADR [15]) provide generalized smart-grid function sets and may be convenient for data interoperability between DERs and DERMS platforms providing grid services. On the other hand, adopting device-specific standard protocols (e.g., OEM-specific EV protocols) can offer a higher level of granularity in terms of visibility and control, focusing on customer preferences as well as OEM asset maintenance and management. Primarily, the utilization of proprietary protocols undermines interoperability and hinders the engagement of numerous diverse grid actors.

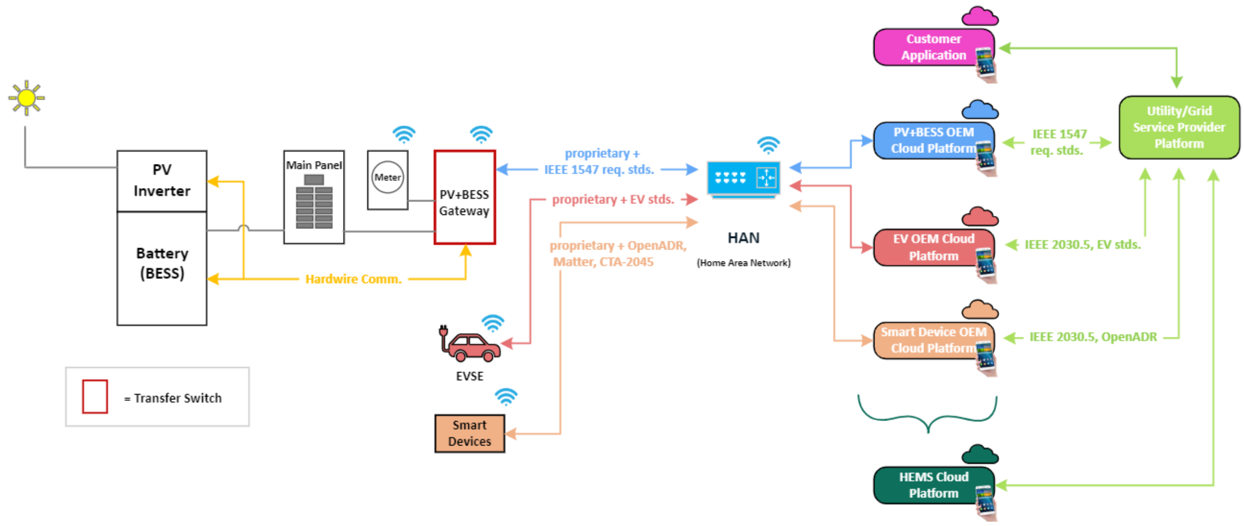

Figure 3: Device communication via OEM aggregator pathway

Device communication via site-based gateways as shown in Fig. 4 may include ecosystem or device specific gateways (e.g., Tesla [17]), smart meters (e.g., Itron [5]), and grid operator or DERMS vendor supplied gateways (e.g., Kitu [9], [1]). This establishes a largely new, standards-based communication network at the device level. Device-agnostic smart-grid protocols are used between utility or grid service provide platforms and DER gateway(s). Utility or grid service provider communications can extend to each induvial DER's gateway device or a single gateway at the home that serves multiple DERs. A single gateway device mentioned can be implemented as part of a smart meter or a stand-alone device.

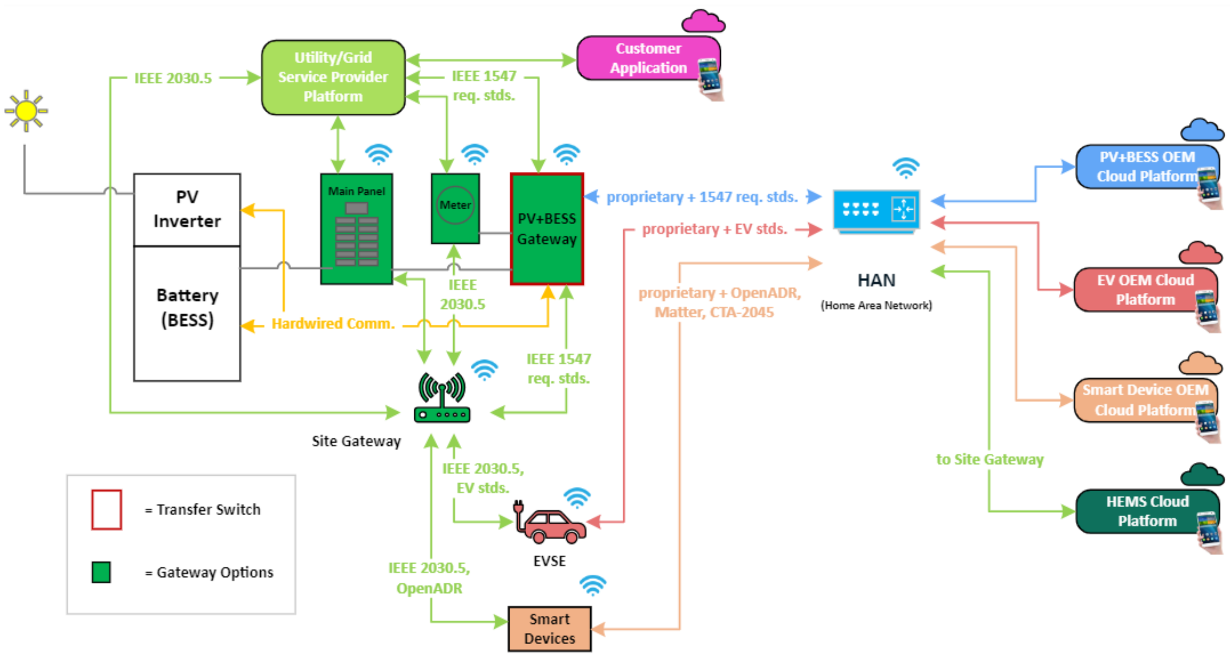

Figure 4: Device communication via DER Gateway pathway

Device communication via Home Energy Management Systems (HEMS) (or Smart Home Energy Management Systems, SHEMS) as shown in Fig. 5 may be coordinated by a utility or a 3rd party service provider platform via cloud platforms or via locally sited, gateway intelligence. As such, the aforementioned interoperability pathways, which encompass both architecture-related pros and cons, may be applicable. It is impractical to employ methods for individual home optimization (e.g., MPC) at this high level given that grid-service providers primary focus is on the greater distribution system. Customers "wants and needs" are naturally prioritized by a HEMS; however, grid operators can utilize tools such as price signaling and lump-sum participation incentives to align HEMS actions with their own grid-management objectives. Different HEMS providers may leverage AI-based optimization [26], Model Predictive Controls (MPC) and Building Energy Modeling (BEM) engines for HVAC systems [14], wireless meters [20] and smart panels [22] for monitoring non-intelligent loads, and other developing technologies. There is currently only one EnergyStar certified SHEMS on the U.S. market [21][19] but end-to-end HEMS solutions are projected to emerge rapidly in the coming years especially given industry convergence on smart home device communication standards [11].

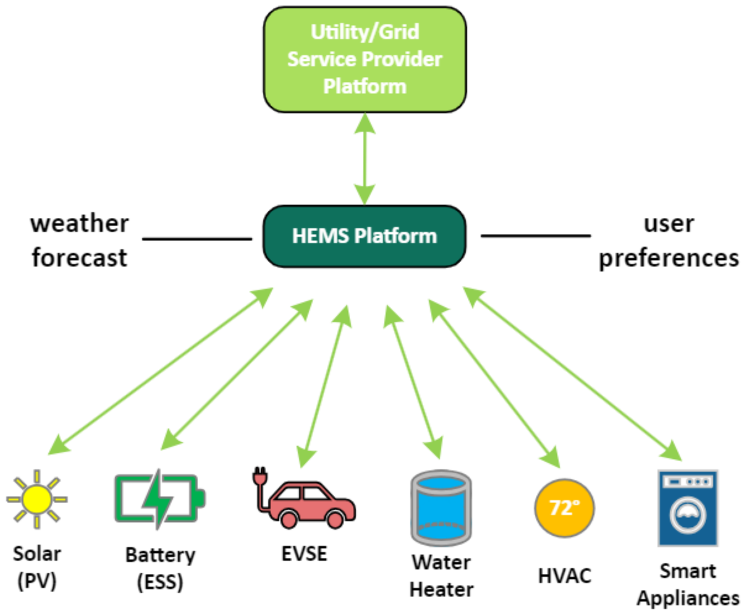

Figure 5: Device communication via Home Energy Management System (HEMS)

Comparison of Customer-Domain and Grid-Service-Domain Interface Methods

In the previous section the three methods of interfacing between the customer and a utility or grid service providers were described. In this section several key criteria are used to assess the strengths and weaknesses of these interoperability methods, results summarized in Table 1. This is not a comprehensive quantitative evaluation, but an assessment based on product offerings on the market, and communication protocol and architectural capabilities of each method. Furthermore, it is important to acknowledge that the comparison between the various methods may vary depending on the specific use case selected for implementation, as indicated in Fig. 1.

Table 1: Comparison of Customer-Domain and Utility and Grid-Service-Domain Interoperability Pathways

Assessment Criteria	**Communication Performance**	**Cybersecurity Resilience**	**Scalability & Flexibility**	**Grid Support Functions**	**Customer Comfort**
OEM Platform	Low-to-Mid	Mid-to-High	High	Mid	Low-Mid
DER Gateway	High	High	Mid-to-High	High	Low-Mid
HEMS	Low-to-High	Mid-to-High	Low	Mid-High	High

Communication Performance: A communication standard itself does not define specific communication latency values as it depends on various factors such as the underlying communication technology, network setup, device capabilities, and the complexity of the operations being performed. However, several assessments can be made based on the number of communication layers, software overhead used in communication, and applicable communication equipment and systems. Direct communication allows for immediate and real-time response as there is no intermediary layer. On the other hand, an OEM platform has more software layers which introduces further delays. Availability of the link is also lower than the direct communication because of use of customer Wi-Fi and internet compared with direct communication. DER Gateways and customer-sited HEMS allow for direct communication with the utility or grid service provider management platforms via public or private cellular networks. An additional layer is the cloud-to-cloud communication between OEM platform and the managing entity required to complete the end-to-end communication. HEMS may utilize either communication pathway; optimizing devices in a cloud platform adds yet another layer of cloud-to-cloud communication while optimizing devices in a gateway maintains a single, direct path for communication.

Cybersecurity Resilience: Each OEM platform selects their own communication protocols, and, in most cases, these are propriety protocols although standards-based protocols can also be used. he selection of security mechanisms, including firewalls, authentication, and encryption, is at the discretion of each OEM. Consequently, from the viewpoint of a utility or grid service provider, the attack surface expands with the number of OEMs it interfaces with, while this parameter remains relatively constant in the case of direct communication via DER Gateways. A breach of a single OEM platform may not necessarily threaten the rest of the system as DERMS communication with OEM aggregators is specific to those distributed (scattered) assets. This is in contrast to DERMS communications associated with site-wide gateways or HEMS platforms that convey location-aggregated information and control. Building-level aggregation does however have the benefit of allowing devices to be hidden behind a single, securable gateway [13].

Scalability and Flexibility: As the number of DERs increases, managing them individually through DER Gateway devices and HEMS becomes increasingly challenging. Implementing a uniform program for customers to adopt standardized devices could alleviate this difficulty, but it may also incur additional costs. On the other hand, aggregator platforms are specifically designed to handle large-scale aggregations, offering a potential solution to the growing complexity. In other words, with OEM aggregators, the complexity of interfacing with individual DERs is largely hidden from managing entities. Therefore, this approach allows for a more straightforward and streamlined interconnection and interface process. In essence, OEM aggregators simplify the management of DERs, enabling seamless integration into the grid and optimizing their collective potential. Conversely, the advantage of device communication via gateways is that once the gateway infrastructure is in place, a utility or any third-party service provider can utilize standard-based protocols to establish communication with gateway-based devices to implement their use cases and programs.

Spectrum of Grid Services: Use cases and functionalities that are expected from aggregation of DERs are of foremost importance in selection of the right interface method. The communication link and edge intelligence play a pivotal role in supporting these functionalities. For instance, an OEM aggregator with a communication latency of 1 minute or more would be unsuitable for use cases that require swift response times, such as frequency regulation markets or emergency grid services. Furthermore, data-sharing is imperative; if the OEM aggregator fails to provide the location of individual DERs, the utility DERMS would be unable to assess the low-voltage impacts of the DERs' services. Therefore, a well-considered choice of interface method, coupled with efficient communication and data-sharing capabilities, is paramount for realizing the full potential of DER aggregation.

Customer Comfort: The role of electricity customers is evolving from being pure consumers to becoming prosumers. However, their primary objective remains the same - to reliably meet their electric energy demand. It is essential for customers to sustain their comfort level while seamlessly aligning with the grid objectives. HEMS can play a vital role in achieving this balance. By having insight into customer appliance usage levels, timings, frequency, and preferences, HEMS can automatically schedule and set devices to align with grid service requests. This includes determining the appropriate combination of resources to offer to the grid service provider, ensuring both customer needs and grid requirements are met simultaneously.

Conclusion

A symbiotic relationship between the empowered customer and the challenged grid is becoming vital to establishing a reliable, resilient, and decarbonized grid of the future. Integral to this new paradigm is customer interoperability with their utility and a variety of grid service providers, fostering seamless interaction and efficient asset utilization for grid support functions. This paper explored three methods and their associated ICT for interfacing with customer smart devices: interface via aggregator, local gateway device, and HEMS. Then these methods were compared and assessed based on a selected set of criteria: communication performance, cybersecurity resilience, scalability and flexibility, spectrum of grid support functions, and customer conform.

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