A Review on Active Customers Participation in Smart Grids

Konrad Schmitt, *Student Member*, *IEEE*, Rabindra Bhatta, *Student Member*, *IEEE*, Manohar Chamana, *Member*, *IEEE*, Mahtab Murshed, *Student Member*, *IEEE*, Ilham Osman, *Member*, *IEEE*, Stephen Bayne, *Senior Member*, *IEEE*, and Luciane Canha, *Senior Member*, *IEEE*

***Abstract*—Industrial, commercial, and residential facilities are progressively adopting automation and generation capabilities. By having flexible demand and renewable energy generation, traditional passive customers are becoming active participants in electric power system operations. Through profound coordination among grid operators and active customers, the facilities' capability for demand response (DR) and distributed energy resource (DER) management will be valuable asset for ancillary services (ASs). To comply with the increasing demand and flexible energy, utilities urgently require standards, regulations, and programs to efficiently handle load-side resources without trading off stability and reliability. This study reviews different types of customers' flexibilities for DR, highlighting their capabilities and limitations in performing local ancillary services (LASs), which should benefit the power grid by profiting from it through incentive mechanisms. Different financial incentives and techniques employed around the world are presented and discussed. The potential barriers in technical and regulatory aspects are successfully identified and potential solutions along with future guidance are discussed.**

***Index Terms*—Active distribution network (ADN), ancillary services, energy management, flexible demand, resiliency.**

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K. Schmitt (corresponding author), R. Bhatta, M. Murshed, and S. Bayne are with the Electrical and Computer Engineering Department, Texas Tech University, Lubbock, TX, 79409, USA (e-mail: konradkorkschmitt@ieee. org; rabindra. bhatta@ttu.edu; mmurshed@ttu.edu; stephen.bayne@ttu.edu).

M. Chamana is with the Wind Energy Program, Texas Tech University, Lubbock, TX, 79409, USA (e-mail: m.chamana@ttu.edu).

I. Osman is the Design Release Engineer at Electrification and Power conversion, General Motors, GM Tech Center Road, Warren, MI, 48092, USA (e-mail: iosmanunsw@gmail.com).

L. Canha is with Electromechanical and Power Systems Department, Federal University of Santa Maria, Santa Maria, RS, 97105-900, Brazil (e-mail: lucianecanha@ufsm.br).

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I. INTRODUCTION

IN today's diverse energy market, the security of energy supplies and minimizing risks of instability and dependence are essential and require decentralized and diversified energy management. In this changing landscape of energy demand, the development of renewable energy sources (RESs) can count to be a feasible solution. Environmental concerns and federal and state financial incentives encourage customers to adopt these technologies. These adoptions lead to a rising level of distributed generation (DG) and distributed energy resource (DER) usage integrated into the distribution systems. Until recently, distribution system operators (DSOs) could predict each feeder's typical power consumption curve. However, in recent times, due to the higher level of DERs, utility companies are facing new challenges in operating and planning active distribution networks (ADNs) [1]. The uncoordinated integration of DERs has raised the dynamics and unpredictability of the mated distribution systems. This phenomenon causes reverse power flow and deteriorating power quality (voltage, frequency, and harmonics) to the customers [2], [3]. The intermittency issues of renewable generation also cause disputes regarding the day-ahead economic power dispatch in energy markets [4].

Besides DGs, customers have been adopting intelligent functions for flexible loads [5]. The offered controllability allows customers to optimize their energy consumption by managing load demand and cost savings with energy management systems (EMSs). Adopting controllable loads for residential, commercial, and industrial usage, the customers can become active participants in demand response (DR) for energy-saving operations such as peak shedding, peak shifting, and load shifting [6]. The US Department of Energy defines DR as "DR is a tariff or program established to motivate changes in electric use by end-use customers in response to changes in the price of electricity over time, or to give incentive payments designed to induce lower electricity use at times of high market prices or when grid reliability is jeopardized" [7].

Typical DR algorithms can be distributed at different intensity levels from low to high according to the prioritization, users' comfort constraints, or the maximum power consumption limit, respectively [8]-[10]. Around the world, customers have been using EMS solutions at their facilities with the primary intention of reducing electricity bills. North

American and European countries are well known for high levels of DR [11]. These countries already have had open market programs that encourage customers' acquisition of flexible resources. Eurelectric, the European electricity industry association, suggests that the fundamental goals to ensure the utilization of flexible resources are their efficient integration, effective operation, appropriate development of networks, and a competitive market [12]. For instance, elevated levels of DR potential allow customers to operate their resources in contribution to the grid operation and not only for their own benefit. This type of operation becomes beneficial to both the customer and the grid operator.

The electric power system operators are responsible for developing and executing the methods to ensure the system stability under critical events such as power imbalance which lead to voltage and frequency deviations. These functions are denominated as ancillary services (ASs) and are crucial to securing stable and continuous power generation, transmission, and distribution. Nevertheless, DERs and DR capabilities have created an opportunity to control electrical energy delivery, not only from the generation, transmission, and distribution sides but also from the demand side. With the integration between utility and smart grid-interactive facilities, customers can use their resources to support the system operation during critical periods [13]. Smart facilities can include residential, commercial, and industrial customers with the adoption of DERs and load automation to better manage energy consumption based on available generation, tariff prices, and users' comfort constraints. These resources can provide a fast local response to the system dynamics to support the voltage and frequency recovery within safe limits [14]-[16]. For instance, this customer-side flexibility can reduce the system investment in improving its equipment. Besides, they can be efficiently used to energize critical loads entirely or partially and even neighborhood loads during outage periods [17], [18].

The customers' adoption of intelligent and automated devices is usually encouraged by governmental incentives, utility programs, or environmental actions [19]. The Federal Energy Regulatory Commission (FERC) categorizes DR programs into incentive-based DR (IBDR) and time- or price-based DR (PBDR) [20]. FERC's report shows that most of the potential peak demand reduction comes from the IBDR programs. The PBDR provides customers with a dynamic rate that depends on the value and cost of electricity during different periods. In contrast, IBDR offers incentives to customers willing to reduce their consumption based on the time and cost of electricity [21]. In [22], a three-stage path toward fully flexible distribution networks is presented with short-, mid-, and long-term milestones, starting from controllable flexibility levels until resiliency aspects. Similarly, [23] proposes a multi-stage planning framework that aims to integrate the flexibility available in active elements to transit distribution network to ADNs. The approach starts by setting high-level objectives and considers changes at any stage.

All over the world, utilities have been testing and adapting their agreements to encourage a more significant number of clients to acquire automation systems and be part of the ADN operation. However, there is still a lack of standards today for defining the requirements of customers' EMS controls to be able to join AS, more precisely, how to reward their successful operation for the sake of the grid reliability.

This study investigates the capabilities of active customers in performing local ancillary service (LAS) to contribute to the distribution network operation. A complete analysis of traditional AS and a range of customer flexibilities that can be used to perform LAS are described. State-of-the-art EMSs and financial incentive programs are explored and compared, highlighting the benefits and suggesting future guidance on how to solve their drawbacks. The insights about different countries dealing with the integration of DR potentials to benefit the grid operation are reviewed and upheld, along with discussions on why some countries are ahead of others technology-wise. This study aims to benefit future researchers on customer participation in the distribution network operation through ASs.

This paper is organized as follows. Section II delivers a comprehensive overview of ASs. Section III describes the available opportunities for customers' demand and generation management. Section IV explains how financial incentives can speed up and improve customers' participation in EMSs. In Section V, some of the well-recognized active customer management techniques for EMSs and financial incentives are presented and evaluated. Section VI describes applications worldwide and discusses the existing gaps limiting the advancement of customer AS. Section VII provides the conclusion.

II. Comprehensive Overview of ASs

The electric power system uses AS as a power imbalance control utensil to respond to voltage and frequency deviations, ensuring a secure and reliable operation under different competitive electricity market environments [24]. Through these AS functions, transmission system operators (TSOs) and DSOs can maintain the energy imbalance under a controllable range where the voltage V_i and frequency f_i of each bus i contained in the set of buses ψ_B operate within the standard operational limits, as shown in (1) and (2).

$$V_{\min} < V_i < V_{\max} \quad \forall i \in \psi_B \tag{1}$$

$$f_{\min} < f_i < f_{\max} \quad \forall i \in \psi_B \tag{2}$$

where $V_{\min}$ and $V_{\max}$ are the minimum and maximum limits for voltage, respectively; and $f_{\min}$ and $f_{\max}$ are the minimum and maximum limits for frequency, respectively. Typically, $f_{\min}$ is 59.5 Hz and $f_{\max}$ is 60.5 Hz for a 60 Hz system, and $V_{\min}$ is 0.95 p.u. and $V_{\max}$ is 1.05 p.u., as defined by ANSI C84.1. Voltage and frequency deviations are caused mainly by a power imbalance, a mismatch between the power generation and the total power consumption, or plus technical and non-technical losses [25]. The theoretical complex power balance constraint is defined as:

$$\sum_{i \in \psi_G} S_i^G - \sum_{j \in \psi_L} S_j^L - \sum_{k \in \psi_D} S_k^D = 0 \tag{3}$$

where ψ_G, ψ_L, and ψ_D are the sets of generators, lines, and loads, respectively; S_i^G is the complex power output of generator i; S_j^L is the total complex power loss on line j; and S_k^D is the total complex power demand for load k. Equation (3) can be decoupled into active and reactive power balance constraints, as shown by (4) and (5), respectively.

$$\sum_{i \in \psi_G} P_i^G - \sum_{j \in \psi_L} P_j^L - \sum_{k \in \psi_D} P_k^D = 0 \tag{4}$$

$$\sum_{i \in \psi_G} Q_i^G - \sum_{j \in \psi_L} Q_j^L - \sum_{k \in \psi_D} Q_k^D = 0 \tag{5}$$

where P_i^G and Q_i^G are the active and reactive power outputs of generator i, respectively; P_j^L and Q_j^L are the active and reactive power losses on line j, respectively; and P_k^D and Q_k^D are the active and reactive power demands for load k, respectively.

A. Traditional ASs

Regulating bodies have discussed ASs over the years, but utilities implement them according to their necessity and operation policies. In the US, FERC is an entity that has been suggesting best practices for ASs on power systems. According to [26], ASs are those functions performed by the generation, transmission, and distribution equipment and operators that support the essential services of capacity generation, energy transmission, and delivery. Several functions of the electric power system components can be identified as ASs. Nineteen types of ASs for electric power systems are presented and described in [27]. Currently, FERC identifies the following six types of ASs [28].

1) Reactive Power and Voltage Control

The reactive power control provides injection or absorption of reactive power to ensure the system stability and avoid contingencies that may lead to a voltage collapse. The literature divides reactive power and voltage control into two component levels, i.e., system and local levels. Even though the customer can use correction equipment to regulate reactive and voltage levels locally, only the system operator can understand the required regulation over the power grid [29], [30].

2) Loss Compensation

Active power losses can be categorized into technical and non-technical losses. The technical losses are related to transmitting and delivering the energy to the customer, which passes through resistive elements and has nonlinear nature. The non-technical losses are due to the theft of electricity. Even though reactive power losses are much higher than active power losses, DSOs can control the losses by controlling the grid voltage levels [31], [32].

3) Scheduling and Dispatch

Scheduling and dispatch are responsible for quantifying the energy generation required on different time windows. The scheduling occurs before the real-time operation, looking at months, weeks, days, or hours ahead. The dispatch is a real-time technical-economic control of all generation and transmission resources to match the required demand and optimize the utilization of primary resources [33], [34].

4) Load Following

The generation sector of each control area is required to maintain enough generation capacity to respond quickly to the load variation, except during outage periods. Similarly, the planned reserves will be responsible for supplying the load variation during contingency moments. In an interconnected system, each control area must maintain suitable generation and reserve capacity levels [35], [36].

5) System Protection

Power system protection aims to isolate devices with underperformance, fault, or critical conditions. By removing these elements from the operation, the protection schemes aim to maintain the remaining system in service. The protection is used to respond to more significant changes in supply that may limit the levels of transgress elements' power, frequency, or voltage [37], [38].

6) Energy Imbalance

Energy imbalance is the natural difference between load and generation. Due to the various aspects of the electric power system such as inertia and control delays, energy imbalance is obvious and impossible to be eliminated. Nevertheless, through ASs, the unbalance can be kept under stable ranges and mitigated [39].

B. Customers' ASs

The transition from passive to ADNs has required a higher integration between TSOs and DSOs [40]. Different coordination schemes have proposed models for a possible interaction between these two sectors by considering the utilization of ASs to regulate the point of interconnection between them [41]-[45]. With the elevated levels of DERs and customer-automation systems, DSO has been essential in the power system reliability and resiliency. Integrating load and generation flexibilities over the distribution networks has allowed the bi-directional management of ASs. Beyond that, these DGs have enabled a more comprehensive range of LASs.

It was possible to observe a high adhesion of industrial, commercial, and residential customers for automation and EMSs during the last decade. Besides, DERs have become a technically and economically feasible solution for small- and medium-scale facilities. These demand- and generation-side capabilities have allowed regular customers to become active agents of the electric power system and take advantage of their controllability to support the TSO and DSO operation. Customers' support can be at different depth levels. Once the communication between the customers and the DSOs is established in a reliable and coordinated manner, active facilities can be part of a hierarchical control structure [46]. Integrating utility and customer controls can benefit the electric power system and defer further grid investments. Customers' ASs may include but are not restricted to reactive power and voltage control, scheduling and dispatch, load following, and energy discrepancy.

Smart facilities can manage granular loads, and under a utility request, this operation can become a granular ancillary service (GAS). The GAS may not significantly impact the electric power grid when performed by a few facilities, but mostly when many small facilities or high-demand customers perform it. GAS utilization can also be economically interesting for TSOs and DSOs, as it would avoid the usage of more expensive traditional ASs. Also, both scheduling and dispatch are valuable DERs and have demand management capabilities. Scheduling can be helpful for energy storage system (ESS) operation and customers' load utilization [47]. Similarly, DERs are part of the dispatch service and support the total demand reduction.

III. Available Opportunities for Customers' Demand and Generation Management

The world's energy demand growth rate increased from 0.3% in 2015 to 2.2% before the global pandemic in 2020 [48]. Moreover, the increasing concepts of smart facilities, responsive and controllable loads, and in-site generation have also allowed flexibility on the demand side [49], [50]. With the worldwide energy efficiency awareness campaign and increasing energy tariffs, automation techniques have been being deployed on different levels of electrical consumer facilities. Studies have shown that from 1976 to 2014, the energy savings of building EMS applications increased from 11.39% to 16.22%. During the same period, the energy savings of traditional EMS applications decreased from 18.89% to 10.35% [51].

The increasing controllability of customers' facility levels also help improve data management and storage. Internet-of-Things (IoT) is utilized in customers' automation to solve the big data challenge. IoT allows easier information exchange between customers with aggregators or DSOs. The agents would be able to receive the customers' consumption and scheduling data to compute in real-time grid optimizations and return commands to the network elements and customers.

The LAS capabilities for each customer facility are different and can present variable ranges of controllable power, time of response, and power flow directions. Even though only a small percentage of customers are mounted with both load automation and RES, the LAS can be performed by facilities with at least one of these capabilities and not necessarily both. The load automation enables the DR capability that commands flexible and switchable loads to adjust the power demand on different time windows. Behind-the-meter DER capability complements the load controls once the resultant demand is the difference between their power. Equation (6) clarifies the relation between DER generation S_i^{DER} and load power consumption S_i^C with the resultant demand S_i^D.

$$S_i^D = S_i^C - S_i^{DER} \quad \forall i \in \psi_B \tag{6}$$

Equation (6) is crucial for DR techniques. Usually, S_i^C is not entirely controllable, but only a small percentage of the facility's consumption can be managed. This aspect raises the concept of DR potential, which aims to estimate the levels of available load for power consumption reduction. The estimation is not a simple task but can be facilitated by the advancements in integrating metering and communication on customers' facilities.

This paper categorizes the customers' flexibility into four types according to their load and generation control capabilities, as shown in Fig. 1. Type I only has uncontrollable loads. Type II is mounted with controllable loads. Type III has DERs and uncontrollable loads. Finally, Type IV has both controllable loads and DERs.

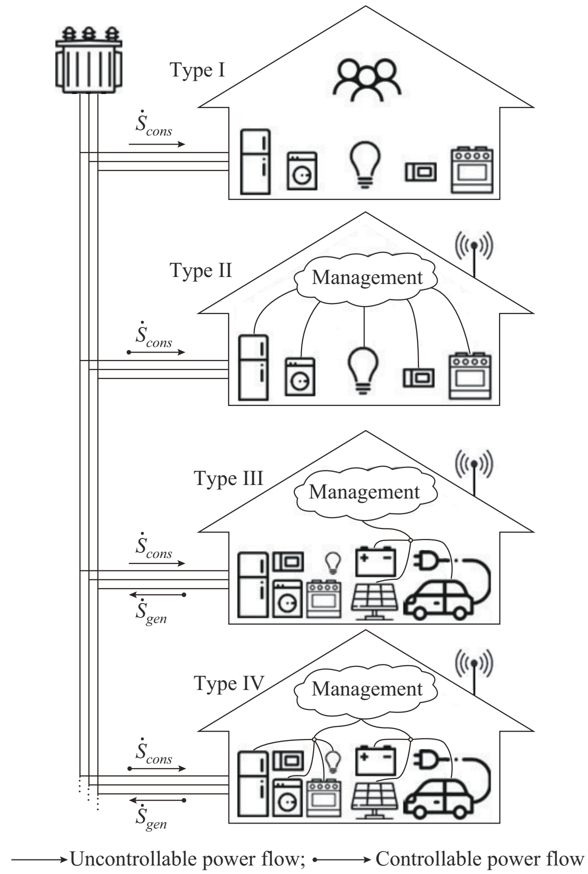

Fig. 1. Categories of customers' flexibility.

A. Type I

In Type I, the local users are responsible for turning on and off the facility appliances according to their preferences and necessities. This behavior is passive and repetitive but can slightly change over weekdays, but it is mainly different on weekends and holidays. Nowadays, smart meters have enabled a reliable electrical measurement at the customers' point-of-connection with the utility, which facilitates the billing calculation using IoT and big data analysis and processing [52], [53]. With smart meters, the utility can collect power consumption information over time and perform load forecasting with higher accuracy to plan their operations [54], [55]. Even though there are several discussions on data privacy with smart meters [56], by using these measurement devices, utilities can better understand and identify the customers' consumption behavior [57]. The load behavior can be affected by several internal and external factors, which can be related to the residents' culture and weather conditions [58]. As soon as the utility models the consumers' characteristics, it is possible to predict their behavior under different tariff structures [59], [60]. The utility uses these historical load consumption data and weather patterns for their load forecasts [61], [62]. In [63], low-energy housing profiles from Australia are shown, and their patterns and estimations are discussed. Figure 2 presents the data from [63] intending to illustrate customers' load pattern change over the weekdays and weekends and year seasonality.

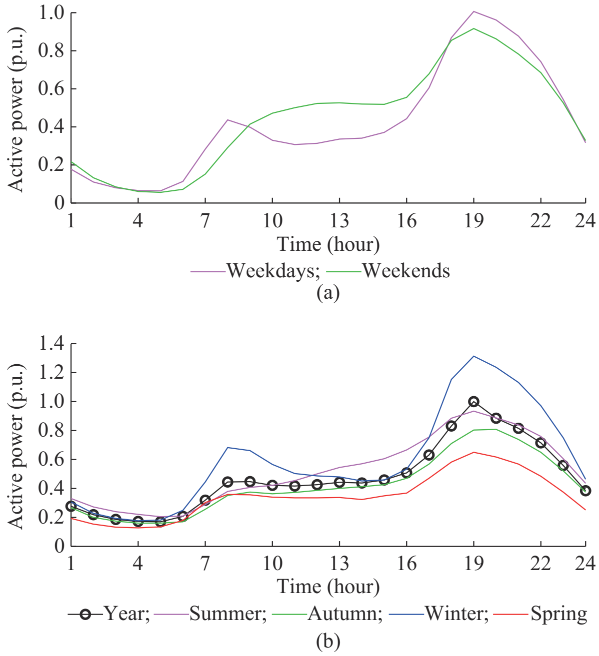

Fig. 2. Customers' load pattern change over weekdays and weekends and year seasonality. (a) Weekdays and weekends. (b) Year seasonality.

B. *Type II*

The facilities of Type II have controllability on the consumption side but no DER. The level of controllable loads can differ from facility to facility. These controllable loads are typically interconnected to a central EMS. One of the main objectives of the customer's DR is to optimize residential power consumption under dynamic tariffs during high-price periods [64], [65]. This central unit can be connected through an agent to provide measurements and receive LAS requests. During the power outage, the utility can request the smart facilities' load reduction to ensure the grid voltage and frequency stability and the power quality to all customers [66], [67]. However, the customer's management will be tied to its available DR potential.

The advanced research on DR techniques has enabled a smart utilization of the facility loads based on several goals, i.e., energy efficiency, load shedding, load shifting, etc. [68]. Even though the DR is mainly performed by controlling loads, electric vehicles (EVs) can be a useful resource in this process [69]. EV charging can be based on facility consumption or dynamic tariff prices. Figure 3 shows the comparison of load consumption under three well-established practices of DR: load efficiency, shedding, and shifting controls. Load efficiency control intends looks to perform the usual tasks that the users perform with less energy but without affecting their day-to-day activities or comfort levels. Load shedding control is the capacity to limit the consumption of facility loads under a certain level, independently of the users' desires [70]. Load shifting control is the ability that EMS has to know the users' behavior and the grid limitations to schedule and shift the utilization of non-crucial loads. This technique makes the load consumption curve smoother, reducing the peaks and valleys.

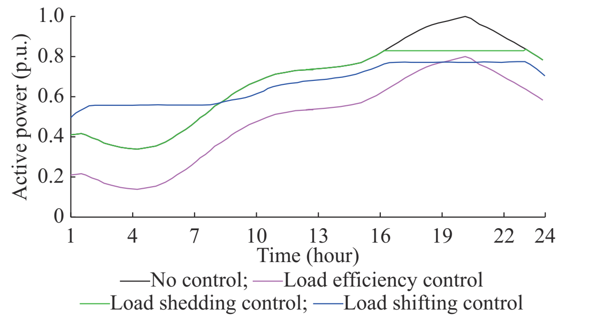

Fig. 3. Comparison of load consumption under load efficiency, shedding, and shifting controls.

Even though each kind of device has its own flexibility and controllability characteristics, heating, ventilation, and air conditioning (HVAC), water heaters, and fans have been some of the most studied devices for DR [71]-[75]. Due to the slow intrinsic dynamics presented in thermal behavior, the short-term interruption of these elements is usually unnoticed by the users [76]. Beyond that, the temperature can be modeled as a storage system, where it is possible to both "charge" and "discharge" or "heat" and "cool" [77]. Lights are another load that can have their intensity managed to provide AS to the power grid with reduced the impact on the users' notice [78].

C. *Type III*

In the search to improve the reliability and security of the energy supply by diversifying the energy matrix, DERs have proven to be a reliable and feasible alternative. Due to the required size and implementation cost, photovoltaics (PVs) have been the most used technology on customers' facility levels, bringing more independence and reducing their energy expenses. However, DERs have also brought several issues and challenges to the operation and control of the distribution networks, like harmonics, voltage and frequency variations, and power fluctuation [79].

Figure 4 illustrates the impact of PVs on a customer's resultant demand profile based on a consumption profile, known as the duck curve.

The California Independent System Operator was one of the first agents to expect and face the duck curve, even though it became more impactful than expected [80], [81]. By this, different agents and countries started to intensely study how economic and technical incentives can affect the levels of PV integration on customers' facilities and their effects on the grid [82].

The studies and solutions of ESS technologies have been advancing for overcoming the impacts and inflexibility of the PV generation characteristic. The ESS controllability allows customers to model their demand profile. As DERs are mostly inverter-based-resources (IBRs), they have the power electronics capability to model and shape the desired current curve, enabling PF and reactive power support. The installation of PV systems shows that this DG can reduce the resultant demand and voltage drop over the grid by generating active power [83]. To compensate for the reactive power, the IBRs can perform reactive power support during their active power injection, correct the reactive power issues on a facility and neighborhood level, and improve the voltage levels as an LAS. Figure 5 shows the usual volt-var control of IBR at different voltage levels.

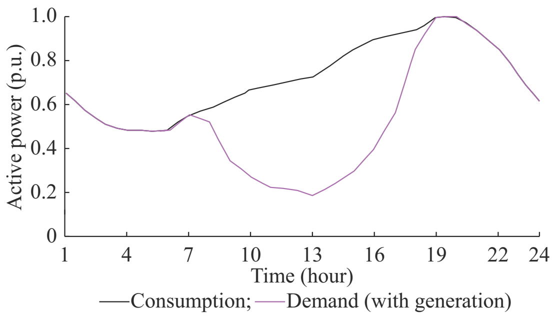

Fig. 4. Impact of PVs on a customer's resultant demand profile.

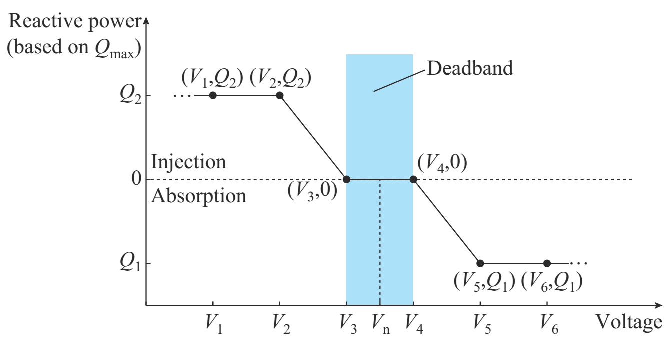

Fig. 5. Usual volt-var control curve of IBR under different voltage levels.

At low voltage levels of operation, the inverter provides reactive power to the power grid, becoming capacitive. At higher voltage levels, it may absorb reactive power, becoming inductive. The injection or absorption of reactive power is based on the inverter's limitations Q_{max}. According to the control project, different voltage deviations V_1, V_2, V_3, V_4, V_5, and V_6 from the nominal V_n will define which level of reactive power the inverter should support (Q_1, Q_2, or none). By providing or consuming reactive power, the inverter may reduce its active power injection to respect the nominal power of the inverter.

Similarly, IBDR can perform frequency response by using Hertz-Watts control. The IBR can adjust the amount of active power injected into the system according to the frequency level. The control curve may vary according to the type of generation resource. While PV and wind systems are usually operated on their maximum power point (MPP), storage systems can have an adjustable amount of energy consumed or injected based on their reserves. Figure 6 shows the usual Hertz-Watts control curve of IBR at different frequency levels. The IBR reduces the amount of power injected into the system at over-frequency levels. Otherwise, the IBR increases its amount of energy injected if any reserve is available at under-frequency levels. An inversed control architecture can be considered for EVs, where the charging level increases in over-frequency moments, and in under-frequency moments, the discharging level increases. In this case, the injection or absorption of active power is based on the inverter's limitations P_{max}. According to the control architecture, different frequency deviations f_1, f_2, f_3, f_4, f_5, and f_6 from the nominal frequency f_n will define which levels of active power the inverter should support (P_1, P_2, or P_3).

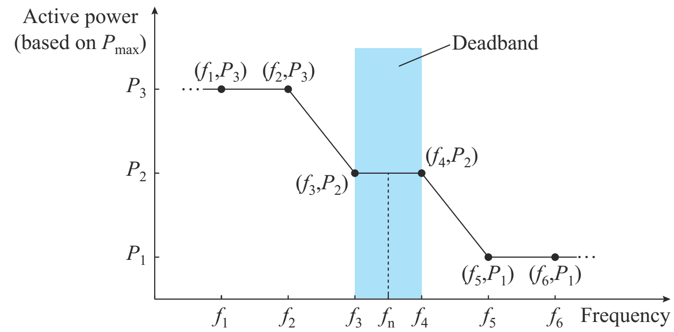

Fig. 6. Usual Hertz-Watts control curve of IBR under different frequency levels.

D. Type IV

By smartly managing both load and generation, it is possible to have a reliable operation with energy cost savings and perform LAS without compromising the users' comfort constraints. The facilities of Type IV are mounted with load automation and DERs (most commonly PV systems). Having an ESS on Type IV customers is also common, which brings more flexibility to both sides.

The fast advancement of EV technologies have provided the mechanisms for bi-directional EVs. Their integration into the power system brings challenges such as feeder congestions, transformer overloads, undue circuit faults, structural limitations, and power quality issues [84]. Nevertheless, customers' acquisition of an EV enables a new opportunity for demand modulation. By managing the charging and discharging of the ESS, the DR techniques can maximize the penetration of RES into the power grid [85]. In [86], the proposed reactive power support technique shows that bi-directional EVs can optimally provide reactive power support without significantly compromising the active power consumption or injection.

The opportunity to control the consumption and the injection of energy into the power grid facilitates the mitigation of challenges related to Types II and III customers, which are to be tied to affect the customer's comfort or be dependent on the generation behavior. Figure 7 clarifies the capability of Type IV customers to shape their demand profile over the operation day. Modulating loads and ESSs can improve the PV injection without creating sharp slopes from the duck curve. Also, lowering peak demand reduces the overall cost of investments for network upgrades [87]. Beyond that, high-demand customers have agreements with the local utility about the amount of power they can consume and their maximum peak demand. The integration of DR and DER management can efficiently coordinate their peak demand to avoid any transgression that may result in penalties.

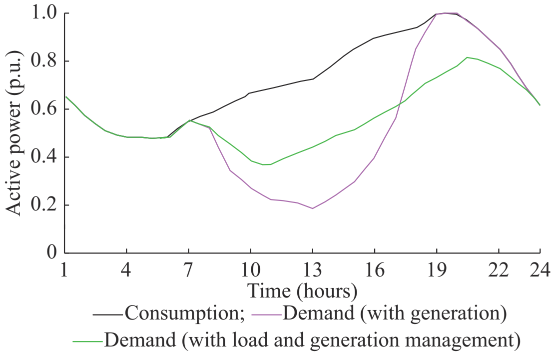

Fig. 7. Capability of Type IV customers to shape their demand profile over operation day.

Even though customers' facilities are primarily projected to operate in interconnected mode, some research and new solutions have enabled them to operate in islanded operation mode. The capability in islanded operation mode reduces the customers' dependence on the power supply of utilities. This capability of operation mode transfer becomes even more interesting in outage scenarios, where the utility is not able to supply all the customers. In islanded operation mode, the total consumption must match the available generation to avoid instability. This aspect is a crucial constraint to ensure stability and prevent complete backouts on the facility, which only Type IV customers can perform.

IV. Financial Incentives

Electric power system planners and operators have been developing incentive-based programs to encourage users to transition from traditional to intelligent facilities so they can become assets during critical operation periods. These plans are primarily based on a time-varying energy price that reflects the need for customers' support to the grid during specific periods [88]. According to the agreement, customers are provided with the time-of-use pricing, critical peak pricing, variable peak pricing, real-time pricing, and critical peak rebates. The customers' participation and successful response during these periods are reflected in their electricity bills [89], [90]. Any of these approaches present a significant improvement in the efficiency of energy resource utilization by focusing on the participation of the consumer side in the transactive energy market. Figure 8 presents an overview of customers' interaction with DSOs and energy markets through aggregators.

In the US, the incentives to implement DR resources into the wholesale market have been carried out by the FERC, regional grid operators, and utility companies. EMS studies based on real-time data monitoring, environmental impacts, techno-economic analysis, and the IoT-based performance have been analyzed in detail in [91], [92].

Direct load control programs have been deployed over the globe, which enables the local utility to control the cycle of air conditioners and water heaters on and off during critical periods in exchange for a financial incentive [93]. Reference [78] proposes a mathematical model for the cost of meeting AS requirements using HVAC systems. The formulation can also anticipate the capabilities of HVAC systems in providing ASs during different periods.

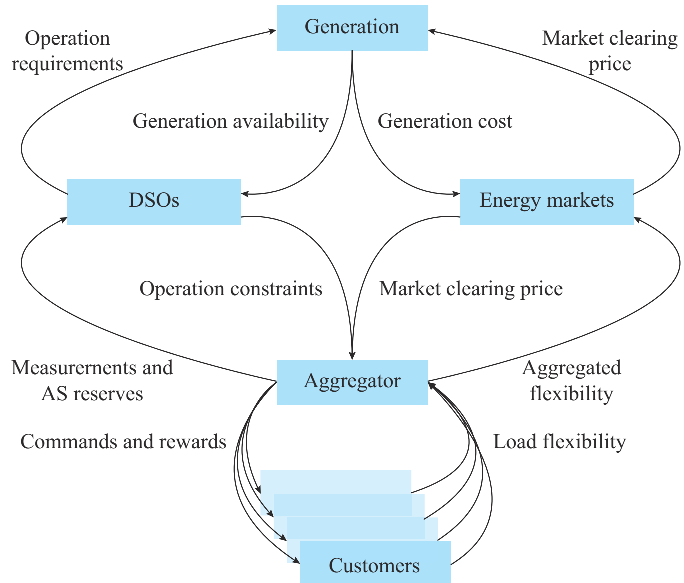

Fig. 8. Overview of customers' interaction with DSOs and energy markets through aggregators.

Beyond the direct control from the utilities, smart facilities can have their local control to respond based on time-varying tariffs and reduce their energy bills while performing LAS. The IBDR takes the retail energy price to schedule the load utilization and manages its operation in real time [94]. Besides that, Type IV customers can add the DER operation as a constraint and efficient support in the AS process to obtain more credits and thus reduce their total energy bills. The customers' DR intensity must follow the dynamic prices, respecting the agreements not to receive penalties due to transgressions. Meanwhile, several studies have investigated the best approach to defining dynamic prices and increasing customers' participation in ASs. In [95], a novel non-cooperative game technique is utilized to determine tariff prices and force the demand-side ESS operations to increase up to 67% of PV energy penetration into the power grid. Even though the energy price can be predicted on a daily and hourly window ahead, it changes in real time according to the availability of energy and operation constraints of the power grid. In [96], a real-time deep neural network approach enables the service provider to purchase customers' energy resources under different grid operating conditions. Currently, most of the customers at a distribution level are under flat rates instead of dynamic energy prices. In [97], a coupon-incentive-based DR program is proposed to overcome the inflexibilities at a flat rate. In this approach, coupons are provided by the load service entities to customers with the primary goal of encouraging their DR during specific periods voluntarily.

The IBDR enables better operation planning. As soon as the incentive-based program is established, it is possible to quantify the DR potential in the power grid and even predict the contribution of each active customer [98], [99]. By this, the AS approach can be performed by both grid and customer agents. Even though integrating utility and facilities through IBDR programs seems interesting for both sides, this data and command interaction introduces the concerns regarding customers' privacy. A privacy-preserving scheme is proposed in [100]. The scheme utilizes cryptographic primitives to preserve customer privacy while enabling the provider to compute individual demand curtailments and rewards.

V. Active Customer Management

The active customers' participation in the smart grids has two main challenges: ① customers support the grid operation with the minimum impact on their daily behavior and supply constraints; and ② the motivation from utilities can encourage the customers' participation. These two challenges must be studied and optimally solved to ensure a fair and reliable interaction between grid agents and customers.

A. EMS Control

Table I presents an overview and comparison of several management solutions proposed in the literature for consumers' participation in smart grids, along with their key considerations and contributions. It should be noted that Y and N in Table I imply yes and no, respectively.

TABLE I
Overview and Comparison of Different Management Solutions for Consumers' Participation in Smart Grids

Reference	DR	RES	Decision	Agent	Consumer	Goal	Contribution	Year
[101]	Y	Y	Electricity market	Multiagent	General	Market-based approach to coordinate profit-based entities	Reduction of 12%-34% on energy costs	2018
[102]	Y	Y	Electricity market	Local	Residential	Load shifting with the surplus power of the customer's PV	Reduction of 46% on the load curve ramp rate	2019
[103]	Y	Y	RES	Local	Residential	Maximize the RES generation and serve as an AS for the grid	Reduction of 15%-20% on the purchased energy unbalance	2019
[104]	Y	Y	Cost, discomfort, and interruption	Aggregator	Residential	Optimal bi-directional energy trading and appliance scheduling	Reduce up to 22.9% of the total load and 45.2% of the energy cost	2019
[105]	Y	N	Incentive and price	Local	Industrial and commercial	Coordinate HVAC, IT workload, and battery energy storage system (BESS) to adjust the power consumption of data centers and perform DR	Thermal deviations of data center are maintained under 0.60 K	2018
[106]	N	Y	Power	Local	Residential	Control of PV converters to balance consumers' demanded currents and to compensate the demanded reactive power	Reduce up to 15.5% network power losses on high radiance days and 66.5% network power losses on low radiation days	2019
[107]	Y	N	Power	DSO	General	Perform DR under a utility's request with efficiency and reduce computational time	DR algorithm presented up to 80% reduction in the required controller computational time	2021
[108]	Y	Y	Electricity market	Multiagent	Residential	Perform a decentralized energy management to address grid overloading and cost optimization preserving consumers' privacy	Increase 15%-20% consumers' cost savings while minimizing storage device degradation	2020
[109]	Y	N	Electricity market	Aggregator	Commercial and residential	Optimize multi-energy storage, substitution, curtailment, and power factor manipulation	Show the ability of different kinds of flexibility to improve the network constraints caused by adoption of electric heating	2019
[110]	Y	Y	Load forecasting	Aggregator	Residential	Reveal the residential DR benefits through an optimal load aggregation and active DR participation under rewards	The approach is efficient when the customers' participation level is less than 80%, reducing generation costs and load profile deviation	2020
[111]	Y	N	Temperature	Distributed agents	Commercial and residential	Novel modeling and control frameworks to evaluate the underlying capability of thermostatically controlled loads	Thermostatically controlled loads provide load shifting and overall energy efficiency, reducing 319 kW from 1000 heterogeneous air conditioners causing an average increase of 3.8 F	2021

Some existing control strategies for facility management are based on proportional-integral-derivative (PID) control, on and off state values, and rule-based controls. Each of them has its own limitations and constraints that impact the system flexibility. The current techniques utilized for advanced EMS control are primarily based on fuzzy control, model predictive control (MPC), and deep learning control. Fuzzy control was firstly introduced in the 1960s, followed by MPC in the 1980s. Even though machine learning has been studied since the late 1940s, the deep learning control was only introduced in the 1980s. Only in the 1990s were digital control devices used for control. At that time, no standards or guidances were defined for digital communication. While the current EMSs available in the market have reasonable performances, the first step to achieve an ADN with coordinated customer participation and efficient contribution to the system operation is to standardize EMS control integration, performance, and response time. Together with this, active customers can become a reliable source of ASs.

B. Financial Incentives

Financial incentives provided by the DSOs are a crucial aspect of improving the customers' advancement in building automation and DERs, besides engaging in LAS programs. Financial incentives have two key characteristics. The first one is encouraging customers to acquire DERs and automate their facilities. The second one is to encourage active customers' participation in LASs in response to the power system needs and operation improvement.

Table II presents an overview and comparison of different types of financial incentive approaches to encourage the customers' participation in energy markets for energy commercialization and LASs. Customers should be able to operate their resources according to their choice to improve their reliability or reduce costs. However, financial incentives for AS operation must depend on DNO's need and available DR potential. If demand reduction is highly required, the incentive should be inversely proportional to the available DR potential of the system. By this, reliable approaches for DR potential estimation must be developed and validated to complement calculation techniques for financial incentives.

TABLE II
OVERVIEW AND COMPARISON OF DIFFERENT TYPES OF FINANCIAL INCENTIVE APPROACHES

Reference	DR	RES	Decision	Agent	Consumer	Goal	Contribution	Year
[112]	N	Y	Reactive power provision	DSO	Residential	An approach for remuneration of reactive power integrated into the blockchain	The blockchain algorithm creates purchase-offer couples where promises are digitally signed and physically performed	2019
[113]	Y	N	Changes in system and/or adverse weather conditions	Load serving entity (LSE)	General	Coupon incentive program to induce DR for a future period in anticipation of intermittent generation and/or price variations	Up to 32.91% cost of energy reduction is achieved, as well as the 61.36% of loss reduction	2013
[114]	N	Y	Power	DSO	Residential	Optimal bidding strategy for customers' energy trading as AS tool	Increasing AS prices and installation rate of EVs can increase AS But increasing installation of PV systems does not necessarily increase the service provision	2020
[115]	Y	N	Power	Aggregator	Residential	Reinforcement learning and deep neural network algorithm to balance energy fluctuations and enhance grid reliability	Win-win strategy is used for both service provider and customers Up to 45.0% reduction on payment cost is achieved	2019
[116]	Y	N	Power	Aggregator	General	DR model involving the utility and elasticity of customers for maximizing the benefits of retailers	As soon as customers have higher elasticity, retailers can make fewer incentive payments and receive more benefits	2017
[117]	Y	N	Power	LSE	General	Reduce costs and improve reliability, as well as increase customer acceptance of a DR program by limiting price volatility	LSE revenue increases with the population of customers For customers' load share bigger than 60%, the LSE benefit is less sensitive	2017
[118]	Y	N	Market price	Load serving entities	General	A deep contextual bandit algorithm is proposed to address the uncertainty of electricity consumption with an optimal pricing policy	Solution improves system reliability, reduces energy cost, and controls the power system ramp rate	2021
[119]	Y	Y	Discomfort level and economic value of load	Microgrid owner	General	Determining an efficient and fair incentive for customers' participation in the DR scheme within microgrid system	The given incentive varies based on the discomfort level of participants and the economic value of loads	2021
[120]	Y	N	Consumer behavior	Not defined	General	Optimize customer actions for the maximum expected rewards under uncertain event schedules	The methodology can identify optimal customer behaviors when the schedule of DR events is uncertain	2021
[121]	N	Y	Set of variables	Not defined	Commercial	Propose and compare two approaches to optimize microgrid dispatch, i. e., one with or without participation in real-time AS markets	Revenue from ancillary service accounts for 12.03% of operating costs; and battery state of charge (SoC) remains higher	2021
[122]	Y	N	Financial incentive	Aggregator	Residential	Optimal customers' responsiveness under different incentives for aggregator's decision-making	Revenue peak of the aggregator is obtained when economic-oriented customers are around 74%	2021

VI. Applications Worldwide and Existing Gaps Limiting Customer AS Advancement

The automation and integration of facilities' EMS and DER have received special attention in the last decade, and some countries have been more advanced than others. In [11], a complete review of DR applications for LAS worldwide is performed.

A. Europe

Many European countries have created programs to encourage DR participation from customers. However, despite these programs and their high potential, the levels of DR in countries like Belgium, Denmark, and Finland remain low. The lack of open markets primarily causes this delay in customers' DR participation.

B. North America

The US and Canada TSOs allow customers' DR to access the AS markets. Different system operations have created similar and aligned rules that standardize the operation and integration of DR applications to the system operation uniformly.

C. Asia and Oceania

In these continents, DR is partially allowed to access AS markets. TSOs have created different programs to encourage the customers' participation in DR. Countries like Australia, China, South Korea, and Singapore have already been utilizing customers' DR as AS, while New Zealand and Japan are still planning and investigating their potential programs.

D. Africa and Latin America

Countries in Africa and Latin America are still developing DR programs to enable customers' participation in AS. None has already had well-established programs, but some countries are already investigating the best ways to create and apply these programs.

E. Future Considerations

A common challenge for all countries that have already had or are developing their LAS programs is the lack of standardization. Currently, with manageable levels of DERs integrated, LAS is still in a stage where the proposed programs can be tested and adjusted to different countries and system needs. However, as customers become more active participants in load management and adopt DERs, the LAS may become more feasible and required by the DSOs. This level will need more well-defined and guided standards and regulations to ensure the safe operation, integration, and participation of LAS, as well as to provide a fair reward for the customers' contributions. Besides the regulatory challenges, the LAS also presents technical barriers. The LAS may only be beneficial when the actions are well-coordinated between the utility or local aggregator and the customer [123]. There is a need for modernizing the electric power system and integrating reliable bi-directional communication links between customers and DSOs. However, this need brings other indirect challenges such as data privacy, cyber-security, interaction of energy markets, and big data management.

VII. Conclusion

The advancement of IoT-enabled controllable loads and DER technologies have enhanced customers' participation in grid ASs. These solutions provide economic benefits to the customers through flexibly managing resources to benefit from dynamic energy prices and increase their energy supply reliability during outage periods. The coordination between load and generation management with energy storage should be used for an efficient model of customer demand and daily behavior.

Nevertheless, customers' independent control can bring higher ambiguities and dynamics to the electric power systems. This issue calls for an urgent requirement for well-established coordination between customers and DSO. With bi-directional communication, both customers and DSO can get benefits. The flexibility of the active facilities is a great option for ASs. Focusing on the distributed LASs over the power grid, the DSOs can provide financial incentives to the aggregators and customers. The DSOs can also avoid using the traditional and more expensive ASs without compromising the system stability and reliability levels. This bi-directional coordination will allow more advanced grid automation techniques such as self-healing, microgrid formation, and energy communities with interactive energy markets.

A comprehensive review of active customers' flexibility for DR as LAS is provided, along with an investigation of existing management techniques, incentive programs, and worldwide applications. Several critical aspects of smart grids in the near future are also escalated, which require solutions and improvements to normalize active customers' participation in power grid operation. The biggest roadblock to this issue is not technological but mostly regulatory. Several countries have adopted strategies and programs to encourage active customer DR participation in power grid usage. Yet, the lack of uniform standards and regulations prevents the rapid growth of these techniques, which could be beneficial for future energy management solutions.

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Konrad Schmitt received the B. Sc. degree in electrical engineering from the Federal University of Santa Maria, Santa Maria, Brazil, in 2019. He is currently pursuing a Ph. D. degree in electrical engineering at Texas Tech University, Lubbock, USA. Since 2020, he has been a Research Assistant at Texas Tech University. He is an active IEEE Power & Energy Society (PES) volunteer member and has already taken local, regional, and global positions within the organization. His research interests include power distribution system control, automation, restoration, self-healing, microgrids, and renewable energy integration.

Rabindra Bhatta received the M. S. degree in electrical engineering from Texas Tech University, Lubbock, USA, in 2020. He is currently pursuing a Ph. D. degree in electrical engineering at Texas Tech University. He is part of the GLEAMM Research Team. He is also an active IEEE Power and Energy Society (PES) member and student leader at IEEE PES TTU Student Branch Chapter. His research interests include smart grid automation and control, renewable penetration in the existing grid, cyber-physical aspects of power systems, cybersecurity, and power system resiliency.

Manohar Chamana received the B. E. degree from Andhra University, Visakhapatnam, Andhra Pradesh, India, in 2009, the M. S. degree from Texas Tech University, Lubbock, USA, in 2011, and the Ph. D. degree from the University of North Carolina at Charlotte, Charlotte, USA, in 2016, all in electrical engineering. He is presently an Assistant Professor in the Renewable Energy Program at Texas Tech University. During his doctoral studies, he conducted research on integration issues with large-scale renewable distributed generation in the distribution grid and microgrids. He has experience in the industry and a national lab where he worked on renewable energy, storage, and electrical load studies on electric distribution systems. His research interests include modeling and analysis of active distribution networks considering power quality, resiliency, and economics of distributed energy resources integration.

Mahtab Murshed received the B. Sc. and M. Sc. degrees in electrical and electronics engineering from Independent University, Bangladesh (IUB), in 2013 and 2018, respectively. He is currently pursuing his Ph. D. degree in electrical and electronics engineering at Texas Tech University, Lubbock, USA. His research interests include renewable and sustainable energy development, energy economics, microgrid control solutions for distributed energy resources, data analysis, machine learning, and power system dynamics.

Ilham Osman received the Ph.D. degree in power electronics and electrical motor drives from the University of New South Wales, Sydney, Australia, in 2020. She worked as a Postdoctoral Research Associate at National Wind Institute, Lubbock, USA, from 2020-2021. She is currently working at General Motors. Her research interests include smart home energy management systems, intelligent EV charging, power electronics for renewable solutions, and control strategies for electrical drives.

Stephen Bayne received the B. S., M. S., and Ph. D. degrees in electrical engineering from Texas Tech University, Lubbock, USA. After completing his doctoral studies, he joined the Naval Research Lab (NRL), USA, where he was an Electronics Engineer designing advanced power electronics systems for space power applications. After two and a half years at NRL, he trans-

ferred to the Army Research Lab (ARL) where he was instrumental in developing a high-temperature power electronic program. He was promoted to Team Lead at ARL where he led the power components team, which consisted of five engineers. As the Team Leader, he was responsible for advanced research in high temperature and advanced power devices for army applications. After one and a half years as Team Lead, he was promoted to Branch Chief of the Directed Energy Branch. After 8 years at the ARL, he transitioned over to academia, where he is a Full Professor and Interim Dean of the College of Engineering at Texas Tech University. His research interests at Texas Tech University include power electronics, pulsed power, power semiconductors, and renewable energy.

Luciane Canha received the B.E. degree, the M.Sc. degree in electrical engineering, and the Ph.D. degree in electrical engineering from the Federal University of Santa Maria, Santa Maria, Brazil, in 1994, 1996, and 2004, respectively. She is a Full Professor and Leader of the Center of Excellence in Energy and Power Systems at the Federal University of Santa Maria. She is a Leader at the Center of Excellence for Energy and Power Systems (CEESP). Her research activities are centered on smart grids, energy storage, energy management, distributed flexible resources, electric mobility, and power system operation and planning.