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An Overview of Demand Response: From Its Origins to the Smart Energy Community

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ABSTRACT The need to improve power system performance, enhance reliability, and reduce environmental effects, as well as advances in communication infrastructures, have led to demand response (DR) becoming an essential part of smart grid operation. DR can provide power system operators with a range of flexible resources through different schemes. From the operational decision-making viewpoint, in practice, each scheme can affect the system performance differently. Therefore, categorizing different DR schemes based on their potential impacts on the power grid, operational targets, and economic incentives can embed a pragmatic and practical perspective into the selection approach. In order to provide such insights, this paper presents an extensive review of DR programs. A goal-oriented classification based on the type of market, reliability, power flexibility and the participants' economic motivation is proposed for DR programs. The benefits and barriers based on new classes are presented. Every involved party, including the power system operator and participants, can utilize the proposed classification to select an appropriate plan in the DR-related ancillary service ecosystem. The various enabling technologies and practical strategies for the application of DR schemes in various sectors are reviewed. Following this, changes in the procedure of DR schemes in the smart community concept are studied. Finally, the direction of future research and development in DR is discussed and analyzed.

INDEX TERMS Load management, demand side management, demand response, prosumers, smart energy community.

I. INTRODUCTION

A. AIMS AND BACKGROUND

Advanced power systems are under pressure due to increased stresses originated from reduced reserve margins, growth of electricity costs, operational problems, and financial risks of network expansion. These reasons have led power utilities to move towards restructuring and electricity markets. With the management of the electricity market and applying significant changes in its structure and functions, the power system operation has been changed from a traditional system to a more decentralized network with a growing share of renewable resources [1].

In restructured power systems, if electricity distribution companies buy energy at different prices from wholesale markets and sell it to customers at a fixed retail price, these fixed rates cannot embrace actual charges of power generation and delivery.

Additionally, in the restructured system, due to the diversity of energy sources on the market, supply stability and flexibility are essential for the entire power system [2]. Annual growth in load consumption, imbalances in energy

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supply and demand, network reliability, and sudden peak load can affect these features. With the deregulation of the electricity market from an economic point of view, it may be reasonable for prices to rise with increasing demand. Due to the high risks of power delivery during peak demand times, there will be probable price volatility, and often price will jump [3].

Furthermore, increasing the power system's efficiency and productivity is another issue that is pursued in the restructured environment of the electricity industry. Energy-efficient networks are one of the goals that power companies are looking for new and creative solutions to manage losses, manage costs, and increase asset performance. To this end, business models should be designed and developed to meet the electricity industry's strategic objectives [4].

Moreover, climate change and the pressure on the electricity industry to reduce greenhouse gas emissions are severe challenges for the industry in the new environment [5]. Applying methods and measures that can overcome this dilemma of the electricity industry in critical and sensitive situations while not imposing higher costs than before is perhaps one of the sector's most critical challenges. Therefore, a rigourous rethink of energy management activities is required.

An effective solution is needed to address the challenges mentioned above; the smart grid. As a result of grid modernization efforts, new digital telecommunications systems, and computer monitoring and control technologies have been introduced at all levels of the power system; from transmission and distribution networks down to end-users [6]. The smart grid is basically refers to as a power system that can integrate all users' behavior and actions to ensure a sustainable supply of electricity at an efficient, economic, and safe level [7]. In addition, the deployment of a vast number of smart meters has provided a platform for offering smart prices to customers. This has made it possible to provide different price rates and cover variable electricity costs [8]. Such infrastructures will enable possibilities to engage and interact with consumers to reduce costs, manage energy consumption, and reduce peak demand.

As one of the most basic strategies for realizing the smart power system, Demand Response (DR) can provide significant flexibility in demand so that the electricity industry can use its economic and technical benefits [9]. This flexibility will be realized as the ability to increasing or decreasing the load within a specific time frame. Therefore, applying DR is valuable for power companies, consumers, energy policy-makers, and regulators as a precondition for decision-making [10]. When dealing with abnormal conditions, DR in the smart grid is a practical approach that can influence different demand behaviors with different pricing or incentive policies [11].

B. MOTIVATION AND CONTRIBUTIONS

To date, a variety of review papers have been presented for DR programs. These studies pursue different goals. In [12]–[14], the approaches and facilities required for the future development of DR implementation are discussed. Some papers study DR for a specific country, such as [15] for China and [16] for the United Kingdom. Overviews of the implementation of DR programs on specific customers such as residential buildings or various industries are provided in [17]–[19]. In [20], [21], the authors overview the barriers and benefits of implementing DR schemes to observe the relevant challenges.

However, there is a knowledge gap in reviewing DR programs from a practical perspective for various customers and utilities. Obviously, DR products as services should help the electricity industry operator achieve his intentions. Likewise, the customers should also have the opportunity to choose suitable DR plans based on their goals. Therefore, a goal-oriented classification of DR programs can provide a new perspective to improve the performance indicators. Meanwhile, the transition of DR plans to smart grid environments and the changes that must be made dealing with new conditions, in practice, can reconsider the views about DR applications. On the one hand, this should be done by considering the components of the smart grid and, on the other hand, by adapting the practical aspects of the DR plans. Therefore, the enabling technologies in different plans should be redefined, and practical strategies in different customer segments should be identified and classified for proper orientation.

Accordingly, a comprehensive and new classification paradigm is needed to make it easier to choose between DR programs based on objective functions and practical views. This classification should be useful for both system operators and customers. In this paper, the type of market (retail or wholesale), reliability, power flexibility, and the participants' economic motivation are proposed as new dimensions for DR program classification.

For the choices, the participating parties and the system operator must consider their limitations and evaluate the benefits and the barriers. These factors that affect the implementation of programs are identified and categorized using the same approach. To complete the study, the technologies used to implement DR programs are also organized and discussed. The description covers the facilities and strategies required for the practical implementation of various DR programs in each application area.

In the final sections of the article, DR plans for smart communities and future DR-related trends are discussed. The contributions of this paper can be summarized as follows:

- proposing a goal-oriented classification of DR programs to integrate practical insights and targets,
- applying market, reliability, power flexibility, and the participants' economic motivation as dimensions of this new classification approach,
- providing a new grouping of enabling technologies and practical strategies of DR programs,
- discussing the DR programs role and their adaptation to novel operational paradigms of smart communities alongside presenting a historical review and timeline.

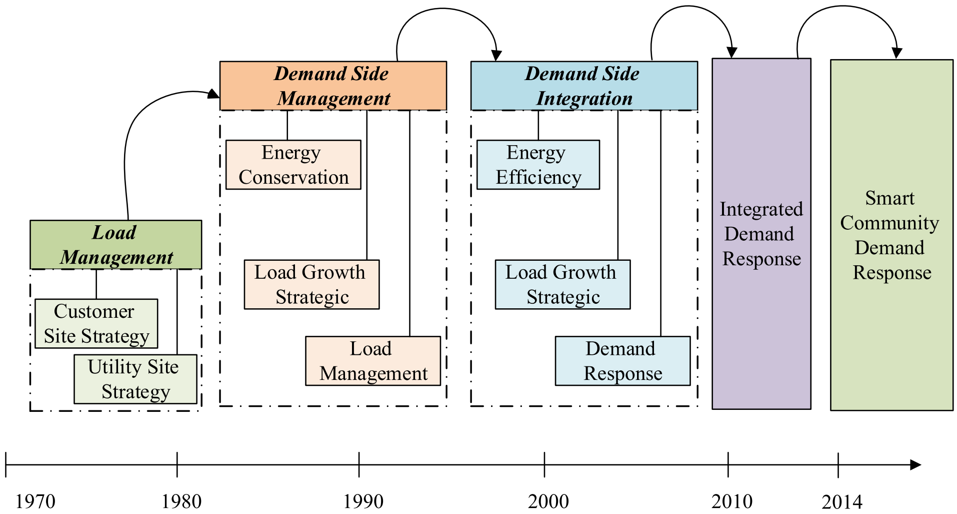

FIGURE 1. **The evolution of the demand response programs in different years.**

C. PAPER ORGANIZATION

The paper's remainder is organized as follows: in Section II, different DR definitions over many years and a related historical timeline are provided. The study classifies various DR programs based on practical insights and explains their advantages and disadvantages in Section III. In Section IV, practical DR strategies are presented. In Section V, the perspective of DR in smart grid and smart communities are discussed. In Section VI, the future trend will be mentioned, and finally, Section VII presents the paper's conclusions.

II. OVERVIEW OF DEMAND RESPONSE

Generally, DR is introduced as a tool for increasing network reliability, reducing peak demand, managing network development, electricity commercialization policies, and deploying integrated technologies in power systems.

On the one hand, a DR plan should focus on upgrading the smart grid information processing requirements [22]. On the other hand, it should increase customer awareness of his benefits to adapt or change the power consumption pattern [23]. The main reasons for encouraging consumers to participate in these projects can be summarized in terms of cost savings, avoidance of blackouts, and liability [24]. Accordingly, the DR program will utilize various resources, including distributed generation, dispatchable loads, storage systems, and other resources that can contribute to the power supply modification [14]. In the following subsections, definitions of DR, types of classifications, advantages, and disadvantages of the schemes will be presented.

A. HISTORY AND DEFINITIONS OF DEMAND RESPONSE

The concepts of modifying or altering electricity consumption patterns are basically tied to the ideas of Demand-Side Management (DSM) or Energy Service Management (ESM). This concept has a long history and goes back for more than forty years. Generally, it referred to all the electricity company's efforts to reform the pattern of energy consumption. Fig. 1 illustrates the evolution of DSM programs over different periods.

The implementation of DSM programs dates back to the 1970s. These programs were born in response to growing concerns about dependence on foreign oil resources and the environmental consequences of electricity generation, especially nuclear energy. Initially, the term Load Management noted all these actions [25]. In fact, electric load management refers to a variety of strategies used to manage power consumption over time. These strategies aim to shift consumption from high demand to low demand time slots to make more efficient production capacity [26], [27]. So the term load management or load control was used even before the invention of DSM. The load management strategies were also classified into two categories: customer side (e.g., thermal energy storage devices, directly or indirectly controlled devices) and utility side (e.g., pumped hydroelectric storage, utility battery storage) [28]. Therefore, load management was scheduling loads to reduce electrical energy consumption or maximum demand and improve the system load factor [29]. Although these programs presented an approach to control end-users' consumption, it was necessary to develop a paradigm with a more comprehensive vision of the electricity utility and customers' preferences.

In the 1980s, due to pressures from rising costs and environmentalists' side, the concept of Demand-Side Management was first introduced in [30] by EPRI. This concept was introduced as a set of activities that power companies undertook to transform energy consumption patterns to maximize benefits, postpone investment, and improve reliability. Later this concept was further expressed in [31] as follows:

"DSM activities are those which involve actions on the demand (i.e. customer) side of the electric meter, either directly or indirectly stimulated by the utility. These activities include those commonly called load management, strategic

conservation, electrification, strategic growth or deliberately increased market share."

Accordingly, DSM includes a range of management functions related to directing demand-side activities, including planning, evaluation, deployment, and monitoring. Generally, this term pursues multiple goals based on load-deformation, which had initial load-shape-based methods as follows: Peak clipping, valley filling, load shifting, strategic conservation, strategic load growth, and flexible load shape [31]. In the past, DSM programs focused more on electricity demand management than heating and transportation (non-electric) consumptions. While, it could consider measures related to non-electrical energies such as co-generation technologies, direct heating/cooling systems, and micro-generation [32].

The term was later modified in response to developments in competitive markets. In this regard, in line with the new goals based on reducing greenhouse gas emissions, energy security, and affordability, a more comprehensive definition of DSM was presented as follows [23]:

"DSM refers to technologies, actions and programmes on the demand-side of energy metres that seek to manage or decrease energy consumption, in order to reduce total energy system expenditures or contribute to the achievement of policy objectives such as emissions reduction or balancing supply and demand."

With the beginning of the 1990s and the progress of the liberalization of the electricity market, the DSM programs were categorized in different ways [33]–[35]. These classifications revealed the orientation of programs' actions in terms of Load Management (LM), energy conservation, electrification, or strategic load growth.

However, with the penetration of distributed generation sources at different voltage levels, load management measures had to take a different form to meet new challenges. In the new approach, the user's position and role in the competitive market environment should be provided, taking into account the utility and user interests. Thus, the concept of Demand Response (DR) was defined by the US Department of Energy in 2006, and in line with this definition, the previously presented categorization titles were fundamentally changed. In [36], the concept of DR is presented as follows:

"Changes in electric usage by end-use customers from their normal consumption in response to changes in the price of electricity over time, or to incentive payments designed to induce lower electricity use at times of high wholesale market prices or when system reliability is jeopardized."

However, the concept was later redefined by the US Federal Energy Regulatory Commission [37]:

"Actions by customers that change their consumption (demand) of electric power in response to price signals, incentives, or directions from grid operators."

According to this definition, electricity customers are transformed from passive actors to active ones to have savings and support the electricity grid by flexibility in their demand. Thus, in [38], to explain the new methods of integrating demand flexibility and controllability within the restructured power system, Demand Side Integration (DSI) was substituted for the traditional DSM concept. This concept's technical scope is also focused on promoting the efficient and effective use of electricity by the end-user, and it includes DR, energy efficiency, and strategic load growth. To be more precise, in the new restructured environment, DR that is the subject of this study should be categorized as a subset of the DSI concept. In fact, the DR or Demand Side Response (DSR) is a new term describing a market-based approach to manage the load. Therefore, unlike the DSM concepts, the concept of DR only refers to corrective actions or changes in the electricity demand of customers in the short term.

DR is gradually moving towards an Integrated Demand Response (IDR) [39], [40]. By developing multi-energy systems as smart energy hubs, the integration of electricity, thermal energy, natural gas, and other forms of energy cause that all kinds of energy users to be active in DR applications. In fact, in an IDR program, energy consumers can not only shift their energy consumption but also change their energy source. Accordingly, the concept of IDR considers the strategy of multiple energy consumption as complementary to the synergy effects of multi-energy systems [41]. Therefore, the IDR values can be summarized as 1) improving the economic efficiency of the energy system, 2) improving the energy security of the system, and 3) extracting potential sources for DR [42].

Recently, due to smart grid technologies, different types of renewable sources and controllable loads have been gradually integrated into end-user premises. Accordingly, a new DR participant with considerable load flexibility is emerged, which is called smart community DR [43]. The introduction of local markets and energy trading, the changing in the load behavior of end-users, which may either inject or absorb electrical energy, as well as the establishing two-way data communication into smart grids, can drastically change the procedures of DR programs. In this way, technical approaches such as blockchain, game theory, and optimization have been used to solve the challenges of implementing DR schemes in the new environment [44]–[46].

Thanks to the smart grid technologies, the deployment of intelligent multi-carrier energy systems has recently received much attention as a next progress phase. Accordingly, developing new strategies that have a comprehensive view in DR for both natural gas and electricity networks is imperative [47], [48]. To this end, in the scientific literature, a model of the smart energy hub is usually utilized. For active participation in DR programs, the IDR problem is integrated into the model and solved by various methods such as reinforcement learning algorithm [49], Nash equilibrium [50], and game theory [51]. In general, the goal is to maximize smart energy hubs' aggregated payoff along with maximizing the utility companies' daily profit.

B. CLASSIFICATION OF DEMAND RESPONSE PROGRAMS

DR was first introduced in the power system to improve reliability with the active participation and quick response of end-users in contingencies. With the development of the smart grid concept, increasing the use of distributed generations, and consumer participation in the electricity market, DR was considered a new resource [52]. In recent years, numerous DR programs have been categorized based on a variety of criteria, actions, and methods.

In [53], various DR schemes are classified based on their control mechanisms, proposed incentives to reduce consumption, and decision-making variables. DR programs are categorized in [54] using various criteria such as activation factor, signal origin, and signal type. In [55], depending on the timing and effectiveness of the actions taken on customers, different classifications are provided for DR schemes. Based on the parties who can perform the load reduction actions, another classification of DR programs is introduced in [56]. From the dispatchable and non-dispatchable perspectives of DR schemes, a taxonomy of these programs is presented in [57]. Also, in [58], an arrangement based on different types of electricity markets is proposed for various DR programs. A categorization based on price changes and incentive offers is considered in [21], which is also referred to in [59] with other titles such as Market-led, System-led, Emergency-Based, and Economic-based schemes.

It can be seen that in different articles, considering different aspects, various categories of DR programs have been proposed. Each class uses a particular perspective to introduce DR programs according to their expectations and specific definitions. In this paper, a new approach to DR programs classification is proposed. The proposed method is designed based on each program's place in the electricity industry chain, and the goal is to provide a guide map to select, plan, and implement the programs much more purposefully. To this end, the goal-oriented classification has been created considering the following points:

- Market-Based: DR schemes are divided into wholesale and retail markets. By doing so, the tasks of each scheme are defined within the particular market environment to specify the interaction between the market and the DR plan. With this segmentation view, party-based separation of programs is also indirectly covered. So, a participant, e.g., typical end-user or utility, can quickly determine and select the programs that fit their targets.
- Motivation-based: If the motivation of each scheme is clear, the selection and implementation processes of that program are evaluated based on that incentive. In general, reliability and economics are two driving forces in DR schemes that must be clarified for each program.
- System-based: Identifying DR schemes that operators can control may be caused to proper management and the conduction of these schemes in critical moments and emergencies. This will be reflected as power flexibility and in the form of dispatchable and non-dispatchable DR plans.

Considering all of the points above, the proposed classification follows four dimensions; market, reliability, economic motivation, power flexibility. Fig. 2 shows the overview of the

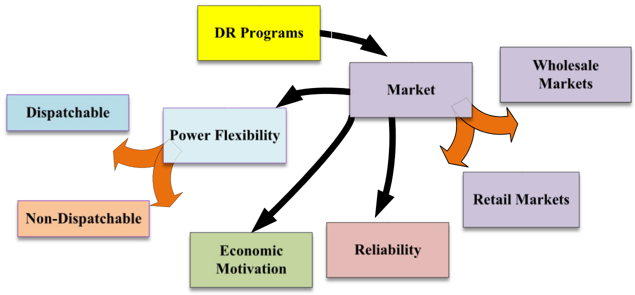

FIGURE 2. The dimensions of the proposed goal-oriented classification.

dimensions of the proposed goal-oriented classification. The classification begins with the separation of programs based on the type of market environment (wholesale and retail). In each market environment, the remaining three dimensions will be applied. Actors in various DR schemes can have reliability-oriented and economic-oriented motivations. Also, the output product of the scheme can be dispatchable or non-dispatchable on the network.

Applying the above distinction patterns, the DR programs classification can be summarized in Fig. 3. According to the process flow diagram, first, the schemes are separated based on the type of electricity markets. Then, from a system perspective, the programs, both dispatchable and non-dispatchable, are identified, and simultaneously the motivations of the schemes are recognized. Finally, all the plans presented in the previous articles are reflected in suitable blocks. In the following, the whole process of classification is described in detail.

1) RETAIL MARKETS-BASED PROGRAMS

This classification is taken from articles [58], [18] and [23]. However, to make the classifications compatible with the electricity markets, modifications have been made in the arrangement of the programs. Also, other DR programs are fetched from articles [21], [1] to keep the comprehensiveness.

a: INCENTIVE-BASED DR

These programs, also called Event-based DR plans, offer discount rates or rebates to consumers in exchange for their participation in load reduction through DR signals and according to the previous agreement. Such an agreement between the consumers and the power company allows the program manager to plan directly to reduce or interrupt the load to save money [60]. In this case, the upper range of individual events and the total number of hours of events per year are usually pre-defined and constant. However, these ranges are basically dependent on consumer availability constraints and DR technologies [61]. There are a variety of Incentive-based DR programs that are introduced below.

- **Emergency DR (EDR):** In a situation with a shortage of supply capacity, power companies have two options [62]. First, the load shedding should be used to maintain the stability of the network and prevent extensive damage to the power system. Second, calling on the

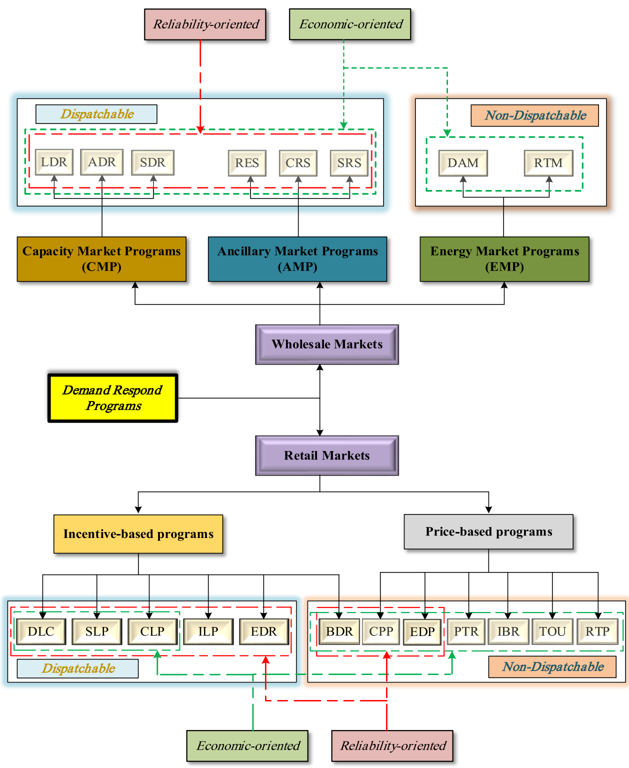

FIGURE 3. Process flow diagram for the proposed classification approach of DR programs.

cut-off program of large commercial and industrial customers who can cut their loads or use backup generation to supply their loads for a short-term period. In the latter case, participants in the program are rewarded only in case of emergency and for their reduced load value [36], but the load curtailment is voluntary. The motivation for running this program is reliability.

- **Interruptible load Program (ILP):** In this case, commercial and industrial customers with loads above 1 MW according to a previous agreement to turn off most or even all of their load, participate in the program for a specific period. The common strategy of customers in this method is based on the use of backup generators when running the program, so the motivation is reliability. Consumers are served discounted rates thanks to accepting service provision requests but will be penalized if they do not participate in the program [63].
- **Curtailable Load Program (CLP):** The goal of these programs is to reduce the load or cut the average loads by about 200 kW to large loads. Participants agreed to perform the program through manual or automatic load adjustment over a while. Like ILP, incentives are offered to customers participating in the program to compensate for this service, and of course, this participation can be optional or voluntary [64]. However, depending on the number of participating loads on the program, there are maybe penalties for non-participation as well. Therefore, the motivation for participation can be based on economic and reliability reasons.
- **Scheduled Load Reduction Program (SLP):** This program is a version of load reduction that gives more control to customers. Participants in this program can choose the amount and duration of the reduction (often up to 4 hours during the week). There are usually two options for customers: reduce the average load by at least 15% per month or a minimum of 100 kW for at least 4 hours one to three times a week [65]. Customers will be rewarded for this participation but will not be penalized if they do not participate. The motivation to participate in this program is also based on reliability and economy.
- **Direct Load Control (DLC):** Within this program, the electricity company can interrupt or reduce the consumption of small commercial and domestic customers during peak demand while they are alerted. Consumers who participate in this program receive incentives to reduce their consumption below the predetermined threshold values. This program is sometimes called the Quantity-based program. Although it is mandatory for participants to run the program, if its implementation causes consumer inconvenience, it is considered possible to override the event [66]. A penalty will accompany non-acceptance of the program in some cases. Hence this scheme can be observed from two perspectives of reliability and economics.
- **Behavioral DR (BDR):** This program aims to modify the peak consumption of electricity through targeted advertising to encourage consumers to save energy. Although these voluntary schemes are based on behavioral changes of customers in limiting electricity consumption, no payment is made for its performance. With the development of smart meters, the effects of such non-dispatchable programs can be accurately measured, and a rewarding mechanism applied for changing the customers' energy consumption habits [67].

b: PRICE-BASED DR

These programs, also called Time-based or Rate-based DR, provide a variety of dynamic pricing schemes for consumers to encourage them to shift their consumption patterns from high-cost to low-cost time slots. In this way, customers react to price fluctuations and move or reduce their loads from peak time [68]. By increasing smart meters, customers are encouraged to manage their demand individually, and electricity prices can vary based on predetermined periods and also can differ dynamically by day, week, or year [69]. There are several Price-based DR programs, and all designed based on economic reasons, which are introduced below.

- **Time Of Use (TOU):** In this type of program, different electricity prices are offered in various periods that can be static or dynamic. This price, which is the average cost of electricity generation and transmission during the period, should be higher for peak periods than for non-peak periods. The most simple TOU rate has two blocks of peak and non-peak periods to encourage customers to change their consumption behavior [70].

- **Real-Time Pricing (RTP):** This program, also known as Hourly Pricing (HP) [71], can inform participants about electricity prices in hourly or daily timeframes. Thus the program can be called one of the most efficient DR programs in the electricity market. Accordingly, in the smart grid structure, devices installed in homes usually provide price signals of electricity companies during peak hours so that customers can instantly and adequately control their consumption in these hours [72].
- **Critical Peak Pricing (CPP):** Such programs are triggered when system reliability is compromised or the cost of generating electricity is high. Under these conditions, within a few days of the year, electricity prices are getting a more elevated level than standard rates, which are usually based on TOU. Critical peak periods occur only a few days or hours per year, so these periods and rates may not be constant [73]. Based on this, it can be said that the CPP tariff is the same as TOU rates, which are offered at a higher rate for a limited number of (critical) hours per year [74]. In addition to the economic drive, participation in this program is also motivated by the reliability factor.
- **Peak-Time Rebate (PTR):** These programs, also called Critical Peak Rebate (CPR), are usually offered to small residential and commercial customers without automatic control technology [75]. In these schemes, the pricing is flat, and the customers who cooperate during the peak load periods to reduce electricity consumption will be rewarded. On the other hand, consumers who do not reduce their electricity consumption pay the electricity price at the standard rate [76].
- **Extreme Day Pricing (EDP):** This scheme is similar to the TOU program, but it applies a high price rate for a limited number of days (critical) [74]. On the other hand, it is similar to the CPP program, except that the price standards are not announced until one day before the actual implementation [67]. In this regard, there is also the Extreme Day CPP (ED-CPP) program, which includes the specifications of both CPP and EDP programs. This scheme calls for CPP rates for peak and off-peak periods during certain days. However, such schemes are often not used in practice [75]. This program can be motivated based on both economic and reliability-related reasons.
- **Inclining Block Rate (IBR):** In this method, which is often used for domestic customers, the price rate increases with the customer consumption rate [73]. The pricing structure of this scheme is usually in the form of a step-by-step manner to encourage customers to reduce electricity consumption.

2) WHOLESALE MARKETS-BASED PROGRAMS

In most articles, definitions of DR programs related to the wholesale market have been briefly reviewed [79], [80], [19]. At the wholesale level, DR can be involved in Capacity Markets, Energy Markets, and Ancillary Markets [54]. The goal of the capacity market is to ensure the reliability of the power system. So, in terms of long-term planning, the market tries to maintain it at a proper level by providing enough megawatts for the future. However, from a short-term perspective, the role of energy markets and ancillary services is prominent, and the reliability of the operation is managed economically. It should be noted that the terms used in the wholesale market section are taken from the PJM (Pennsylvania-Jersey-Maryland) manual [81].

a: CAPACITY MARKET PROGRAMS (CMP)

In these programs, customers are committed to reducing or disconnecting predetermined loads when the contingencies occur, and if they do not cooperate, they will face penalties. These markets are often viewed as insurance policies and are mainly offered by wholesale market providers such as ISOs [64]. Participants in this market usually enter into long-term and medium-term contracts and are notified the day before the event [82]. The CMP programs have a historical background. However, in 2014, the DR resources of these programs were organized by PJM as Limited DR, Extended summer DR, and annual DR and presented as a single scheme called Capacity Performance (CP). These programs, which are implemented during specific response hours, are listed below [83].

- **Limited DR (LDR):** This program is provided to interrupt the load at certain hours of non-holiday days of a specific season of the year (e.g., summer) with specific event numbers (such as ten times per season) and with a pre-defined period (such as 6 hours for each event) [84].
- **Annual DR (ADR):** Such a program is defined for each day of the year, with a limited or unlimited number of power outages for at least a few hours (for example, a maximum of 10 hours) at each time [85].
- **Extended Summer DR (SDR):** This program is defined to apply an unlimited number of curtailment for a specified period of outage time (for example, a maximum of 10 hours) per day. In addition to the summer season, this program can be extended to other months [85].

b: ANCILLARY MARKET PROGRAMS (AMP)

These programs, also known as Ancillary Services (AS), refer to services and actions necessary to support a reliable, secure, and high-quality power system. The response time for these actions can be about minutes, and to participate in this program, the electric load must be repeatedly and carefully dispatched [86]. The program allows customers to participate in the spot market and offer the load curtailment as an operating reserve.

Due to various regulatory issues at the national level, different categories of these services are common worldwide. Therefore, different types of these programs can be identified through their physical characteristics, such as speed and duration of response or frequency of use, which are given below [87].

- **Regulation Services (RES):** This service is defined as a high-speed and accurate control or capacity service that provides an almost real-time continuous balance of generation and load in normal conditions. Based on these services, DR sources are allowed to change their output by following the Automatic Generation Control (AGC) signal of the power management system operated by ISOs [19]. In fact, ISOs can increase or decrease the load of customers in response to the real-time signal. The service is also called Regulating Reserves, Up-regulation, and Down-regulation [88]. It is not only the most expensive Ancillary service but also the most complex in terms of communications and control, as it must constantly respond to the AGC signals of the power system operator [89].
- **Contingency Reserves Service (CRS):** This service, also known as spinning / non-spinning reserve or Synchronized reserve, is used for large (several megawatts) and fast (multiple cycles) contingency events. By definition, a spinning reserve is a portion of the unloaded capacity of connected or synchronized generation units to the network that becomes ready for delivery up to 10 minutes. Also, a non-spinning reserve is a capacity that can potentially be synchronized in 10 minutes and ramped to a specified load [90]. The best sources for this service are the loads and processes that do not require time to respond. In fact, if power consumption is intelligently related to the network state, it can act as a virtual (or negative) spinning reserve [55].
- **Supplemental Reserve Service (SRS):** This service must be synchronized and become ready for power delivery within 30 minutes. These services, also called Replacement services and Day-ahead scheduling reserves, are used typically as a complementary or alternative spinning reserve to restore system frequency and stability [19]. Due to the smaller telemetry content and the minimum size requirement in this service, it is more accessible than other services [91].

c: ENERGY MARKET PROGRAMS (EMP)

The wholesale energy market programs operating at the transmission network level are responsible for ensuring the balance of supply and demand, maintaining the reliability and security of the system, and minimizing the overall cost of supplying demand from the system level to the regional level [92]. These programs also referred to in the articles as Demand bidding and buyback [21], [59], encourage the large consumers to curtail load based on a settled price. Participants in these programs are only considered for periods that rare peak loads happened [90]. Various types of these programs are listed below.

- **Day-ahead Energy Market (DAM):** This market helps participants to avoid price volatility by trading in wholesale electricity on the day before the operating day. In fact, it provides a financial settlement [93]. Since prices in this kind of market are more practical, they can have a greater impact on demand.
- **Real-Time Energy Market (RTM):** This market allows participants to buy and sell wholesale electricity on an operating day. The differences between the previous day's commitments and the real-time demand for electricity generation are balanced by this market, as well as it establishes the secondary and separate financial agreement. This determines the real-time Locational Marginal Price (LMP) that must be paid or received from participants who deviate from their day-ahead commitments into the day-ahead energy market. [94].

3) A BRIEF DISCUSSION

From a practical point of view, every operator or customer should easily identify the required actions related to the proper implementation of DR plans.

In the retail sector, incentive-based programs often seek to reduce (or disconnect) loads through attractive incentives, while price-based programs are typically related to consumer behavior to reduce consumption. In both approaches, proper equipment to monitor consumer behavior is essential. However, in incentive-based applications, expensive equipment such as remote control switches must be used to provide the desired results.

It is possible to call the DR plans of the wholesale level as support of retail-level programs. The view of DR programs at this level tries to implement programs in the power generation sector. The main nature of these programs depends more on selling energy than buying energy. Therefore, at the wholesale level, decisions are made to direct DR programs towards generation management to balance supply and demand in the electricity industry using different alternatives. Such programs are less considered in the industry because they require the participation of the generation sector and the existence of special facilities.

C. BENEFITS AND BARRIERS OF DR

With the development of smart grids, DR has become an attractive option to increase the flexibility of the power system. This concept allows efficient use of system assets and resources. In different articles, the potential benefits and barriers to DR implementation have been identified and categorized differently. They often used some initial assumptions to define their own classification [36], [95]–[96]. The classes were usually formed according to the performance, scheme, and enabling factors [54], [97]. In this paper, in line with the pragmatic mindset, the benefits and barriers of DR are classified based on the concepts of measures and their effects on utility and customers.

1) DR BENEFITS

DR applications can bring many benefits to the network and every customer. These benefits have been categorized in different ways and presented in several studies [12], [16], [98]. In this paper, considering the classification in the previous section, the benefits are divided into three dimensions: Economic-oriented, Grid-oriented, and Socio-environmental-oriented, Fig. 4. Details for each class are given below.

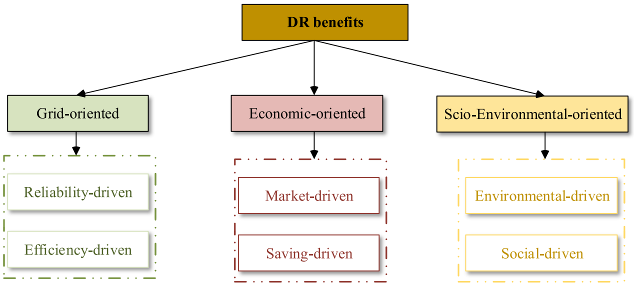

FIGURE 4. DR benefits classification.

a: GRID-ORIENTED BENEFITS

DR programs can have significantly impact the performance of the generation, transmission, and distribution networks. Most of the benefits in this area refer to the electricity company; however, the results will affect the customers. The benefits of this section can be categorized into two categories: Reliability-driven and efficiency-driven.

i) RELIABILITY-DRIVEN

DR schemes have significant effects on risk reduction and improving reliability. The programs that affect reliability were noted in the previous section. In this section, details of the benefits will be provided.

- Reducing the need to upgrade and increase the capacity of transmission and distribution networks: Using flexible demand and reducing peak loads through various methods will reduce the need to increase the system capacity of different sectors of the electricity industry [12]. This allows companies to use existing power plants at a fixed capacity. Transmission and distribution networks are not subject to the stresses of sudden or seasonal overload, and network upgrading is postponed [99]. DR programs, especially to maximize the penetration level of electric vehicles, can delay investment in network capacity [100].
- Increasing the generation reserve margin for emergencies and unforeseen events: In emergencies, the generation reserve margin plays a vital role in increasing the reliability of the generation section. Due to the controllable nature of demand, DR schemes can significantly increase the reserve margin of generation units [95]. This reduces unplanned outages caused by generation deficiency.
- Reducing the congestion in substations and transmission or distribution lines: The use of electrical equipment with maximum capacity or above the nominal capacity, even for the short term, will increase the risk of the power outage due to possible failures. DR programs can play an essential role in controlling the equipment loading and congestion by managing the increase in demand levels and reducing the peak load in lines and substations [101].
- Improving the security of important loads by managing outages: Load flexibility can often be a great help in fast-moving recovery. Thus, in the event of a power outage, network recovery has a high priority for essential and critical loads [102]. Therefore, with the help of various DR schemes, it is possible to increase the service availability for critical loads while reducing the outage time.

ii) EFFICIENCY-DRIVEN

Increasing the performance and efficiency of network assets is another benefit of DR programs. These programs serve as a way to modify the demand on intelligent networks to help improve the performance of network assets. From this attitude, the following advantages can be achieved.

- Network loss management: DR programs that seek to reduce consumption, especially during peak hours, will significantly impact network losses. Along with network reconfiguration, various DR schemes can affect network operation from the power loss viewpoint by modifying consumers' consumption patterns [6].
- Capacity utilization improvement: The utilization factor of network equipment can also be improved with the help of DR schemes. As customers' load curves are flattened, the use of the nominal capacity of the power system infrastructure will improve [103]. It is also possible to help optimize flexible electricity assets' operation using special tariffs such as capacity-based rates [104].
- Increase the life of the equipment: Extending the lifetime of the main assets of the power system is another advantage of DR schemes. Peak load management programs significantly impact the healthy performance of network equipment and can increase equipment life by controlling the operating capacity to nominal capacity [105].
- Supply and demand management in renewable systems: Due to issues such as variability, lack of controllability, and flexibility of renewable resources, the ability to maintain supply and demand balance is always one of the main problems of these resources. Uncertainty in the generation of these resources has led to DR schemes as a standing reserve is able to improve system performance [106]. The optimal distribution system operation can also be achieved by using a combination of network configuration and renewable resources [107].

b: ECONOMIC-ORIENTED BENEFITS

The economic benefits of DR programs can be considered one of their most attractive merits. By examining the cost-benefit of different programs, the best plan can be selected for planning and implementation. So recognizing these benefits can help determine the optimal scheme more accurately [108], [109]. These benefits are categorized into Market-driven and Saving-driven groups.

i) MARKET-DRIVEN

With more efficient use of existing infrastructures and the flexibility of consumer demand, the overall price of electricity is expected to fall significantly. In fact, by DR programs, it is tried to transform the structure of the power system from an integrated vertical model to a competitive and market-based environment, which will also increase the economic efficiency of the industry. The following profits can be summarized in this matter.

- Decreased market power: Despite the implementation of market mechanisms, the problem of market power in the generation side has caused inefficiencies in the electricity market [110]. DR programs can affect market mechanisms. By participating in the schemes, participants can have the opportunity to influence the market by managing their consumption, thereby preventing market power and rising prices [111].
- Reduction in price volatility: In electricity markets, price volatility happened from time to time due to uncertainty in prices, can be triggered for various reasons at peak loads [112]. To avoid such price spikes, various DR schemes can be used. Motivating by the financial incentives of the DR programs and reducing demand, consumers can prevent such a sudden price rise [113].

ii) SAVING-DRIVEN

In general, DR programs look for ways and means to reduce the costs of the company and its customers. These schemes, through financial incentives for consumers, make it attractive to change their behavior. Accordingly, DR programs can save on end-users and the electricity industry costs. The details of these merits are given below.

- Avoiding or delaying the costs of infrastructure expansion: By implementing DR programs, it is possible to postpone the development plans of the electricity system. Accordingly, by appropriate peak reduction programs and with the help of cost-effective methods, it is conceivable to save infrastructure costs [114].
- Reducing operating costs of electrical infrastructure: DR programs such as reduction or shift of peak loads can also affect equipment operating costs. Saving on fuel costs, repairs, maintenance, and operation of the equipment are essential issues. Therefore, by examining the impact of different DR programs on operating costs, optimal DR schemes can be used to reduce generation and power grid costs [115].
- Reducing consumption costs of customers: Participants who cooperate with DR schemes receive rewards. Because these programs are customer-centered, the rewards should effectively reduce the cost of their consumption, which will motivate them to participate more in the programs [116].

c: SOCIO-ENVIRONMENTAL-ORIENTED BENEFITS

Reducing energy consumption, increasing energy efficiency, using renewable energy production, and reducing greenhouse gas emissions are some of the benefits of socio-environmental-oriented DR programs. Although these actions are motivated by financial incentives, the role of the non-financial incentives of pro-environmental advocates who are taking steps in this direction should not be overlooked [98]. However, few articles have examined and noted such benefits. These benefits are categorized into two areas: Environmental-driven and Social-driven, which are described below.

i) ENVIRONMENTAL-DRIVEN

One of the significant benefits of implementing DR programs is reducing the power industry's destructive environmental effects. In the past, in most articles, ecological benefits were seen alongside economic benefits [117], [118]. However, due to the variety of actions taken, it is possible to point out the critical aspects of its benefits.

- Reducing greenhouse gas emissions: By reducing electricity consumption, electricity generation will also be reduced, which will reduce the fuel consumption of large power plants and, consequently, reduce greenhouse gas emissions. This will make the use of renewable energy sources more reasonable. This advantage is one the most tangible and measurable environmental benefits of DR, which is a criterion for cost-benefit analyses 119], [120]. An ecological, economic dispatch model can ensure the optimal operation of the network with various renewable energy sources in the presence of DR schemes to reduce the emissions of greenhouse gases and air pollutants [121].
- Reducing environmental destruction: Since one of the goals of DR programs is to defer the electricity infrastructure expansion, this will prevent the need for ecological destruction to develop these infrastructures. Although no accurate estimate or study has been made of this perspective, it can be expected that such an advantage of DR programs will not be out of reach.

ii) SOCIAL-DRIVEN

The social benefits of implementing DR schemes are also rarely popular in the literature. These benefits, which are the external effects of DR programs, can be summarized as follows.

- Increasing the health of the community: One of the external effects of reducing greenhouse gases, which is related to the implementation of DR programs, is the improvement of public health. Studies in this area have often been appreciated in environmental benefits, but it must be acknowledged that this is one of the most important benefits to human society [122], [123].
- Promoting social welfare: Increasing customer satisfaction after implementing DR programs can also be considered as one of the DR benefits. Issues such

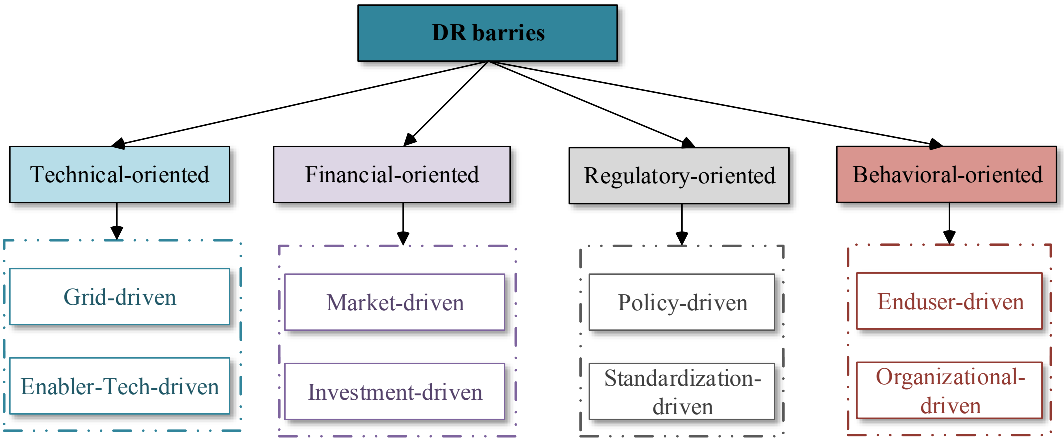

FIGURE 5. DR barriers classification.

as reducing consumption costs and managing power outages can be considered as factors affecting the promotion of the social welfare of customers, which can be sought by various methods of pricing [124], [125]. Also, studies show that in a subsidized market, DR programs with different incentive-based tariffs can satisfy consumers [126].

2) DR BARRIERS

Due to the highly distributed nature of DR programs, intrinsic and complicated relationships with people, and the need for enabler technologies, there are significant barriers to implementing these programs. Identifying these challenges and related factors is key to understanding how to overcome them and increase the influence of DR programs. In various studies, obstacles and challenges to the implementation of these programs have been presented. In this paper, as observed in Fig. 5, the classification of existing barriers is presented based on four categories, financial-oriented, technical-oriented, behavioral-oriented, and regulatory-oriented. The details of each class are given below.

a: TECHNICAL-ORIENTED BARRIERS

The technical challenges of implementing DR programs can be considered from two perspectives: enabler technology-driven and grid-driven. From the view of enabler technology-driven, the main obstacle is the need for reliable and efficient technology infrastructure to conduct DR programs. The grid-driven barriers are related to the capacity and structural constraints of the power grid.

i) ENABLER TECHNOLOGY-DRIVEN

Essentially, smart meters and ICT technologies are the primary enablers of DR [23]. These are used to accurately and locally measure the flexibility of demand, interactive communication between the DR producer and the participant, as well as on-premises automation [127]. The lack of these infrastructures will be major obstacles to implementing DR schemes, which are discussed below.

- The need for proper measurement, computational, control, and communication capabilities: Energy markets need a good platform with high measurement resolution to conduct accurate transactions. In fact, it is crucial to know how to implement measurement technology. Therefore, the need for accurate and reliable measurement of values in such a way as to identify the flexibility of demand will be one of the essential obstacles [127]. Long calculations must also be performed over excessive data to determine the DR potential. Excessive data computation considering uncertainty in DR potential and its prices can be an obstacle to choose the optimal DR program [128]. Assuming that the measurements of the data and the calculations on it are done carefully, the correct transfer of information to the decision-making centers can be considered another obstacle. In addition to this issue, compliance with information security and data privacy can be a significant challenge in this area.
- The need for standardization of technology: As the integration of DR and other renewable resources in the smart grid grows continuously, the decentralized character of the energy grid will increase. With increasing decentralization, the need for sophisticated information systems to manage this complexity increases [127]. To match the different parts of this complex technology, the lack of a clear and codified standard can be a significant obstacle to other technologies' entry.
- The need for experts in technology: Proper design of technology, its proper implementation, and good local support requires skilled professionals, the absence of which is a significant obstacle in the performance of DR programs [128].

ii) GRID-DRIVEN

Since the implementation of DR programs depends on the operation and development of the power grid, its value will also be flexible. Therefore, the inherent limitations and conditions of the grid can be a significant obstacle in the implementation of DR programs.

- Grid capacity limitations: In general, the loading of the power system to the maximum capacity, which then requires upgrading the existing network, is one of the main obstacles to implementing DR programs. In fact, the value of DR is very high in parts of the system that need to be upgraded, but in cases where there is spare capacity, its value is usually low [16].
- Lack of coordination between different parts of the network: In the liberalized structure, for specific times, some participants can provide power supply downstream of the network, whereas the limitations in transmission capacity can lead to an obstacle to transferring power. Accordingly, attempts to incorporate multiple goals on a time horizon with competitive effects are impractical and may lead to opaque economic incentives [79].

b: FINANCIAL-ORIENTED BARRIERS

Another major obstacle to implementing DR programs is its financial difficulties. In general, these problems can be divided into market-driven and investment-driven categories. Establishing an efficient market environment, creating the right business environment, and effectively controlling demand through price signals are related to the market-driven group. Cost-related issues for DR schemes can be seen in the investment-driven category. The details are given below.

i) MARKET-DRIVEN

Numerous studies from different countries have been issued about barriers to the electricity market to integrate DR schemes. These barriers can vary depending on the geographical location and the nature of the market. In this section, the financial barriers arising from the market mechanism that prevent the proper implementation of DR programs will be investigated and presented.

- Lack of accurate evaluation of DR programs: Due to the uncertainties and issues related to calculating the value of generation capacity costs, it is difficult to determine the cost-benefit of DR schemes. If the importance of these programs is underestimated, incentives will be considered lower, so less participation will be provided by customers [19].
- Improper structure of incentives: Time-based rates can often reflect the time changes in the cost of electricity and financial benefits, while most DR tariffs do not follow this pattern [97]. In practice, this makes it difficult to persuade customers, especially industrial ones, to participate in DR programs, as they may be reluctant to take the risk of adverse effects of DR on their production quality 129].
- Lack of identification or estimation of hidden costs: Increasing these costs related to market participation, such as negotiation and contract costs, can be a serious obstacle to DR programs. Such costs should be considered, especially for small participants, although they can be outsourced in the organized markets [130].
- Lack of willingness of the network operator to implement DR: Due to the reduction in revenue from implementing some DR programs by electricity companies, network operators are reluctant to implement them. Therefore, these companies introduce the lack of cost recovery mechanisms resulting from DR as the main obstacle to implementing DR actions [131].

ii) INVESTMENT-DRIVEN

The initial investment in technologies to implement DR programs is obvious, but the optimal and cost-effective contents are always the severe decision-making challenges. Also, DSOs use the flexibility of DR schemes to reduce their investment costs, which can sometimes lead to security issues of the power system.

- Lack of rationale for the initial investment in technology: Installing smart meters and other DR enabler equipment is costly. For creating a credible business environment, the costs and benefits of flexible demand must be shared between the consumer and the actor, which is a severe challenge. Therefore, the value of DR should be distributed within the power supply chain, along with the participation incentives of each actor under completely transparent models [132].
- Lack of proper investment in the power grid: The main reasons for DR implementation are to reduce capital expenditures, maintaining and operating costs while maintaining the reliability and security of the grid. However, setting marginal costs regarding DR programs is always one of the most severe challenges. Therefore, a lack of timely investment and network security risk can be considered one of the main obstacles to realizing DR schemes [133].

c: REGULATORY-ORIENTED BARRIERS

In this section, the obstacles resulted from government policies embedded in regulations will be explained. These are divided into two groups: Policy-driven and standardization-driven. In general, these barriers are related to the implementation and standardization of DR programs.

i) POLICY-DRIVEN

The role of regulators is essential to provide an appropriate policy framework to implement DR programs in the power system effectively. Therefore, from this perspective, identifying policy barriers that are a barrier to the future development of demand flexibility services can help find solutions to these obstacles. Therefore, their details will be reviewed and presented below.

- Lack of transparency in rules and regulations: The more DR services are distributed within different agents, the greater the transparency of the role and responsibilities of DR providers should be established to develop these services efficiently and fairly. In some articles, the effects of distortion on government policies are sometimes referred to as market failure [134]. With the widespread entry of aggregators and other actors into DR services, as well as the availability of renewable resources, a lack of clear and transparent policies can be a significant obstacle to the development of these services 135].

- Variable tax policies: In addition to customers' energy costs, their final bill includes various items such as taxes, payment of public service obligations, which changes in each of these factors can affect the final cost of customers [12]. Therefore, energy tax can have a direct impact on customers' incentives [136]. From the legislature's point of view, tax differences between substitutable goods such as electricity and gas could disrupt the operation of the DR. Moreover, if the consumer uses renewable resources, inappropriate tax tariffs can seriously hinder the implementation of DR programs [137].
- Lack of creating a competitive environment: If the regulations are set in such a way that it prevents the competition of substitutable products in the market, it can be a significant obstacle in the implementation of DR. Once system regulations are established based on the traditional networks, it will be difficult to run them on smart networks. Another challenge arises when regulations prevent market price signals from reaching end-users. This will affect the business situation of the market and its efficiency 138].
- Types of policies in different countries: Each country has its own rules and policies regarding DR programs. Lack of attention to research and development, lack of a well-codified DR executive program, and lack of transparent policy are severe obstacles to developing DR programs in various countries 139].
- Lack of data sharing regulations: There are no specific rules on privacy and data security related to DR. Current rules are essential for processing data associated with preparing customers' bills. At the same time, DR schemes require a significant amount of data and processing. The method of data sharing between different actors is also one of the severe challenges for which a clear and codified policy has not been defined [140].

ii) STANDARDIZATION-DRIVEN

Despite the significant impact of standardization of DR services on investment, competition, and market liquidity, there is no broad and comprehensive standard in this regard. Notwithstanding the introduction of guidelines for smart meters in some countries, there are still no minimum legal requirements [141]. The same is true of the standard for measuring and approving DR products, which is discussed below.

- Standardization of DR products: Energy and capacity as DR products can be standardized based on some of their features, such as the amount of time of the transaction. However, it should be noted that if the definitions of standard products are very limited, they may prevent the delivery of the product by DR providers, or the full value of DR may not be achieved [135]. This standardization can reduce search and dispute costs so that it can be a severe challenge to the regulator [142].
- Lack of standard approach to measuring and approving products: The performance of DR schemes is typically calculated from the difference between the actual level of demand and the level of baseline, so in this way, consumers are paid for what they have not consumed [143]. However, the current approaches to measuring and validating this performance in different companies are entirely different, and there is no standard procedure for it. While standardizing the DR product measurement and approval approach can significantly impact consumer engagement [19].

d: BEHAVIORAL-ORIENTED BARRIERS

These barriers can be considered from two perspectives: End-user-driven and organizational-driven. These categories cover the behavior of end-users and organizations about DR schemes, which are described below.

i) END-USER-DRIVEN

The combination and interaction of some critical elements such as technology infrastructure with consumer behavior can determine the ability and vision of DR in the end-user domain. Consumer behavioral barriers can be described as factors that cause individuals to deviate from an utterly logical state (in classical economics) [144]. These can include the following:

- Incorrect exchange of information: If the information sent to the consumer is not consistent with his behavior, one should not expect a proper response from the consumer [145]. Therefore, the form of the exchanged information can play an important role in the type and accuracy of the behavior of DR's service buyers.
- Decreasing the level of credibility and trust: Due to the importance of exchanges between DR providers and buyers, low levels of credibility and trust related to parties can be a severe obstacle to DR. Therefore, the issue of trust is introduced as an indicator for DR acceptance [146]. This can be easily seen in the consumer's preferences for choosing a DR provider.
- Lack of proper understanding of DR benefits: This barrier, which can be associated with other barriers such as financial barriers, often reduces interest in DR schemes; thus, it prevents parties from paying attention to invest and gain benefits from DR. In fact, the lack of DR recognition preclude the development of appropriate tools such as systematic business models in this area [147].
- Consumer behavioral uncertainty: End-users may engage in or not interested in DR schemes, regardless of their knowledge, so this makes it challenging to

predict DR accurately. If user values such as independence, ownership, authority, and control conflict with DR actions, the customer may be reluctant to cooperate or reluctantly participate in DR schemes [148]–[150].

- Existence of different administrative steps: Participants, in addition to provide specific requirements, usually use aggregators to manage their DR participation. Spending extra time and engaging in bureaucratic steps can be a barrier to collaboration in DR schemes.

ii) ORGANIZATIONAL-DRIVEN

These barriers include those imposed by the actions of organizations associated with DR programs. Important cases that are based on organizational barriers are presented below.

- Lack of agents' ability: If the organization responsible for implementing DR programs cannot install technology or invest in increasing flexibility, there may be obstacles to establish these programs. Agents' inability can also be linked to a lack of organizational culture or belief in DR schemes, which can be a significant obstacle to program implementation [151].
- The poor performance of agents: If end users are not satisfied with the performance of third-party aggregators, they will not be willing to participate in DR programs. Lack of awareness and inappropriate behavior of aggregators about the value of DR generated by some customers, including industrial consumers with huge loads, can be a significant obstacle in implementing these schemes [152].

D. UNCERTAINTY IN DR

In general, the successful practical implementation of DR programs depends on considering uncertainty. This uncertainty can be divided into two categories: physical uncertainty and informational uncertainty [153]. The weather condition, customer behavior, and inaccurate electrical appliance consumption modeling can be considered physical uncertainty. Due to the exogenous nature of these factors in the power system, they are difficult to model accurately. By contrast, informational uncertainty is due to utility/aggregators not having full access to all load information for various reasons. Nevertheless, even if they could access the states of every load, it is very hard to forecast the actions of consumers correctly [153].

In various articles, modeling of these uncertainties has been addressed. In order to measure the combination of both renewable sources uncertainty and DR uncertainty, a technique of fuzzy stochastic conditional has been utilized in [154]. In this way, the three-stage unit commitment model is proposed by pre-emptive goal programming to achieve the best trade-off between system reliability and economic goal. Due to addressing the uncertainties imposed by the renewable sources in the energy hubs, an approach based on the information gap decision theory (IGDT) is proposed in [155]. This approach introduces two different strategies for the energy hub operator to face price uncertainty. In [156], a scenario-based approach is applied to solve the power system economic dispatch problem in the presence of uncertain DR providers. The proposed approach improves the performance of the day-ahead market considering the high uncertainty of DR programs. The uncertainties in industrial DR scheduling are analyzed using a chance-constraint formulation in [157]. In this method, an optimal DR scheme is proposed using electricity price and product demand uncertainty. In [158], a mixed-integer linear programming (MILP) approach has been developed to quantify the impacts of DR uncertainty on unit commitment (UC) of microgrids. By a proposed procedure, the impacts of shiftable and curtailable loads are simulated on the UC status of various power sources.

III. DR TECHNOLOGIES

The rapid development and deployment of smart grid enabling technologies, including advanced information and communication technologies (ICT), has led to significant technological advances that will allow the use of DR. This, along with technology standards such as OpenADR, facilitates the establishment of DR technical infrastructure. The combination and interaction of these technologies with consumer behavior will provide DR capabilities on the customer domain [159]. The existence and deployment of these technologies should be examined from two perspectives: utility-domain and end-user-domain. Considering these two perspectives, referring to the literature, the required enabler technologies that should be provided for DR actions can be divided into four categories: metering and monitoring devices, control devices, communication systems, and software programs. Fig. 6 shows the outlines of the classification, and details are provided below.

A. ENABLING TECHNOLOGIES FOR UTILITY-DOMAIN

These technologies provide a platform for exchanging and controlling data and between customers' entry to the power company. In fact, the built-in infrastructure in this section enables the electricity company to control, monitor, and manage required actions to provide DR schemes for the customers. As mentioned, such technologies are offered in four levels, which are described below.

1) METERING AND MONITORING DEVICES

Distribution system operation control centers in most power companies have a variety of systems for network monitoring and control facilities. Systems such as Supervisory Control and Data Acquisition (SCADA), Distribution Management System (DMS), and Network Information System (NIS) often monitor power network performance and analysis data. Due to the effects of DR schemes, the functions of these control centers need to be updated. DR product confirmation, generation and load forecasting, network state estimation, and power transmission control are essential requirements that should be provided by technologies related to distribution system control centers to enable DR programs. To this end, the

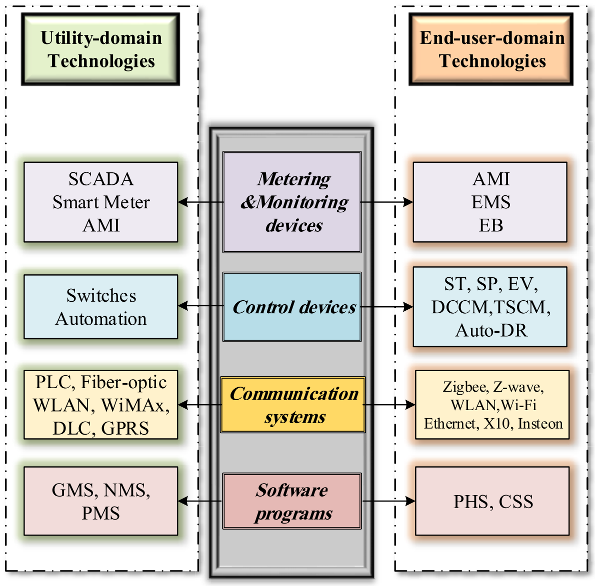

FIGURE 6. Classification of DR enabling technologies.

DR Management System (DRMS) as an interface between DSOs and other parties in the DR market, such as aggregators and business firms, must be created to enable and manage DR schemes [20]. In fact, it enhances the capabilities of existing facilities of distribution systems so that they can be used for DR purposes.

In a common connection point with the end-user, smart-meter systems consisting of an electronic box and a communication link are used. A smart meter measures the consumption of end-users electrically and possibly other parameters over a while and transmits these values through the communication network to the electricity company or other agents responsible for measurement [14]. For DR activities, smart meters can receive signals from the load-serving entity, such as the maximum allowable level of power supply in a given period, through two-way communication or price signals dynamically determine [20]. With the advent of Advanced Metering Infrastructure (AMI), a network of millions of smart meters was created to speed up the DR implementation through embedded platforms. An AMI refers to a complex measurement system that includes smart meters, communication networks, and data management systems [20].

2) CONTROL DEVICES

For effective participation in DR programs, the provision of automatic control by the intelligent energy management system (EMS) structures in the end-user environment is essential. In the conventional EMS structure, information signals are received from the various loads of the end-user, and accordingly, the optimal strategy is selected such that the consumer is satisfied [20]. Control devices such as control switches or smart thermostats, either stand-alone or integrated into the EMS, are employed by large installations or other customers to execute controlling tasks. With the right communication platform and switch automation, real-time control can be applied to implement DR schemes to the system. In fact, such infrastructure at the network level can play an important role in the effective participation of DR in wholesale markets [94].

3) COMMUNICATION SYSTEMS

An essential requirement for effective DR deployment is the ability to handle large amounts of data transfer. These systems must be designed to deliver market and emergency signals through one-way or two-way communication platforms between the utility and consumers. The medium-bandwidth and low-latency specifications are important for the effective transfer of DR commands and the fast implementation of relevant responses to ensure better performance of DR strategies. There are many communication mechanisms available to achieve the low-latency and bandwidth criteria. In general, communication technologies can be classified into two categories: wireless and wireless. Wireless communication technologies are less expensive, the technology is subject to signal losses [20].

In designing network architecture and communication technologies at the utility level, commercial, regional, and consumer-side premises communication systems are usually considered. Based on this and depending on the application type, three following networks can be used; Wide Area Network (WAN), Regional Area Network (RAN), and Neighborhood Area Network (NAN) [160]. The wired technologies used can be Power Line Communication (PLC), fiber optic, or copper wire. For wireless options, technologies such as WiMAX, WLAN, DLC, GPRS, VHF / UHF, and new cellular technologies can be used at different levels of the network [161].

4) SOFTWARE PROGRAMS

Digitalization by software makes the interoperability of future energy systems in the smart grid. The new grid dynamics to manage supply and demand have increased the need for a more flexible and intelligent approach, and this could highlight the role of advanced ICT infrastructure and software-based future in the grid [162].

The transition of traditional centralized energy systems to decentralized systems has also created new features and software-based landscapes in smart grids. In this regard, Grid Monitoring Software (GMS), which plays a vital role in leading DR projects, should be used to monitor the status of the network [163]. Implementing DR with the help of control devices, network management, and operation systems requires using Network Management Software (NMS) [164]. This software selects the best network configuration, considering DR and other distributed or renewable energy sources, and issues the necessary commands to establish such a network. To control and balance network loads using new energy market solutions such as dynamic pricing, it is necessary to use Power Market Software (PMS) to handle

DR schemes [165]. Based on load forecasting, Energy Management Systems (EMS) software should conduct the market incentives for network load management.

B. ENABLING TECHNOLOGIES FOR THE END-USER DOMAIN

On the side of the end-users premises, there must be special technologies to provide a suitable platform for DR deployment. In general, such technologies are based on the four features mentioned above. Still, depending on the structure and facilities of the consumer, they can have specific characteristics that will be presented below.

1) METERING AND MONITORING DEVICES

Having AMI infrastructure for the end-users will also allow them to monitor consumption. Consumers can make decisions about the implementation of DR by receiving on-line information from AMI. Also, for better analysis and decision-making of DR schemes, customers use EMS to automate and monitor the consumption of their loads. These systems, which can often be used for large commercial and industrial customers, as well as possibly residential ones, measure the overall consumption or individual loads and other required parameters and establish a good interaction between the customers and the electricity company [166]. So, they help to implement DR programs better. In more uncomplicated cases, using an Energy Box (EB) as a tool along with metering devices while displaying consumption and other quantities required for consumers can also establish the possibility of communication between aggregators and consumers to manage and run DR programs [146].

2) CONTROL DEVICES

On the end-user side, there are a variety of controllable loads. Such loads, which can range from cooling and heating devices on a variety of scales to appliances such as refrigerators and freezers, can also include lighting loads. Additionally, a variety of industrial loads can be considered as controllable loads in DR schemes. Most controllable loads are small-scale and dispersed, and real-time information must be available to control them [167].

The charging control of an electric vehicle (EV) also provides a good opportunity for such loads to participate in DR schemes [168]. Optimal management of EV charging during the hours when their potential can be used to exchange power to the network is one of the appropriate control actions on the end-user side [169], [170].

Besides, loads such as air conditioners, heat pumps, and water pumps as Thermostatically Controlled Loads (TCLs) have a high potential for participation in DR programs. Smart Thermostat (ST) technology is a common way to control these loads [171]. To control the devices such as refrigerators and freezers, two main mechanisms are used as the Direct Compressor Control Mechanism (DCCM) and the Thermostat Set-point Control Mechanism (TSCM), which can be implemented in different ways [172]. Using Smart Plugs (SP) is an excellent way to control devices such as washing machines. In this way, the feedback of customers' behavior on the control of electrical appliances can be studied [173]. As a DR program, end-users also use various technologies to control lighting in commercial and residential centers, such as a common Dimming Control (DC) [174]. Also, controlling the electricity consumption of industrial customers requires in-depth knowledge of the processes, activities, and practices of the industry. Given that most industries have centralized control systems, they have good potential for Auto-DR (Automated Demand Response), enabling DR schemes to run automatically with the features mentioned above [175].

3) COMMUNICATION SYSTEMS

The general requirement of communication systems for running DR programs is to provide two-way data flow through communication infrastructure that must be created between different entities and consumers participating in DR. Features of such infrastructure should include security, flexibility, interoperability, and service quality [53]. The domain of data communications within residential premises is referred Home Area Network (HAN), Building Area Network (BAN), and the industrial areas called Industrial Area Network (IAN) [146]. These domains are a gateway to control devices and controllable loads so that by receiving the input signals of the utility or other entities, they can implement appropriate DR actions through the relevant domain [20].

Like utility-domain communications systems, these communication technologies can be categorized into two categories: wireless and wired. Technologies such as Zigbee, Z-wave, WLAN, and Wi-Fi are examples of wireless technologies. Wired technologies include Ethernet, X10, and Insteon [176].

4) SOFTWARE PROGRAMS

With the entry of active electrical devices such as electric vehicles in the area of customers and their role in the participation of DR programs, the existence of software that can adequately use this potential will be more necessary than before. Therefore, the use of Plug-loads Handling Software (PHS) for managing various loads (active and inactive) that are related to the market software is crucial [177]. Such software, in interaction with market software, provides optimal load reduction or curtailment without customer dissatisfaction. By implementing DR schemes, customers' bills will be converted from traditional to rewards/penalties for participating in various programs. Managing these partnerships and coordinating with DR pricing programs to provide the customers' bills requires advanced Customer Services Software (CSS) [178]. In this software, subscriber power consumption data and DR contracts, are used to calculate their final bill.

IV. DR PRACTICAL STRATEGIES

In this section, DR practical strategies are investigated. This survey will be based on the popular and available facilities for managing the consumption of various residential, industrial, office, and commercial loads, as well as the distributed generation (DG) on the way DR schemes. Due to the nature and variety of loads in different sectors, these strategies are expressed for each sector, and then practical cases will be presented in some different countries.

A. DR STRATEGIES IN THE RESIDENTIAL SECTOR

Regarding the new nature of prosumers for residential customers, two types of the active and inactive loads of this sector can be considered in DR schemes. Due to the variety of electrical loads in the home sector and the necessity for household satisfaction and welfare, DR strategies should be defined according to the type of electrical appliances. In general, some residential electrical appliances, such as detectors, should always be activated, and some, such as televisions, are uncontrollable because turning them on is entirely unpredictable. Furthermore, the different automation levels can be considered manual, semi-automated, and automated DR in this sector [179]. The use of generation units in the home sector has also been growing. Therefore, practical DR strategies based on a variety of household loads and generation resources will be selected. These strategies are introduced in the following.

1) UNCONTROLLABLE LOADS (UL)

Due to the nature of such loads, it is almost impossible to control them. Devices such as computers, televisions, lighting systems, and razors are among the devices that, due to the comfort of the household and the lack of forecasting of their consumption, are often impossible to be controlled for DR. Although the use of smart plugs has increased the level of controllability of such loads, the level of household satisfaction is effective in changing the behavior of these loads [180]. According to these reasons, such loads cannot have any role in DR strategies.

2) SHIFTABLE LOADS (SL)

These loads are also called postponable appliances or non-interruptible loads, including dishwashers, washing machines, and tumble dryers. According to the operating time, these devices can shift the power consumption, so it is possible to manage their power consumption time with proper planning [181]

3) CURTAILABLE LOADS (CL)

Electrical appliances such as electric water heaters and even hybrid electric vehicles are among the devices that can be turned off during certain hours. These loads, also called interruptible appliances, can be turned off during peak hours to manage the network peak load. These loads can be handled using smart plugs or thermostatic controls [182].

4) THERMAL LOADS (TL)

Loads such as air conditioners and heat pumps are covered in this category. By setting the temperature of these loads, DR peak load management schemes can be performed over specific periods. This control is often applied through programmable thermostats. Besides, there are a variety of control techniques for optimal management [183].

5) NON-DISPATCHABLE GENERATION RESOURCES (NGR)

Such generation resources generally do not participate much in DR schemes due to their lack of controllability and continuity of output. DGs such as PV and wind power are among these categories and are often used in participation with other DR programs [184].

6) DISPATCHABLE GENERATION RESOURCES (DGR)

Small domestic generators and micro CHPs are considered in this category of generation resources. Due to their appropriate controllability, these resources can participate in DR schemes. Considering the variety of DR incentive schemes, DGRs can contribute to power generation at the right times [185].

7) STORAGE SYSTEMS (SS)

These systems can provide great flexibility for customers due to the two-way power transfer. Combining these systems with NGR will also provide DGR resources for residential customers. Participation in DR programs to reduce costs is one of the incentives to use such systems [186].

8) ELECTRIC HEAT PUMP (EHP)

EHP pumps in residential premises that have limited demand for space heating have created an opportunity to create an energy market based on this technology. By considering this potential and combining it with other strategies, it is possible to participate in various DR programs properly [187].

Different articles present a report on the DR strategies used in different countries in the residential sector. Examples of these are given in Table 1.

TABLE 1. DR strategies used in the residential sector of different countries.

Ref.	Country	Strategy						
		SL	CL	TL	NGL+SS	DGR	SS	EHP
[187]	UK	-	-	-	-	-	×	×
[188]	Netherlands	×	-	-	-	-	-	-
[189]	Belgium	×	×	-	-	-	-	-
[186]	India	×	×	-	-	-	×	-
[185]	Netherlands	-	-	-	-	×	-	-
[190]	Australia	-	-	×	-	-	-	-
[191]	Italy	-	-	×	×	-	-	

B. DR STRATEGIES IN THE INDUSTRIAL SECTOR

Implementing DR for industrial customers is much more complicated than other types of loads. This complexity is inherent due to special considerations such as the precise timing of industrial production processes, the need for on-line monitoring of the production line, and mismatch between supply and demand of energy in industrial facilities [191]. Basically, the processes and equipment used in an industrial facility can be classified into production and support services. The first section deals with cases related to the industrial process itself, in which the absence of electricity will stop the productions of an industry. The second category, which is a relatively small load, is not in the manufacturing sector but in the administrative and staffing sectors of industry [19]. Re-programming of industrial processes to participate in DR schemes requires costs that are often undesirable. Although case studies have been examined to determine the capacity to implement methods to reduce or curtail loads in some high-power industries [19], [192], DR schemes should be considered in each industry exclusively and based on the type of process, production duration and sensitivity to the power outage. Industries must also automate the production system in order to deliver and make efficient DR services. Therefore, all DR strategies that are based solely on the reduction or disconnection of industries loads are categorized as Industrial-Load based DR or ILDR.

However, there are other strategies in different industries to participate in DR programs, which are described below:

1) ON-SITE GENERATORS (OSG)

Most large industries use on-site generators to increase their reliability. These facilities (either traditional or renewable) provide good potential for participation in DR programs. The types of DGs available or embedded in the industrial location can be justified for the possibility of entering different DR programs through cost-benefit analysis [67]. This provides an excellent attraction for industrial customers to participate in retail and even wholesale market schemes without the need to interrupt the production process. In this regard, industrial microgrids and their participation in various DR schemes is a novel method used in industry [193], [194].

2) COMBINED HEAT AND POWER SYSTEMS (CHPS)

This technology is widely used in industries that need hot water for their products. These dispatchable and low-cost systems can continuously generate energy, and so, participating in various DR programs does not need to stop the product line [195].

3) STORAGE SYSTEMS (SS)

Many industries are capable of rapidly changing large loads, but these changes are often discontinuous. In such a case, the load is quickly disconnected or reconnected, but the recovery of each state cannot occur immediately. SS in such industries will make it possible to provide various DR services, especially in emergencies [196].

Various articles [197]–[199] present a report on the DR strategies used in multiple industrial sectors.

C. DR STRATEGIES IN THE COMMERCIAL SECTOR

The strategies used in small and large commercial sectors are almost different. In small commercial sectors, the methods are almost similar to those in the residential sector. Also, to save costs and reduce the negative effects for these customers, intelligent facilities are used to control commercial loads so that they can participate in DR schemes [197]. DR applications for large commercial customers are almost similar to industrial customers such as OSG, CHPS, and SS. Furthermore, various DR strategies have been conducted on data centers in internet service companies in recent years [198]. Generally, other examples are used for these customers as follows:

1) ELECTRIC VEHICLE SYSTEMS (EVS)

Most commercial loads use cooling and heating devices that require high power consumption during peak hours. Besides, the electric cars of customers who visit these malls have good potential to exchange power during peak or non-peak hours for DR schemes. With proper cost control, commercial customers can use this strategy [199].

2) ELECTRIC HEAT PUMP (EHP)

These pumps are used in commercial buildings and have great potential to reduce peak load due to their thermal inertia characteristics. This strategy is often used with renewable resources in DR programs to help commercial customers to manage costs [200].

In [201]–[203], various reports on the DR strategies used for different countries in the commercial sector have been presented.

D. DR STRATEGIES IN THE OFFICE SECTOR

In general, the flexibility of an office load depends on factors such as working hours, type of activity, the number of clients, and the pattern of the electricity consumption of the office building. Almost all of the strategies mentioned above can be used in this sector, but these factors, along with energy policies, play a decisive role in using relevant strategies. Therefore, due to the type of office loads, the most general practical method of DR to manage the lighting load is to upgrade them to intelligent lighting systems and integrate them with renewable resources [204]. This has also been developed using battery storage to reduce or curtail loads that do not have a significant effect on staff performance [205]. Perhaps one of the greatest potentials of DR schemes is the control of cooling and heating systems (HVAC), which is often done by the mentioned strategies for other loads [206], [207].

E. DR STRATEGIES IN THE TRANSPORT SECTOR

Since most electric vehicles are parked at homes, streets, parking lots, or garages most of the time, their battery capacity can be utilized when needed as a DR potential. On this basis, EVSs could serve as shiftable loads in the charging period and as DGs in the discharging period [208]. Additionally, from a fleet operator's point of view, DR schemes seem compelling for the financial benefits because they can reduce electricity bills by adjusting the time slots of energy usage and taking advantage of lower prices in certain periods [209]. A popular DR strategy used in this sector is the EVS's chargeability. To this end, by estimating arrival times and park durations, the charging of individual EVS is controlled by the car park operator or a smart metering system [210]. The integration of EVS charging stations with renewable resources can provide another strategy to help DR goals. Despite a lack of flexibility in the energy source of renewables, this strategy is popular because it helps preserve the environment [211], [212].

Recently, smart EVS charging is deployed for system benefits and to optimize consumer savings. This strategy can become a key driver for cost-conscious consumers to engage with smart tariffs and participation in other DR schemes. When the perception of smart tariffs, smart meters, storage and automation technologies, and other DR-enabling technologies are combined, a more novel approach would be created to consumer engagement with DR-supporting services [213].

V. DR IN THE SMART ENERGY COMMUNITY

The IDR approach is to combine and utilize the various available DR programs. With the development of smart grids, the IDR view also upgraded within such grids via the concept of smart energy hubs. Also, the creation of a local market space at the distribution level, which is usually based on a decentralized structure, led to the emergence of new models for energy transactions.

In general, utilizing different distributed generation technologies, electric vehicles, and various loads of end-users has changed the traditional definitions of customer loads. The emergence of prosumers that they can generate or absorb electricity locally is one of these changes. Therefore, considering these, the flexibility of a community can be broadly divided into three categories: 1) passive users without participation in DR programs, 2) active users who can control via DR signals, 3) prosumers that can inject and absorb power [46].

Under these conditions, the type and amount of participation in DR plans should be decided according to each user category. In other words, the authorities of DR products must plan the type of cooperation and its amount by recognizing the potentials of each type of end-users. Accordingly, DR aggregators can play a key role in implementing a variety of DR programs so that their performance as a virtual power plant should be considered in the power industry chain [214].

To present DR products in the local distribution market, it is required to have an appropriate two-way local communication and pricing mechanism. Although a centralized model was used early on to solve this challenge, moving to a decentralized system to solve the dilemma was inevitable. Concepts such as peer-to-peer and community-based trading, defined under a participatory economic principle, facilitate exchange between all members and peers. With such a structure, each end-user can trade in a private and secure environment so that the dynamic balance of supply and demand can be controlled through economic mechanisms. In this approach, all end-users can participate in various DR programs based on different motivations [215].

Also, different approaches to implement DR programs play an essential role in building user trust. The blockchain technical approach as a distributed platform has become prevalent recently to develop local markets. By using this approach, smart contracts can be embedded in the local market environment through which agreed energy transactions between users can be executed safely and at any time. Due to the decentralized nature of smart contracts, a highly dedicated and competitive environment can significantly contribute to present various DR products in the market. The diversity of flexibility services will be attained and handled by managing multiple DR aggregators at the distribution level [216].

In the new environment, views on the implementation of DR programs will be different. In general, decision-making principles for actors participating in a local market are based on the win-win principle. Considering this, in a local environment, the interests of all market parties must be met so that everyone can participate. This can be done in either individual or community styles. In the first, each actor's role is seen independently in the market, and in the latter, communities consisting of a number of actors collaborating in different plans are considered, and the result will be presented [217]. For these styles, the decision-making model has been studied in various articles. The general technical approach can be based on game theory, double auction, and even optimization of the objective function, which seeks the best and highest participation of actors in the local market. Different DR schemes are evaluated for end-users in these models so that each user's involvement is automatically defined and implemented. Such automatic response, alongside the introduction of the blockchain approach, has led to defining smart contracts to showcase diverse DR plans through intelligent collaboration [218]. However, considering DR plans in a local market will require accurate price and quantity parameters, which will assist in careful decision-making. In fact, what makes it difficult for decision-makers is the presence of uncertainty in assessing these parameters. To determine the price, the amount of energy trading, and choose the DR scheme by peers, decision-makers must utilize behavioral models of the peers and appropriate implementation manners. For example, maximizing social welfare can be a good approach to decision-making. Due to eliminating the third party on the blockchain platform, these uncertainties in decision-making will be significantly reduced [219].

VI. FUTURE TREND

In recent years, DR from an emergency program of network problems-solving turned to a comprehensive approach to manage the growing power industry. The decision-makers and stakeholders of this industry are also looking for excellence and further development of DR goals to increase the practical capabilities of these programs.

Furthermore, moving towards a transactive energy system seems to be a promising step to fulfill the needs of energy utilities. These systems anticipate that generation and consumption can automatically negotiate their actions with each other using energy resource systems and electric market algorithms, allowing a dynamic balance of supply and demand. In such a new paradigm, the concepts of DR programs and transactive energy can widely be used to solve the current problems of the electricity industry.

In general, the direction of future actions of DR programs can be categorized as follows:

- Development of communication systems and telecommunication platforms within consumer premises in such a way that, it is possible to establish two-way communication with devices and manage them to run DR programs. In this way, data sharing between the company, third parties, and consumers should be possible so that all stakeholders can see the implementation results of DR programs, compare costs or rewards. Also, they can plan to participate in DR schemes with each other's help.
- Instead of focusing on centralized markets, develop small local markets to promote DR programs. The small markets make DR programs smaller to manage the network better and use all of its potentials to meet the goals of the bulk electricity grid. Local markets need to provide solutions and attract customer engagement by targeting small capabilities at electrical loads and identifying all available load response capacities.
- Developing novel technologies such as smart meters and moving towards real-time prices can lead the DR programs to be run in real-time conditions. In this case, consumers should always monitor electricity prices, especially at different times by themselves or their agents, and if it is necessary, be able to change their consumption or possibly their contracts.
- Identify the potential of DR schemes in gaps that resulted from the uncertainty of local power generation, such as PV, EV, and wind at certain hours. These energy sources can cause problems for the network when they are interrupted. Therefore, the definition of specific DR strategies in these situations should be clear so that the necessary planning can be done in case of an emergency.
- Integrating all energy sources, including gas and oil, with electricity can also include replacement other resources in DR programs if it is necessary. By examining all the potentials of energy in consumer premises, these actions can plan the DR approaches to other resources while conducting their activities in an emergency condition.
- Standardization of DR schemes can also make DR actions practical in all countries. A standard definition of DR activities, along with their range and performance, can be useful in consumer-type-based planning. This can be seen locally or overall, or even in any area so that the actions are entirely targeted considering the defined limits.

VII. CONCLUSION

DR programs play an essential role in today's electricity industry. With the widespread grid integration of renewable energy sources, DR schemes have a greater importance in grid operation and planning, and on the overall performance of power utilities. Therefore, the use of practical and effective solutions of DR programs should be fully targeted and planned in this industry.

In this paper, applying a practical perspective, a new categorization of DR programs was presented. Accordingly, regarding the impact of different programs on the grid, economic issues, motivations of actors, and the market, these categories have been introduced. Furthermore, to implement these programs, the required enabling technologies and practical strategies have also been thoroughly studied and presented for each demand sector.

Furthermore, with the advent of transactive energy systems, DR is a crucial factor in the settling of power balance in future systems with renewable energy resources and new technologies. Accordingly, the standardization of DR schemes, developments in small local markets, integrating all energy sources, information, and communications technologies are introduced as essential areas to be further investigated in the scope of DR.

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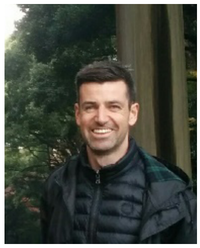

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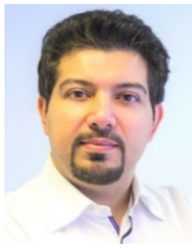

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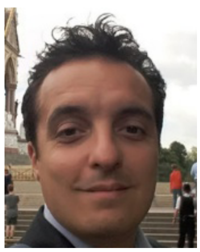

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