Chapter 5
Distribution Network Oriented Demand Response

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Abstract This chapter reviews promising concepts for distribution network oriented demand response. Current demand response (DR) programs are designed for wholesale markets and utility level issues, neglecting local challenges that distribution network operators (DNOs) face in daily operation. Deployment of DR to specific parts of distribution networks can enable additional services and benefits. The literature hosts promising concepts and methods that gain popularity. However, there is a number of conflicting cases that require particular consideration. This chapter presents insight into use of DR in distribution network planning and operation with special focus on promising service opportunities, developing concepts and integration of local DR programs with utility-driven DR programs.

Keywords Electric power distribution · Demand response · Distribution networks Incentive-based programs · Price-based programs

5.1 Introduction

Power grids with aged infrastructure and conventional management methods are having radical changes. Main issues like continuously growing demand with its peaks, raising concerns on CO_2 emissions and increasing volatility of consumption motivate researchers for finding new solutions. The main challenges of today's power system are summarized in Fig. 5.1. Although advances in energy storage technologies and reduction in imported fossil fuels bring a number of advantages, integration of renewables in generation and electric vehicles into networks are expected to breed new issues. In Fig. 5.2, the problems that are expected to become

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A. Arefi et al. (eds.), *Electric Distribution Network Management and Control*, Power Systems, https://doi.org/10.1007/978-981-10-7001-3_5

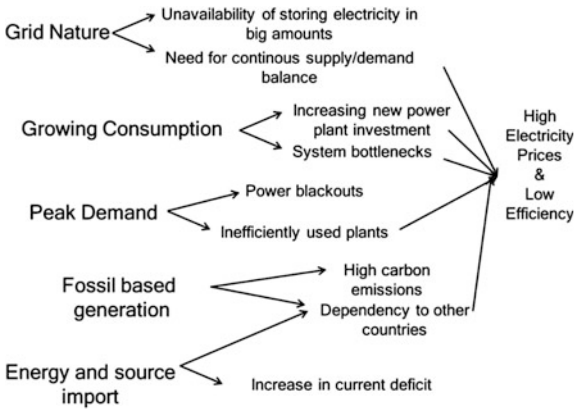

Fig. 5.1 Main challenges in today's power systems

less critical are colored with green, while possibly growing problems are colored with red. Because utility scale conventional methods are limited to costly capacity investments that take long time and dispatch of high cost/low efficiency peaking plants or periodical avoidance of renewables, electric distribution network operators need to exploit more flexible and cost-effective, fast responding resources. At this stage, demand response is one of the topics that researchers put spotlight on.

Demand Response (DR) focuses on achieving consumption changes at the customer side (either in direct way through remote control by an entity or indirect way via tariffs and notifications to motivate voluntary participation) according to the needs of the grid. It is one of the most customer dependent topics of smart grid. It is mainly located among the applications like microgrids that are enabled through establishment of proper control and communication infrastructures and structured upon the valuable experiences gained from smart meter deployments and substation automation. It also has strong correlations with home energy management systems (HEMS), grid responsive distributed generation and storage management activities. Beyond conceptual development, DR has become an essential part of operation in modernized utilities. According to the sectoral statistics of US in 2014, 9.3 million customers enrolled in DR actions, saving 1.4 million MWh of energy, reducing peak demand by 12.7 GW and receiving $1.2 billion of incentives in turn [1]. It is also noteworthy that, the majority of the participators are residential in number and energy savings, while industrial customers achieved the highest demand reduction and incentives.

The research areas for DR can be categorized under two main groups: technology and non-technology related areas [2]. There are three technology related areas, namely planning (generation capacity planning, transmission planning and forecasting), enabling technologies (end-use device capabilities, communication, measurement, verification, automation and control) and integration (into day-ahead and intraday grid operations, integration of utility-scale renewable energy). Non-technology related areas are forecasting (DR potential and valuation), markets (customer preferences, business models and etc.), methods and policies.

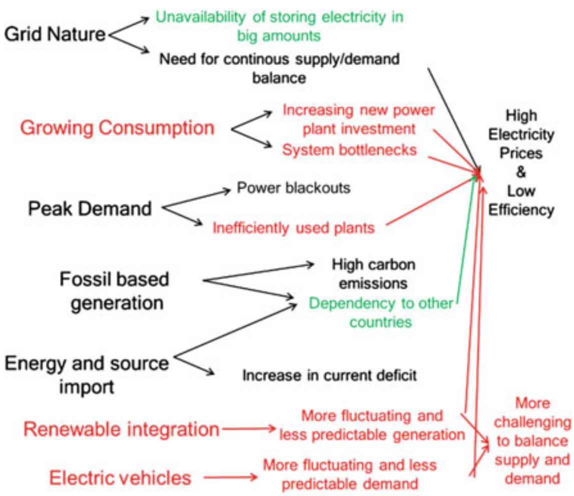

Fig. 5.2 Expected changes in power system challenges in the near future

DR applications usually follow a bottom up approach from device level to grid level with distinctive requirements at each stage (Fig. 5.3).

Today, DR in all areas of application is based on managing flexible demand to cope with utility scale challenges. On the other hand, there is an increasing interest for using DR to aid distribution network operation.

This chapter reviews promising concepts for distribution network oriented demand response to improve knowledge of interested audiences and foster research

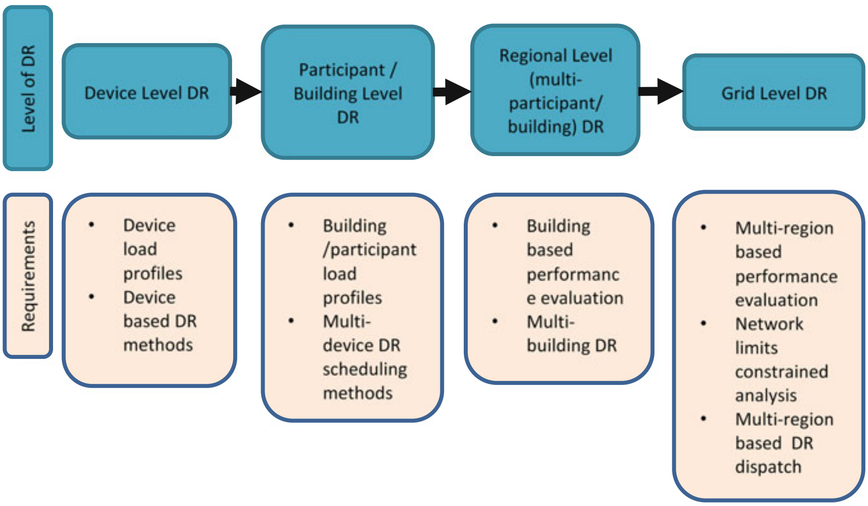

Fig. 5.3 Different levels of DR with distinctive requirements

activities on the related area of study. Following the discussion of current DR program characteristics and imperfections, distribution network services that can be provided by DR are described. The next section comprises enabling concepts for distribution network oriented deployment of demand response. New approaches including, developments in network planning methods, innovative programs and renewable integration focused DR deployment are presented in this section. The adjacent section is on challenges that can be faced with during concurrent application of utility-driven and electric distribution network oriented DR actions and the last section concludes the chapter.

5.2 Overview of Current Demand Response Programs

Understanding of today's DR implementation options is important for development of distribution network oriented concepts and estimation of prospective challenges. The existing DR programs can be mainly categorized as time-based programs and incentive-based programs [1, 3]. There are currently 10 program types, 3 of which are time-based and the remaining 7 are incentive-based (Fig. 5.4).

This section describes the characteristics of each program, provides a general comparison and emphasizes imperfections.

5.2.1 Time-Based Programs

In time-based programs, changes in daily market prices and main trends to maintain supply-demand balance are indirectly reflected to prices of different time periods. In

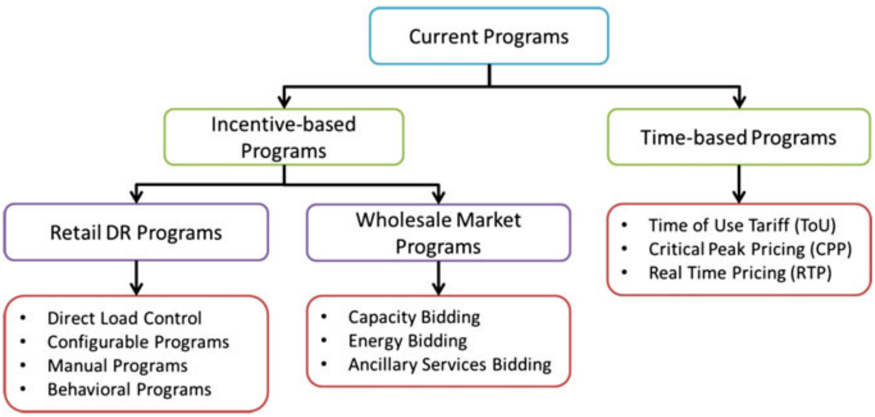

Fig. 5.4 Current DR programs

response to changes in electricity pricing rates, the consumers are expected to make changes in their consumption and ease supply/demand balancing efforts.

Time-based programs mainly differ in frequency of price changes. Performance of time-based programs depends on how effectively price changes are reflected to customers and how effectively customers can make changes in relation with price of each time period. However, advanced programs in which pricing the periods are small and changes are frequent, require advanced communication, measurement and control infrastructures.

In transforming utilities, grid operators initially prefer basic programs based on small number of pricing periods in a day and manual customer responses. In order to grow benefits, frequency of price changes is increased progressively, while notification and automation systems are improved. The time-based programs are described below from the perspective of complexity in ascending order.

5.2.1.1 Time of Use (ToU) Tariff

In this tariff structure, the day is divided into a number of periods. The most basic ToU tariff include two periods namely peak and off-peak. Electricity prices for each period are announced well in advance and they are rarely updated more than a couple of times annually. There are also some other ToU types with more pricing periods. For instance, in Canada weekdays are divided into three periods, while weekends and holidays are considered as off-peak periods [3]. Additionally, pricing periods of weekdays are different in summer and in winter. Although ToU tariffs are well suitable for manual DR actions, pioneering automated DR activities are available in the field for maximizing achievable benefits.

5.2.1.2 Critical Peak Pricing (CPP) Tariff

CPP is based on application of a high price during critical peak times that occur for short periods in a year. It can be applied either individually or together with a ToU tariff. Unlike ToU, the time periods in which a high price will be applied are not known before they occur. The price for those periods can either be a certain amount that is announced earlier or it can differ according to severity of each peak period.

5.2.1.3 Real Time Pricing (RTP) Tariff

In RTP, hourly wholesale market-clearing prices are proportionally reflected to customers in real time. There are three diversified applications of RTP. In day-ahead RTP, the hourly prices of the next day are determined and announced to the customers; while in intraday RTP, the prices are available just a couple of hours prior to the related hour [4]. In the last type, a demand reference profile is defined for customers and consumptions covering both under and above of that profile are priced expensively. Due to hourly varying dynamic prices, RTP tariffs require advanced communication and automation infrastructures to be effectively deployed.

5.2.2 *Incentive-Based Retail Programs*

Time-based programs have limited flexibility, due to their certain operation cycles and predetermined rates. For more effective use of DR in grid operation, a number of incentive-based programs have been developed. These programs usually reward customers using incentives based on the event content (duration, targeted amount of demand management) and participator performance (achieving the requested change in demand for the related period). There are also some programs in which the incentives are paid upon the acceptance of participation or authorization of a remote demand managing entity.

5.2.2.1 Direct Load Control (DLC)

DLC is based on remote dispatch of manageable loads by an operator through radio signal, internet and etc. A dispatch action may or may not be announced before the event. It is one of the most effective programs for reducing peak demand in US [5].

5.2.2.2 Configurable Programs

Similar to DLC, some loads can be remotely controlled by an operator. The distinctive part of this program is that, device owners can make further changes in control settings to allow or restrict the actions. It is one of the most popular program types.

5.2.2.3 Manual Programs

These programs are based on manual control of devices by their owners according to event notifications. Events can be announced using a home energy management device, SMS, e-mail, social media accounts, mobile phone application or web application. Manual programs are not popular except places where the consumers are automatically subscribed. However, they are low cost, easy to deploy programs and usually preferred at the initial step of DR implementations in a utility.

5.2.2.4 Behavioral Programs

These programs aim to socially motivate consumers to make changes in their consumption behavior without providing any monetary incentives. Behavioral programs usually use weekly/monthly reports, real-time feedback using in-home display and e-mail messages to promote energy management [6]. They can also be combined with other program types to increase engagement and operational performance.

5.2.3 Incentive-Based Wholesale Market Programs

The programs that are conducted by the system operator and regulatory organizations are categorized under this title. Achievable benefits generally depend on market-clearing prices and demand response success. The use of DR as a tool in a market mainly reduces the dependency to power plants and other service providers, resulting in lower market-clearing prices [7].

5.2.3.1 Capacity Bidding

It is based on the manageable power that will be used, when power grid operational limits have the risk of being violated. Up on the confirmation to provide this service, a prepayment is settled. If the promised amount of demand reduction is not achieved during an event, the participators are penalized.

5.2.3.2 Energy Bidding

The customers can either directly (mostly industrial customers) or indirectly participate (rather residential and commercial) in the energy market through their bids. The conventional type is day-ahead market, while intraday markets are also established at the further stages of grid modernization. Participators' performances are evaluated according to the performed changes in their estimated base consumption profiles.

5.2.3.3 Ancillary Services Bidding

The reserve bids are in this program. A prepayment is offered after placing a contract. This service type requires frequent dispatch of fast responding devices for short durations of time, offering rather higher incentives compared to other market-driven programs.

5.2.4 Characteristics and Imperfections of Current Retail DR Programs

The existing programs can be compared considering different characteristics. In [5], a number of important characteristics are provided and the programs are evaluated. Geographic specificity can be defined as the local or zonal applicability of a DR request. A system-wide deployment has low specificity, while deployment at medium voltage distribution scale have medium and low voltage feeder specific deployments represent the highest. Signal variability is another characteristic that represents the change in the content of the signal to describe events or requests in a more detailed way. Signals with only a static value to trigger DR actions have low variability, while a number of different cases can be represented with predetermined several signals in medium variability and system/market states are effectively reflected to DR actions through dynamic signals. Temporal variability, is the ability of a program to trigger DR actions at specific time periods or whenever needed. Availability, represents how frequent DR can be deployed and advanced notice corresponds to time needed for notification before each event. The last characteristic is automation, representing the level of automation needed to deploy a program effectively.

The common imperfection of all the programs is geographic specificity. There is generally medium and high level of signal variability and temporal variability, while availability is limited except RTP programs. Time needed for notification before DR events is rather shorter in incentive-based programs, where automation is not a must except remote control programs.

5.3 Prospective DR Services for Distribution Networks

Distribution network operators (DNOs) have a number of challenges in operation, which can be aided by DR actions [5].

One of the most critical challenges is overloading. DNOs should always ensure that electric distribution network equipment and line loadings are inside tolerable operational limits. Beyond maximum demand forecasting and necessary infrastructure investments at planning stage, operational relief mechanisms are deployed in electric distribution network threatening overloading and peak demand cases. Maximum Capacity Relief, is a proactive and planned mechanism to prevent estimated cases in the near future (such as peaks in hot days), while Emergency Load Transfer is a reactive real-time service to cope with unexpected peaks or equipment failures. The main strategy is to reduce loading of the related section. It is achieved through transfer of some loads from one feeder to another, either locally by directed field personnel or remotely by reconfiguration systems. From the perspective of DR, flexible loads at the related area can respond to such cases and aid capacity relief actions. Compared to many other distribution network services, events are infrequent, have up to tens of minutes to prepare and they require duration of response for a couple of hours.

Another essential issue is to maintain voltage levels inside acceptable bounds. In Steady State Voltage Management, voltage magnitude is continuously monitored at substation level and corrective actions are done through on-load tap-changers of transformers, regulators and capacitor banks. DR can be used in several ways to help voltage management. One solution is to manage flexible loads regardless of their type to decrease loading of a feeder, resulting in reduced voltage drop at consumer nodes. An alternative solution is based on specific management of inductive loads and inverter-based loads to decrease reactive power consumption or even to inject reactive power to the electric distribution network. For voltage management, closeness to the affected area is of importance, requiring high geographic specificity.

Power quality is also among the challenges in distribution networks. Transients and harmonics have the risk of affecting devices and processes, causing comfort reduction and additional expenses. It is not quite feasible for DNOs to use advanced monitoring devices with high sampling rates continuously to identify severity and sources of power quality problems. In customer reported cases, specific monitoring and analysis are conducted at the customer facilities followed by establishment of compensation or filtering equipment. Inverter-based loads can be a part of the solution by making changes in the consumption of manageable loads and reducing the severity of transients.

Phase balancing is a typical problem especially in residential areas with high percentage of single phase loads (Fig. 5.5). It may have several impacts on the electric distribution network such as voltage problems, overloading and increased losses. The theoretical solution, transferring some loads from a highly loaded to phase to a lightly loaded phase is not widely deployed by DNOs. DR can offer a fast and significant alternative by reducing or increasing the demand in different phases. One approach can be reducing the demand of two loaded phases, bringing their loads closer to the lightly loaded third phase. However, in some cases there may be a huge gap between the most loaded and the least loaded phases, requiring dispatch of many loads from one phase. An alternative idea is to make changes in the loadings of two extreme phases (the most loaded and the least loaded) and bring them closer to the medium loaded third phase. For the latter option, demand increment is needed for the least loaded phase, which requires consideration of inactive loads and active loads with load increment potential. Steady State Voltage Management, Power Quality and Phase Balancing are frequently occurring events, needing rapid and continuous response.

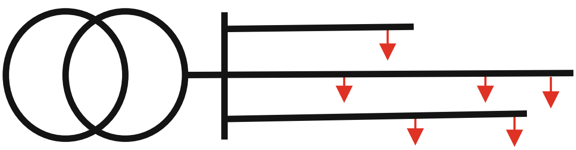

Fig. 5.5 A representative diagram of a distribution network with phase imbalance due to different single phase loads

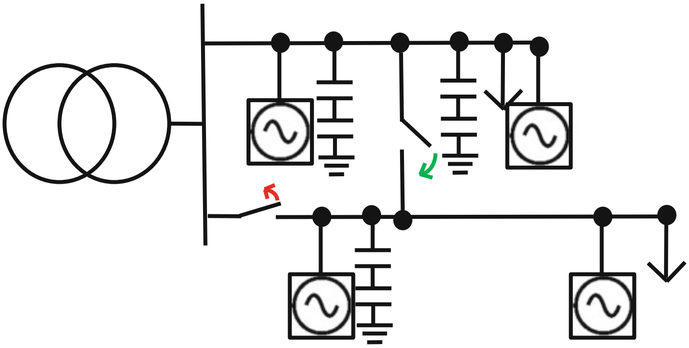

Fig. 5.6 A representative diagram of reconfiguration in a distribution network comprising local generation and storage devices

When a part of the electric distribution network is subject to outage, recovery times have crucial importance. After a long outage period, thermostatically controlled loads (such as water heaters, air conditioners, refrigerators, deep freezers and many more) may become undiversified and cause extreme loading during reconnection with the rest of the grid. Consequently, outage time and energy not supplied increases. Conventionally, it is coped with using manual reconfiguration (Fig. 5.6) and load recovery by field crew. DR can be used for coordinated and staggered load pickup, reducing recovery time and reconnection issues. The events are infrequent and usually need a response time of less than 1 h. On the other hand, wide deployment of DR actions can affect load diversity and rebound effect can cause unexpected peaks and overloadings.

As explained with details in this section, DR actions can be deployed to provide many different services in distribution networks. These use cases lead to development of enabling concepts comprising effective methods, tariffs and programs.

5.4 Enabling Concepts for Distribution Network Oriented DR

There is a growing interest towards distribution network oriented DR studies in the literature. This section provides a number of the promising approaches.

5.4.1 DR Integrated Active Distribution Network Planning

Network expansion and reinforcements are planned considering a number of worst-case scenarios with future estimations evaluating reliability and security.

These scenarios include maximum demand during times of minimum supply (from distributed generators) and maximum local supply during minimum consumption throughout the network. Rather than single values that represent extreme cases, the trend is through the use of load profiles, in order to better consider stochastic nature of aggregated demand and impacts of demand response in network planning [8]. The load profiles are usually organized to represent different days (such as weekday and weekend) from different seasons. Data resolution may range from 1 min to 1 h. Customers with similar behavior may be clustered.

During planning stage, one method for taking into account the impact of DR actions is to reflect the permanent consequences of DR on consumption patterns. This method requires accurate estimation of DR options on future load profiles. This can be done through observed percentages of DR effectiveness in pilot field applications. Another method is to tolerate overload cases with low probability, assuming certain level of support from DR rarely. It is also important to consider local participation rates. As indicated in [9], dispersed participation provides more benefits in rural areas, while concentrated participation is in favor of urban networks. The main benefits are deferral or avoidance of network reinforcements. Economic benefits are heavily dependent on network topology and congestion level. A study provides an additional perspective by explaining the reduction of social costs (emissions, losses, occurrence and duration of outages) due to deployment of DR in distribution network during emergency cases [10]. However, DR may not always guarantee reduction of energy losses in long term. This is explained as reinforcements are delayed, some equipment will be loaded more causing higher energy losses. On the other hand, there are financial benefits for participating customers as incentives or savings from their energy bills and for the DNOs as reduced investment need. In another study [11], researchers suggested use of probabilistic analysis with uncertainty rather than deterministic to better analyze the promising impact of DR in planning. It is noted in the same study that, DR payments should be included as financial costs for more effective analysis and better evaluation of available solutions.

Probabilistic analysis with numerous DR options that can be preferred solely or in combination with electric distribution network reinforcements, adds complexity to planning processes. In [12], probability density functions are used together with Monte Carlo simulations, representing a multi-objective optimization problem. It is beneficial for planners to make use of iterative or recursive algorithms to optimize investment strategies [13].

It is also of importance to include negative impact of utility-driven DR on distribution networks during planning stage. Wide deployment of DR can affect diversification and cause high simultaneity. Since network equipment is sized considering maximum coincidence coefficients, critical loading of components and violation of voltage limits are the major risks. It is stated in [14] that, rural electric distribution network tend to face voltage problems prior to loading issues, while urban networks with high load density and short line pairs are more likely to have loading problems before extension of voltage limits.

5.4.2 Innovative Retail Programs

Value of different DR services provided by different customers may have dissimilar values for a distribution network. For this reason, pricing of the services provided by DR participators to DNOs, needs particular consideration. There are several options for packaging and pricing DR services [15]. Granular retail rate, based on discrete pricing of each service is one of the options. The rates for using or providing a specific service are the same, indirectly motivating customers to deploy DR actions for achieving savings. The services like peak reduction, power factor control and voltage support can be rewarded using different rates and monthly revenues can be summarized to the participators via addition of some details to their energy bills. Determination of prices according to location and time (such as use of higher rates in an electric distribution network that requires update in the near future) is a topic open for debate. An alternative model is buy/sell arrangement based on different pricing of used and provided services. Payments for provided services can be in the form of bill credits or direct payments. Similar to Direct Load Control (DLC) programs, customers can be rewarded for accepting to participate and additionally for their response performance in each event. As mentioned in granular retail rate explanations, rates can be location-specific. An innovative model is procurement, in which third-party aggregators have direct business relationship with DR participators with competitive pricing. In this model, several aggregators submit bids to meet procurement needs announced by the network operator. Aggregators with winning bids have to coordinate their customer portfolio to achieve successful response. It is mainly done through contracts between the third parties and customers, including several incentives without strict constraints of regulations. Another option is to price different devices that provide DR individually, considering their distinctive response characteristics. This approach can also be useful to promote grid-responsive products. For instance, customers with controllable electric water heaters can be charged less (or rewarded more) than others.

For design and implementation of new pricing options, a number of issues exist. The first is design considerations. It is a challenge to keep a balance between effective feedbacks and simplicity in monthly bills and reports. On the other hand, customers with advanced monitoring and control options become more interested in energy management than past. Time-specific and location-specific pricing is also an important design element. Pricing structure can be one or a combination of fixed charge, energy based charge, demand based charge including comparisons with observed peaks or installed capacity. Furthermore, hourly data measurements can be used to identify permanent high capacity users and rarely peak consumers. The second is deployment options. DR participators can be considered as a separate class and benefit from special rates. Moreover, pricing can be mandatory, opt-out (customers are automatically enrolled with freedom to change their tariff) or opt-in (customers should apply voluntarily for joining to the new tariff). The third issue is interactions with existing policies. There may be possible conflicting cases that need further modifications of pricing programs at the design stage. There are also some other implementation issues like feasibility of the new methods, market structure with competition and long term changes in the value of provided services. During design stage of new pricing models, evaluation criterions like economic efficiency, fairness, customer satisfaction, utility revenue stability and customer price stability should be taken into account.

5.4.3 Distribution Level Energy Market and Locational Marginal Price

Deregulation of electricity markets and privatization of electricity generation pave the way for transparent and competitive environments at transmission level. In modernized day-ahead and intraday markets, utility operator announces needed amount of supply for specific upcoming time slots and many different market players place some bids that can fully or partially meet the request. The bids are sorted according to their prices and a market clearing price occurs when the total value of bids meet the requested amount. A company with an accepted bid have to fulfill its goal at the time of event. Otherwise, it should find another supplier with relatively higher cost of service to fill its gap, or the market operator finds another supplier and makes the company with accepted bid to pay the expenses. Because of the lack of proper communication and automation infrastructures, dynamic changes are not directly reflected to end users, limiting electric distribution network flexibility and demand elasticity.

A promising method is to reflect spot market prices proportionally to the consumers at distribution level. This is expected to facilitate DR in an effective way for retailer-spot market relations [16]. The second option is to deploy a real time pricing program based on distribution locational marginal prices (DLMP). In [17] it is found that DR can reduce peaks and congestions through the use of locational marginal prices. Another method is a distribution level market, where prices reflect the state of the local network considering energy costs, losses and congestions [18]. It is assumed to be a real time intraday market, with short time slots. Since it is totally based on the locational state of distribution network, it can even be used in islanded microgrid operation cases. Such a market will require automated transactive controllers at customer sites for flexible loads. These controllers are expected to consider current state of the electric distribution network, customer preferences, flexible device operational settings and price forecasts to bid their manageable demand. Aggregators are in contact with several houses and bid their aggregated demand to the local market. The market operator is considered as DNO that will select suitable bids, announce market clearing price and determine prices of each bus of the local network. An additional benefit of using locational marginal prices is observation of the highly loaded and stressed parts of a network for further reinforcements and investments [19].

5.4.4 DR for Maximizing Distributed Generation Hosting Capacity of Electric Distribution Networks

The concept of distributed generation (DG) grows in popularity throughout the world. There are numerous technical, financial and environmental advantages that foster its development [20, 21]. Contrarily, high penetration of renewable-based DG into electric distribution networks can breed new issues. The prominent challenges are increasing volatility in daily net load profiles (which is named as duck curve) [22], extreme surplus supply from DGs [23] and bidirectional power flows [24]. These stimulate the use of high cost/low efficient peaking plants, cause periodical avoidance of renewables and limit the penetration of DGs in generation mix [25, 26].

Low voltage (LV) radial distribution networks with high R/X ratios are more severely affected by DG penetration than the distribution and transmission networks with higher voltage levels. Conventionally, secondary distribution networks have been designed for one-way power flow from substation to consumers using a radial topology (Fig. 5.7).

If a distributed generator is established at one of the busses, it serves as a sending bus for some neighboring busses (Fig. 5.8).

Whilst bidirectional power flows in a radial network may cause overvoltage and line overloading problems, they can also increase the electric distribution network losses. In addition to the point of connection, neighboring busses are also being affected [24]. Considering penetration levels, distribution networks are affected even at early stages of DG deployments [27].

Conventionally, distribution network operators consider the most threatening operating conditions to scale the capacity of new DG installations. However,

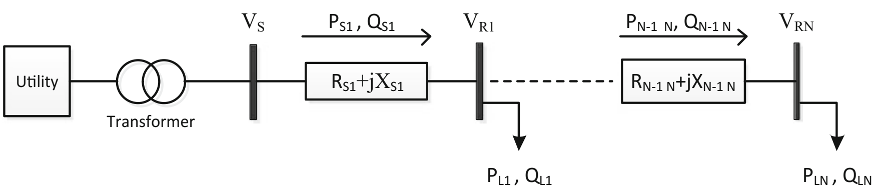

Fig. 5.7 Unidirectional power flow in a radial LV distribution feeder with multiple busses

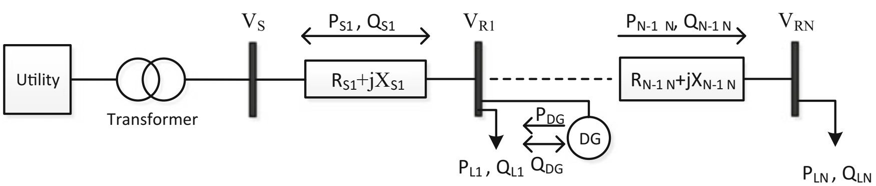

Fig. 5.8 Bidirectional power flow in a radial LV distribution feeder with DG

determination of tolerable DG hosting capacity of electric distribution networks depending solely on the worst-case scenarios is very constraining for the utilities [28]. Wind turbines generally operate at a level less than their rated capacities, because of variation in wind speed. The highest output from wind turbines is generally provided for a couple of hours after midnight, while photovoltaic (PV) panels reach their peaks during midday just for a short period of time. Therefore, peak outputs of wind generation and photovoltaic generation rarely coincides. Moreover, developments in distributed storage facilities can provide more uniform generating profiles and more effective utilization of renewable generation. Besides, common load factors for buildings are approximately 40%, reducing the occurrence possibility of extreme (minimum generation-maximum loading) conditions [29].

DR can be used as an additional tool to cope with rarely occurring overloading and under/over voltage issues due to high integration of renewables in distribution networks. As stated in [30], impact of DG on a network is dependent on customer load at the same feeder. Closeness to DGs make DR one of the most effective tools for mitigating the negative impacts on the network. The main idea is to stimulate self-consumption or nearby consumption, shortening the path of inverse power flow on the network, reducing losses and voltage issues. Reference [31] introduced contribution of DR to wind turbine hosting capacity and to reduction of losses in a distribution network. Another study shows that load shaping is among the solutions for solar intermittency problems and flexible loads in a residential house can be scheduled to operate in synchronization with high generation from PV [32].

5.4.5 Optimal Power Flow Considering DR

Demand response is majorly based on using flexible devices located at distribution level to serve the need of the transmission level. As DR becomes widespread and reaches high number of participation rates, it may have unintended impacts on distribution networks. The possible impacts are reduced diversity of loads, rebound effect (similar to cold load pickup) after a long DR period, phase imbalances, uncoordinated voltage regulation related response performance reduction and increase of energy losses in transformer and capacitors [33]. Therefore, DNOs should consider impacts of wide DR actions in their analysis to prevent possible violations. A study that uses optimal power flow at the planning stage of DR is proposed in [34], demonstrating rebound and location effects.

5.4.6 Demand Response in DC Distribution Networks

DC distribution grid is one of the research areas that gain interest in recent years. Especially in undeveloped countries, villages far from urban areas and without proper infrastructure nearby are electrified through islanded DC microgrids. These electric distribution networks usually use PV panels, batteries and residential loads which are connected through a DC bus. Use of DC in small microgrids can overcome many disadvantages of AC electric distribution networks such as reactive power flow, synchronization need, phase angle and many more [35]. There are two pioneer companies that have field applications. BBOXX provides monitoring, remote control of devices together with home appliances and have activities in Kenya, Rwanda and Uganda [36]. Another company, SOLshare has modular devices that allow peer-to-peer electricity trading for rural households [37]. They have a pilot in Bangladesh. A study investigates DR methods in DC networks, to keep loading of DC power sources in operational limits and to deliver power fairly to different locations in a DC network [38]. The researchers develop their approach for more effective use of energy generated from PV panels in another study [39]. DC microgrids is a promising solution especially for rural and islanded communities with physical and economical grid connection barriers in Brazil [40].

5.5 Challenges in Concurrent Application of Utility-Driven and Distribution Network Oriented DR

Current demand response (DR) programs have the risk of triggering local or regional problems in distribution networks while providing services to wholesale markets for the favor of the transmission grid. As an example, responding loads to a utility scale demand increment action (to balance surplus generation from renewables for a short time) may cause overloading of some critically loaded distribution lines and transformers. Similarly, a demand reduction to mitigate insufficient supply may cause overvoltage in some parts of distribution networks with high amount of generation from distributed generators. Furthermore, simultaneous dispatch of high numbers of loads in a distribution area can affect their operational diversity and cause unexpected peaks. Moreover the equipment can be subject to many switchings and transients fastening aging and reducing lifetime.

It may be possible to categorize flexible loads in a local network and assign different objectives. The flexible loads of a distribution feeder out of the zone of a prospective local undervoltage issue (Fig. 5.9)—a highly loaded zone, consisting of a group of loads at the end of the feeder with a group of distributed generators near it—can be managed to increase their consumption, because of a utility driven DR case that requires load increment. At the same time, the flexible loads in the zone of prospective local undervoltage issue can be managed to reduce their consumption to mitigate the changes in the specific bus voltages and reduce the load of the highly loaded line pairs. In the case of a local overvoltage (Fig. 5.10) and load reduction request from utility, a similar combined approach can be preferred. Combined DR

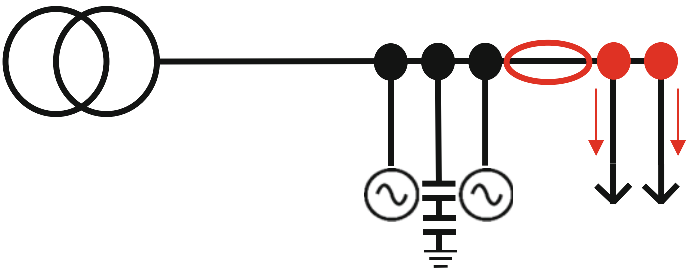

Fig. 5.9 A general representation of local undervoltage case for a distribution feeder with DG and/or storage

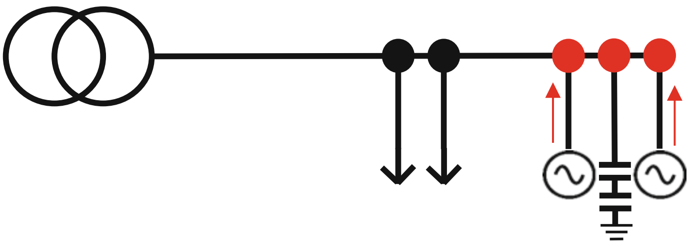

Fig. 5.10 A general representation of local overvoltage case for a distribution feeder with DG and/or storage

applications based on specified load reduction for the utility and specified load increment for local overvoltage can be implemented.

For responding loads, transition from utility-driven DR to local DR may be needed in the case that local problems become more severe. For instance, the flexible loads of a distribution feeder out of the zone of a prospective local overvoltage issue—a group of distributed generators with high amount of supply, located at the end of the feeder, followed by a group of loads closer to the substation—can be managed to reduce their consumption, because of a utility driven DR case that requires load reduction. At the same time, the flexible loads in the zone with prospective local overvoltage issue can be managed to increase their consumption to mitigate the changes in the specific bus voltages; but it may not be sufficient as a solution. In this case, the loads used for utility response can be used for mitigating the local overvoltage issue by transition to an opposite DR action (from demand reduction to demand increment).

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