The rise of AGILE demand response

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The rise of AGILE demand response: Enabler and foundation for change

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The distributed resources – distributed generations, storage, electric vehicles and smart appliances – have fueled many disruptions in the conventional grid dynamics. Increasing tough and competitive situations at demand-side have led the stakeholders of power system to reform, because people are more informed and can make decisions that has given rise to turbulent and volatile electricity markets. In such highly diversified and open market environment, the integrated control strategy has expedited the concept of Demand Response. Currently, the important questions in the area of demand response are likely to shift from whether to adopt dynamic pricing to how to achieve fast demand response by the combination of technology and a competitive retail electricity market.

This paper assembles the part and parcel in the light of existing technologies for the development of the concept of agility in demand response, that can play a role as a service package which is designed to meet the customer satisfaction efficiently and reliably as well as improve the market responsiveness. For the first time, this paper encompasses the concept of Agile Demand Response that is defined as the ability of power system to survive and prosper in the competitive retail market by reacting to the market needs fast and effectively which are driven by the customers. This paper also presents the key enablers of the agile demand response, which are (1) Retail Market, (2) Virtual Supply-demand matching mechanism, (3) Integrated information system and (4) Stay Committed. The paper concludes that by bringing the enablers together – Agile DR improves the responsiveness to the retail market changes unambiguously.

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1. Introduction

In 1996 the EU agreed to liberalize the electricity sector, thus resulting in the establishment of Electricity wholesale markets in most of the member states. Recently, electricity wholesale markets have enabled the electricity producers, the distributed energy suppliers, and some consumers to trade openly. Similarly, the introduction of green certificates has also had an important impact on the electricity market, because the “opportunity costs” have been included in the wholesale electricity price to a greater or lesser extent. On the other hand, the introduction of carbon emission tax also had an impact on the electricity market either due to a reduction in demand as a result of price increase or due to the replacement of carbon fuels by renewable energy resources.

Although the wholesale markets set the prices that are then passed to the consumer, most domestic consumers pay a fixed price for every unit consumed. Moreover, they have either little or no idea how much their energy consumption actually costs at given time. Thus, trade-off between risk and price varies across the asset holders [1].

Together with the perceived challenges in the electricity market, the rapid evolution of customer engagement via Distributed Generations (DGs), transport electrification and smart appliances has put the conventional electricity business at risk because customer engagement has enabled nimble competitors and new market entrants (mostly referred as energy service provider). Consequently, the turbulent and volatile nature of electricity market has become the norm, such that the price of the electricity can be 10 times higher at peak hours than at any other time.

To face such new financial and operational challenges, the asset holders as well as the stakeholders of the grid are seeking measures to reform and manage the existing assets effectively. Author in [2] declares that the virtually integrated approach that includes dynamic pricing and engaging smart appliances at domestic and small commercial customers is an active means to improve system performance and operating efficiency.

The roadmap to successful transformation into virtually integrated approach comes from a concept of retail electricity market environment where customers can choose their own energy suppliers [3]. Moreover, it provides the capability to match the demand of customers for short delivery times and makes sure that available supply can accommodate the peaks and troughs of demand [4].

Over the past decades, smart metering and developments in information and communication technologies (ICT) have embraced the concept known as Demand Response (DR) [5]. DR enables the energy supplier to perform load control in order to overcome the issue of peak demand during peak hours either by shifting or curtailing the demand. A number of researches and pilots present the implementation of DR and its different kinds [6,7]. However, increasing attention to the customer satisfaction, privacy and customized services has led researchers to find a method which is more responsive to the needs of the electricity market [8].

Therefore, in this paper, an attempt has been made to introduce the innovative concept and enablers of AGILE Demand Response. It is also found that the agility in demand response differs from the pricing strategy in the previous study [2], which only addresses the challenges to asset management, renewable integration and demand optimization for an industry or a utility. Consequently, dynamic pricing as a strategy for leaner and more agile network of the industry or the utility has a relative weak effect on power system and affect highly the openness of the retail electricity market. Nevertheless, the concept of Agile demand response, that invents the economic-foundation of distributed market competition at retail level in real-time, is a comprehensive design and strategic response of demand to fundamental and irreversible power system.

For these reasons, to have “Agile DR” in power system means to be more responsive to changes because stakeholders do not only require metering, ICT infrastructure and data processing but also require adaptability and maneuverability to demand i.e. an ability to respond to future changes rapidly and cost-effectively. However, for the customers, “Agile DR” is translated into the customer enrichment. Hence, this paper encompasses the concept of Agile DR which in general a complete solution to the customer needs – it explains in detail not only a product but also about the key enablers which can make it reality.

2. The paradigm definitions

First it is good to make the key definitions that are required in the concept development so as to avoid any ambiguity in further discussion.

To begin with the general definition of DR which is stated by the US Department of Energy as “Changes in electric usage by end-use customers from their normal consumption patterns 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” [9].

As referred earlier, a number of researches have discussed the concept of DR and its classification. However, DR approaches have been broadly categorized on the basis of two major dimensions i.e. pricing and control [10]. In the light of literature, Fig. 1 arranges the different DR approaches across four critical domains: (1) the price variability, (2) the demand elasticity, (3) the focused customer volume and (4) the ICT infrastructure.

The frequency based and the direct load control have been recognized as a Direct DR approach. It is evident from the literature that both approaches are developed for very limited customers i.e. industries or large consuming customers. Moreover, the approaches are usually centralized where participants are bounded by long-term contracts. Thus, the customer has either fixed or limited variety in payments against the DR service. Although in

![Fig. 1. Categorization of Demand Response along four critical dimension.](image-url)
this case demand response is predictable and able to schedule beforehand, the approaches have faced the highest degree of customer renunciations due to the lack of customer satisfaction and privacy.

On the other hand, all price-based DR programs fall in the category of an Indirect DR approach because they are planned to facilitate large community of customers at once. Price-based DR offers an energy tariff having the limited levels of price depending on time and season. In addition, Price-based DR is also referred as the indirect DR approach because it has communication to and from smart meters for monitoring and the alteration of price tariff but the demand has been dispatched manually by the customer. That is why, the demand is highly volatile and hard to predict because of many social and environmental factors.

Earlier two DR approaches are usually referred as demand-driven strategies rather then market-driven because the customer is provided with options out of which it commits to one for a long term. Furthermore, once the customer made the selection, it could not be changed easily and frequently as well as would not be able to influence pricing. On the other hand, in market-driven, options are customized by the customer. The incentive-based DR programs that are governed by open competitive electricity market are usually referred as market-driven approaches.

In contrast to Direct DR, LEAN DR is a market-driven approach. Here, the customer selects a service provider in the retail market which fits its requirements and needs and the service provider acts as a representative of customers in the wholesale electricity market as shown in Fig. 2. Thus the service provider is responsible for taking care of the customer as well as for maximizing the total profit. That is how LEAN DR achieves its ideology of “to do more with less”. Although the incentive options to the customer also get limited once it is committed to the service provider for an identified time period, the customer can further negotiate and might alter or withdraw the option for the next identified time period. That is why, LEAN DR is more common among large consumers like industries and commercial building which can commit considerable amount of power curtailment. Thus, LEAN DR has faced the challenges when attempts are made to implant it in the retail market environment where the domestic customer can trade demand response directly into the retail market through an aggregator, thus arising the concept of AGILE Demand Response.

In the arena of market management, the service that provides a capability to survive and prosper in a competitive retail market of continuous and unpredictable change in real-time is referred as AGILITY. The route to agility in the electricity market, initially, was emerged when it is realized that it can be achieved by using the advance ICT infrastructure because it can enable rapid responsiveness to the retail market needs [11]. Now, the idea of agility in electricity retail market is extended in the wider context by applying the economics model of supply demand at the domestic electricity customer [12].

Although the goal of AGILE demand response enables the service provider to implement a new kind of dynamic pricing, it also presents a solution for accommodating the needs and preferences of every customer. In short, the AGILE demand response can be translated as the customer enrichment in the electricity retail market. Hence, the challenge in Agile DR is not to determine it but to utilize it effectively.

Last but not least, the term aggregator is used quite often in the literature. In the existing DR research, it is usually discussed as an intelligent system that makes optimal decision for the controllable loads by the help of ICT [13]. However, in the developing concept of Agile DR, the aggregator is an independent smart system that provides Agile DR services to the linked customer and helps them to stay connected with the retail market. The details of the aggregator in the context of Agile DR will be discussed in Section 4.

3. The route to agile DR

To be truly AGILE, demand response services should possess few distinguished characteristics which are the enablers of Agile Demand Response, as shown in Fig. 4.
3.1. Market sensitivity

Conventional power system is based on a paradigm that seek to solve the economic dispatch problem for power production. Complex formulae and algorithms exist to support such dispatch models for matching supply-demand. Paradoxically, power system is now learning that a single organization is hardly able to respond quickly to the changing needs of the electricity market due to the increasing penetration of DGs, storage, transport electrification and smart appliances. That is why, control mechanisms mostly suggested for DR are demand-driven because it has been fed forward from the electricity market by the set of data based on actual customer requirements. Thus, Agile DR programs often schedule the loads on the basis of past consumption and demand forecast.

The high visibility of local demand via automatic measuring systems as well as the unbundling of power system enable the realization of the retail electricity market. Thus, the break through in Agile DR is to transform control mechanisms for the retail market environment. Moreover, in Agile DR, the control mechanism should be capable to respond rapidly to the needs of the retail market as well as the requirements of the customer in short period of time. Hence, the first step to enable agility in the arena of demand response is the existence of the retail electricity market.

3.2. Virtual matching mechanism

Virtual matching mechanism at the retail market is the coordination of different retail market players, i.e. Distribution System Operators (DSO), Energy Supplier (ES) and customers through advance electronic commerce. In this way, the virtual matching mechanism provides a distributed information-based approach rather than centralized reserve-based.

Thus, the next step for the Agile DR is the development of a system that embraces virtual supply-demand matching, having aim to transform the existing grid into smart grid by virtually interconnecting retail market players via advance ICT. Since Agile DR supports virtualization, so physically distributed actors (e.g. distributed generators) could collaborate with each other at any time, that would consequently increase the retail market responsiveness.

3.3. Integrated information system

In order to economically configure the Agile DR, a reliable software representation of each market player is required. In spite of the fact that it is challenging to have a generic information system at the low voltage level of the distribution grid when there are wide variations in the nature of participating customers (due to their social and demographic preferences). As a consequence, the integrated information system (IIS) becomes more complex due to physically disperse players. Moreover, each market player may have its own IIS based on its respective operation and control strategy. That is why, it is important in Agile DR that IIS must be standardized, so as to allow every player to explore the information and exploit the retail market effectively. For effective IIS in virtual matching mechanism, technology should support the following functional objectives:

- **Openness** – reliance on public and widely implemented interface protocols, so that anyone can use it and can offer services through Agile DR.
- **Scalability** – the ability to access the services down to the device level.
- **Extendibility** – services can be added, improved, removed or substituted at any time, with incremental change in performance.
- **Compatibility** – with legacy system.

3.4. Stay committed

In this concept of Agile DR, the confederation of the market players, that is their commitment through a virtual link to the local objectives, provides the fourth ingredient of Agility.

Thus, it can be acknowledged that the route to the Agile DR lies in being able to stay committed and leverage the strength and competitiveness of each market player to achieve rapid responsiveness on the way to the retail market.

4. The node of aggregation

In past, one of the major issues in the power system was the limited visibility to real-time demand due to lack of monitoring and ICT infrastructure. However, during the last few decades, power system has evolved a lot in the field of grid monitoring and the implementation of ICT. Thus, in the recent scenario, one of the challenges that has gained an essential importance is to identify a node at which the real-time demand should penetrate into upstream of the power system. This node is usually cited as an Aggregating Node (AN) or a Node of Aggregation. In addition, an entity or a service provider responsible for the demand aggregation is often referred as the aggregator, as discussed in Section 2.

Although researchers have been proposing many solutions and frameworks since long regrading the aggregator, a few researches has pointed into the issue regarding the location of AN in the supply-demand matching mechanism. In the light of the literature, here it is implied that the location of the AN in the supply-demand chain also plays a vital role. First out of the two main reasons behind this interrogation especially in the retail market environment is that actions and decisions of market players are depended on the real-time aggregation of demand which is aggregated at the AN. Second, it could be possible to build up a virtual monopoly or monopsony within the retail market if the AN is only controlled by any particular market player. Thus in order to make the market fair and competitive, the AN should be located such that no energy service provider or retailer should be able to dominate and exert powerful control over the AN otherwise it would result in a virtual monopoly. On the other hand, no energy supplier should
exclusively supply electricity or else the supplier can reinforce a virtual monopsony within the retail market environment.

In Fig. 5, different locations of the AN within the supply-demand chain are depicted with reference to different DR programs. It means that the upper two DR services, i.e. frequency-based and direct load, are performed within the wholesale market environment. However, DR services, i.e. price-based and lean, could be performed within the retail market environment. In price-based, the AN is held either by the transmission system operators (TSO) or the distribution system operators (DSO). In this case, the supply-demand chain may incur monopolistic DR Service. In contrary, in LEAN DR, the AN is held either by the distributor or the retailer. So, later the supply-demand chain may experience monopsony. In order to avoid the building up either monopoly or monopsony within the retail market environment the node of aggregation should be branched into two independent nodes. Herein, the first one is usually referred as Domotic Node (DN) [14]. DN should lie practically as far downstream as possible in the supply-demand chain. Hence, the AN represents all independent DNs within the retail market environment. By segregating the data and information among different nodes, no entity can reinforce the retail market environment, thus enabling an opportunistic Agile DR which can significantly improve the responsiveness to the retail market change as well as help in managing the data flow efficiently.

5. Building a foundation

In fact, there have been many initiatives which have already realized the enablers of Agile DR autonomously. Accordingly, it is implied by the following attempt that there have already been scattered blueprints for the agile DR but world is unaware of the rising concept of the Agile DR. Therefore, in this section an attempt is made to present the measures that have already been taken by research institutes and other organizations in order to recognize at present the enablers of Agile DR, as discussed in Section 3.

5.1. Retail market

As it is discussed earlier that the retail market environment is a key to achieve the Agile Demand Response.

Researchers have already recognized the economical importance of the retail market in the future power system [4,15,16]. Ref. [17] proposes some models for the upcoming retail markets in the power system. However, the concept where DR is treated as a trading commodity in the retail market was introduced in few literature [18–20]. Nguyen et al. [18] devise a DR Exchange, in which buyers and sellers trade DR in a pool-based market. This market is modified in [19] where Walrasian market clearing technique is used instead of the former pool-based method. Relatively different approach is presented in [20] where a coupon-based method is formulated in which incentives offered to the consumer are determined according to the market price.

In line with the concept of the retail markets, [20] presents that DR could be utilized as a commodity for hedging the risks associated to the market stakeholders. In [21], Baldick et al. evaluate two different interruptible load contracts namely pay-in-advance and pay-as-you-go. Authors also indicate that the contract can help in alleviating supply-demand challenges associated with the spikes of price in a deregulated market. They also conclude that the competition between retailers results in lower value and can cause less frequent interruption.

However, authors in [22] present interruptible loads as energy resources that could be used by the distribution company for congestion management. Similarly, authors in [23] use interruptible loads to alleviate the uncertainty of pool markets faced by a load serving entity. In [24], Li et al. present a concept in which distribution companies can use the interruptible load to place bids in the market and they also present a short-term deterministic model to solve the challenges of supply-demand in the retail market.

It is implied that the development of the retail market would enable the coordination among the distributed resources by trading the Agile DR as commodity. In addition, the concept would support the power system (1) by solving power quality issues to avoid the violation of grid stability limits and (2) by providing ancillary services to improve responsiveness to the retail market change. Moreover, the local trade of the Agile DR with the retail market would reduce (1) the local electricity price by taking advantage of the locally available generation and consumption and (2) the transmission losses by realizing energy trading between the distributed suppliers within the close proximity. Thus, it can be inferred that first step towards the agility has been enabled by liberalizing the electricity market environment and allowing DR to be traded as commodity within the retail market environment.

5.2. Market-based control mechanism

In the literature, the methods have been proposed for the implementation of the retail market environment and the deployment of Agile DR.

Therefore, in the modern power system with the advanced ICT and the unbundled electricity market, Market-based Control
Mechanism (MCM) is one of the emerging mechanisms for implementing the Agile DR. One of the interesting features of MCM is that the value of demand flexibility is used as a commodity, and is transacted in retail market via demand-side bidding.

Authors in [11,12,25] present a market-based control mechanism (MCM) in which the Agile DR of domestic consumers is traded as commodity in retail market. In [11], it is presented that the distributed control of time shifting-loads over price signals optimizes the resource allocation by considering their constraints (i.e. temperature, cycling power, etc.) with an aim to minimize the total energy cost. Similarly, EnerNOC has used a methodology of energy bidding for large consumers [25]. Herein, the organization calls the participating consumer to reduce the power available at their disposal during the given time period. In the exchange of this service, incentive payment is paid to the consumer according to the market-price. Ref. [26] reports that the incentive-based load control mechanisms have already been implemented over consumer’s thermal appliances. Similarly, a platform has been developed in [27] for the commercial or large consumers which enable them to manage their bid online.

Refs. [12,28] share the implementation of MCM by using multi-agent systems, where each downstream agent communicates a bid as a function of demand to the upstream agent. In response, the downstream agent gets a price to act accordingly. One of the interesting features of this approach is the consideration of the demand elasticity as a commodity, and it is transacted in the retail market via a bid even by the domestic consumer. The consumer that takes part in this program is usually referred as an active consumer. Furthermore the retailer generates incentive price to utilize the available demand flexibility provided by the active consumer. Hence if the consumer's bid is accepted, then it is paid by the incentive payment.

Although ICT infrastructures are advanced enough to implement Agile DR within the retail market environment, there are still many challenges to cope before making the Agile DR a reality.

5.3. Integrated information system

Agile Demand Response require an integrated information system (IIS) which should be open, scalable, extendable and compatible as discussed. A large amount of work have already discussed many physical level architectures of IIS in detail for the implementation of the Agile DR by using different networking and communication technologies [29–31]. Ref. [29], in detail, reviews the existing standards available and ICT advancements for all different levels of the power system in order to achieve smart grid.

Nevertheless, the concept of integrated information system for Agile DR is different from the integration of ICT in the grid. It has layers of strategic planning which are linked via ICT infrastructure aiming to offer traceability to every physical player.

In order to form such an integrated information system (IIS), an open system approach is required to recover data from market players and then transform the data into a joint set of information. However, the major challenge for IIS is an open architecture for interoperability and ubiquity which can guarantee the commitment of a large number of physical devices within the retail market environment.

In 2002, Lawrence Berkeley National Laboratory (LBNL) developed a methodology within a software environment for open automated demand response (OpenADR). In 2007, California Energy Commission released first version of OpenADR [32]. It provides an open and standardized way for service providers and system operators to communicate demand response signals with each other and with their customers using a common language over any existing internet infrastructure. In 2010, OpenADR Alliance was formed as an industry consortium to foster further development and deployment of automated demand response into the marketplace. In 2012, the first OpenADR 2.0 is released by Alliance, and continues to improve the profiles that can be implemented and deployed [33].

On the other hand, Universal Smart Energy Framework (USEF) is an initiative by The Netherlands in this domain [34]. USEF has an objective to provide a framework that enables market players to seamlessly co-create a fully functional smart energy system, and provides an open and consistent framework of specifications, designs and implementation guidelines. It is also a partnership between energy suppliers, network operators, electrical equipment manufacturers, and ICT companies. Concurrently, the applied research organization of The Netherlands (TNO) and the network company Alliander have formed an alliance of companies and institutions that jointly develop and manage the open source platform which is called Flexible Alliance Network (FAN) [35]. In 2013, first version of the methodology within a open source environment under the Apache 2.0 license was released officially by FAN [36]. The platform is called Flexible Power Alliance Interface (FPAI), which is guided by the principles of cost efficient scalability, interoperability and customer autonomy. Recently, during the European Utility Week 2014, USEF and FAN have agreed to join forces to develop standards for the emerging two-way energy markets [37].

Thus, initiatives have been taken by international research institutes to develop an open source platform for smart grid. It means that world is not far enough to achieve the most important element of the Agile DR i.e. IIS.

5.4. Distributed system approach

Distributed system approach is the main essence of agility which distinguishes it from Lean. The use of distributed system approach to control the power system has become attractive because of an increasing density of distributed resources [38]. In order to cope the challenge, researchers have explored a multi-agent system approach to find the optimum solution for managing physically resources effectively [39,40].

Multi-Agent system (MAS) is a better choice for Agile DR because of two main reasons: (1) it is scalable as MAS opens the market for every new entrant and service provider and (2) it gives freedom to each market player to implement internal system as per its preferences. In this way, MAS provides a virtual environment to each participant for Agile DR trading in the retail market by creating and managing an agent community. An agent is a virtual representation of each market player which has a control over the demand elasticity of the consumer. In this agent community, every agent coordinates with the whole community to achieve local and global objective. In line with the concept of node aggregation, in MAS the domotic node could be referred as intermediate agent and the aggregating node could be referred aggregating agent, as shown in Fig. 5.

In the literature, the application of MAS technology in power systems is broadly spread into four different application areas i.e. (1) Modeling and Simulation [41–43], (2) Protection [44,45], (3) Monitoring and Diagnostics [46–48], and (4) Distributed Control [49–52]. However, in order to achieve agility, the MAS should be capable to encompass all of its application areas. Autonomous Regional Active Network Management System (AuRA-NMS) presents an approach which encompasses multiple application areas within a MAS. Herein, the MAS provides an integrated platform for active distribution network (ADN) by making optimum decisions required for power flow, voltage control and network optimization [53]. Recently, commercial products namely PowerMatcher and Intelligator which provide MAS based solution to demand side management has been launched [12,54]. The system aims to dynamically match the supply-demand at the domestic level by introducing an open retail market environment.
Thus, it is implied that the final element of agility can be achieved through the MAS and the enormous contribution has already been made to the rise of agile demand response.

6. Conclusion

Currently, the burning in the debate over structuring the electricity retail market is the extend to which the market should be open and transparent for the competition. Another debate is whether DR trading as a commodity ought to be restricted to the wholesale market or extended all the way to the retail market. In order to argue about the mutability of the electricity market, this paper presents new and innovative approach for a DR which is referred as Agile Demand Response.

For this reason, in this paper, first efforts have been made (1) to compare the direct, indirect, lean and Agile as well as highlight their similarities and differences, (2) to assemble the founding blocks of the Agile DR by illustrating the various enablers, and (3) to present other research experiences covering different aspects of Agile DR. These efforts helped

By elucidating the different DR approaches, as shown in Fig. 4, it is understood that neither of the demand response is better nor is worse than the other because they could be complementary to each other as well as could be implemented autonomously. Thus it is declared that DR is dependent upon where in the supply-demand chain the node of aggregation is located, as shown in Fig. 5.

From our preliminary look at different DR approaches and relative node of aggregation, the paper argues in detail about the Agile DR, thus concluding that the Agile DR can produce distributed and fast responsiveness to the market needs if the enablers are being implemented (Fig. 6).

This paper also highlights that the enablers of the agile DR have been realized in many works but till today each enabler covers different strands of functionality. This paper makes an effort to envision them together for the foundation of the Agile DR. Thus, it concludes that the future of agile demand response is in the well-organization and integration of the enablers in a system. Hence, this paper offers potential research directions for the development and the operation of Agile Demand Response. Last but not least, the world of Agile DR is coming into being.

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holds and businesses.


