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Design of a Framework for the Aggregator using Demand Reduction Bid (DRB)

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Abstract

Demand side management (DSM) in smart grid paradigm is an energy management strategy of the grid using advanced data communication and networking. The aggregator, a third party entity, is appearing as a key player in managing the demand during the peak hours between the utility and the consumer. In this work, a general framework is discussed and focuses on the interactional issues between the utility, the aggregator and the consumers. The paper also discusses the role of communication in the context of interaction among the three players. In addition, it also presents the model of the framework which can enable the consumer to effectively participate in the DSM. The proposed model considers the direct load control (DLC) program which uses the concept of demand reduction bid (DRB) in aggregated demand response.

Keywords: Aggregator, Demand reduction bid (DRB), Direct load control (DLC), Framework

1. Introduction

The increase in consumption of energy resources have highlighted the importance of energy saving across the globe. In past, the main source of energy have been fossil fuel. Therefore, now sustainable energy technologies are poised to become an integral part of the energy supply chain in order to cope the skyrocketing energy demand. Various countries are planning and developing strategies and giving incentives to public for the promotion and development of sustainable energy projects [1]. It has been recognized that investments in Peak Power Demand Management such as load curtailment programs could be significantly more cost effective than building new power plants to supply the peak demand load [2], [3].

Researchers have identified significance of demand response in demand-side management program and consequently have presented many scheduling algorithms and formulated policies and strategies for demand-side management [4], [5]. However, in the emerging electric power market structures, there are opportunities for third-party aggregators to provide demand side services to multiple consumers. The aggregated response of these can have a significant effect on the power demand if the consumers are willing and committed to load reduction programs [6].

Till today, the implementation of aggregated demand response across the distribution and transmission network have not been addressed in the details. This paper develops the design of a framework for enormous consumers and the ways to model it. Section II presents the general design of the framework. Section III of the paper discusses the interaction between the utility and the aggregator and Section IV discusses the interaction between the aggregator and the consumers. Section V presents the communication strategy for the framework. Section VI proposes a model of the framework for implementation. Finally, section VII concludes the paper.

2. Design of Framework

The paper proposes a framework for the main implementation issues: the interaction of the aggregator with the consumer and utility, communication/control network and the design of an incentive program. The aim is to form a proper and effective DLC strategy and to be able to control dispatchable loads when needed. The key players in this framework are the consumers, the aggregator and the utility as shown in Fig. 1. In the following sections, the role and responsibilities of all three players is discussed along with their nature of interaction and possible communication strategy among each other.

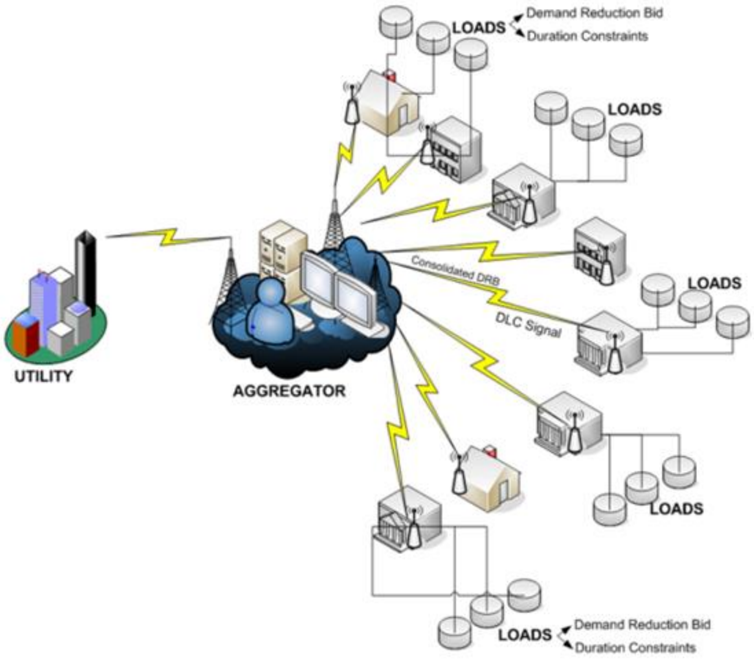

Figure 1 Framework

3. Utility and Aggregator

Till today, there is no precise definition for the aggregator. But, in general, aggregator is an energy service provider between the utility and the consumers. The aggregator has an objective to shave the peak demand as well as support the utility in supplying uninterrupted and high quality power to commercial, industrial, institutional and domestic as well as electric vehicles during peak hours with ancillary services [7].

As, it would be very demanding for the utility to directly communicate and control data and information from thousands of consumers. Therefore, the Utility sees the aggregator as a large consumer and an important factor in the smart distribution network. There can be two types of interaction between the utility and the aggregators which are discussed below;

3.1 Mutual Interaction

Aggregator can act as a retailer that buys electrical energy at the day-ahead energy market and the utility also makes an ex-ant validation regarding the price bid by the aggregator. On the other hand, the utility provides information and expected demand curve in advance for a particular peak period to the aggregator.

3.2 Directed Interaction

In other case, utility directs the aggregator that it has to curtail certain bulk of power whenever it requires. For this service, it would be rewarded by the utility. So, one of the issue in this kind of agreement is that what would be the rewarding mechanism? Because the utility may pay a fixed reward to aggregator against its services or this reward could be based on any dynamic pricing model like time-of-use, critical peak pricing etc. Nevertheless, most of the business models either proposed by the researchers or implemented by the utilities stand on bilateral contract with dynamic pricing model based on critical peak pricing [8], [9].

3.3 Contractual Matters

Contracts between the utility and the aggregator may be bilateral or unilateral. If the contract is bilateral, then it is an agreement in which the utility promises to pay the aggregator and in exchange the aggregator promises to curtail the identified power. It means both parties i.e. utility and aggregator are contractual bound to obey the terms and conditions of the agreement. However, if it is a unilateral contract, then only utility might promise to pay the aggregator if it curtails the identified power. It means that aggregator is not under any obligation to curtail the identified power, but utility is under an obligation to pay a reward to aggregator if it does the job.

For reference, PG&E has started non-tariff program named “Aggregator Managed Portfolio program” according to which it signs bilateral contracts with aggregators by which it may call power curtailment events during high-price periods, emergencies and tests with price-responsive pricing mechanism [10].

4. Aggregator and Consumer

After the advent of Domotics, the controlling of home appliances become easier and cost effective [11], [12]. Therefore, nowadays the aggregator and the consumers can easily interact with each other. On the other side, aggregator has to control the load of the consumers by developing systematic control strategy such that it achieve the win-win condition i.e. maximize its own revenue, minimize utility's operational cost and provide incentives to the consumers. Since long it has been an issue for the aggregator to attract the consumers for demand side management (DSM) and retain them. Therefore, lot of effort has been made by the aggregators in order to attract and motivate the consumers such that they allow aggregator to directly control their dispatchable loads during the peak hours. Thus, the interaction between the aggregator and consumer can be classified into the following three types:

4.1 Direct load control (DLC)

DLC is a conventional demand side management technique according to which the load is controlled by the aggregator at any time but in exchange consumer is not rewarded at all [13], [14]. Because of this DLC was not considered as a successful DSM technique and was not appreciated by the consumer.

4.2 Price based control

Currently, many aggregators are providing price-based manual or automated DLC programs to their consumers. By this strategy, consumer may be rewarded in many different ways, among these the most common reward is that consumer would gain fixed price against the load reduction. On the other hand, most of the aggregators are offering dynamic pricing mechanism and thus the consumer would be rewarded with the price based on real time electricity market [15], [16].

4.3 Incentive based control

However, very few researches considered incentive-based program for the aggregator such as energy bidding pricing model [17], [18]. Indeed it could be an opportunity for developing nations that are currently either planning for or implementing the smart network, to consider incentive-based DLC model for commercial and domestic level. Because, incentive-based pricing mechanism effectively caters the social issues like consumer satisfaction and privacy than price-based methods and it also enables consumers to directly interact with energy market by bidding against their power curtailment. The implementation of aggregated demand response with these new features will attract a large number of consumers to perform demand response and gain full benefit from it without altering their life style and personal space.

4.4 Contractual matters

Similarly, contracts between consumers and aggregator may be bilateral or unilateral. If it is a bilateral contract, then it is an agreement in which the aggregator promises to pay the incentive to the consumer and in exchange the consumer promises to switch off or regulate the specific loads to reduce the required consumption. However, if it is a unilateral contract, then only aggregator promises to pay the incentive to the consumer if it switches off or regulates it's load. It means that the consumer is not under an obligation to control the load, but the aggregator is under an obligation to pay a reward to the consumer if it shuts the loads.

Most of the contracts implemented by the aggregators or proposed by the researchers for either European, Scandinavia or North America consumers are bilateral contracts because unilateral contracts mainly support the indirect load management strategy which may result in uncertainty and severance during the time of contingency. However, bilateral contracts provide provisions for a variety of load management strategies i.e. indirect, automatic and direct load control.

Table I. CONSUMER CONSTRAINTS IDENTIFIED TO THE AGGREGATOR

Dispatchable Load	Power Ratings $\mathbf{R}^n$(kW)	$\mathbf{Q}^n$ ($)	Consumer 1 $\mathbf{T}_{OFF}^{n\ max}$ (mins)	$\mathbf{T}_{ON}^{n\ min}$ (mins)	$\mathbf{T}^{n\ max}$ (Hrs)
d_1	3.3	20	20	35	2.5
d_2	1.1	30	5	15	0.5
d_3	0.6	25	20	30	1.9
d_4	0.4	7	30	50	7
d_5	0.3	4	30	55	3

It can be inferred that most of the literature developed the business model of aggregator with price-responsive mechanism and thus it is easier to implement it for those nations who have already implemented smart network at their domestic level [19], [20].

5. Communication Strategy for Interaction between the Players

The bi-directional communication networking of the smart grid infrastructure enables many demand response (DR) technologies, which control hundreds or thousands of distributed energy resources over vast geographic areas [21]–[24]. There are a number of communication access methods that can be used for the data transfer between the distributed consumers, aggregator and the utility. Wireless communication net-working is a capable option having a wide-coverage area and low installation and maintenance cost. But the consistency and dependability of wireless communication is to be understood; since, Demand response systems requires repeated exchange of data among the end devices and the aggregator, so the quality of the wireless communication is one of the major factors that needs to be taken care of.

How to design, implement, and practically integrate efficient communication infrastructures with power systems towards an operable, cost-efficient, and backward-compatible communication solution, such a fundamental question should be elaborated in all critical aspects, including detailed communication requirements, system reliability as well as satisfactory system performance [25]. The major issue while deploying a communication network is to select the network design topology on the basis of which a wireless network infrastructure is constructed using a single or a multi-hop architecture design technique. The optimal routing topology can be selected by running simulations on a hypothetical DLC model using different routing algorithms.

The ZigBee technology can also be used for communication between the dispatchable loads and the central controller of the consumer. Because ZigBee offers very low costs and a very high flexibility (up to 65,000 devices can be added to the same network). While, communications between the consumer and the aggregator may have secure Internet link or EDGE technology.

6. Modelling of the Framework

In this section framework is modelled and presented for an implementation by the aggregator. This proposed model suggests the directed interaction between the aggregator and the utility. However, on the other hand, the aggregator will follow the concept of demand reduction bidding (DRB) as an incentive based program for the consumers. In this program, the aggregator and the consumers mutually sign the bilateral contract, by which the aggregator can curtail the power of the consumers during the peak period and in exchange it is bound to pay the bid price identified by the consumer and also satisfy the other constraints.

Now, assume there are N number of consumers which are in contract with the aggregator and agreed to participate in the DRB based incentive program. For instance, assume any nth consumer out of N consumers which has identified D loads having ratings R^n. Moreover, in this framework which presents the demand reduction bid based incentive program for consumers, where consumer also identifies bids to decommit each dispatchable load during a control interval $|H|$ which is denoted by Q^n. Depending on the importance of each load, consumer should specify Q^n because by this consumer will be able to translate its "Desire of Use" of appliance. On the other hand, over expected load utilization and curtailment capability of every dispatchable load, the consumer also provide "duration constraints" that are $T_{On}^{n^{min}}$ i.e the minimum durations for which each load of nth consumer must be ON continuously, $T_{Off}^{n^{max}}$ i.e. the maximum duration for which each load could be OFF continuously and $T^{n^{max}}$ i.e. the total durations for which each load of nth consumer can participate in load reduction. Thus, the introduction of these "consumer constraints" will not motivate the

$$< Q^n , R^n, T_{On}^{n^{min}} , T_{Off}^{n^{min}} , T^{n^{max}} >_{\text{n=1……..N}}$$

consumer to participate in the program but also try to achieve the consumer's satisfaction, privacy and security. For an explanation of this modelling, assume an example of a consumer who signed an agreement with the aggregator for the 5 dispatchable loads *{d_1, d_2, d_3, d_4, d_5}*. Moreover, at the time of deal, consumer identified bidding and timing constraints as shown in Table I. Each of the consumer have a specified $< Q^1 , R^1, T_{On}^{1^{min}} , T_{Off}^{1^{min}} , T^{1^{max}} >_{\text{n=1}}$ for each device which they have decide as per there convenience and consent.

It can be inferred that demand side bidding does not only motivate the consumers to participate but it also portrays it's 'Desire of Use". For instance, it can also be observed from Table I that for consumer 1, d_3 might be significant enough that he/she bid high for this load. Similarly, consumer 1 bid least to its ***d5***. In addition, the given duration constraints and bidding prices for each load also help the consumers in completely translating their needs and wants. For instance, in the given Table each load has some time bounds which the aggregator has to follow while turning the load on or off. For instance, for consumer 1, the maximum time for which the load ***d3*** can be turned off for maximum of 20 mins continuously. Although, after turning ***d3*** on, the minimum time it has to be continuously on is 35 mins, it means that after turning it on, the aggregator has to wait for a minimum of 35 mins to again turn it off. One more timing constraint is the total time that a particular load can be turned off during a complete day. As shown in Table I, ***d3*** has the total maximum off time of 2 hours i.e. it can be turned off for a total of 2 hours.

Furthermore, it can also observed that the maximum off time for the load ***d2*** is merely 5 mins which signifies its importance to the consumer. Also, ***d2*** has a significantly greater continuous on time as compared to other loads while the total maximum off time is only 30 mins i.e. the aggregator can only turn it off for just 30 mins in a day. Now, coming to the pricing, load ***d2*** has the highest bid among all the dispatchable loads, it suggests that ***d2*** is of critical importance to the consumer and the consumer discourages the aggregator to curtail this load repeatedly. However, in the condition of greater power shortage, the aggregator can turn ***d2*** off despite of its high bid price and lower total off time.

Thus, in short, these constraints collectively able to achieve the following functions:

- Consumer motivation (by Demand Side Bidding)
- Consumer desire of use and satisfaction constraints (by Duration Constrains).
- Energy Payback Effect

Energy payback effect can be easily caters by the duration constraints such that at the time of the deal aggregator will ex-ant these duration constraints by the help of define load models so as while controlling they cause less energy payback effect. Moreover, they will also know the ON and OFF timings of each dispatchable load which will help in pre-analysis and eventually support in coping this problem. Moreover, since last decade, the load scheduling has been one of the major area of research and development for the aggregators. The aggregator has to develop an optimal control strategy for load scheduling that enables it to manage and satisfy the consumers as well as efficiently achieve the business functions i.e. Respond quickly to Utility's requirement for power curtailment and Make profit out of this service.

7. Conclusion

The integration of domestic and industrial consumers under Direct Load Control Program with Demand Reduction Bidding Mechanism will help the grid in coping the demand peak during peak hours. On the other hand, the utilities and energy regulatory bodies have a new player to do business with i.e. the Aggregator. The aggregators are the key third party agents for implementation of the proposed framework of DLC with DRB to be successful. By signing the contracts, they have the potential to make revenue of this service. Future work include the design of consumer selection techniques to optimize the proposed functions of the aggregator. The major obstacle in the implementation of this program are initial investment, consumer awareness and willingness and government policies and strategies. Thus, the key players which include Government, Regulators and Appliance Manufactures should take measures to materialize this concept of aggregation.

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