DEMAND RESPONSE MARKET-CONCEPTS AND CHALLENGES

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ABSTRACT

Modern electricity markets should favor healthy competition between the supply side and the demand side in the provision of ancillary services. In restructured power systems, there are many independent players who benefit from demand response (DR). These include the transmission system operator (TSO), distributors, retailers, and aggregators. This paper presents concept—demand response eXchange (DRX)—in which DR is treated as a public good to be exchanged between DR buyers and sellers and related challenges.

INTRODUCTION

Since the 1990s, power systems around the world are being restructured and deregulated. The main driver for this change is the perceived need to introduce competition in generation and retailing, thereby reducing inefficiencies, lowering operation costs, and increasing customer choice. As a result of restructuring, local utilities have been broken up into a number of independent players including: generator(s), transmission system operator (TSO), distributor(s), retailer(s), and aggregator(s) (see Fig.1). Such a partition, however, can potentially bring new problems associated with maintaining a reliable power supply. These problems could be categorized as market-based and network-based. The former occurs when generators and retailers face financial risks caused by spot price volatility in the electricity market. The latter occurs when the TSO and distributors have to maintain reliable power supply during times of peak demand when constrained networks are operating at their limit.

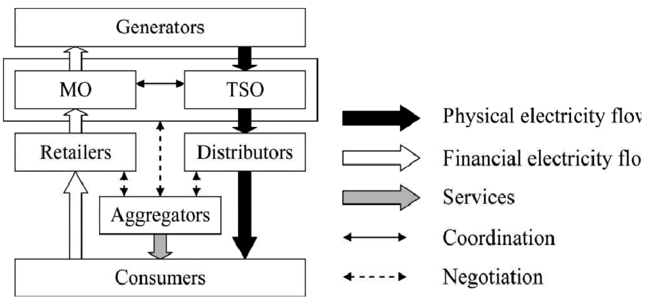

Fig.1 Current restructured power system

Unlike many other goods, electricity is difficult to store in large quantities so it must be consumed as it is generated. This fundamental property has created many challenging problems in both generation and delivery of electricity to satisfy consumer demand. Firstly, electricity sources are limited. When demand is high, expensive peaking power plants are required to boost generation, which increase the market price for electricity exponentially. Secondly, electrical power must be delivered through a physical network that is always constrained by safe operational parameters such as voltage, frequency, line loading, etc. Ensuring these parameters are within their limits during peak demand requires considerable effort by network operators. Demand response (DR) has been introduced as a potential solution to the above mentioned market and network problems. DR generally refers to the adjustment of electricity usage by consumers in response to changes in market prices or when network reliability is jeopardized [1].

This paper focuses on DR performed by small-scale consumers as they are the main drivers of demand peaks which usually occur in the morning and early evening hours of a working day. In view of the benefits that could be achieved through exploiting the flexibility of the demand, the issues concerning the participation of the demand side in electricity markets have acquired great importance among system operators and market regulators worldwide. If a power system is operated by a monopoly utility company, both network reliability and market efficiency derived from DR would benefit the utility alone. However, as power systems are currently being restructured and deregulated, DR benefits must now be treated separately so that the benefits can be fairly distributed amongst the independent players including: the TSO, distributors, retailers, and aggregators [2].

The TSO can benefit from DR by using it to improve reliability of the transmission network. Improved network reliability results from reducing the probability of forced outages when system reserves fall below desired levels [1]. By reducing electricity demand at critical times (i.e., when a generator or a transmission line is unexpectedly lost), DR dispatched by the TSO can help return system reserves to pre-contingency levels. As with the TSO, distributors can benefit from DR by using it to manage network constraints at the distribution level [3]. In general, such benefits could be classified into two main categories: 1) relieving congestion in distribution networks, and 2) enhancing the quality of power supply. Unlike TSOs and distributors, retailers have another interest in DR benefits. By purchasing electricity from the wholesale market at spot prices and selling electricity to consumers at a flat tariff, retailers are exposed to financial risks over short time horizons due to spot price volatility. To cover this risk, retailers may financially reward their consumers to reduce consumption during times when spot price spikes occur [5]. The final players interested in DR are aggregators. An aggregator is an independent company that combines two or more consumers into a single unit to negotiate the purchase of electricity from retailers [6]. The aggregator also negotiates combined DR of these consumers with the TSO, distributors, and retailers, where the negotiation financially benefits both the aggregator and the consumers it represents. In this case, DR is the business of the aggregator. Examples of aggregators engaged in DR business are EnerNOC in the U.S.A. and Energy Response in Australia.

This paper presents addressing this issue and related challenges. Also the paper presents concept-DR eXchange (DRX)-in which DR is treated as a public good to be exchanged between DR buyers and sellers. Buyers need DR to improve the reliability of their own electricity-dependent businesses and systems. Sellers have the capacity to significantly modify electricity demand on request. DRX model in form of a pool-based market, a DRX operator (DRXO) collects DR bids and offers from the buyers and sellers, respectively. It then clears the market by maximizing the total market benefit subject to certain constraints including: demand-supply balance, and assurance contracts related to individual buyer contributions for DR.

LITERATURE REVIEW

Although the benefits of DR are well understood, distributing benefits fairly across all players in a competitive environment is a challenging problem.

Such a distribution means determining players that should benefit more than others, based on a range of pre-determined DR provision costs incurred by each player. In general, those incurring higher DR costs deserve a larger share of the benefits. Despite the steady stream of DR research, very little attention has been paid to developing a fair scheme for scheduling DR that considers benefits across all players. Such a scheme is important because without it, DR benefits may become suboptimal [6]. The underlining reason is that DR is clearly a "public good", which is a special type of resource with each single instance jointly "consumed" by multiple independent players (i.e., a retailer, a distributor, the TSO). In this situation, allowing any player to "freely" benefit from DR paid by other players—as can be observed in most current studies—will cause a substantial distortion to the market as a whole. Consequently, there is need for a new DR scheduling scheme which fairly allocates DR payments across all players based on the benefit each player gets from DR, with the aim of ensuring optimum market efficiency.

This section reviews published works in this area. They can be classified into three broad categories based on which independent players are central to the analysis (see Table I).

TABLE I
SUMMARY OF DR RESEARCH

Categories	Participants	Types of DR	Major issues
Retailer-based	Retailers, Customers	Price-based, Reward-based	Volatile spot price, fixed retail price
TSO-based	TSO Customers	Reward-based	System security
Distributor-based	Distributors Customers	Reward-based	System security

Retailers

Retailers buy electricity at volatile prices on the wholesale market and resell it at generally fixed tariffs to small customers. The major challenge for them is the losses they incur when the wholesale price suddenly exceeds the retail tariff . To mitigate this financial risk, retailers exert considerable effort forecasting demand from their customers. Based on demand forecasts and self-imposed risk constraints, retailers develop an optimized purchasing strategy to maximize profits when dealing in a volatile wholesale market. This strategy is referred to as stochastic demand bidding [7]. Strategies catering for volatile demand and prices, however, may not necessarily cater for unexpected demand peaks causing extreme price spikes. Such price spikes may entail substantial losses for retailers, sometimes to the point of bankruptcy as occurred during the 2002 California electricity market crisis.

To overcome this problem, some researchers suggest augmenting demand bidding with DR so that retailers can also request customers to curtail loads, in order to moderate the level of peak demand. This strategy is referred to as DR-aided demand bidding. Note that DR by customers and demand bidding by the retailer are different activities. With DR-aided demand bidding, the main issue is to motivate customers to conduct DR as requested by the retailer. In [7] , the authors assume that customers are exposed to wholesale market volatility and therefore schedule loads in response to price signals. This is not an obvious assumption as small customers generally buy electricity at retail prices that are not tied directly to wholesale prices. To deal with the motivation problem, researchers are discussing the feasibility of implementing two types of innovative DR contracts offered by retailers to customers: price based and reward-based [8]. Price-based contracts refer to dynamic retail pricing, which aims to motivate customers to use less electricity when wholesale prices are high. Reward-based contracts refer to financial rewards given to customers, if they curtail their loads during times of peak demand.

TSO

The second category of DR research is related to the TSO. In a restructured power system, the TSO plays the key role in operating, and also maintaining the security of, a transmission network. Security assessment refers to determining whether the network operating in a normal state can withstand credible contingencies. If the normal state is found to be unsecure, action must be taken to prevent limit violations during the contingencies. One possible action is requesting customers to deliver DR in the form of load curtailment. DR supported network security also needs effective ways to encourage customers to curtail load. In [9], the authors assume that customers will tolerate short-term inconvenience, and therefore will voluntarily curtail their loads without being rewarded. This assumption is difficult to substantiate as previous experience has shown that customers often need financial incentives for providing DR. Consequently other researchers have considered using *economic* valuation to manage network security. This entails the TSO calculating the financial benefit of the security enhancement delivered by DR, and then rewarding the customers accordingly. Such a method is proposed in [10], where customers are rewarded if they curtail load following a TSO request. The reward determination is based on both the customer benefit and the TSO security benefit.

Distributors

The final category focuses on distributors who are responsible for maintaining distribution networks consisting of radial feeders connected through substations to the transmission network. As with the TSO, distributors benefit from DR by using it to enhance the security of distribution networks, relieve voltage constrained power transfer problems, and defer new network investments. A recent study [11] attempted to demonstrate such DR benefits. In this study, distributors directly schedule and pay for load curtailment by their customers. Similarly to the TSO scheme described above, the determination of rewards is based on both distributor and customer benefits. The latter can be estimated by either surveying customers or using historical data obtained from the same DR program.

Limitations

All three DR categories considered above constitute only partial solutions to the general requirement for an effective DR program because they focus on DR benefits for only a subset of participants in restructured power systems. For example, the retailer- based approaches described above focus on benefits for retailers acting independently who may, as a consequence of their unilateral DR activities, have an adverse impact on the TSO or distributors. It is important to understand that all players rely on DR capacity provided by the *same* set of customers located within a single geographical area. In light of the shared underlying resource, any partial DR scheduling approach could be significantly sub-optimal technically, financially, and socially. From a technical point of view, optimizing DR benefits for individual players can result in conflicts over how the same DR capacity (i.e., customer load) is scheduled. For example, a distributor can produce a plan specifying optimal DR scheduling to fix reliability problems in the distribution network while, at the same time, the TSO might produce another plan to address a contingency within the transmission network. Since these two contingencies appear to be independent events within different networks, the plans produced by the distributor and the TSO would be developed separately. Should there be some overlap in the scheduled DR capacity, serious grid management problems could arise. Additional resource scheduling conflicts arise from retailers using DR to mitigate the impact of spot market price volatility. Such volatility originates from generators responding to supply shortages and the increased cost of running peaking power plants. Consequently, generation costs are financially decoupled from network contingency management, which results in another source of DR scheduling conflict. In this instance, an optimal DR plan produced by a retailer to deal with the spot price volatility could conflict with a plan produced by the TSO and distributors to deal with network contingencies. From the economic perspective, any partial approach is inefficient. Since DR benefits for each player are determined unilaterally, it is difficult to calculate the *social* benefit (i.e., the sum of benefits for all individual players). The social benefit is probably more important than individual benefits since it indicates the usefulness of DR for all stakeholders. Due to conflicts between individual benefits, the social benefit of DR can be significantly reduced or even become negative. Finally, any partial approach results in *lower* returns for customers who provide DR capacity, because this approach assumes that customers are rewarded by a single player requesting DR. In reality, customers should be able to offer their DR capacity to all players, and thereby, increase the value of that capacity. Limiting the range of DR-involved players reduces the reward to customers, and thus reduces the supply of DR, as has already been seen in U.S. electricity markets. Because of these issues with independent DR programs, there is a great interest in finding a comprehensive approach to DR scheduling considering benefits across all players. This approach would be both more reliable and efficient than any partial approach since it aims to optimize the overall benefit of DR. Similarly, it will reward customers better by allowing them to deal with multiple DR-involved players. The problems with partial approaches motivate the authors to propose a comprehensive DR concept called the demand response eXchange (DRX).

DEMAND RESPONSE EXCHANGE

In general, there are two competitive approaches to scheduling DR considering cost and benefit allocations among participants, namely "contract-based" and "market-based". Under contract arrangements, each customer negotiates DR bilaterally with those intending to use the DR (i.e., the TSO, retailers, distributors), on a monthly or yearly basis. The negotiation involves both DR quantity and payment. Determining the best contract options offering optimal benefits to both parties is a complex problem. The market-based approach is investigated in this paper. By the term "market", we mean that DR is treated as a virtual resource that can be traded between a group of buyers and a group of sellers. DR buyers (TSO, distributors, retailers) want DR, in the form of load curtailment, for their benefit. DR sellers (aggregators, customers) supply DR and are paid for it. A unified market for trading DR between all buyers and all sellers is referred as a Demand Response eXchange (DRX) [6]. As with all other open markets, DRXs require a market clearing scheme. By "market clearing", we mean that DR is to be scheduled, in terms of quantity and price, with the aim of optimizing overall market efficiency. In [6], the authors developed a type of market clearing termed "pool-based". Under this scheme, sellers and buyers are required to submit offers and bids reflecting their own DR marginal costs and benefits. Using this collected information, the market operator maximizes the total market benefit under economic constraints such as the demand-supply balance, and the contribution of each buyer for DR as a public good. This pool-based scheme, following a standard market design, is a formalization of the concept DRX. However, there are several technical concerns about the pool-based scheme. These are given as follows. First, market clearing requires buyers to submit their demand bidding curves independently from electricity market conditions. It is not sufficiently clear how this can be done. The authors pointed out that the demand curves can be derived using a cost and benefit analysis of DR. However, taking into account that both DR costs and benefits always depend on electricity market conditions (i.e., generation dispatch, loading level), it will be difficult to derive a separate DR demand curve. Second, the core parameter of a pool-based DRX model is contribution rates that reflect the contribution allocation among buyers who jointly use a common DR. It is not clear how this parameter can be predetermined. The authors pointed out that the contribution rate assigned to each buyer must be proportional to the predicted benefit that the buyer will gain from future DR trading. This, however, raises concerns about benefit prediction. As power systems are always subject to uncertain factors such as the network instability and market volatility, predicting future DR benefits that heavily depend on these factors is not easy. Without an accurate benefit prediction, the calculated contribution rates may become inappropriate, making the market clearing suboptimal.

CONCLUSION

This paper proposes a new concept, DRX, in which DR is treated as a public good to be exchanged between two groups of players. Players in the first group are treated as DR buyers since they need DR and are willing to pay for it. Players in the second group are treated as DR sellers since they can supply DR and receive payment for it. The DRX concept can be considered an implicit market in which DR is a separate commodity to be traded through a virtual pool. The theory behind the DRX scheme is based on a well-known demand-supply model incorporated with an assurance contract used for solving the free-rider problems in microeconomics. Most importantly, this theory brings together DR buyers (i.e., TSO, retailers, distributors, each with their own reasons to demand some DR from time to time) and sellers (i.e., customers through the aggregators) under a common DRX "umbrella". The DRX market-clearing scheme has an additional advantage in that it rewards customers better by allowing them to deal with multiple buyers in a competitive way. Such a reward and competition based scheme can motivate customers to participate in DR programs more actively than in the past.

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