MARKET INTEGRATION OF FLEXIBLE DEMAND AND DG-RES SUPPLY - A NEW APPROACH FOR DEMAND RESPONSE

Cor Warmer, Maarten Hommelberg, René Kamphuis and Koen Kok
Energy research Centre of the Netherlands
{warmer;hommelberg;kamphuis;j.kok}@ecn.nl

ABSTRACT

In this paper we discuss the shortcomings of traditional Demand Response programs in an environment in which a large amount of distributed generation is available. An innovative approach is given in which true Customer Site Integration is obtained in the spirit of the liberalized electricity market, by making use of the load flexibility of underlying processes of production and consumption devices. The approach is based on distributed control mechanisms and incorporates new market models for distribution and aggregation costs, load losses, and network constraints.

INTRODUCTION

Generally, demand response programs involve customers at the distribution level into network operation by letting them respond to market signals. This is the case in price reactive systems, being the topic of a number of demand response pilot projects around the world [1]. The management and control of such systems is primarily done in a centralized way, in which the network operator sends a price signal to its customers, who react either voluntarily or according to a previously determined contract. Basically, one-way communication is required, from the network operator to the customer, although feedback may be useful. Individual customers have no influence on the energy prices, but can only react to them.

This paper introduces an alternative way of demand side integration (DSI), which includes supply by dispersed generation, through genuine market integration of customers who actively participate on a market by placing bids for their power consumption or production according to their flexible needs. Central dispatch is no longer needed, since producers and consumers join together at electronic markets in a price-forming process. At ECN the PowerMatcher concept has been developed [2], in which this decentralized control has been implemented. The PowerMatcher combines microeconomic market principles with standard control theory and utilizes multi-agent systems for a massive coordination of supply and demand. The PowerMatcher concept is applied in several simulation studies and field trials performed in The Netherlands, aimed at different goals, such as peak load reduction, local energy balancing, virtual power plant control, and variable load control.

The PowerMatcher approach offers a natural way of including a large share of dispersed generation and renewable energy resources. It has a number of advantages, such as a high scalability, including 1000's of installations, self-organization of local power networks, network stability over time, and inherent local autonomy of each consumer.

The described market integration leads to an expansion of the liberalized electricity market to small customers. They can participate in a price-forming market, rather than being limited to fixed tariffs and taking part in price-reactive demand response programs.

CUSTOMER SIDE INTEGRATION

Demand Response

Demand response closely mimics load management. In the traditional utility world, before liberalization, demand response was contained within the general term "Demand Side Management". Load management, however, has a utility centric approach with dispatching schemes behind. Traditionally DSM was implemented using 'programs'; today Demand Response is marketed via 'products'.

Demand Response is defined as the adjustment of electricity consumption in response to an external signal. Demand Response focuses on a user centric approach and is contracted by companies, which are not the traditional utility companies. DR products focus on transmission congestion avoidance, mitigation of price spikes and load shedding in critical power network circumstances. Some energy markets (e.g. Australia and some states in the US), nowadays, can't exist anymore without demand response. From a user perspective, price-aware intelligent air-conditioners or heating systems are used most extensively worldwide.

A recently finished project from IEA on Demand Response Resources (IEA-DRR in the DSM programme) gives an extensive summary of DR-opportunities and threats and also has given rise to formation of a number of national stakeholder groups that have implemented models for DRR [3].

Market Integration of Demand and Supply

The main focus in Demand Response programs lies on customer demand. Large scale introduction of distributed generation has to lead to a shift in focus to customer supply. In our view there is no fundamental difference in supply and demand, since supply can be regarded as negative demand. Therefore solutions for customer control should include both supply and demand and can lead to true Customer Side Integration (CSI). In accordance with the liberalization of the electricity markets microeconomic principles are introduced in order to create market-based solutions for coordination of local demand and supply in networks with a high share of distributed generation.

DECENTRAL COORDINATION & CONTROL

Traditional grid control influences the upper grid levels using a top-down dispatch mechanism. Extending the span of control to lower levels using this centralized approach appears to be a formidable task from the control and ICT perspective. The same holds for many applications that aim to include control of distributed generation. In many cases centralised optimization algorithms are used, that tend to be non-scaleable when large numbers of dispersed devices are included. In this paragraph a number of concepts are introduced that allow decentralised control and coordination mechanisms to overcome this problem. In this paper these concepts are used to take the step from planning (hours before) to coordination (minutes scale). Underlying ICT architecture should also support the step to decentralised real-time control (frequency and voltage; harmonics).
In an electricity network that is completely distributed with millions of consumers and producers on different grid levels this approach is the only feasible way to control such a network.

Agents

Software agents represent a new type of Information Systems (IS) architecture particularly suited to distributed applications in networked environments such as Intranets, Internet/Web, or the electricity grid.
Agents can be defined as pieces of software that are capable of acting with a certain degree of autonomy in order to accomplish a task on behalf of its owner. The owner of an agent can be a human or a machine, e.g. network component in an electricity grid. Agents become a powerful paradigm when they are able to interact with other agents in so-called multi-agent systems. In this way agents can be applied to embed intelligent system techniques in large distributed systems. It is the belief of the authors that agents are indispensable for coordination and control of the Smart Grid [4] in order to provide reliable, flexible and cost-effective power supply. Other research also identifies agents as a means of grid control [5], [6], [7].

Active networks and Cells

The current electricity market does not have large incentives for small scale local generation. In general the price for delivering back to the network is low. The value of local generation can be increased considerably if it can be utilized at or near the place of production. In the first case the use of electricity is balanced behind the meter. In the second case transmission and distribution cost and losses can be saved to a large extent. However, it requires local coordination in order to improve simultaneousness of demand and supply. This process has to be automated, since it is unfeasible to shop around for electricity in the usual way.
In an active network software agents representing electricity producers and consumers can perform this task. Moreover they can offer the flexibility of the demand side and the supply side (e.g. by load shifting) in order to get a better coordination between demand and supply. At the same time the flexible sites can adapt themselves to variable loads that are not controllable. If a majority of all end users participate in this local coordination process, electricity can be put to value where and when it is valued at its highest.
In order to enable local coordination we have to create local coordination centers, organized in network cells. A logical cell structure in the grid already exists, from in-house networks to low-voltage cells and medium-voltage cells. One could also connect to a concept such as the flexible cell as introduced in [8] where cells can be reconfigured based on real time power flow needs or need for fault handling.
Cells can be organized in different ways. A hierarchical network fits the transmission and distribution network as it is laid out in large parts of Europe. Loosely coupled networks such as the MicroGrid [6] concept can be seen as an alternative, in which autonomous operation of the cells is an option.

PowerMatcher market-based coordination

The PowerMatcher [2] is developed as a market-based coordination mechanism for electricity supply and demand in a distributed fashion. Each consumer and producer node in the network is represented by a 'software agent', which makes a central optimization algorithm superfluous and keeps the communication overhead very limited. All that is exchanged between the agents and the agent platform (the 'matcher') are bids. These bids express how much an agent is willing to pay (consumer) or receive (producer) for which amount of electricity. The matcher determines a market clearing price, which is returned to each agent and sets the actual power consumed or produced by the agent (Figure 1).

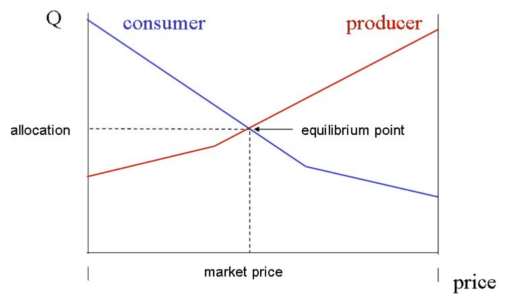

Figure 1 Bid functions with market clearing price

In the PowerMatcher model each device is represented by a control agent, which tries to operate the process associated with the device in an economically optimal way. The electricity consumed or produced by the device is mediated by the device agents on an electronic exchange market [9], [10].
The electronic market is implemented in a distributed manner via a cell-based structure of so-called Power Matchers, as depicted in Figure 2. A PowerMatcher coordinates demand and supply of a cluster of devices in a cell. Different types of devices can act as underlying consumers and producers. PowerMatcher cells can be organized in a hierarchic way such that a PowerMatcher in

a higher level cell receives an aggregated demand and supply curve from a lower level cell. A PowerMatcher cannot tell whether the incoming agents are device agents or other PowerMatchers, since the communication interfaces of these are equal. Thus the concept is highly scalable to include large numbers of device nodes.

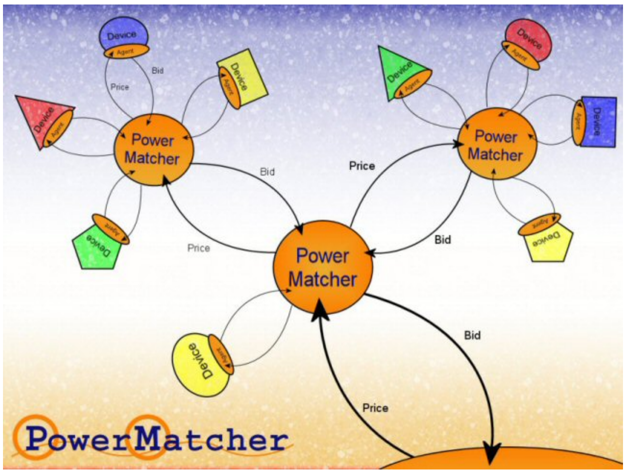

Figure 2 PowerMatcher cell-based control

Normal, critical and emergency control

To demonstrate its potential the PowerMatcher has been used in several field tests in The Netherlands: mitigation of load variations in distribution network containing residential micro-CHPs [11]; and reduction of imbalance caused by wind power in a commercial portfolio containing distributed generators and responsive loads [12]. Until now the customers have participated by placing bids under normal market circumstances: if no balance is reached, then there is always a possibility to import electricity from outside a cell against a fixed fee.

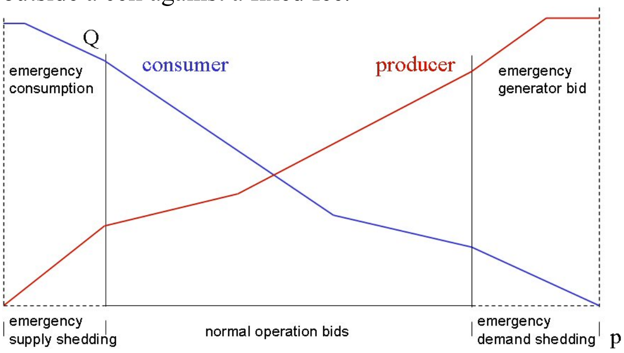

Figure 3 Bid functions with emergency bids

In critical circumstances the latter assumption may no longer be valid, e.g. if a shortage of supply is prevalent. Demand response programs are developed to counter these problems. However, the PowerMatcher concept already embraces demand response in a natural way and even broadens its possibilities, since both the demand side and the supply side are integrated in a natural way. A simple extension of the bid suffices: an agent not only expresses its normal bid in its bid function, but also communicates its behavior in emergency situations, i.e. whether it allows any type of load shedding or the switching on of emergency generators. Even today TenneT, the Dutch transmission system operator, uses street lighting in daytime as a means of load relief. Figure 3 shows the extended bid function. This bid not only shows a possible demand response action, but the shape also indicates the real-time willingness and the amount of power reduction. Also the response is not a shedding of during a longer time period, since in every market round (1-15 minutes) each device has new chances. Local generators such as micro-CHP, that are normally operated based on heat demand, may thus in emergency situations be switched on based on electricity demand, thereby producing waste heat, which would be undesirable otherwise.

MARKET INTEGRATION

The two field tests that have been performed with the PowerMatcher concept were organized as coordination tests. No real markets with real payment schedules were involved. Introduction of the concept for applications in a competitive environment requires arguing not only about technical, but also about commercial feasibility. Business models from a profitability/economic value point of view have to be constructed, either within current market structures, or by developing new ones.

First one should consider whether the PowerMatcher concept should lead to real market prices, or that it is applied purely as a coordination mechanism. Real market prices fit well into the liberalized market and the idea of 'Power to the people'. However it should be doubted whether small customers are willing to commit themselves to a market where prices are uncertain and could even be unlimited. It should be noted that modern Information and Communication Technologies (ICT) allows such real-time pricing schemes and support on-line settlements of contracts.

Alternative business models may be more suited as a first step, such as rewarding customers who take the service from the utility or the system operator. The service company operates the local devices, making a profit from balancing the demand and supply, and pass on part of this profit by giving a discount. Note that the PowerMatcher concept allows full customer autonomy, since their devices are operated within their operational limits, just as a thermostat controls a heating device. This means that the customer takes the service without any intrusion into his/her private live. The emergency operation then may be part of a separate contract, similar as contracts that allow load shifting or demand response actions.

An overview of household response to different pricing schemes is given in [13]

Distribution costs and losses

Besides a commodity component electricity tariffs include a component for transmission and distribution. Local balancing of demand and supply may change the structure of these costs: flows can be assigned to certain cells in the network, or flow from one cell to another. Also large scale distributed generation may lead to models for aggregation costs apart from distribution costs. Another aspect of load flows is the distribution losses that increase when the distances grow. A cell agent can take control of both distribution costs and losses.

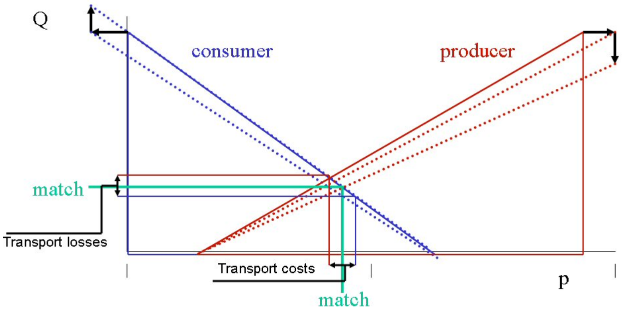

Figure 4 Bid function transformations for inclusion of distribution losses and costs

A possible way to include distribution costs or losses is by transforming bids. The current method is suited for non-circular networks, but better versions are being developed. In Figure 4 the transformations are depicted by the dotted lines. A market agent in each cell takes care of these transformations for the (aggregated) bid that leads to a power flow from the cell to another cell. In this way both losses from one cell to another can be taken into account, and each cell (or line from one cell to another) can impose its own distribution cost.

Network constraints

One of the consequences of a completely distributed control system for the electricity network is that a load flow calculation the way it is performed now becomes very difficult. The ideal situation would be that the entities trading electricity in this distributed market take into account network constraints.

First simulations have already been performed to include line constraints in the PowerMatcher concept, by creating line guardian agents that guard the load on the line. Main task of these agents is to cut off the (aggregated) bid function that passes the line to make sure that the resulting load satisfies the line constraint.

If certain areas are connected through weak links to other parts of the network, this approach is likely to lead to local electricity price differences. Matlab simulation yielded exactly similar results for these PowerMatcher bid transformations as an approach based on Locational Marginal Pricing (LMP).

CONCLUSIONS

Distributed solutions for coordination of supply and demand, such as the PowerMatcher, offer a number of advantages over traditional Demand Response programs in an environment in which a large amount of distributed generation is available. Solutions are based on two-way communication between agents on cell-based agent platforms and provide additional opportunities such as inclusion of network constraints and market models for distribution costs.

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