Impacts of Distributed Generation from Virtual Power Plants

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Abstract

As CO_2 emissions and sustainable energy production have entered the focus of attention in politics and industry, ecologically advantageous alternatives are strongly promoted. We address virtual power plants from an information technological, economic and legal perspective in order to enable decentralized sustainable generation. For the realization of virtual power plants we draw on a peer-to-peer infrastructure with market coordination and legal coverage to manage the distributed generation units and we focus on the combination of power and heat. Based on our prototype for a decentralized market platform, we examine the economic and ecological impacts of an increasing pervasiveness of distributed generation and virtual power plants as well as their potential influence on society.

At the social level, we consider questions of local immission, but also of growing awareness for power issues. With regard to the ecology, we expect a reduction of overall primary energy demand resulting from reduced transmission and transformation losses and increased use of combined heat and power plants at a local level leading to a reduction of emissions. Finally, since local distributed generation makes more efficient use of primary energy and long-distance transport lines can be reduced, we expect lower costs for the complete system as well as reduced uncertainty with regard to amortization of investments. Besides a description of the methodology our presentation will include selected results.

KEYWORDS: Virtual Power Plants, Decentralized Energy Generation, Market Coordination, Cost Optimization

1 Introduction

There is a continuing tendency in the energy market to employ smaller generation units for both electricity and heating. Beyond sustainable energy sources, fuel cells for the cogeneration of locally distributed electricity and heat are gaining importance. For examining the impact of this distributed generation, we focus on virtual power plants (VPP) from an information technological, economic and legal perspective. We define virtual power plants as pools of autonomous generation units primarily for electricity and heating. Typically, they employ small to medium sized generation units like fuel cells. The fuel cells produce both heat and electricity. While the former can only be provided to consumers locally, the latter is in principle suitable for long-distance transfer. Still it is intended to provide the electricity of VPPs locally since this offers additional advantages presented in this text.

For fostering an overall balanced provision of energy within a VPP, a way of controlling and optimizing the per se autonomous distributed units must be chosen. Since we see markets as both capable of coping with the complexity and particularly suited for the distributed nature of VPPs, we chose market coordination for controlling them. We examine three different scenarios of coordination with increasing degrees of freedom. First, we consider a natural monopoly of one energy company controlling and optimizing a VPP with all its decentralized units, coupled with a reduction of load curve peaks via non-linear pricing on the demand side. Second, we presume independent generators of energy that are coordinated by a central market operator. Third, we consider a market model with bilateral contracts and a non-profit market operator for the local distribution network.

To examine virtual power plants and their impact, we chose the methods of theoretical analysis and simulation. For conducting the latter, we implemented the prototype of a market platform for automated optimized trading of electricity and heating contracts in the project SESAM[1] . The prototype is based on a peer-to-peer infrastructure corresponding to the decentralized nature of VPPs. Basing on this infrastructure, we strive to develop a market structure that supports our main requirements for virtual power plants, namely spontaneity and self-organization. In this paper, we focus on the prerequisites for and consequences of such structures.

The rest of this text is structured as follows. Section 2 presents the system architecture of SESAM including the market structure, modeling technique, and the juridical component. In section 3, we take a closer look at the economic considerations of virtual power plants. We address optimization in section 4 and conclude with summary and outlook in section 5.

2 System Architecture

The system architecture employed in the SESAM project encompasses three important aspects: Market structure, support for legal transactions and peer-to-peer infrastructure. Of these the first two will be detailed here. The market model for virtual power plants in the context of SESAM has to be specified in such a way that both spontaneity and self-organization are supported. Where hierarchies and fixed pricing schemes rely on predefined, commonly agreed-on, and long-term relationships, markets per se deliver individual just-in-time links between participants. To further foster spontaneity, the harmonization between different participant groups must be advanced. These groups are traditionally divided into countries with different legal frameworks, incompatible IT-systems and last but not least different market segments with various trading mechanisms.

2.1 Spontaneity and Self-Organization in Markets

Harmonizing users in market terms means providing them with a market model they all can rely on for a shared understanding of the market structure and a common terminology. Harmonization and increased spontaneity, respectively larger degrees of freedom for the individual, allow and require self-organization for the functioning of a complex system. For virtual power plants in particular, we see larger markets after harmonization meaning a bigger choice of suppliers and less transaction or switching costs within and between different VPPs. The market itself provides a way to organize such systems. It can be employed as an algorithm by the central planner, it can serve as a coordination system with a central market operator and processing of decentralized information, and it can even truly epitomize self-organization with bilateral communication links between all participants.

2.2 Market Model

In order to systematically derive a market model for virtual power plants that can realize all mentioned aspects, we start with the notions of a minimal market model [1] that applies to any kind of market. With respect to implementation, this basic model identifies the six concepts *participant, product, attribute, intention, agreement*, and *offer* as follows:

- *Participant:* A participant represents an agent of any kind that takes part in a market. Market participants submit intentions to a market.
- *Product:* A product can represent any good or service.

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[1] SESAM is a project at the Universität Karlsruhe(TH), Germany, funded by the Federal Ministry of Education and Research (BMBF)

- *Attribute:* Attributes are used to describe properties of products and market participants. A product attribute can be declared *forMatching*. This means that the respective attribute is mandatory for consideration when matching the underlying intention with others.
- *Intention:* An intention represents the smallest closed entity of purpose within a market. An intention is defined by two groups of products, namely the incoming and outgoing products. Incoming products are the ones the participant wants to receive while outgoing products are the ones he is willing to give away in exchange.
- *Agreement:* An agreement is always derived from two fully specified intentions that are declared binding. It indicates that the two associated intentions match and that the respective participants have committed themselves to exchanging the products of the involved intentions.
- *Offer:* Each offer contains one or several intentions and serves as a container of control data for communicating these intentions. Its timestamp is set upon receipt of the offer by the runtime environment. An offer can be a *BindingOffer* or a *NonBindingOffer*. Binding means that the associated participant is committed to the precise embodiment of the offer, while non-binding offers just deliver noncommittal information.

In order to derive our specific market model for virtual power plants (VPM), we start by taking a closer look at the energy domain in order to identify the characteristic embodiments of each one of the aforementioned concepts and to integrate them into the VPM.

We consider the products *Electricity* as well as long-distance *Heating* to be central to the energy market. Furthermore, we add the product *Money* that is common in many markets. Accordingly, we derive three such subconcepts from the original *Product* concept.

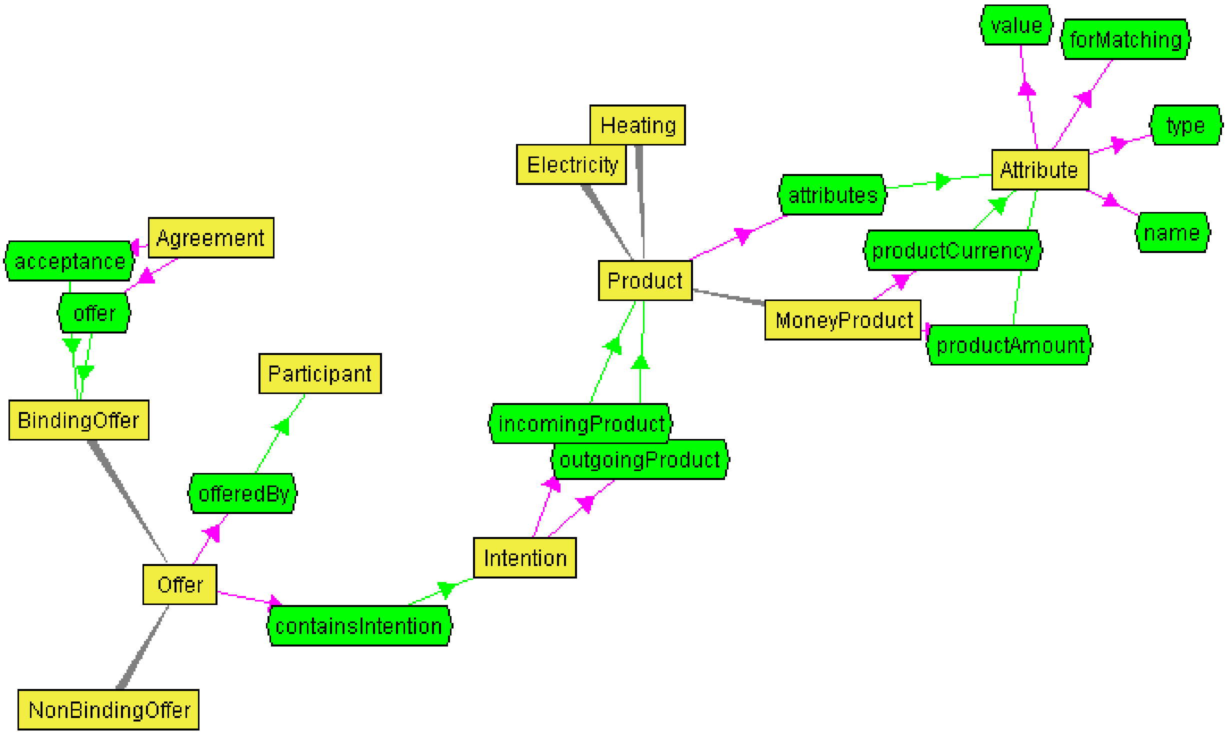

Figure 1: The MMM, including electricity, heating and money

Figure 1 comprises the introduced six concepts of the MMM. The product concept has the three subconcepts for *Electricity*, (long-distance) *Heating*, and *Money*. For briefly exemplifying more details of our approach, we add two concretized attributes to the product *Money*, namely *productAmount* and *productCurrency*. As the names suggest, *productAmount* specifies how much money a participant is willing to pay; *productCurrency* specifies the currency of this amount.

The two products *Electricity* and *Heating* both have many more attributes than *Money*. *Electricity*, for example, contains an elaborate system of 54 price slots, an additional base rate field, share of ecological electricity, contract duration, etc. Since the data structure is not explicitly accessed, we omit the detailed display of all attributes in this paper for the sake of clarity.

For our prototype, we use ontologies to represent the VPM in RDFS [2] documents. Hence, every new participant interested in joining our platform can learn the full employed market model by receiving the VPM RDFS-document.

With this document in hands, any participant of the market can address any other participant in a common terminology. However, the VPM aspects sketched so far only cover the market perspective. To enrich the VPM for implementation and law-abiding application, we integrate all required security and law aspects. Security in our context particularly encompasses digital signatures, encryption and certificate handling for secure communication, authentication, etc. For the scope of this paper, we presuppose this infrastructural layer and will not examine it in detail. The juridical aspects, on the other hand, have to be explicitly elucidated and integrated as will be done in the following subsection.

2.3 Juridical Component

In order to support a participant in changing between the supplier and the buyer role, we rely on an agent-based contract service. We have two types of agents in the contracting process – called contract agents – making use of a “legal mediator”. The legal mediator guarantees the legal correctness during a contract conclusion. The contract agent consults the legal mediator during the different steps of the workflow needed to buy or sell energy. In the virtual power plants scenario, participants can switch the role of customer and supplier; a customer of energy and heat can become a supplier by offering his excess production on the (local) market. The role of traditional utility providers is limited in this scenario to providing the local distribution network and satisfying excess demand not met by decentralized units. In addition, a utility company can possibly offer services to the private suppliers and buyers that enable them to automatically conclude a contract.

Since in our setting, switching roles instantly is possible, it is important that the conclusion of the contract can also take place spontaneously, i.e. with as much automation as possible. In order to quickly obtain a legally valid contract in the highly regulated utility domain, immediate automated legal consultation is particularly important. Consequently, the mediator can be interpreted as a kind of personal electronic lawyer of the participant. The entire process of concluding a contract is carried out by a contract agent. This agent’s task embeds the transaction into the internal workflow of the energy management system on the customer’s side.

In the following, the architectures of the contract agent and the legal mediator are presented. It can be stated that the fully automated support of the contract service results in high qualitative and monetary advantages for buyers as well as suppliers. The quality of the final contracts with respect to provableness and effectiveness is substantially increased. The basis for the legal mediator is the formalization of the code of law. We borrow ideas from the domain of Artificial Intelligence (AI). Our architecture corresponds to the basis architecture of an expert system [2]. The main criteria for our choice of rule engine are the control of forward chaining and backward chaining. Also non-monotonous reasoning must be supported. In order to integrate the mediator into the SESAM framework, we chose a Java implementation. The basis of the rule engine is an ontology for legal terms that in turn is an extension of the minimal market model ontology: On the one hand, we extend the ontology by synonyms for the different concepts and properties. On the other hand, we concretize concepts of the general minimal market model in order to meet particularities of European utility regulation and national basic law. This finally delivers a comprehensive virtual power plant market model.

In general, SESAM follows a service-based approach [3]. As explained, the core juridical services are represented by agents. This fits into the specifications of the SESAM project for an implementation based on peer-to-peer technology. For agents in a decentralized setting, it is necessary that the peer structure provides a semantically rich environment. Accordingly, we based the internal structure on the reference architecture for agents [4].

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[2] Resource Description Framework Schema, see http://www.w3.org/TR/rdf-schema/

For running the system, the two agent types must each be deployed for every market participant: The contract agent assumes the task to represent the personal interests of the market participant. It contains the personal preferences of the market participant it represents as well as the economic criteria that should be employed. These contribute to the goals that the agent pursues. Since goal conflicts are nearly inevitable, the conceptual challenge to handle these conflicts during the process was answered as proposed by the BDI theory [5]. The contract agent will negotiate directly with the contract agent of other participants.

The legal mediator – our kind of personal lawyer – cooperates closely with the contract agent and receives requests from it. While it is reasonable that a contract agent commonly represents its market participant it is conceivable that legal mediators can be specialized in a certain legal domain. Therefore the legal mediators may advice several market participants and one participant may consult several mediators. The requirements for the legal mediator differ fundamentally from those of the contract agent. Due to strict law requirements the mediator is constructed in a modular way. The process of systematically answering legal questions is subsumption. To enable subsumption in an electronic environment, we modelled the required law paragraphs in rules, which are processed in a inference engine within the legal mediator.

The juridical architecture thus allows us to flexibly represent and handle the different legal frameworks in order to enable automatic contract conclusion between participants.

3 Economic Considerations

In this section, we discuss the impacts of decentralized power generation from a mainly economic perspective. We consider five factors that are crucial for the success of virtual power plants as we consider them here: Decreased need for peak load generators, decreased transmission capacity demand, decreased transformation losses, reduced investment risk and benefits of cogeneration of power and heat. Furthermore, certain types of virtual power plants may lead to increased use of demand side management as shown in section 4, if the generation units are directly controlled by consumers as intended in the more advanced scenarios.

3.1 Peak Load Generation

From the supplier’s point of view, virtual power plants represent an attractive way for reducing the share of peak load generators in the company’s generator portfolio, thus allowing lower average production costs. From the customer’s perspective, decentralized generation as a substitute for peak load demand is attractive with respect to the price that needs to be paid for adequate electric supply.

However, this potential for cost reduction strongly depends on the control mechanisms of decentralized generation units. In the first scenario with one central energy company controlling the VPP (see section 1), optimal results can be achieved via centralized optimization and dispatching of the decentralized units. In this scenario, central peak load generators are basically substituted by decentralized ones. Spontaneity or self-organization do not occur here.

The two more advanced scenarios (see section 1) using market coordination are more promising in this respect. Since dispatching is done here by a neutral local operator, or customers even have direct control over their generation units, and all necessary information is communicated via the price, optimization takes place locally. It is important that the technology used in the units supports this degree of spontaneity: Since the type of units used in decentralized generation usually has short ramping up times, spontaneity becomes possible much easier than in conventional settings. Equally, the organization pattern moves away from a hierarchical coordination to a self-organized one that is based on market mechanisms.

Thus, flexible price and cost structures as well as appropriate market design become vital for the functioning of the whole system. From a technical viewpoint, the model presented in section 2 allows the exchange of offers and the conclusion of contracts. From the economic perspective, it is equally important that the incentive structures in the market allow efficient solutions. For this, some conditions must be met: In addition to the common conditions for market efficiency [6], the technology and the cost structures of units used in decentralized scenarios must be compatible with the goals set.

Concerning the costs, the following considerations should be taken into account: If, for example, the price of a KWh produced by the cheapest decentralized unit is higher than that of the most expensive central plant, decentralized units will not be dispatched (an exception can be justified by the considerations in section 3.4 concerning risk premia, but here we are more concerned with short term unit commitment problems with given investments). If, on the other hand, costs of a KWh generated decentrally should ever drop lower than those of central base load generators, the decentralized units should be dispatched first and would run continuously, thus replacing the cheap but inflexible base load plants. In that case, if decentralized generation is not capable of providing sufficient peak capacity, central peak load generators would have to be dispatched – quite not what was intended in the first place. Of course, given the facts shown under 3.5 these are just theoretical considerations at two extreme points.

In order to substitute central peak load generators as proposed in the introduction, variable energy prices for decentralized units must be located between base and peak load prices. Furthermore, an important condition is that the offers given to the market reflect real costs and are not influenced by strategic behavior of market participants. Otherwise, big energy suppliers could be tempted to deter decentralized competition by artificially lowering the peak prices in order to secure the further use of their investments.

3.2 Transmission

Evidently, virtual power plants consisting mainly of units installed at the consumers’ sites also make a contribution to take load from long-distance transmission lines. First, due to the fact that the power is already at the desired location, transmission losses can be dramatically reduced. In typical transmission systems, about 1-3 per cent of transported power are lost per 1000 km during transmission.

Even more important effects occur when the market succeeds in reducing peak load demand from central sources. Since power lines are designed to transport the maximum amount occurring during rare peaks, large parts of the capacity lie idle most of the time. Using decentralized peak generators, the gap between minimum and maximum required capacity on the lines connecting power plants and distribution networks is diminished. Consequently, spare capacity is unleashed that can be used in two ways: Further growth in energy demand is possible without the need of new power lines or their extension. In the long term, if demand stagnates, replacement investments can be avoided or at least reduced due to this fact.

A more steady use of transmission lines has another positive side effect: since due to a reduced percentage reserved for peak demand, at the same fixed cost, more of the capacity is used over time, the price for the use of transmission lines can be expected to drop accordingly. If the supplier can effectively reduce his peak demand, he can choose a less expensive tariff for transmission line usage.

Finally, since decentrally generated power is already in the desired location, it has a cost advantage whose height may correspond to the price usually charged by transmission network operators and the value of the transmission losses.

Unfortunately, these positive effects only occur with local generation. If the virtual power plant includes a high percentage of renewable energy sources that are not at the customers’ sites but, for instance, in an off-shore wind park or in a remote area with a high number of sunshine hours per year, these effects will be less pronounced or even reversed. Another problem with this kind of renewable energy sources is that they cannot be subjected to a conventional unit commitment plan since they depend on climatic effects. Although a recent study has shown that sun and wind power complement each other well [7], the basic problem persists.

3.3 Transformation

In order to reduce losses on transmission lines, high voltages are used on these lines. Consequently, losses are incurred in transforming and retransforming, but these are evidently smaller than those that can be expected on a low voltage line. Thus, long distance transmission always implies transformation.

In an average system, transmission and transformation losses amount to 5 per cent of the energy transported which results in correspondingly higher prices.

Analogously to the argumentation given in the last section, these losses can be avoided with decentralized peak generation as well as smaller costs of transformation equipment. Consequently, investment in transformation can be reduced following a similar argumentation.

3.4 Investment Risks for Generation Units

The liberalization of energy markets has brought increased uncertainty with respect to investment decisions. When they still had a monopoly for their respective area, utilities were able to project demand for long terms from current data. Today, fluctuations of the customer base are common and will become even more pronounced in the future. Since big power plants require many years from the investment decision until they are operable and usually have a lifetime measured in decades, their construction cannot be planned on a short-term basis.

On the other hand, small, decentralized generation units require less time from planning to operation, have shorter life times and smaller investment requirements, thus offering at least a part of the flexibility required in deregulated markets. Already, there is a trend in Germany to replace old plants with smaller, less expensive (in terms of fixed costs) ones. Their downside are the higher variable costs: First, the technology in itself has higher fuel costs, e.g. gas turbines versus nuclear power. Second, economies of scale for personnel, training, maintenance, fuel delivery etc. cannot be realized on this small scale in the same way as with big centralized plants.

However, there is a possible way to justify these potentially increased total costs of decentralized units: They can be interpreted in this context as a risk premium that suppliers (obviously) are willing to pay in order to avoid long-term engagement in plants that may not be needed in a few years' time.

3.5 Cogeneration of Power and Heat

As discussed in the last paragraph, decentralized power generation alone will always have cost disadvantages compared to centralized units, even if it may be justified by risk reduction considerations. This is where the biggest advantage of decentralized power generation comes into play: The possibility of naturally combining power and heat provision.

Traditionally, the generation and distribution of heat – contrary to electricity – has always been limited to a local level. This is due to the high losses in steam pipelines allowing only the traversal of short distances.

Small generation units tend to have a lower efficiency than bigger ones – between 30 and 45% electrical efficiency [8] – when used only for power generation. On the other hand, in big power plants the excess heat from power generation is typically lost due to the fact that its transport from the plant to the supplier is not economically feasible. Since the heat is already at the right place when using small generation units in the consumers' garage or basement, transport losses are minimal when the heat is inserted directly into the house heating system. Thus, the energy normally going to waste in centralized plants is used and serves to increase the efficiency of the system. When using integrated units for electricity and heat, the total efficiency of the system reaches 85 to 90%.

4 Optimization for Customers and Growing Awareness for Power Issues

For most customers, electricity is a "low interest" product. From their perspective, there is no need to deal with load curves or tariffs because there is no benefit. Customers with high electricity demands are more amenable to such issues and are more flexible in their demand, and usually try to maximize synergies and cost saving potentials. Most of the small and medium sized customers, however, have a tariff that is independent from the time of day the energy is used. These customers pay for the energy used without any limitation and independent of the time of usage.

One goal of the SESAM project is to take advantage of the potential that lies in the demand patterns of small customers. Such customers, however, must be motivated to change their habits and to actually deal with "energy" as a topic. For most of these customers, a financial incentive will make them think about and ultimately change their habits.

The first step to get a financial benefit is thus to create new - and cheaper - tariffs that at the same time reflect the real cost structure for producing energy, e.g. higher prices at noon and lower prices at nighttime.

Almost all of the home appliances that spend a significant amount of energy, e.g. cookers, hairdryers or lamps, are needed at a specific time and there is no possibility to move the consumption to a time where the price for electricity is lower. There are, however, other home appliances that could easily be moved to cheaper time slots with their activities, e.g. washing and drying machines since customers can rather freely decide when to turn on those devices. Some other devices have a certain flexibility in when energy is used, but the customer is not able to control this, e.g. a refrigerator. The refrigerator has to run when the temperature reaches a certain level. When the temperature is low enough again, the refrigerator stops automatically. By cooling/freezing to a lower than required temperature, the time until the next start can be extended and the start of such an interval can be chosen freely. Despite such general possibilities, a customer will neither be able nor willing to control manually every electric device he owns. To overcome this, there is a need for devices that can be controlled automatically. One way to control a device is to send the current cost for electricity to the device for such device to decide when to use energy or to have the device use energy always at a specific time.

In the SESAM project, customers will be allowed to model their energy needs in a detailed manner: They are able to model every single device as needed with every possible degree of freedom, as well as limitations and constrains as desired. Dependencies between devices can be modelled as well as additional costs as penalty for late dispatching.

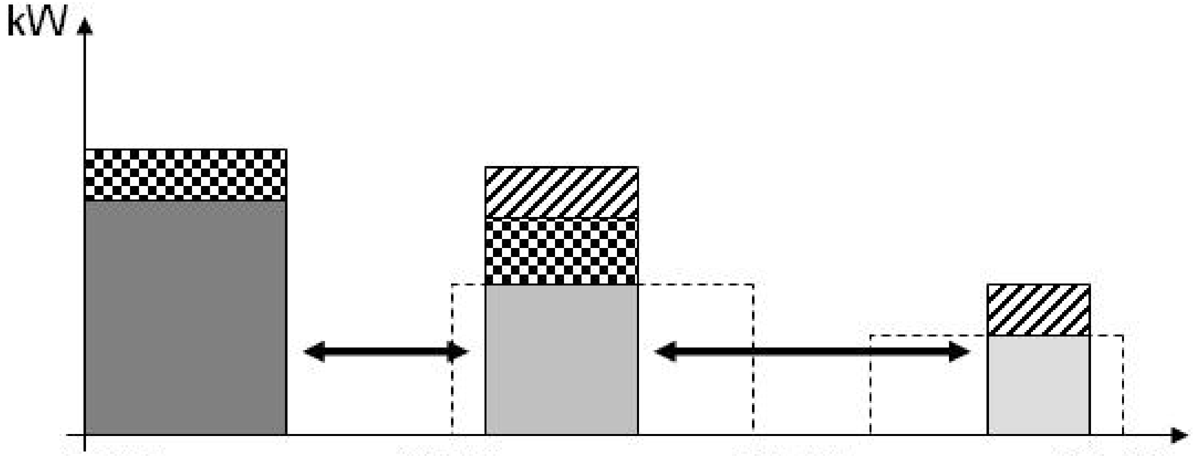

Figure 2: Load curve example

Figure 2 shows an editor where a refrigerator is modelled. The solid rectangle shows the block of energy usage, the dashed rectangle shows the possible start times and the patterned rectangle above the solid one shows penalties that occur when the interval between two points of time is increased. In this editor, every electric device can be modelled in a new diagram or devices can be combined in one diagram to model dependencies. Devices modelled in different diagrams have no dependencies and can be dispatched independently.

When the load curve is modelled, the customer can choose between 3 different kinds of optimization and can even combine them.

The three types of optimization are:

1. For a given load curve: Find the optimal tariff in the market
2. For a given load curve and a tariff: Find the best dispatching to reduce the costs
3. Find potential customers which could cooperate to get a better tariff.

The first optimization is rather simple as it only determines the costs for every available tariff and selects the one with the lowest overall costs.

The second optimization uses the modelled load curve to adapt to a given tariff. This is a lot more complex than the first optimization. The complexity grows with the degree of freedom for the devices. The outcome though will minimize the costs for the given tariff.

These two optimizations can of course be combined to find the best combination of tariff in a dispatching plan. The complexity for such a combined optimization is rather high and can only be calculated completely for small problems. For larger and more complex issues, heuristics are needed which may not lead to the global optimum but will find an acceptable solution in a given time.

The degree of freedom for a single private customer is not very high and the potential financial benefit will be rather small. To gain a greater benefit, customers can cooperate with each other and optimize their overall energy consumption. The cooperation of customers leads to a higher overall energy demand and could enable such customers to obtain better tariffs (i.e. industry tariffs). The organized devices can be dispatched independently which may lead to a better load curve.

In the last optimization, the best potential customers should be found.

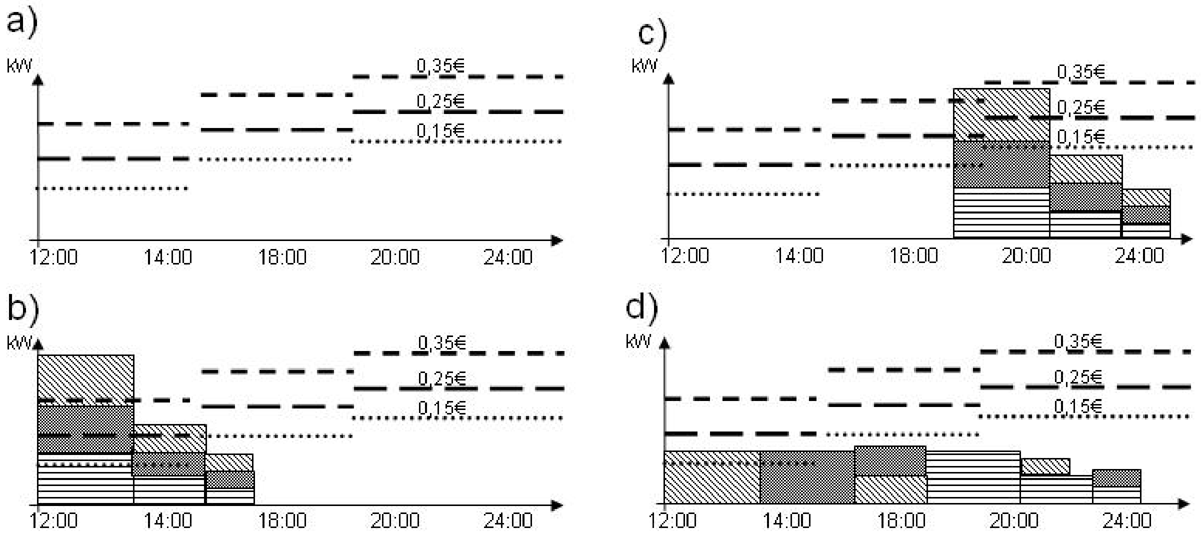

Figure 3: Load curve optimization

Figure 3 shows a possible scenario. In a) the costs for different times and different amounts of energy are shown. In b), c), and d) the customers' demands are depicted by differently filled rectangles. In b) no customer optimizes his demand at all and use their energy as early as possible. The overall costs are very high. In c) the customers have the same degree of freedom but optimize independently. The resulting load curve will be the same for all customers. The overall costs are slightly lower then in b). In the last diagram d) the load curves are optimized together which leads to a better balanced load curve. Usually, the more the load curve is balanced, the lower the overall cost will be, because the cheaper base load can be used in order to satisfy this demand profile.

All optimizations can be combined. In such case, the best tariff, with the best load curve, and combined from different customers is found. The complexity of this problem is obviously much higher than the optimizations presented above.

These possible optimizations lead to a better awareness with regard to power issues and, as a result, to a better use of energy. Looking at the results of the optimization, a customer may find out that besides some peaks his energy demand is so balanced that it would belong to the base load band.

In order to gain financial benefits for base load, the consumer needs to procure his peak demand from other sources. One way could be to run his own a little power plant – e.g. combined heat and power plant as proposed in section 3.5 – to cover his load peaks. When the costs for such a little plant and the base load are lower than the costs for a tariff which covers the peaks in his load curve, this would be a feasible solution. Since a power plant also produces heat, the costs for heating could be reduced which would lead to an additional reduction of the costs. Usually, those plants will only be profitable when the heat is needed and used. The reduced cost for base load tariffs alone will not be sufficient to finance the plant. Although the plant is primarily designated to cover the peaks in the load curve, excess energy could also be sold. Whenever the price for energy exceeds the price for turning on a consumer’s own plant it is profitable to sell the energy.

The costs for a small power plant will be too high for a single customer but in cooperation with his neighbors, such costs may be acceptable. The customers benefit from this solution because of the reduced costs. The energy producer reduces its costs because of its lower top load and a better exploitation of its power plants. The following subsection sets forth an example of a possible cost reduction through customer optimization.

Decentralized power production with small units may also have some social effects. First of all, the awareness for power related problems is raised. The customers will try to optimize their energy demand and electricity is no longer a "low interest" product.

Despite the change of mind some other social problems may arise: decentralized power creation leads to stronger emission at the places where the plant is placed. Larger power plants are normally placed offside where only emissions like CO_2 have an impact on the inhabitants. Small power plants have to be near the demand site to achieve the optimal effect (reduced transmission losses, use of the heat). Thus, the emission – i.e., noise or dust – will have a direct impact on the neighborhood. The emission will return as immission to the local neighborhood where the plant is placed. Because CO_2 will spread out over a large area, the emission will be the same as from a large plant, independently of the amount of the CO_2 emission. Therefore, CO_2 is not a local problem and can be neglected here.

Dust, noise, vibrations (e.g. from diesel aggregates) or other pollution will affect only the direct neighbors and such impact must be taken into account when planning a small power plant. Especially dust and noise can have a negative impact on the living conditions and may lower the standard of living. It is thus not possible to place a plant in any highly populated region.

Another problem is the heat created from such a plant. In the cold months of the year, the heat can be used for heating or warm water. Usually, such a plant will produce enough heat to satisfy the demand. But in the summer, there is nearly no need for heat anymore. Nevertheless, the heat will be created when producing electricity. The heat is now garbage and must be disposed of. In some regions, it could be very difficult to get rid of the heat when everybody has produced too much to satisfy his electricity needs.

4.1 Results for Load Curve Optimization

In this section, we will present first results obtained by applying the optimization techniques mentioned above to a single standard load curve for a private household. The demand pattern was taken from [9], a data set containing load profiles for standard consumers widely used in Germany.

First, we assumed that 10% of the household's power consumption can freely be redistributed over the day. As prices, we used the internal costs of generation in a fictive, but representative power plant pool as could be found with one of the four big suppliers currently active in Germany [10]. Prices for transmission and distribution as well as ancillary services were not taken into account as these normally represent a fixed share of the energy bill and thus do not change with the kind of optimization discussed here. The case where a consumer changes the load class with his network operator and thus pays less for transmission is not considered here.

With this setting, if one customer optimizes his costs with a variably usable share of 10 per cent while no optimization takes place with the other customers, the total bill decreases by more than 1.56 per cent. If the fraction of freely redistributable demand is increased to 20%, the payload decreases by 2.69 per cent. The diminishing marginal utility of a higher percentage of freely distributable load indicates that the relation is not linear and decreasing with the percentage. This effect will be investigated further in order to determine the exact relation between these variables.

If the load curve optimization is employed independently by every customer, the reduction decreases to 1.14 per cent respectively 2 per cent for each customer. The reason for this effect is clear: When only a small share of customers optimizes the load curve, base load can be used in times of low demand. If, on the other hand, all customers use load curve optimization, additional plants that do not belong to the base load class have to be used which increases the cost. Although the potential is thus a bit lessened, load curve optimization represents an interesting approach for reducing a customer's energy bill while using efficient plants.

Furthermore, as has been discussed in the last section, even greater potentials can be achieved by customers jointly optimizing their demand patterns.

5 Conclusion and Outlook

In this paper, we have described the framework used in the SESAM project in order to analyze the impacts of decentralized generation or virtual power plants. We have sketched the architecture of the framework and the prototype with its aspects concerning market and law. Furthermore, economic considerations for the success of virtual power plants were derived and presented. Finally, as a first result we have presented ideas for optimizing the behavior of a participant in an energy market where prices are time dependent, communicated to the customer and where the customer can choose to generate a part of his own demand. First results show that optimization of the load curve, where applicable, have the potential to lower the electricity bill of a consumer. Further cost reduction will be achieved when the optimization integrates other customers and also takes into account the possibility of active (peak) load reduction via local generation.

There are still many questions open that we will pursue during the coming months: How do customers react to the new possibilities given to them? How can spontaneity and self-organization be automated by the respective systems in order to lower the acceptance threshold of customers? What is the probable position of traditional suppliers?

Besides these aspects, it will be interesting to also analyze the supply quality produced by virtual power plants. Will they be more or less reliable than the generation structures that predominate today? It is especially this criterion that is crucial for the acceptance – and thus the success – of decentralized energy generation.

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