Energy communities in Smart Markets for optimisation of peer-to-peer interconnected Smart Homes

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Abstract— **Energy management in Smart Grids and Smart Homes will play a decisive role in future power system. Due to the rising decentralised power generation and its supply to the local grid, the individual households have to become more and more a participant in the Smart Market. Therefore approaches are presented for a framework to design and generate value-added services for management Smart Grids and Smart Homes. It offers users the possibility to design services for managing decentralised energy devices and resources as well as optimise the energy consumption by intelligent energy management and automated service generation and optimisation. These new approaches are based on interconnection of households and algorithms for automated optimisation of energy consumption in single households or whole regions, without assistance of third parties. The interconnection of the households is based upon the peer-to-peer principles for communication and automated optimisation as well as forming a social network, as a so called energy community between the participated peers.**

I. INTRODUCTION

A. *Adjustment in future power supply system*

Today the power supply system is static. Primary large central power plants like coal-fired and nuclear power plants supply companies and households with energy. In the future the number of decentralised power plants will increase and the central power plants will be reduced. That leads to much more households installing a photovoltaic plant or a micro block heating power plant (BHPP). Furthermore, the number of wind power plants in communes will increase, as well as power generation by biogas. Due to the fact that large power plants will be reduced, the still needed adjustment of the power system cannot only occur in the maximum voltage grid. Adjustment in the Distribution Grid is recommended by controlling and monitoring the decentralised power plants and energy consumer. Controlling of these decentralised devices requires fusion of information- and communication technology and energy technology. This will lead to a Smart Grid.

B. *Smart Grid*

"A Smart Grid is an electricity network that can intelligently integrate the actions of all users connected to it – generators, consumers and those that do both – in order to efficiently deliver sustainable, economic and secure electricity supplies" [6].

C. *Smart Market*

Separating Smart Grid and Smart Market is mainly based on the consideration of whether quantities of energy flows (market sphere) or capacity (power sphere). Primary subjects of Smart Grid considerations are not the amounts of regenerative energy produced fortunately, but Smart Grids consider the requirements for capacity resulting to the amounts of regenerative energy. Because the core business of energy network operators is to deploy, maximize, and optimise the network capacity. All actors who provide or consume energy can be participants in the Smart Market. They can cause a temporary reduction as well as an increase of the load according to price signals. The energy consumption and the energy supply will be driven by variable energy rates and/or variable energy network access fees. The user becomes a participant of the energy market which consumes, supplies and stores energy optimised by economical aspects. Smart Grids and Smart Markets should help to increase the usable capacity of conventional power lines through intelligent solutions (smart grid aspect). Furthermore Smart Grids and Smart Markets should utilise the available capacity of existing networks and improve its average load by supply and load shifting (Smart Market aspect). Both will be able to make economically optimal network expansion [3].

D. *Solutions for Smart Grid and Smart Markets*

Comprehensive possible solutions for Smart Grids are:
1. The central adjustment (monitoring and control) of distributed generators, storages, and consumers in so-called virtual power plants. This is the preferred solution on the current state of research. In this approach for example, distributed wind power, biogas, photovoltaic plants supplying energy to the primary or secondary distribution Grid can be controlled by the energy provider as well as large energy consumers are switched off for reducing the load. Furthermore, the problem is that the small energy consumers or the power generators and storages in the local grid (households of the customers) cannot be involved in a central control, because the legal basis and technical solutions for controlling of any devices in the user's sovereign territory are missing. Therefore, a more decentralised solution is necessary for optimisation

of the energy consumption and energy supply in Local Grids.

2. The decentralised adjustment of distributed generators, storages, and consumers by integration of households in energy management. Here, the energy consumption and the energy purchase are adjusted, controlled and predicted for every household. This approach requires the integration of the customer (in the following "user") and the consideration of their needs. But this is hardly possible because their needs are not known.

One option is energy management or develop/design solutions through value-added services which the user can design active. In addition, the user defines certain boundary conditions and criteria which are used to achieve an added value for the user to optimise energy consumption.

Following approaches will be introduced to allow a control of distributed energy management and monitoring of the power system. With value-added services and the integration of the user in the development and definition of value-added services, a new means of regulating the power grid and controlling the Smart Homes is presented. These approaches will be extended by the automated generation of value-added services and the optimisation of single households. Finally, approaches are presented to achieve optimisation in a Local Grid, through the peer-to-peer internetworking of one or several regions of households (peers) and forming a special energy community between these peers.

II. SERVICES AND SERVICE PLATFORM FOR ENERGY MANAGEMENT

In Smart Home domain some approaches exist to use web services for energy management and connecting heterogeneous systems. [7, 14] adopt service platforms for Smart Homes where services are provided by external service providers. [12] also proposes using web services extended for service orchestration. For fast and easy service creation literature proposes orchestration of web services and composition of services out of reusable building blocks using a service creation environment (SCE). The LOMS-, and the MAMS-project and the open source initiative SPAGIC expose the advantages of graphical service development [5, 8, 13]. To solve the permanent rising requirements for services and the underlying heterogeneous communication and execution layer, the projects SeCSE and PLASTIC propose self adaptive service oriented applications [1, 2].

As described above, several approaches exist in different areas to generate and orchestrate services. Currently, no approach exists where users get the possibility to design personalised services or workflows for energy management in the household, fulfilling their personal needs, including automatic service generation and deployment. Additionally, the approaches are focused on concrete target groups or concrete fields of application, mostly in business field, and are not applicable for users in simple households. Therefore, design and orchestration requires expert knowledge. Currently, there are no known publications that name automated solutions for provisioning of user composed services in Smart Grids and Smart Homes.

Therefore, a continuous solution is needed, oriented at the personal needs of users, to offer cost-efficient energy management, according to user personal needs, and integration within their house automation.

In order to involve users into Smart Grid or Smart Home management a service creation environment (SCE) is needed, which brings the possibility to design and configure value-added services, according to the personal needs of the users, to offer cost efficient energy management and optimised usage of energy networks. A service delivery platform (SDP) is needed to provide automated solutions for service provisioning, service controlling and service management. The following will figure out new approaches for a Service Management Framework (SMF) consisting of SCE and SDP that allows centralised controlling and management of resources and devices in Smart Grids and Smart Homes.

A. *Energy management in the Local Grid*

The adjustment of the power supply system is currently only possible on the upper layers of the power grid through the centralized large power plants by regulating the power generation and supply. Despite the reduction of large power plants still a adjustment is required. The control must be in Distribution and Local Grid, where the local power generators supply the current to the power system. The decentralised generators and consumers must therefore be mandatory involved in the adjustment.

Figure 1 shows the increasing decentralised power generators in the Local Grid, and the Service Management Framework which is used for controlling and cross linking of the decentralised generators and consumers in households in the Local Grid as well as decentralised generators in the Distribution Grid.

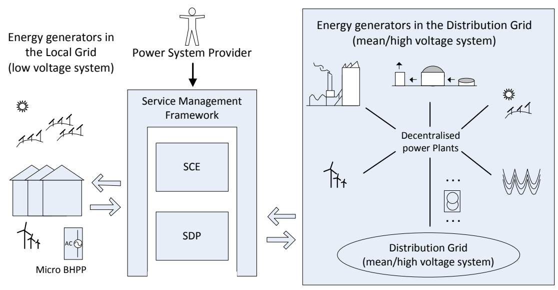

Figure 1. SMF for controlling centralised and decentralised energy resources

The approach through the provision of communication and control services through a Service Management Framework offers power system providers the possibility to implement a central control and monitoring solution in Distribution Grids in general as well as in the Local Grids. Furthermore, it is possible to predict the energy demand: whereby the power system provider gets the advantage of providing energy resources timely and with reasonable limits.

As described above, today the consumers, generators and storages in the households cannot be involved in a central control because the legal basis is missing and users perception of comfort would be affected. Therefore in next sections approaches for decentralised solutions are presented by integration of users in the service design.

B. *Services for Smart Home inclusive energy management*

The TeamCom SCE offers the possibility to describe the application flow of a service in a graphical SCE with BPEL (Business Process Execution Language) as service description language. The service described with BPEL will be compiled and deployed on a JAIN SLEE (Java API for Intelligent Network Service Logic Execution Environment) Application Server [4, 9]. This approach comes with the possibility for fast service creation, but recommends knowledge in BPEL and offers no mechanism to integrate these services in Smart Grids or Smart Homes.

The SCE contained in the proposed Service Management Framework makes it possible for the user to design services for its Smart Home in a simple way. Designing services for smart homes requires networking and controllable devices (up to the final consumer). This leads to the connection of electrical devices in households with IT technologies.

Figure 2 shows different energy consumers and energy generators in a smart home, which are connected to each other through various communication networks and controlled by the Service Management Framework.

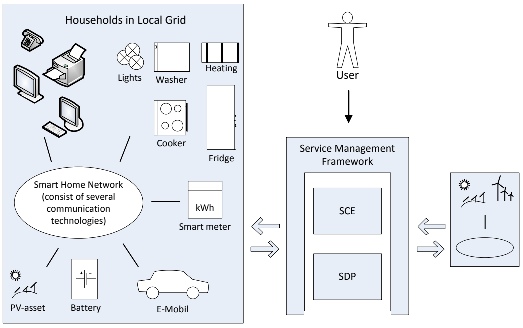

Figure 2. SMF for controlling decentralised energy devices

Power generators and consumers provide device-specific functionality (e.g. timer for start-up and shutdown of equipment or controller for the power supply of power generating facilities). These functionalities can be configured and invoked by the user via the SCE and integrated in the designed service. Generators and consumers are represented graphically in the SCE and form the design interface between the user and the devices. The SCE gives the user the possibility to design own services. In addition, the user can obtain and integrate pre-configured services in the SCE. These services can be offered e.g. as apps from the device manufacturer or a service provider. Thus, for example services can be produced which improve the comfort of the user, reduce the energy costs or increase security. Examples for those services: Disabling certain devices when the user leaves the apartment (e.g. ensuring that the cooker is switched off). Remote monitoring users place or remote unlocking doors if children have lost their key. Increase comfort by scheduling starting and stopping of equipment, so they finished their running until defined end points (e.g. washing machine ready when the user comes home). Reduce energy costs by charging the local power storage when energy rate is convenient and using the local power storage as energy resource in inconvenient periods. Also, a service can be designed in order to supply locally produced energy at the best terms to the power system.

In this approach the task of the SCE is to provide an interface for service design and configuration. Additionally, the task contained in the SDP is the execution of these services and the abstraction of communication between the devices in a smart home.

Another function of the SCE is to give users a graphical overview of the energy consumption in its households, the energy consumed by the devices, based on the past and for future planned services. The visualisation of energy consumption also strengthens the awareness of users to use energy more efficiently.

According to the actual technologies, only isolated devices exist which offer the possibility for remote configuration and control. In order to communicate and interconnect devices no unified standard exists. According to the manufacturer devices use proprietary protocols which are incompatible with each other, so networking between devices of different manufacturers currently is hardly possible. To rudimentary activate and deactivate devices, at present approaches are existing using intelligent sockets, which can be predefined to interrupt the power supply. In this new approach, the SMF will offer the possibility for unified communication between the interconnected devices and the integration of device functionalities in user designed services.

C. *Automated service creation and optimisation*

As described above the Service Management Framework will enable the user to create services to control the devices in the Smart Home. This functionality is extended to the automated service creation and optimisation of services and energy consumption. For this, the user can define boundary conditions for energy supply and optimisation, under whose account the SCE generates an optimised service automatically. The user can e.g. define criteria for the price, which advises the SCE not to exceed certain price limit for energy purchases. Or the user defines a lower threshold so that devices only start if the price is below this threshold. Furthermore, users can define criteria for device control and thus define the earliest starting times and latest end times. Similarly, the user can e.g. set the type of power generation for its purchased energy (wind power, hydropower, etc.).

Considering the above-mentioned conditions a service will be composed by the SCE and run by the SDP, which satisfies these criteria and also represents an optimal solution with respect to energy consumption. By scheduling the devices the most continuous energy demand is generated in a household, so that peak loads can be reduced or avoided. An application can e.g. consist of the optimised implementation for the procurement of electricity, where supply, storage and consumption are optimised that the load curve of a household is as flat as possible.

The optimisation of energy consumption by optimal load distribution reduces the load in users' households (scheduling, eliminating temporal peak loads by using batteries for power supply). Forecasts for locally generated and consumed energy calculated by the SCE and sent to the energy vendor enables to keep power plant capacity available within reasonable limits to avoid over- or under-capacity.

Within a household there are regulating units (as part of SMF) which perform the optimisation. Depending on the optimisation goal regulating units are used for e.g. smoothing load profiles or to maintain voltage stability. These regulating units ensure the optimisation of the controlled system (producer, consumer and storage in the household or cluster of households). The controlled system can be influenced by interference quantities resulting in a change of the controlled value (output value of the controlled system, e.g. load or voltage). As input, the regulating unit receives the optimisation goal (reference input variable). By determining the feedback variable and forming a control difference from the reference input variable and the feedback variable the regulating unit calculates a correcting variable which influences the controlled system and causes a correction of the controlled value.

Figure 3 shows a standard load profile of an average household (continuous line) [11], and the estimated load curve of a household has been optimised by the SCE.

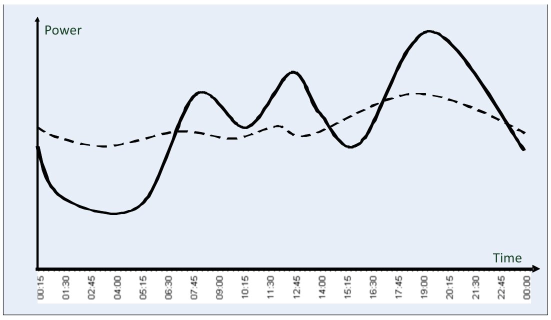

Figure 3. Smoothed load curve in households based on Value-added Services

The maxima, which represent the peak load, can be smoothed considerably, achieved by optimising the load (dashed line). The result is that for these periods no extra costly power plant capacity will be kept.

III. PEER-TO-PEER INTERNETWORKING AND ENERGY COMMUNITY

The approach to optimise a single household is critical because smoothing of the load curve is not sufficient enough to influence the power system without limitation of users comfort. A central control of all households by the energy operator cannot be implemented, caused by legal reasons. Since a central control is not feasible, a decentralised solution is needed. The following additional approaches will be introduced to achieve an impact on the power system by simultaneous optimisation of many households combined. This offers the possibility to optimise the demand of limited regions (e.g. the area of local transformer substations) and adjustment of the voltage in this area by enabling or disabling distributed power generators or batteries (for solving the range of tolerance to +/- 10%).

A. Peer to Peer internetworking

A simultaneous optimisation of households requires a network of households. Therefore, communication between the households must exist for exchanging information, which can be used to adjust the energy consumption of a single household on the energy consumption in the region concerned. Figure 4 shows a cross-linking of the households by the Peer-to-Peer principle.

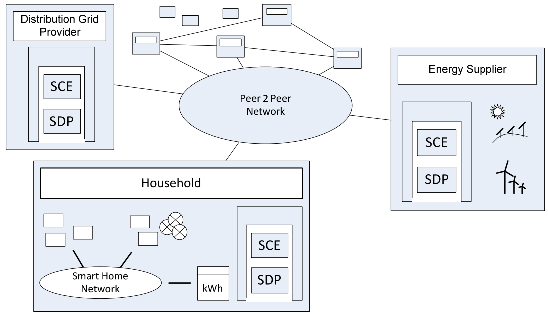

Figure 4. Peer-to-Peer connected households

In this approach, the Peer-to-Peer (P2P) networking is chosen because no central authority for control is integrated and the structure is mostly self organised as well as the data storage is distributed. Each household will be considered as a peer in the network, which communicates anonymously with other peers. In addition, the other players in the power generation and distribution, e.g. power supplier, distribution system operators, etc., are also considered and integrated as peers in the network.

A self sustained optimisation of every household in a region should lead to an optimisation of the energy requirement in this region. This new approach provides a special algorithm for optimising a single household and the whole region, without assistance of the energy provider, by management and control of the consumers, especially of the generators and energy storages. For the optimisation the exchanged information between peers and the knowledge concerning the own household is used. The exchanged information may include current consumption, forecast of consumption, possible power supply etc.

To ensure the data security and protection of privacy the communication between households has to be anonymous and encrypted. While sharing information between the participating systems, it must be ensured that a third party (e.g. a neighbour) cannot assign this information to a specific household for example, the information about the planned power consumption. To ensure the anonymity, the communication occurs via the Service Management Framework and is not transparent for the users of the respective peers. The communication between the peers should occur based on IP-Technology because of existing mechanisms for security, availability and quality of service, preferable via Next Generation Networks.

B. Constituent parts of communication

The information exchanged between the peers include the quantity of estimated demand for energy of a household, the actual consumption, possibly capacity of energy supply, variable energy network access fees, and variable energy prices as well as the corresponding time slots, the kind of energy (regenerative energy or gas etc.). Further parts of the exchange between the peers are information about existing energy storages (batteries, their capacity, charge condition) and existing energy producers (e.g. kind of energy producers and deliverable power) as well as forecasts of load profiles in households (calculated by the SCE). Batteries in electrically powered cars are excellent energy storages. Because of their mobility, the information has to be provided that these energy storages have no static location.

C. Approaches for Peer-to-Peer networking

In the course of this project, the possible approaches for a P2P internetworking are examined (e.g. Trusted Proxy Provider, Certificate-based P2P networking, etc.). Additionally the different P2P models for the provisioning of value-added services will be analysed for their application in Smart Grids and Smart Homes. Three different models were proposed by prior research as shown in Figure 5 [10]. The 1st model (Hybrid P2P model) is semi-centric with at least one centric checkpoint and client-server as well as P2P communication. The 2nd model (Pure P2P model) is fully distributed as well as structured (linked to a special topology) or non-structured organization of the peers. The 3rd model (Super P2P model) is an enhancement of the hybrid P2P model, centralized checkpoints are substituted by P2P network of super nodes and interaction between super nodes and normal peers is based on client-server model. Using the Hybrid P2P model with interconnected distributed servers is preferred, hosted for example by the Energy Community introduced in the next section.

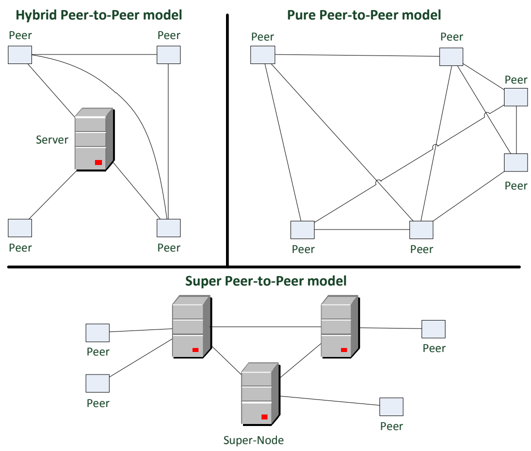

Figure 5. Different Peer-to-Peer models

D. Energy Community

The approach of the P2P networking will be extended by the mechanisms of social networks to form a community between households. This approach offers a solution to solve users rights and privacy restrictions and provides a legal construct for administration of a energy network (e.g. server in P2P network) as well as a mechanism for joining the network.

The member of the community have common shared interests and follow the same economic goals. This may include: energy saving, cost reduction, environmental conservation. In a region (e.g. households connected to a local transformer substation, city districts) subcommunities can be formed, which appear as part of the whole community. The previously described optimisation of households in this approach occurs between members of the community or within subcommunities. Figure 6 shows the concentration of households in a community consisting of various subcommunities.

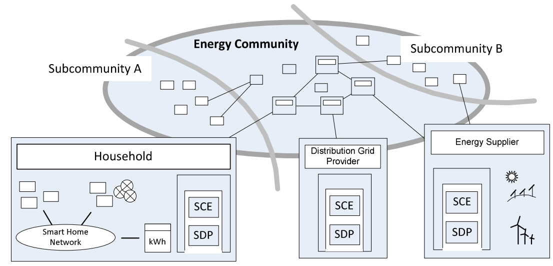

Figure 6. Energy Community with subcommunities

According to the principle of a social network, the community may grow independently and every participant may accede to his free will. The community is not limited to the electrical energy supply and consumption, e.g. other kinds of energy can also be included (e.g. gas). The possibility to join on a subcommunity voluntarily, which matches users' interests promotes the willingness to participate in this system and creates a personal benefit.

Through subcommunities the different interests of the members are considered. Members sharing the same interests come together to achieve their personal goals regardless of other members in the community. Thus, a variety of targets can be achieved e.g. to save energy costs, to reduce CO_2 emissions or to protect the environment. The target may also be to have lower energy consumption than other members of the community. The subcommunities can interact with each other and compare the fuel economy of different regions e.g. challenges may arise with the target to find out which subcommunity achieved the lowest energy consumption (or the largest monthly reduction in energy consumption relative to the previous month).

The energy suppliers and power system operators can also occur as part of this community and offer, e.g. for the members of a community, special billing models. Thinkable are flexible tariffs with the possibility to change tariffs and providers dynamically, variable energy network access fees or prepaid billing models. Subcommunities can be formed for the area of local transformer substations.

Through this approach costs for local transformer substations can be reduced by avoiding energy network enhancement or automation of local transformer substations. Because the Local Grid still needs little intelligence the operational costs will be permanent marginal as well as the costs for automation and enhancement of the Local Grid can be saved by the Smart Market approach, presented in this paper.

Subcommunities can also occur as a service provider for the control area provider by offering adjustment, active and reactive power. Services that are implemented for a subcommunity could include the optimisation of power consumption and purchasing. Furthermore, smoothing the load profile for a community which in turn can be honoured by the energy provider with a better deal. The forecasted or determined load curve of the households can be used for smoothing this load curve or for optimizing the energy consumption of many households in the area of local transformer substations. Variable energy network access fees could be communicated to subcommunities by the distribution grid provider (e.g. low fees between 9h and 10h, afterwards rising). The distribution grid provider (as part of the community) can deliver a aspired load profile to the community. If this load profile is solved on e.g. 20 days per month, they will get a bonus or no energy network access fees. Subcommunities try to reach this load profile by optimizing every member in collaboration of energy consumption and offering positive or negative regulating energy.

IV. Conclusion

This paper presents approaches for a service management framework to control and monitor decentralised energy consumers, storages and generators. In these new approaches the user is integrated in design and configuration of the services for energy management which offer the possibility to follow its personal needs.

The algorithms for automated optimisation and generation of services by controlling decentralised energy consumers, storages and generators, offers the possibility to reduce the energy consumption in households or whole regions. This leads to a possible reduction of costs or environmental benefits. In addition, the power supply system is discharged by reducing load peaks and smoothing the load curve of households and regions. In order to communicate and interconnect the Service Management Framework is used, thus the integration of different devices gets possible und the privacy of involved users is ensured. On the first time approaches point out the peer-to-peer interconnection of households in Smart Grids. Also firstly energy communities were built up for decentralised optimisation of energy consumption as participants in the Smart Market.

In the next research topics algorithms for optimisation of energy consumption between peer-to-peer interconnected households are examined, as well as techniques for abstraction energy devices. In the first step energy consumer in households will be considered as a single block and the adjustment will occur by the local energy generators as well as the local energy storages.

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