New approaches for energy optimisation in Smart Homes and Smart Grids by automated service generation and user integration

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Abstract

This paper describes approaches 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. New approaches are introduced that offer automated service generation and optimisation. This 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 rests upon the peer-to-peer principles for communication and automated optimisation as well as forming communities between the participated peers.

Keywords

Smart Grid, Smart Homes, Energy Management, Service Creation, Peer-to-Peer

1. Introduction

Today the power supply system is static and consists of dedicated categories. It has been defined where energy is produced and where energy is supplied to the grid. The energy flow basically takes place only in one way: from power generator in the maximum voltage grid to the energy consumer in the Local Grid. Primary large power plants like coal-fired and nuclear power plants supply companies and households with energy. Energy generation is focussed on central appointments in the power system. The transfer of energy occurs with as much as possible electric tension because of the meanest loss rate. Figure 1 shows the structure of the power supply system today.

The power supply system is separated into four levels of electric tension which are used for transfer and distribution of the energy: Transmission Grid (maximum voltage), Primary Distribution Grid (high voltage), Secondary Distribution Grid (mean voltage), and Local Grid (low voltage). In order to reduce the electric tension to transfer or rather consume the energy on the next lower level, transformers are used at the transition points.

The supply of energy by the central power plants takes place at several levels of electric tension, according to the amount of produced energy. Large power plants like nuclear power plants supply at maximum voltage level, wind parks at high voltage level, small wind power plants at mean voltage grid and sporadically, e.g. photovoltaic power plants at the Local Grid.

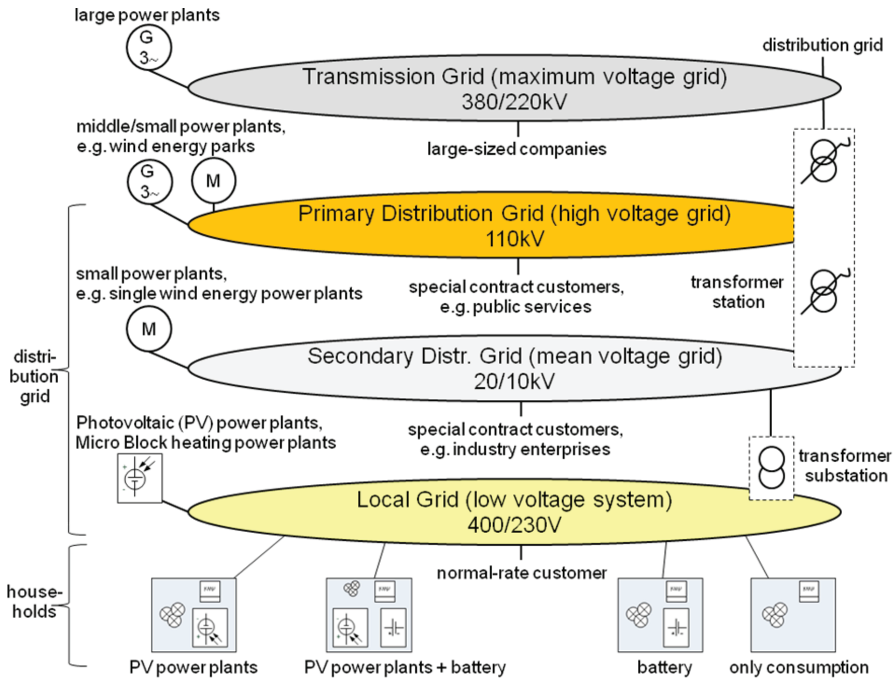

Figure 1: Structure of the power supply system today

The connection of the customers to the different level depends on their demand for energy. Large companies with very high demand for energy are directly connected to the maximum voltage grid. Companies with an average demand are connected to the mean voltage grid and the normal customer is connected to the Local Grid.

In the power supply system a balance of electric current is very important. This implies that the produced and supplied energy has to be equal to the consumed energy. If this is not the case, adjustment control is necessary. Adjustment control today occurs mostly by the central placed power plants. In the Local Grid, where most adjustment is necessary (because the demand for energy is different in specific areas), insufficient possibilities for adjustment exist. The frequency in the grid is one basic indicator to detect the balance of electric current. The 50Hz frequency is measured and corrected on demand. The type of energy used for adjustment is called regulating energy. This energy is very expensive because it has to be provided permanently. Using forecasts allows to detect how much energy will be needed. The more correct the forecast the less adjustment is required and the more convenient is the power production.

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. Because the 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.

"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"(GSGF 2012). As a first step towards Smart Grids energy suppliers already install smart meters.

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. Decentralised solution for the 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. This 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 communities between this peers.

2. 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. (Verschueren et al. 2010, Jisun et al. 2010) adopt service platforms for Smart Homes where services are provided by external service providers. (Shudong et al. 2010) 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 (Keiser et al. 2008, Freese et al. 2007, Spagic 2012). 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 (Baresi et al. 2006, Autili et al. 2007).

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.

2.1. Energy management in the Local Grid

Monitoring and control respectively adjustment of decentralised power generators and consumers is currently possible on the upper layers of the power grid by the large power plants. Despite the reduction of large power plants still a regulation 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 2 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.

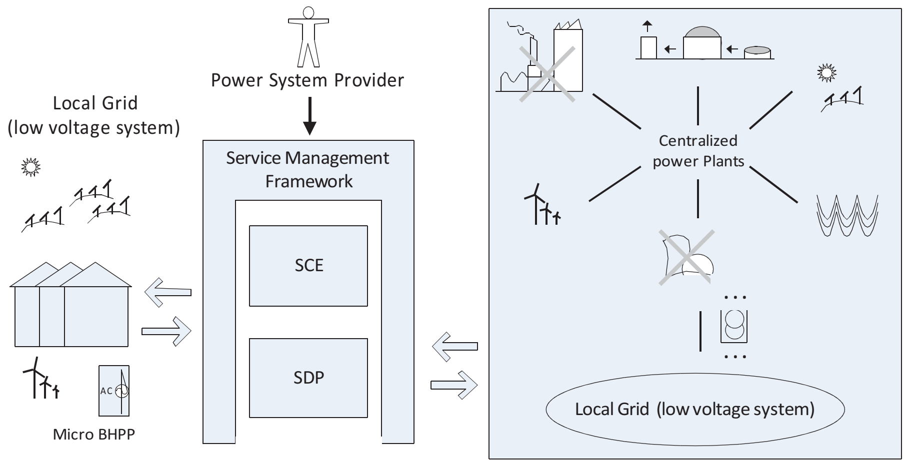

Figure 2: SMF for controlling centralised and decentralised energy resources

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 Transmission and Distribution Grids as well as in Local Grids. Furthermore, it is possible to predict the energy demand: whereby the energy operator 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. Therefore in next sections approaches for decentralised solutions are presented by integration of users in the service design.

2.2. 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 (Eichelmann et al. 2009, Lasch et al. 2009). 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 3 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.

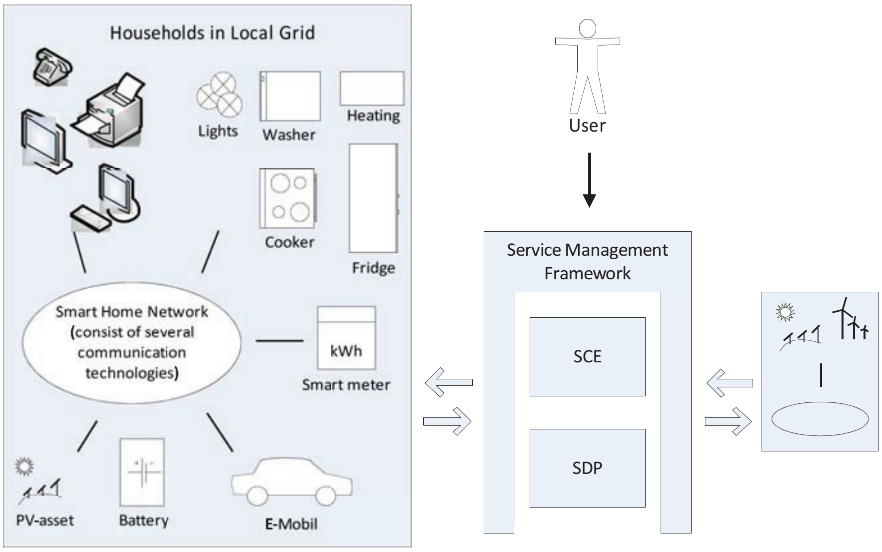

Figure 3: SMF for controlling decentralised energy devices

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: Increase security by disabling certain devices when the user leaves the apartment (e.g. ensuring that the cooker is switched off). 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.

2.3. 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 designed 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.

Figure 4 shows a standard load profile of an average household (continuous line), and the estimated load curve of a household has been optimised by the SCE (PVU Netze 2012).

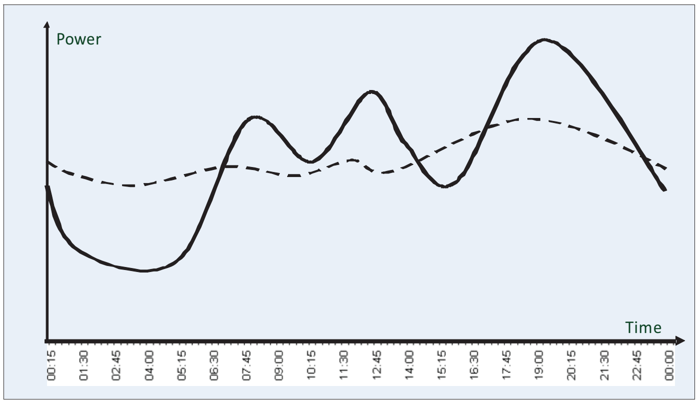

Figure 4: Smoothed load curve in households based on Value-added Services

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 power plant capacity will be kept.

3. 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. The following additional approaches will be introduced to achieve an impact on the power system by simultaneous optimisation of households. Since a central control is not feasible, a decentralised solution is needed.

3.1. 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 5 shows a cross-linking of the households by the Peer-to-Peer principle.

In this approach, the Peer-to-Peer (P2P) networking is chosen because no central authority for control is integrated. 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.

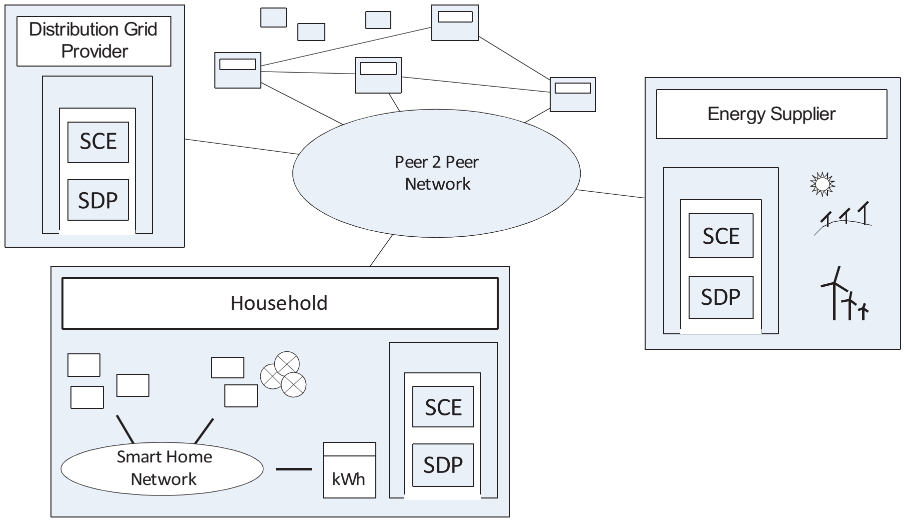

Figure 5: Peer-to-Peer connected households

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.

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 peer-to-peer models for the provisioning of value-added services: Hybrid P2P, Super P2P, Pure P2P (Lehmann et al. 2008) will be analysed for their application in Smart Grids and Smart Homes.

3.2. Energy Community

The approach of the P2P networking will be optimised by extending to the mechanisms of social networks to form a community between households, which 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 in a street, city districts) sub-communities 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 sub-communities. Figure 6 shows the concentration of households in a community consisting of various sub-communities.

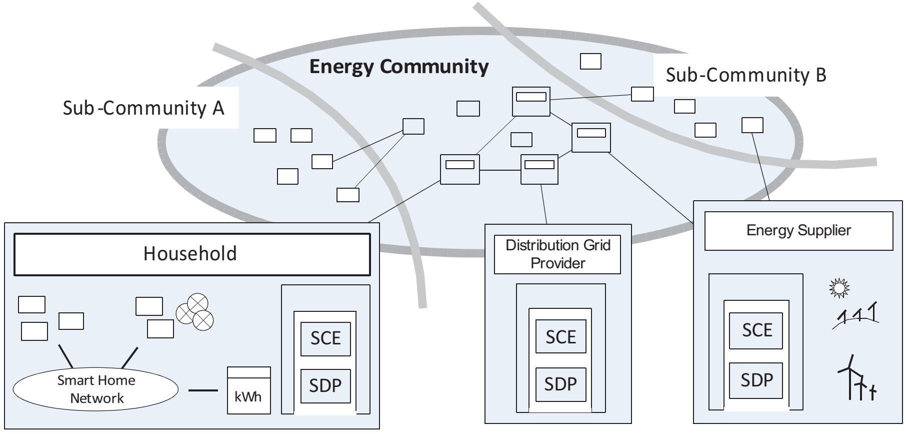

Figure 6: Energy Community with Sub-Communities

According to the principle of a social network, the community may grow independently and every participant may accede to his free will. The possibility to join on a sub-community voluntarily, which matches users' interests promotes the willingness to participate in this system and creates a personal benefit.

Through sub-communities 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 sub-communities 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 sub-community 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 or prepaid billing models. A sub-community 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 sub-community 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.

4. Conclusion

This paper presents approaches for a service management framework to control and monitor decentralised energy consumers, storages and generators. In this 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 and build up communities for decentralised optimisation of energy consumption.

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.

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