LOAD REDUCTION IN DISTRIBUTION NETWORKS THROUGH P2P NETWORKED ENERGY-COMMUNITY

Michael Steinheimer[1,2], Ulrich Trick[1], Patrick Ruhrig[1], Woldemar Fuhrmann[3], Bogdan Ghita[2]

[1] Research Group for Telecommunication Networks, University of Applied Sciences Frankfurt/M., Frankfurt/M., Germany
{steinheimer|trick|ruhrig}@e-technik.org
[2] Centre for Security, Communications and Network Research, University of Plymouth, Plymouth, UK
{michael.steinheimer|bogdan.ghita}@plymouth.ac.uk
[3] Department for Computer Science, University of Applied Sciences Darmstadt, Darmstadt, Germany
woldemar.fuhrmann@h-da.de

ABSTRACT

The increasingly volatile and decentralised power generation as well as the lack of transparency within distribution networks raise a number of challenges for the current power distribution paradigm. This paper aims to address the lack of flexibility of the current architecture by introducing the concept of a peer-to-peer networked energy community. The proposed approach includes a service management framework based on the dynamics of value-added services to provide personalised services for the Smart Home, especially the energy management, and includes the integration of multimedia communications. In addition the concept provides a mechanism for convenient networking of households, energy suppliers, distribution network operators and others with the objectives cost savings, avoidance of grid expansion, energy savings, CO_2 reduction etc. Approaches for optimisation algorithms for reducing the residual load offer a set of instruments for cost reduction in households, environmental protection or the assurance of energy supply. Initial simulations confirm the effectiveness of this new and powerful approach, most notably the benefits of battery storage in homes.

KEYWORDS

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

1. INTRODUCTION

1.1. Adjustment in future power supply system

In the electric power grids of the future, the likely trend will be to increase production of more volatile renewable energy using wind power and photovoltaic systems. Based on this trend, the proportion of centralised energy generation will decrease, to be replaced by distributed generation and supply; this shift has already started, within the non-monitored local energy grid. To still ensure stability and good quality in the power supply, the local network has to be expanded and especially has to get smarter through information and communication technology. This development is commonly described by the term "Smart Grid" [2]. To solve these problems, different, in part complementary approaches are discussed. Mentioned are the keywords “Grid Expansion“ [2], “Virtual Power Plants“ [2], "automation of distribution networks" [2], "forced shutdown of producers and/or consumers” [3], as well as "control through price signals" [4]. The German Federal Network Agency covers the last topic with the term “Smart Market“ and describes it as the preferred solution [1].

Despite extensive research and development activities in the areas of Smart Grid and Smart Home in recent years, the published solutions outline the following gaps or deficiencies:

• The user of a Smart Home gets offered services for home automation and energy management [5], but the user gets no or only rudimentary support by communication, especially multimedia communication.

• Even the self-development of services for energy management by the users themselves is treated in projects [6], but they are limited to pure configuration and also do not allow communication services.

• While there are solutions for the automated optimisation of energy in a single household or a cluster of households, the intelligent control system typically uses a centralised or hybrid centralised/decentralised approach [4, 6]. A completely decentralised solution, while it is more complex to establish, would have indisputable advantages in scalability and reliability as well as in networking based on private initiative. Only one such approach with limited scope was found in [7].

• Also not been considered yet is the independent clustering of households, i.e. how households join together to form clusters for energy management in a comfortable way. Previous solutions [4, 6] are based on a cluster organisation by a central authority. The advantage of the new approach here could be an interconnection through voluntary energy community to enable the self-organisation of the network, to address issues of data protection, to define common interests of households, etc.

To close the gaps mentioned above, in October 2011 the BMBF-project FHprofUnt 2011 "Easy-Service Creation for Home and Energy Management (e-SCHEMA)" was initiated [8, 9, 10]. Within this project four solutions on “households in Smart Grids“ (based on each other) get connected. These solutions are described in the following. All of these solutions are assigned to the field of "Smart Market".

2. SERVICE PLATFORM FOR HOUSEHOLDS

In the first part of this new overall solution for individual home and energy management the user gets the possibility to develop personalised services for home and energy management on its own, according to its personal needs, using a Service Management Framework (SMF) which may be integrated in the DSL-Router [12, 13]. Through a SCE (Service Creation Environment), the user becomes able to design value added services by graphical combining of device/service blocks, delivered by the manufacturer of home appliances. This device/service blocks describe the control functions of devices and basic services and make them available in the SCE. In the simplest case, the user configures the scheduling of home appliances in line with the corresponding price variations for energy at different time intervals in the day. The personalised energy management service is running on a SDP (Service Delivery Platform). The required measurement values for the services are provided by the connected Smart Meter. On this basis the SMF, consisting of SCE and SDP, delivers information about the energy demand in the future and in the past. The advantage of this solution is that users’ needs and rights are continually considered. Disadvantage is that the optimisation of the power consumption takes place only from the perspective of the individual user.

In a second step, the SMF provides a special mechanism which composes automatically a value added service, according to restrictions of the user (allowing combining permissions and restrictions, such as no time limits for cooking, minimising the cost of electricity, or limit the tolerable energy consumption). The aim of the resulting service for example is to minimise the variations in the load curve of a household according to users’ restrictions, to avoid expensive peak power. Here the energy optimisation is not only from the perspective of the user, but of the complete household. This is especially effective when not only energy consumers, but also producer and/or storage in the home are available.

In both cases, the performance of the SMF is much better than in current Smart Home control solutions because the SMF does not only integrate the described energy management and IT services (e.g. access to the calendar before charging the e-car), but also integrates communication applications (e.g. SMS or call if the washing machine has finished). Since the SMF is connected definitely via IP to external networks such as the internet or fixed and mobile networks, this offer as application layer protocols SIP (Session Initiation Protocol) for signalling and e.g. RTP (Real-time Transport Protocol) for user data [10]. Therefore, the SMF is a combination of a Smart Home control and a SIP Application Server, whereby the realisation is based on OSGi (Open Services Gateway initiative) [17]. Figure 1 shows an overview of the relevant parts of the SMF.

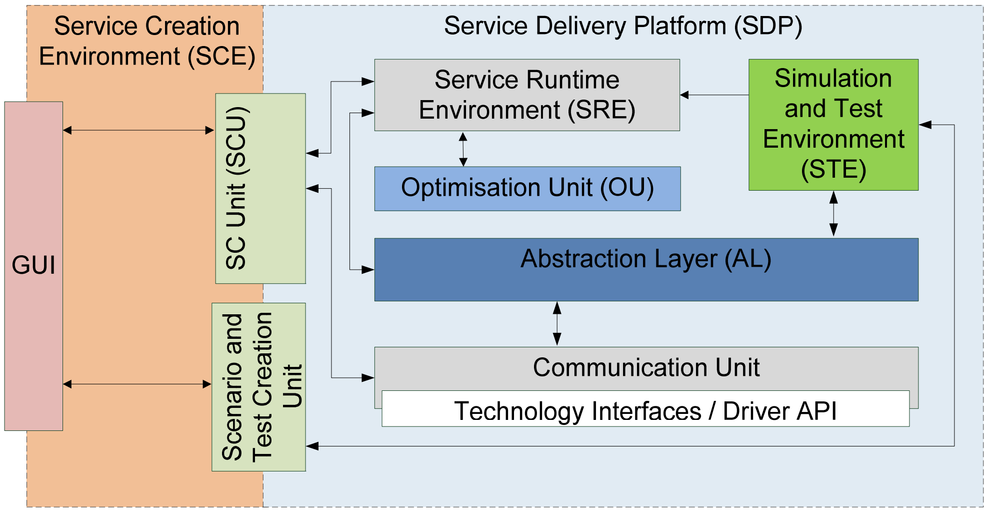

Figure 1. Overview of relevant parts of SMF

With the GUI (Graphical User Interface) the user creates and configures services to control its Smart Home. To create the service, the user applies device/service blocks that are provided by the device manufacturer. This device/service blocks include a description of the device and its capabilities. This information is used to represent the device in the GUI and make it available to the user as part of a service. As a simple example the user can define a service to start charging of an e-car (represented in the GUI using the device description and capabilities of the e-car) if the energy price is below a defined threshold. The user also defines, via this GUI, boundary conditions and goals, which are taken into account in the optimisation (e.g. for an optimisation service the user can define the optimisation goals like "price optimisation", "load reduction" etc.). The task of the SCU (Service Creation Unit) is to make the GUI available in the form of a website. Another task is to describe the service defined/configured by the user in a formal notation and deliver this description to the SRE (Service Runtime Environment).

The SRE interprets the service description and executes the actions described in the formal service notation. For this, the SRE communicates with the AL (Abstraction Layer) and thus controls the actions in the connected devices. Actions for example are activation or deactivation of devices to save energy or discharging existing energy storage in a household. As further functions the multimedia communication has been integrated. That allows, under defined conditions, e.g. if the e-car is fully charged or the motion detection device is triggered (in case of using for intrusion detection), for example to initiate a video call or to send an IM (Instant Message).

For abstraction of communication and connection of different bus systems for Smart Home controlling (e.g. KNX, EnOcean, MBus, ZigBee) an Abstraction Layer (AL) has been designed. This makes it possible to connect a variety of smart home and multimedia communication techniques, as the AL unifies communication between services, part services, Smart Home bus systems as well as elements for multimedia communications. This coordinates the control of different types of equipment and thus offers the possibility to define services for Smart Home control without depending on the technologies used.

To implement this integration of different communication and Smart Home systems, the architecture includes a CU (Communication Unit), which is connected directly to the AL, allowing the device and technology specific control of devices. All connected devices are registered at the AL and are controlled within the services in an abstracted way. Devices APIs, provided by the CU, are driven by the AL and form the interface to the various technologies (like KNX, EnOcean, MBus, ZigBee, internet browsing, multimedia communication).

The OU (Optimisation Unit) implements the above described optimisation of services through re-configuration of defined services. This is done taking into account the constraints and optimisation objectives which the user has defined via the GUI. Optimisation can be done by re-scheduling the devices, e.g. shift the charging of an e-car to time slots in which the energy price is low (if the user defined cost saving as optimisation goal). Another task of the OU is to organise the coordination of multiple households for control and optimisation. This can be done by coordinated scheduling of large consumers in different households or by discharging energy storages if the load in a region is about a defined threshold.

In order to test and simulate the effectiveness and accuracy of the created services based on definable test cases, the architecture also includes a Scenario and Test Creation Unit (for creation and presentation of test cases) as well as a STE (Simulation and Test Environment).

3. P2P INTERCONNECTED HOUSEHOLDS AND ENERGY COMMUNITY

The independent optimisation of individual households does not automatically lead to optimisation of the local or distribution grid; the critical factor that leads to optimisation is statistical aggregation through cooperation within a cluster of consumers. In order to provide this level of aggregation, the SMFs of individual households are connected using a SIP-based peer-to-peer (P2P) network [13] (Figure 2). The peers represent households, energy suppliers, distribution network operators and other market participants. The communication between the peers is anonymised and encrypted, also each peer only provides user authorised information. Based on this communication channel, the peers exchange a number of parameters, such as the current or forecasted consumption, key indicators for energy producers and storages (including electric vehicles) as well as energy prices and network charges. On this basis, the SMF provides an algorithm that automatically optimises the aggregated energy consumption for the whole P2P-network (up to complete local grid), taking into account the information from all other peers. The necessary data management is distributed based on DHT (Distributed Hash Table) and the Chord algorithm [18].

The method of joining the network on a comfortable and legal basis has not been resolved up to this point. Creation of an energy-community considers this issue and forms a new comfortable way to join the network, whereby the connection of households is done by joining the users to a social network for energy-peers. (Figure 2). Therefore, the SMF also provides functionality for the energy community and joining the P2P network. The members have the same interests and economic goals (e.g., energy consumption reduction, cost savings, environmental preservation), their profiles could include the energy consumption as well as existing storage and generation capacity. The formation of sub-communities is also possible (e.g. based on a street, geographical proximity, secondary substation, customers of an energy supplier or distribution network operator).

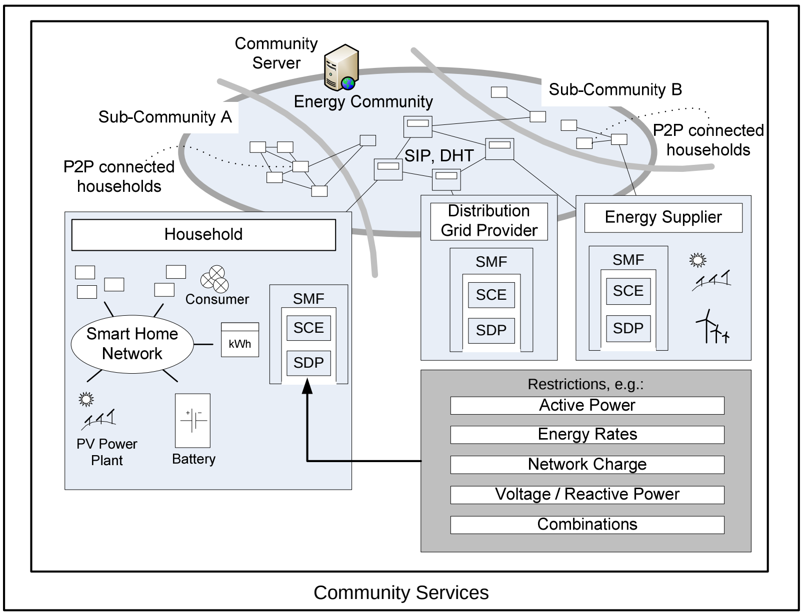

Figure 2. P2P connected households with energy-community

The whole community or a sub-community can appear together and offer e.g. regulation energy. Moreover, competition between sub-communities could be possible, for example aiming to reduce energy consumption, where comparable households exchange their consumption values. Another possibility is to compare energy consumption profiles with the building and user profiles of other participants. On this basis opportunities for optimisation can be presented to the participants of the community. The energy consumption optimisation is carried out from the perspective of the whole community and also across local network areas. Therefore, the two combined approaches (P2P network and energy-community) represent a comprehensive new solution for the creation of a Smart Market for households.

The community server provider could be third party, such as a city or county, which may have energy savings as part of their objectives or agenda. The introduced energy community with P2P networking households is a very powerful instrument to optimise the energy distribution in the local grid, and additionally provides potential for price and cost reduction.

4. LOAD REDUCTION BY INTELLIGENT CONTROL

The households connected by an energy community or by sub communities, as introduced in section 3, can work together and implement application scenarios, such as avoiding peak loads, avoiding regulation energy, optimisation of the energy costs, incentives to save energy etc. (see [19]). They use the more flexible options that come up through the use of distributed storages, generators and/or time shifted activation of consumers (demand-side integration (DSI)). Depending on the use case, this may result in benefits to the distribution system operator, the balancing group managers, energy suppliers, consumers or the environment etc. In the following (Figure 3) a section of the complex algorithm is presented, which is used for a scenario for peak load reduction in a region.

Firstly, each peer determines the residual load in the region concerned, which represents the difference between the energy demand and the supply by renewable energy. If the calculated residual load for the region exceeds the defined limit, energy storages present in this region will discharge and supply additional energy to the grid.

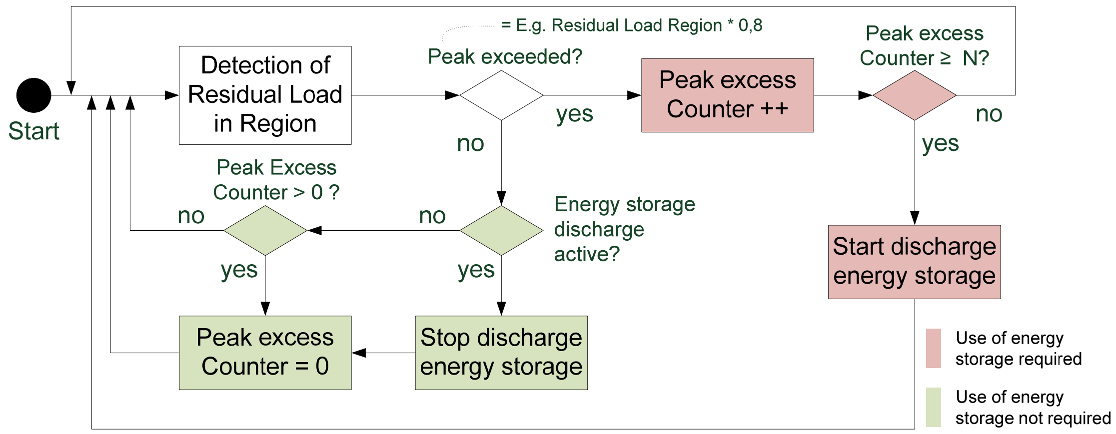

Figure 3. Section of algorithm for peak load reduction

The demand will be met locally through the local supply, preventing the supply of additional power from upper voltage level. Recharging the energy storage takes place in line with defined lower limits of the residual load.

Figure 4 shows the part of the algorithm responsible for the calculation of the residual load in a region. Each peer receives the energy requirements of all other peers. The required data is transmitted via SIP messaging, based on the internetworked households described in section 3. After the energy demand of all households was received, the individual energy requirement is determined and distributed to other peers. The distribution of consumption data will be anonymous as described in section 3. To determine the residual load, each peer adds its energy demand to the sum of the received energy demands of all peers. This determination of the total energy demand is the basis for the decision to discharge existing energy storage as described above.

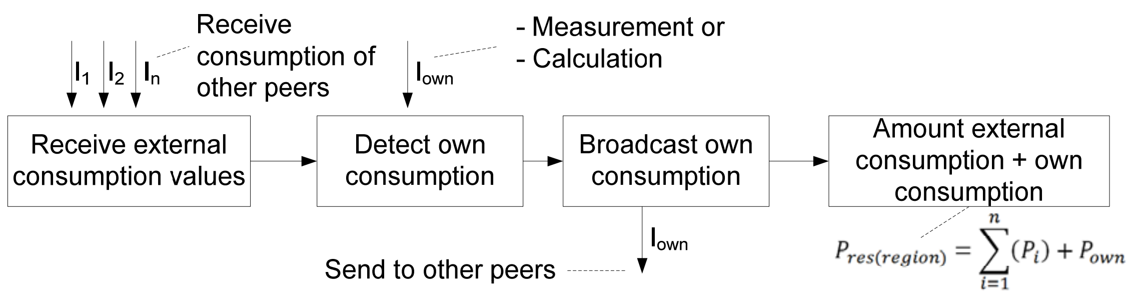

Figure 4. Responsible part of algorithm for calculation of the residual load

To demonstrate the effectiveness of the outlined energy community below two concrete, simulated application scenarios are discussed.

The simulations are based on the following parameters: households with 1-5 persons, based on determined or estimated values for consumers (cooking, washing, freezing, lighting, office equipment, consumer electronics, drying, water heating and miscellaneous e.g. ironing), energy generators like photovoltaic and energy storages as well as probability distributions to households, equipment availability and usage [14, 15]. As energy storage a commercial battery model is used with the following parameters: charge capacity: 1400-5400Wh; maximum charge/discharge power: 4800W / 4000W; efficiency: 97%. The applied PV system delivers 4000W peak power. Moreover it should also be noted that the simulations consider only 24 hours, i.e. devices can be activated from 0 a.m. and not be active for more than 24 hours, moreover, the storage capacity amounts 30% load at midnight.

To demonstrate the performance of the simulation, in a first step, the pure power consumption for 1000 households or 2024 individuals was determined, using a distribution of 39,7% 1-, 34,6% 2-, 12,7% 3-, 9,6% 4- and 3,4% 5-person households [14]. This simulation was compared with the German standard load profile H0 for a working day in the summer [16]. The result is shown in Figure 5 (left). The good agreement between the two curves shows the quality of the underlying simulation model, and the calculation for an infinite number of households reveals an even better match.

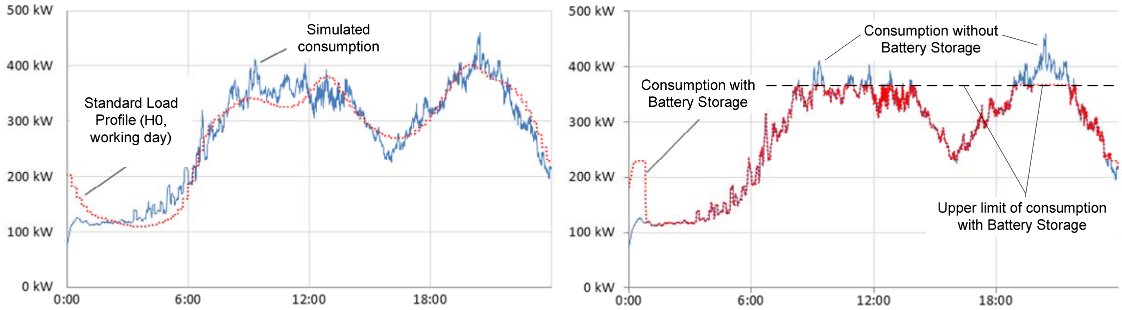

Figure 5. Comparison simulated consumption with standard load profile H0 (left), Consumption with Battery Storage (right)

The Scenario covers "avoidance of peak load" by using battery storages for a community of 1000 households. The results shown in Figure 5 (right) indicate that, for a 20% peak load reduction (from 45.9kW to 36.7kW), already 23 battery storages are sufficient, that means only 2.3% of households would have to be equipped with one battery storage. Worth mentioning here is that not the storage capacity of the battery, but the maximum discharge power is the limiting factor.

The simulation shows that battery storages are very effective for peak load reduction. This result was also confirmed by the simulation of additional scenarios on the same topic "Avoiding peak load" (see [19]).

5. Conclusions

This publication presents a novel solution for optimisation of the aggregate energy usage. The concept of personalised services and above all the P2P networked energy-community forms a new and very powerful solution for the Smart Home and especially for the Smart Market. The presented solution may be successfully applied in the distribution grid, as confirmed by a preliminary set of simulation results. Apart from the optimisation service that it provides, the proposed solution also allows the user to individually create/compose control services for its Smart Home. At the same time it contributes to reduce the load of the distribution grid and thus reduce the costs. The solution takes into account the personal needs of the user and its defined optimisation goals at any time. Benefits are not only for the customers, but for all participants in the value chain. Approaches for an optimisation algorithm were presented to reduce the residual load in a region and can be extended in the future to consider both financial aspects as well as other optimisation objectives of grid view. Thus, a set of instruments for cost reduction in a household, environmental protection or the assurance of energy supply is available. Further studies, including the various application scenarios and their interdependencies as well as economic, security and privacy aspects are necessary.

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