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Smart Metering in the context of liberalized energy markets

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Abstract— **At least since the European guidelines for energy efficiency in 2006, Smart Metering has been an important module of today's idea of a liberalized energy market. Since then, automated meter reading has not only become accustomed in industrial sectors but also more and more private households are being supplied with the new technology.**

With this publication the authors outline the transition from automated meter reading from an industry-based mechanism to an opportunity for private customers to increase energy efficiency and save costs by the use of flexible tariffs. Several chances go hand in hand with the new technology: consumers expect an increase in energy efficiency through a better consumption control and system operators intend to optimize their distribution grid's operation. Supported by this theory, a field study conducted in a small German town is being introduced, where a flexible tariff along with a device to visualize consumption is used to integrate private customers into system operation. First outcomes indicate that private customers align their consumption significantly to an applied flexible tariff which shows that such a tariff can be used for improving the distribution process.

***Index Terms* — Direct / Indirect Demand Side Management, Smart Meter, distribution grid**

1. Introduction

Although Automated Meter Reading (AMR) is not a new invention – the first electronic meters that could communicate the consumption of large industrial consumers via ripple control are available for more than 20 years – it has not been until the last few years, that it came to insular pilot projects in Germany. This development has several reasons. First, one has to distinguish between Digital Metering, Automated Metering and Smart Metering.

Digital Meters are just further developments of Ferraris Meters which became necessary to prevent manipulations on the metering process, by the use of braking magnets for instance. Digital meters are now insensitive against harmonic content and feature Hall Sensors to detect external magnetic fields.

AMR had been possible with analogue meters already; there are several ways to create defined impulses in the counting process of Ferraris Meters. On the one hand a mechanical contact can be mounted on the device's rotating disc which leads to electric impulses on each rotation. Such an impuls defines a specific amount of energy and has to be accumulated by an Energy Data Management System (EDMS). The total amount of impulses will give evidence about the respective consumption. On the other hand there are visual systems that are able to detect a mark on the rotating disc so that – like above – an impulse signal for a certain amount of delivered energy can be created.

2. Smart Metering Technology

The term Smart Metering was brought up a few years ago and refers to a further development of AMR. While AMR was primarily intended for billing of large industrial consumers with separate communication lines to their suppliers, Smart Metering goes hand in hand with political efficiency initiatives and targets private households preferentially. These new devices are able to communicate through existing networks like Ethernet, GRPRS or power lines (Power Line Communication – PLC) and some of them feature extensions like digital picture frames to visualize consumption. Others have several registers to meet transparency requirements in the billing process.

The Smart Metering process always requires measurement and communication units. They can be integrated in one single device or operate independently. Another approach is the Multi Utility Communication (MUC) where one communication interface accumulates and transmits values from several metering devices such as electricity, heat, water or gas meters. In the field test which forms the basis of this paper, 120 electricity meters with integrated PLC communication modules as well as meters, which are communicating via MUC devices, are being used.

The Powerline Communication standard on which half of all project-related smart meters are running can be specified as high speed narrow-band PLC or Distribution Line Carrier

(DLC) and meets the EN 50065 standard also known as CENELEC.

Since the distribution system has a radial character, each string is equipped with a data concentrator (DC) which first of all contacts all installed Smart Meters which follow the particular – yet proprietary standard and later collects all data which has been answered. The DC is connected to the interconnection point via virtual private network (VPN) which uses a GPRS connection in the case of the field test at hand. Finally the measured data can be imported to an EDMS. The data format for transmitting smart metering data is usually MSCONS (Metered Service Consumption report message). The device setup and communication concept of a common, available Smart Metering System which transmits its data via PLC can be viewed in Fig. 1:

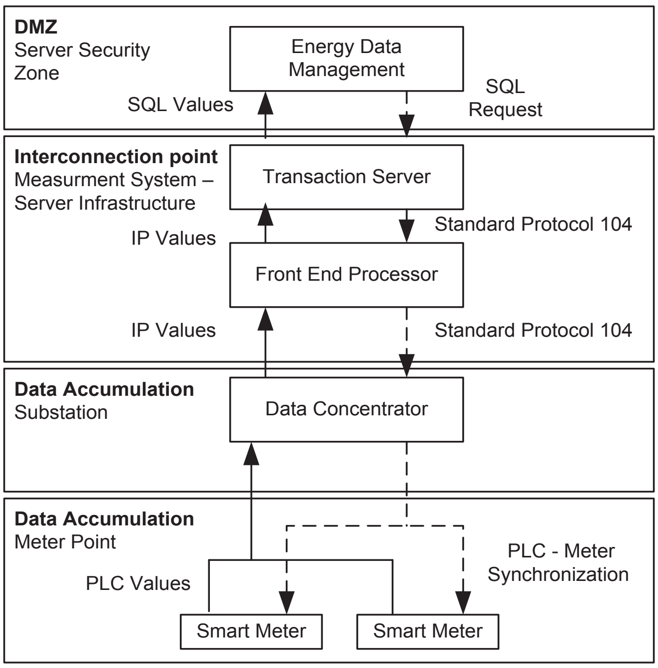

Fig. 1: Smart Metering communication structure (PLC)

Smart Meters which transmit their data directly via a GPRS connection do not require a data concentrator or any specific interconnection point. A server which runs the proprietary Automated Meter Management (AMM) software and can receive information via internet is sufficient.

Although several smart metering manufacturers claim to release information concerning their communication protocols in order to develop one single communication standard for every device there is no significant process yet to be seen. DSOs still have to decide on proprietary standards making it nearly impossible for customers to freely choose their own Smart Meter and have it connected to an already existing infrastructure. Therefore an agreement on communication standards by producers of smart metering technology would mean a significant increase in feasibility of the already existing liberalization of German electricity metrology.

3. MARKET SITUATION

Utilities in integrated energy markets can rely on stable forecasts as such as standard load profiles as well as thermal, controllable generation and therefore offer a set price p_{fix} which consists of operational costs $c_{operation}$ and generation costs $c_{generation}$.

$$p_{fix} = c_{operation} + c_{generation} \quad (3.1)$$

Due to diverse market roles which evolve in a liberalized market and are being fulfilled by an even greater number of market players, p_{fix} is facing influences from generation – which due to unbundling of market roles has to be referred to as procurement – metering and operation in a far more complicated way than before.

The regulatory conditions for today's electricity market in Germany are being defined by the law on the energy industry (EnWG) as well as its by-laws. As such they are realized in different contracts and agreements between the particular market players. For the consumer contracts for grid access as well as agreements for grid usage are necessary. Furthermore the delivery contract between retailer and customer as well as Meter Point and Meter Service contract are needful. Moreover a contract between Balance Group Responsible and Transmission System Operator is required but shall not be specified in this work. Today's contractual relationships as partially described above are being illustrated in Fig. 2:

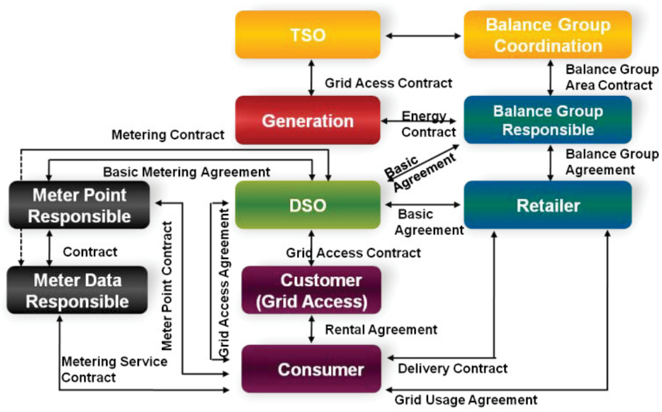

Fig. 2: German electricity market situation

Understandably price formation has yet become a complex issue, which is being influenced by more or less all market players. The price for electricity now becomes highly time and load relevant. For political reasons it also becomes highly influenced by renewable energies. Since these three components have an yet undefined impact on each other the relation remains undefined:

$$p_{lib} = f(c_{operation}, c_{procurement}, c_{renewable}, c_{metering}) \quad (3.2)$$

Although the specific influence of each market player is unclear, p_{lib} suffers high volatility. For energy retailers there are several ways to handle price fluctuations. Of course risk premiums can be added to a price set before to avoid losses during times with high market or operation prices. But on the other hand the volatility can be passed down to the consumer who not only receives the risk of price fluctuations but also get a chance to use electricity whenever prices are low and save money therewith. As a consequence energy markets would become more efficient and more competitive [9].

4. Indirect Demand Side Management

The very basic idea of Indirect Demand Side Management is to motivate private as well as business consumers to align their energy consumption to factors like price or renewable supply.

In an unbundled market, large companies usually purchase energy either at exchanges or directly from energy trading companies ("over the counter" – OTC). Since companies are facing major risks with the purchase of balancing energy when not aligning their consumption at the previously negotiated timetable, they have a strong monetary motivation to control their usage. Clearly, these companies have to assure, that energy is only consumed at times it has been purchased before [6].

But also private customers can benefit from volatile prices in energy markets. Obviously it is not likely for customers to purchase electricity directly from the producing company, which in the case at hand would be the power plant operator. It would not only mean too much effort for the producer to accumulate customers and satisfy their demands. Also the present market unbundling in Germany does not allow aggregation of consuming and retailing companies. But as mentioned above private customers can benefit from volatile energy prices. With the new smart metering technology utilities can offer variable tariffs and offer customers a chance to use energy in a way that is cheaper than a fixed price which covers all possible consumption scenarios and procurement risks.

Such instruments were first introduced for the German market in 2007 with the so called "Meseberg Decisions" and aim to improve the German energy efficiency with several approaches [7], [8]. With this program the German government wants intelligent meter reading procedures combined with variable tariffs to contribute to CO2 saving objectives until the year 2020.

There are several aspects which can be regarded when implementing a variable tariff. Load variable tariffs base on the actual load the customer causes. Therefore the price per kWh changes according to the power the customer requires. In addition the price per kWh can be determined by the total amount of energy the customer purchases in a defined period of time which is usually one year. Such energy variable tariffs are common to encourage customers to increase their energy consumption. With an increasing quantity there is a decrease in costs per unit. In supply systems which are suffering a deficiency in production units the opposite way of energy variable tariffing can be found. The more energy a customer consumes, the higher is its price per kWh. Finally time and with it the procurement price of energy can be an indicator for a variable tariff. Such a volatile price, which changes depending on the time electricity is being used is referred to as time flexible tariff [9].

A first indication of a time flexible tariff can be made by a closer look at price forward curves; instruments which are used to predict energy prices at market places like exchanges or OTC-platforms. The volatile character of these curves can be transformed to a time flexible tariff. In the later described field test a three step time flexible tariff has been introduced, which seemed a reasonable compromise between complexity and effect. Surveys show, that customers are able to understand the billing system and benefit from savings which can be achieved by consumption adjustment. In this context, consumption adjustment simply means to start an electricity consuming process – for instance a dishwasher – when the energy price level appears low enough. A qualitative model of a price forward curve and its resulting three step flexible tariff is shown in Fig. 3.

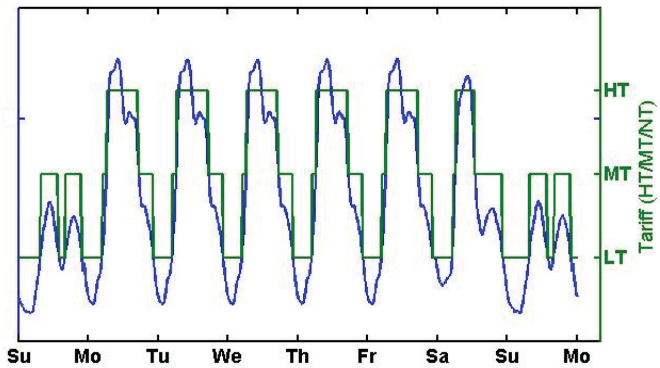

Fig. 3 Time flexible tariff development by use of a price forward curve

Furthermore the load prognosis for the feeding transformer station of local mid voltage grids can be used to develop a time flexible tariff based on grid aspects. By setting defined boundary values regarding the transformers utilization rate as indicators for tariff step changes, the load structure can be included in the sale process representing the operational costs in an electricity supplying system.

5. FIELD STUDY

To underline these considerations, a field study in a German small town distribution grid is being conducted by Ilmenau University of Technology and Fraunhofer Gesellschaft which brings notable outcomes to this theory [10].

In 2010 a three-step flexible tariff was introduced to the local utility`s customers, combined with a best-price clearance, which guarantees that customer billing is being conducted the cheaper way: either with the use of the flexible or the set tariff. To measure the customers' electricity consumption 200 Smart Meters were installed at the participants measurement points. Half of the devices are working with Powerline Communication and the other half are using mobile GPRS. At the same time a substation with a mixed structure of private customers and no business customers was metered to gain reference values.

To inform the participants about their energy consumption Fraunhofer developed a web based energy information tool which illustrates the specific consumption and their time-of-use to the participating customers. With this application, they are able to inform themselves of when energy prices are at which level. With this information energy intensive household processes such as washing machines or dishwashers can be started in LT-times. It has to be pointed out, that participation is on an absolutely voluntary basis and with the best price clearance participants can choose to be billed after their original tariff in case the flexible tariff model leads to greater costs.

The outcomes visualized in Fig. 4 were taken in November 2010 in a substation supplying standard tariff customers and it is obvious, that the load profile follows the standard load profile (SLP) quite well:

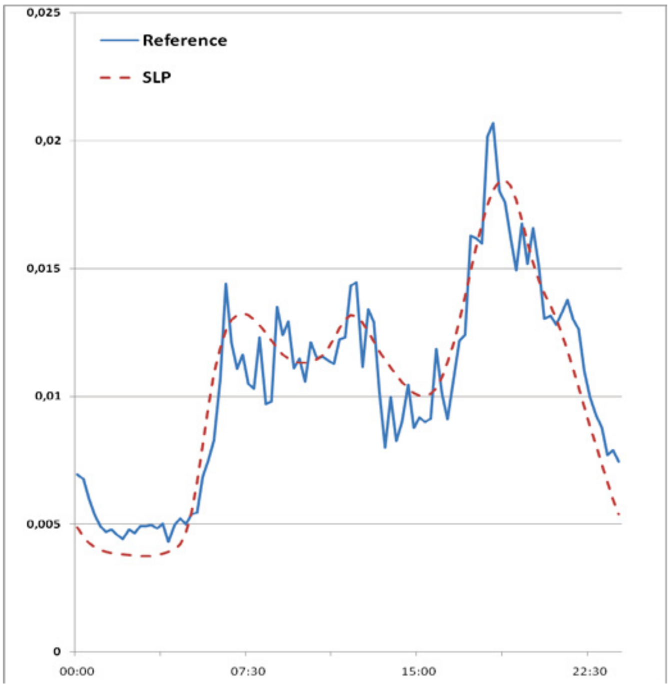

Fig. 4 Reference load profile over standard load profile

On the other hand, a single day's view of the participant´s load profile shows, that load shifting with flexible tariffs is possible. The underlying tariff structure in Fig. 5 shows the different levels: high, medium and low and also matches very well with consumer behavior, which is not exactly covered by the SLP. Clearly, the load characteristic still matches roughly the pattern given by the SLP. Therefore the conclusion can be drawn, that customers do not shift their load completely into night hours despite the monetary incentives. But there are certain significant changes in the characteristic:

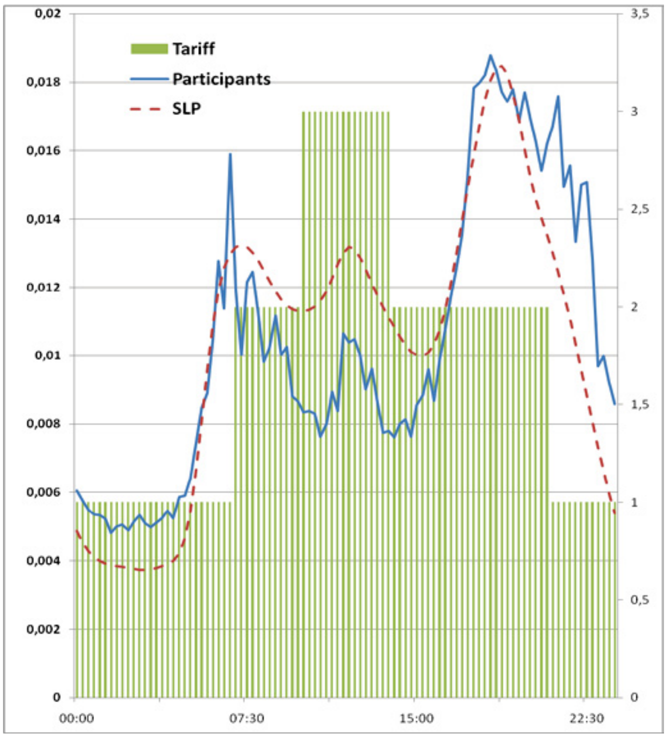

Fig. 5 Participant´s load profile with flexible tariff and SLP

From a general point of view, there is a load peak shortly before 7am which drops sharply at the beginning of MT. Although this development is clearly a consequence of the flexible tariff and shows that customers react, it is not desirable to create such sharp peaks in a distribution system. Future studies will have to determine, which measures can prevent these kinds of load peaks. On the other hand, the overall consuming level during mid day is significantly lower than at the reference node. In the evening hours after 9pm, the consuming level is considerably higher than the SLP or the reference values would suggest. Not only that the consumption level remains high, but there is a significant rise in the participant´s consumption directly after 9pm. The outcomes clearly show that customers align their consumption to a time flexible tariff.

To validate the outline, the averaged and standardized values were tested for statistical distinctions. Hereby x_1 stands for the averaged participants 15min energy value, x_2 represents the 15min reference value [11].

$$\bar{x}_D = \bar{x}_1 - \bar{x}_2 \qquad (5.1)$$

With the standard deviation s_D and the total number of values per tariff N one appropriate way to distinct the graphs would be the t-test [12].

$$t_{N-1} = \frac{\bar{x}_D}{\frac{s_D}{\sqrt{N}}} \qquad (5.2)$$

Statistical tests showed that although the consumption during MT does not change significantly (t=-0.158; p=0.875, df=39), there are considerable changes during HT (t=-9.22; p<.0001, df=15) and NT (t=4.56; p<.0001, df=39).

Table 1: Energy consumption (means and standard deviations)

Tariff / Values		$\bar{x}_D$	s_D
HT	Participants	$8.9*10^{-3}$	$2.5*10^{-4}$
	Reference	0.0117	$4.1*10^{-4}$
MT	Participants	0.0127	$6.0*10^{-4}$
	Reference	0.0128	$5.2*10^{-4}$
NT	Participants	$8.7*10^{-3}$	$6.5*10^{-4}$
	Reference	$7.5*10^{-3}$	$5.0*10^{-4}$

Considering these outcomes it can be noted, that customers shift significant amounts of energy from HT to NT zones. The incentive behind this is clearly monetary because the ecological aspect has not been explained to the participants yet. It has to be observed if the participants` interest in taking part in the study remains as high as it was at the point where the first values were analyzed or of participation decreases and proven effects start to blur.

6. Simulation of effects

By taking a quick look at the load profile, one notices the so called "TV-peak", a sharp rise of consumption at about 8pm. It is obvious that this time of the day – usually when consumers are arriving at home, switch on the light and the TV – there is a high demand of electricity. Such a sharp increase of consumption always leads to a loss of efficiency in the generation as well as the transport process. Therefore the first idea would be to change the tariff to HT in order to lower the voltage level.

Unfortunately, this step would not just raise tension among customers – it would certainly put the recreational process after work to unease – in the case of the field study it is not necessary at all. Power flow simulations conducted at Ilmenau University of Technology show that the particular cities consumption is highly influenced by business load profiles – especially from 8am until 6pm. By assuming that every household in the city the field test was conducted in has the same behavior as the field test participants a new load profile can be derived. This assumed loadprofile is shown in Fig. 6 and compared to another profile derived by the proportional use of several business and private customer SLPs. It consists of a full week starting with Monday and shows the city's original load profile (dotted line) as well as the simulated transformer utilization.

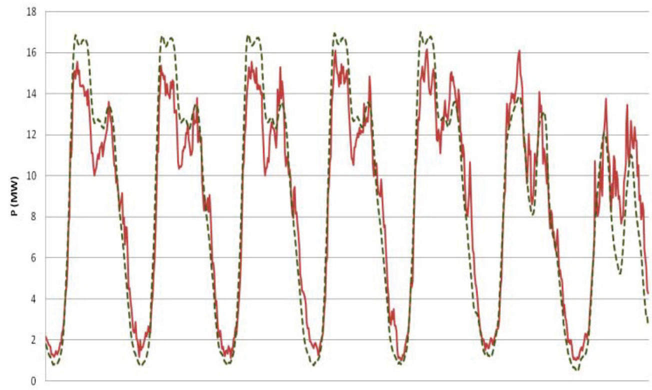

Fig. 6: Simulated load profiles at feeding transformer station

Clearly the maximum consumption during mid day has a slight decrease. This could help boosting efficiency since the consumption is shifted towards later hours in the evening and therefore the load curve is straightened significantly. Also grid access fees to the upstream transmission system could decrease since the yearly maximum load – by which the access fees are determined – also decreases.

7. Constraints

Although Smart Meters offer great opportunities for system operation and more direct market participation of private customers there are some constraints.

First, the smart metering technology suffers from high investment and maintenance costs. Meters who are AMR-ready cost more than five times as much as basic digital meters.

The utility also has to purchase secondary systems like data concentrators and servers as well as software and licenses. These devices and software modules ensure data encryption, transportation and management as well as other tasks like synchronization of system time – but only on a proprietary basis, which is the second major constraint. The utility has a narrow freedom to choose its metering devices once the secondary system is installed. Also customers – which could choose their own metering devices due to the metrology liberalization are limited in choice and have to check on the utility's or metering service provider's communication and AMM system.

Clearly, there is a missing link between sales and system operation. What mainly separates both – retailers are considering market aspects while system operators (TSOs as well as DSOs) operate incentive based. Thus – due to regulatory reasons – cross-subsidization is impossible for utilities which want to offer a time flexible tariff regarding market and system operation aspects. Also the measured data from those devices cannot be used by the DSO to optimize system operation.

Although a legal framework for a liberalized energy metering market has been provided by Germany's regulator Bundesnetzagentur, the effects remain sparse, especially because system operators do not have certainty, that their investments will be granted. As a consequence, investing in communication technology which allows a broad rollout of smart meters remains a high risk.

8. Conclusions and Outlook

With this paper the authors describe development, benefits and necessities of Smart Metering in Germany in the context of a liberalized energy market. Examples for variable energy billing and an introduction to Indirect Demand Side Management are given.

Furthermore a field test in a small German town is presented where Smart Meters have been installed as enabling technology in a real distribution system in order to obtain real time IDSM data. In a first step a three level tariff structure has been tested. First test results show that there is a significant impact on the load behavior of the customers. The tariff is suggested to become flexible in way to optimally adapt the consumer load consumption pattern to e.g. renewable infeed into the power system. For future investigations it is of utmost importance to investigate the impact of DDSM and IDSM combinations focusing on price variations within a certain time interval. As a second step the operation of storage units or appliances with storage characteristics needs to be integrated into the entire system. It is expected that such measures will further leverage load shift capabilities with respect to different tariff times.

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