The Role of Smart Meters in P2P Energy Trading in the Low Voltage Grid

Christina Sigl[1], Alexander Faschingbauer[1], Andreas Berl[1],
Jakub Geyer[2], Rudolf Vohnout[2], Miloš Prokýšek[2]

1. Institute for Applied Informatics, Deggendorf Institute of Technology, Freyung, Germany,
email: {christina.sigl, alexander.faschingbauer, andreas.berl}@th-deg.de

2. Institute of Applied Informatics, University of South Bohemia, Ceske Budejovice, Czech Republic,
email: {geyer, vohnout, prokysek}@prf.jcu.cz

Abstract: **There are different approaches for energy trading shown in the paper. The peer-to-peer approach is the most interesting one of them. Therefore, the underlying subsystem is essential for fast and accurate trading. Smart meters are one of the most important parts within the infrastructure to provide high quality information and services for smart contracting and also for controlling the grid. Therefore, smart meters have to fulfill dedicated requirements. Especially the lowest layer of smart metering – the smart meter itself – is considered here. A very basic view on data acquisition and a possible architecture for a test bench are presented in this paper.**

Keywords: **smart grid, P2P, energy, trading, smart meter.**

I. INTRODUCTION

Smart grids are based on smart measurement and control of energy supply, transportation and demand. The intelligent control of all components can be seen as a virtual grid, where energy can be traded over short (low voltage grid connected to a sub-station) and/or long distances (middle- and high voltage grid). In both cases the complexity of the control and trading system is very high.

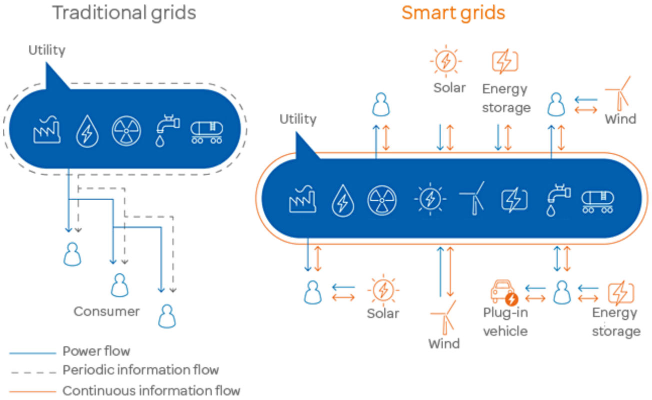

Fig. 1. Grid schematic [1].

Fig. 1 compares the traditional grid with a smart grid. In traditional grid architectures there are producers (utility) and consumers. Whereas in the smart grid renewable energy sources and storages are integrated and therefore a consumer can take the role of a producer as well.

In case of peer-to-peer (P2P) trading also both roles (prosumer) are used by each participant, which changes their behavior. As such, to enable this system to be dynamic and flexible it needs respective agile components to be able to provide production-consumption control. Thus, smart meters (SM) are important in such a P2P network. SMs provide information about power consumption and distribution for billing (longer time intervals as for grid monitoring). Maybe, they can be used to detect problems in the power grid, too [1]. Within a P2P network SM are very important. Therefore, required technologies, protocols and data quality must be analyzed regarding to P2P trading. Thus, a simplified consideration of measurement accuracy is given and some gaps in the measurement chain (e.g. timing issues) are depicted. Additionally, a test bed, especially for analyzing SMs acquisition accuracy, is introduced. Moreover, in P2P trading, business models and means of trustworthy evidence of the contract (for example smart contracting/block chain) must exist. Hence, P2P systems, business models as well as energy pricing models are considered.

The Paper is organized as follows. In section II, related work is given. Section III presents P2P energy trading models and a comparison of energy prices between Germany and Czech Republic. Information, that SMs have to provide for P2P trading, are shown in section IV. Required technologies and protocols are pointed out in section V. The significance of data quality, for P2P trading, is stated in section VI. A test bed setup for analyzing SMs is shown in section VII. Finally, the paper is concluded in section VIII.

II. STATE OF THE ART

P2P trading, smart contracting and micropayment are modern concepts, which are widely used nowadays. There are several pilot projects and examples dealing with this topic. Murkin et al. show an example platform for P2P energy trading using the block chain technology. This makes the trading process accurate, authenticated and secure [2]. Alvaro-Hermana et al. use electric vehicles for P2P energy trading [3]. In general, there are different approaches of P2P energy trading systems on that we will take a closer look in this paper.

Matamoros et al. investigated P2P trading between two micro grids, thus looking at central versus distributed control [4]. Zhang et al. submit that communication and control networks are very important for P2P energy trading. They also show a future scenario of P2P energy trading [5]. For control of the P2P trading system data form smart metering must be used.

P2P energy trading bases on timing, a reliable communication layer and accurate metering. Marshall et al. did some investigations/simulations about the impact of accurate metering. Most commercial metering systems measure net flow only in intervals of 30 seconds or 30 minutes, which is a barrier for accurate accounting. Therefore, sub-second level timing is required. Economic impacts through faster energy fluctuations, than the measurement intervals, lead to economic inefficiencies and also possible inaccuracies through meter timing (the question is stated, which time period is the best) [6]. Capodieci et al. [7] present a hardware/software solution for energy trading using agents which use only six time intervals per day for trading. The hardware architecture consists of a real SM which is connected to a SM gateway through a SM interface. The data is sent to an energy trading platform.

Nonetheless, SM accuracy also depends on temperature effects of SMs [8]. SM accuracy is determined considering ADC resolution, SINAD and THD [9]. Thus, we take a closer look on data quality that is required especially for P2P trading and to evaluate SMs a test environment is set up.

III. P2P Energy Trading

In general, there are differences concerning the electricity market of the neighboring countries Czech Republic (CZ) and Germany. In CZ, the current electricity market can be divided into several levels or areas. At first, there is a market for trading energy between producers and suppliers operated by market operator (OTE [10]). There also exists Power Exchange Central Europe (PXE [11]). This market is powered by EEX and provides also services for end-users, especially bigger consumers as municipalities or SMEs.

In Germany, there are two different business models for the electricity market. The first one is the traditional producer/consumer model. The second one can be called prosumer model. It is based on own production and consumption. Every customer (private/company) is connected to the grid by a distribution network operator (DSO) (e.g. Bayernwerk AG). The DSO is a direct customer of the four transmission system operators (TSO) (e.g. TENNET). Each customer has a contract with an electricity supply company (e.g. E.ON), which does billing. Electric energy is typically traded on the stock market.

In a smart grid environment, the control of consumer behavior and demand could be based on many things like social influence or responsibility, but the price for energy is the most important factor. Hence, the metering of consumption and production is the crucial part of all P2P trading systems (See TABLE 1 for overview).

Current pricing model

Electricity for smaller consumers is in CZ delivered by energy suppliers, usually based on an end-user agreement. For households, there are two common pricing models. For smaller consumers (mainly in high density areas with prefabricated houses) the price of energy is constant and calculated from several parts, mainly from the price of power, distribution costs and taxes. For bigger consumers like houses there is a system of high and low tariffs.

Fig. 2 shows pricing components of consumed energy (E.ON, distribution rate D01d, 2018, [12], for Germany see [13]) excluding fix costs (monthly fee for consumption point, reserved input fee).

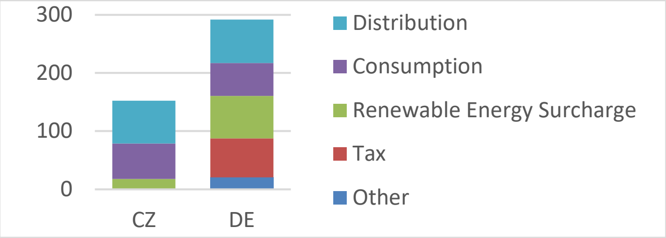

Fig. 2. Energy price components (excluding fix costs).

Scheduled flexible pricing

A flexible pricing model is based on PXE trading system and uses intraday trades. The system is now usually operated manually or with a low level of automation. This kind of trading system is a good base for further P2P business models and more advanced solutions. The amount of traded energy is based on prediction of consumption and could be supported by data gathering from smart buildings. For trading in PXE a license is required. Therefore, a mediator with license (usually an energy supplier) is an easier choice for end-users.

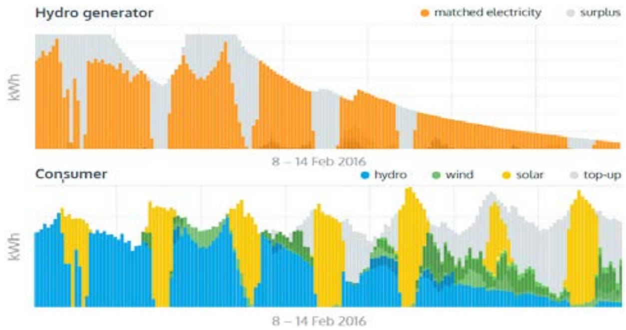

Fig. 3. Energy source matching [14].

Linking energy production resources

The system of linking/matching produced energy with consumers is based on flexible pricing and fluctuating power production of renewable energy sources. The idea is to offer cheaper energy to consumers when there is a surplus of energy and provide clear data about how the energy is produced. Consumers can than prioritize from which energy source and for what price they want to buy energy and move some energy consumption tasks accordingly. This allows savings for consumers while it also helps balancing local energy production and consumption.

P2P energy market

P2P energy market is based on a similar idea as the linking of energy production resources, the idea of balancing local energy production and consumption. However, in this case, any consumer can also become producer (prosumer) and his energy surplus is primary offered to other local consumers (usually for a better price). If the offer is accepted by another local consumer, the transaction is realized (often using block chain mechanisms). Any additional surplus (or if there is no consumer at the time) is bought by a distribution company according to the agreed pricelist.

TABLE 1. P2P ENERGY TRADING PRINCIPLES OVERVIEW

	Scheduled flexible pricing	**Linking energy production resources**	**P2P Energy market**	**P2P Energy trading platform (with battery storages)**
Companies / Projects	PRE	Piclo, Vandebron, AmperMarket	TransActive Grid, PeerEnergyCloud	SonnenCommunity, Lichtblick Swarm Energy
Objectives	Dynamic pricing based on estimated electricity production	Linking electricity demand and local energy resources	Direct local energy trading	Distributed energy trading with power reserves and grid balancing capabilities
Peers	Producers–Distributors–Consumers	Producers–(Distributors)-Consumers	Prosumers – Prosumers	Prosumers – Prosumers
Key Features	• Price driven energy consumption estimates • Weather prediction • Consumption prediction	• Local energy production profiles • User consumption visualization • User energy resources preferences	• Tokenization • P2P payments (block chain)	• P2P payments (block chain) • User consumption prediction • Weather prediction • Virtual grid
Infrastructure Level	Any	Micro-grids / grid-cells	Micro-grids / grid-cells	Any
Smart Meter / Gateway Demands	• Daily / weekly / monthly readings	• Daily / weekly / monthly readings	• Readings several times per hour • P2P market support (online communication)	• Readings several times per hour • P2P market support (online communication) • Gathering user data consumption (profile)
Prosumers Control	Manual / parametric consumption adjustment (scheduled)	Manual / parametric prosumers adjustment (scheduled)	Manual / parametric prosumers adjustment (dynamic)	Dynamic control based on user profile, weather prediction and grid (community) demands
Benefits	• Dynamic pricing for consumers • Load distribution more optimized to production	• Local production and distribution more optimized to production • More transparent billing information • Price reduction for adaptive consumers • Possible direct support of renewable energy sources	• Local consumption and distribution more optimized to production • Price reduction for consumers buying local energy • Higher selling price for prosumers	• Consumption and distribution more optimized to production • Price reduction for consumers buying from prosumers • Higher selling price for prosumers • Peaks shaving • Power reserves • Grid balancing
URLs	• https://www.pre.cz	• https://piclo.uk/ • https://vandebron.nl • http://www.ampermarket.cz/	• https://lo3energy.com/ (TransActive Grid) • http://www.peerenergycloud.de • http://www.smartmpower.com/	• https://sonnenbatterie.de/en/sonnenbatterie • https://www.lichtblick.de/

P2P energy trading platform (with battery storages)
A P2P energy trading platform consist of 3 key parts:

- P2P energy market
- Virtual grid with distributed battery storages
- Grid operator/distributor cooperation

Surplus energy can be stored and used in moments of low production (peak shaving) if a battery storage is added to the prosumer system. Based on the energy consumption profile (done by prediction), the stored energy can also be sold. With grid operator/distributor participation this can help balancing even across multiple grid cells.

IV. Smart Meters in P2P Trading

Especially in the P2P trading market a smart metering solution is required, which is able to actively participate in the smart shared grid infrastructure. This system has to report electricity consumption values and trends. Additionally, it has to provide information for P2P trading to enable it. Such information is:

- Current demand of power consumption by a household/SME
- Total power budget available for trading in the (micro) grid shared (sub-) infrastructure
- Tariff and/or price per kWh of redundant power to be used
- Price for using/renting the infrastructure (distribution costs) for such model
- Length of the contract (for example one hour) and smart contract block chain evidence
- Amount of electricity units to be contracted
- Guarantee power supply to be provided for at least contacted time frame and for unit price agreed

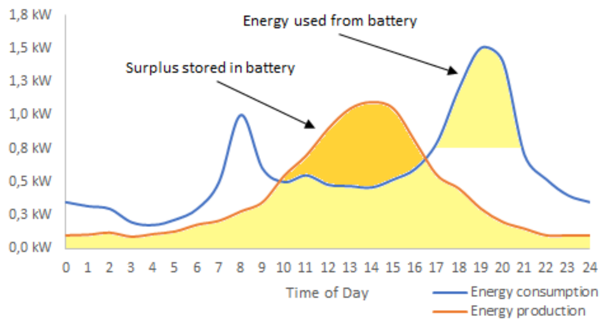

Fig. 4. Prosumer energy consumption profile (with photovoltaics and battery).

The role of SMs in such a situation is to provide control over the implementation phase of the P2P (smart) contract. As such, the internal real time clock accuracy and synchronization should be not lower than 5 x 10^{-3} seconds. Because of the nature of smart contracts, SMs used in the smart contract enabled grid infrastructure (with tariff less trading) have to be able to store enough historical values. Therefore, SMs primary oriented on distributed infrastructures and based on tariff templates will not be suitable for this scenario. Smart metering solutions available on the market differ in several aspects. For our model, the minimum accuracy level (we count only on transformer connected SMs) must be 0.5 S (better 0.2 S) to be able to provide a fair smart contract for parties involved even in low power demand conditions.

V. Technology/Protocols

From the standardization point of view, SMs can be divided into two groups:

- Using proprietary communication protocols and security. Backward compatible with SM standard protocols such as DLMS or PRIME Alliance.
- Using standardized metering devices, certified by DLMS and/or PRIME Alliance.

The first group is mainly intended for island or isolated smart grid installations, where no interactions with other smart grid domains are expected and usually leads to vendor lock-in situations. Most of the smart grid solutions use standardized (certified) interoperable equipment to be able to exchange information not only within the same grid (domain), but also outside, to other installations supporting the same communication languages. For P2P trading we need only selected elements of xDLMS protocol structure protocol structure, avoiding those intend for energy distributor purposes.

VI. Data Quality

Data quality is one of the most important topics in the context of P2P energy trading. All parts of the described subsystem can affect data quality. This starts at the very low layer, where the signals are taped from the grid lines, as it can be seen in the upper part of Fig. 5. Also the timing of the whole system must be known. Some blocks have a non-deterministic timing, which can lead to problems if the fluctuation rate of supply and demand is higher than the data processing by the P2P trading layer.

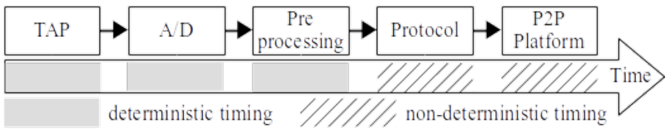

Fig. 5. Timing of Data Acquisition Process

The accuracy of the measured values is another important topic. There are several parameters which affect accuracy and data quality:

- Sensor type, attached to the grid lines
- Temperature
- Data reduction
- Communication protocols/gateways
- Processing speed
- Acquisition bandwidth (harmonics)

Fig. 6 shows a simulation of the measurement error, resulting from lowering the acquisition bandwidth, especially for reactive power in dependence of the number of harmonics considered.

The following assumptions were done: Line voltage Urms = 230 V, line current Irms = 10 A, grid frequency f = 50 Hz, sample rate Fs = 100 kHz. The signal of the line current is a sine wave superimposed with harmonics (damping by 100).

The calculation is done 100 times, starting with adding 100 harmonics to the base signal and decrementing it after each calculation step. For each loop the relative error is calculated, using the actual test signal in relation to the first signal.

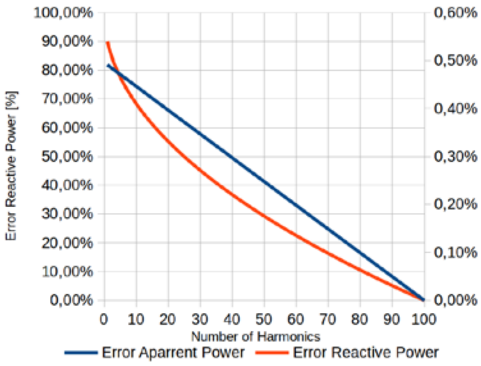

Fig. 6. Measurement Error in Dependence of Considered Harmonics

VII. Smart Meter Test Setup

The whole data processing chain from grid to the control system must be well known for well-balanced P2P trading. Fig. 7 depicts a simple test setup for testing SMs concerning their time delay.

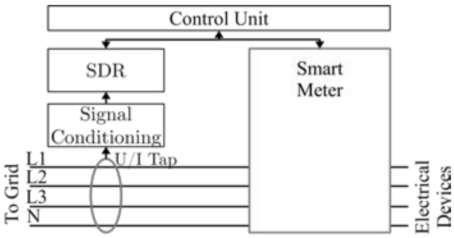

Fig. 7. Architecture of a SM test setup.

The grid signals are fed into a Software Defined Radio (SDR) through a voltage/current tap. The type of the current tap is a Hall sensor with higher frequency bandwidth compared to current transformers. Both signals (voltage and current) are applied to the SDR through filters, amplifiers, attenuators and impedance matching circuitry. The SDR is directly connected to a computer for controlling and processing the incoming data. The used SDR provides extremely high flexibility through the possibility of reconfiguration. The SM is also connected to the grid lines and considered as a black box, because the signal conditioning and processing is not accessible from the outside. A digital interface allows only access on the measurement results. Both acquisition systems are connected to the same computer to get synchronized datasets, for easier post processing and comparison.

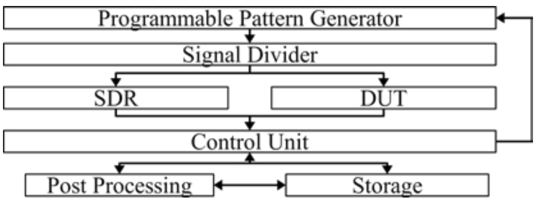

Fig. 8. Test Setup.

Fig. 8 shows the test setup in detail. The device under test (DUT) is a SM. DUT and SDR are both connected to a programmable pattern generator. Test signals, like a sine wave with a frequency of 50 Hz, superimposed by a variation of distortion signals of different speed, are applied. The distortion signals frequency is varied until the SM can't detect any further changes.

VIII. Conclusion

This paper is focused on differences between traditional and smart grids from the view of business and metering. We identified the important role of smart metering and its necessary parameters for different business models of a P2P trading systems. We also discussed the price of energy for end-users/consumers on Czech and German energy market, where the component of energy distribution was identified as the most important and its reduction due the innovative trading scenarios could be the crucial motivation factor for P2P trading spread. Finally, we introduced a schema of a smart metering test bench, developed by Czech-Bayern cross-border laboratory of smart grid for testing different scenarios of P2P consumption-production analyses and security tests.

Acknowledgement

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