Local Energy Markets in Clustering Power System Approach for Smart Prosumers

D. Holtschulte*, A. S. Erlangga*, E. Ortjohann*, J. Kortenbruck*, S. Leksawat*, A. Schmelter*, T. Premgamone*, D. Morton**

*South Westphalia University of Applied Sciences/Division Soest, Luebecker Ring 2, 59494 Soest, (Germany),
**University of Bolton, Deane Road, Bolton, *(U.K.)*

***Abstract*—Decentralized, renewable energy sources has grown fast as a sustainable and clean alternative energy to overcome the carbon emissions caused by conventional power plants. However, this change leads to several challenges related to grid control, resulting in a need of new smart grid concepts. Therefore, Clustering Power System Approach (CPSA) has been introduced as a suitable smart grid concept. Meanwhile, the impact of small prosumers in power supply operation increases continuously and they will emerge from being passive to become active participants in smart grid and smart market operation.**

In a previous paper genetic algorithms (GA) has been introduced as an adequate optimization technique tackling the issue of economic optimization of smart prosumers in a case study. In this paper a case study for a whole cluster network with smart prosumers/households operating under individual requirements is carried out. Additionally, a market model containing auction based local energy markets (LEM) suitable to be implemented in the CPSA is introduced. This is the next step to achieve the goal of smart grid and smart market under the foundation of the CPSA. The results show that the GA based optimization in combination with the involvement of LEM provides economic benefits for smart prosumers.

***Index Terms*--Clustering power system approach, genetic algorithm, local energy market, renewable energy sources.**

I. Introduction

Since the last two decades, a global trend on activities for sustainable life and a reduced human footprint on earth's environment are observable. One main issue is the reduction of the carbon emission emitted through several energy-consuming processes. One of the main drivers of carbon emission are conventional power plants based on fossil fuels. To overcome these issues renewable energies are considered as a sustainable and clean alternative. One example in this context is Germany, where the electrical energy production by renewable energy sources (RES) has already reached a third of gross electrical energy production in 2015 [1], initialized by the German Renewable Energy Sources Act – RES Act [2]. One key driver of this successful development are the millions of decentral energy supply systems owned by individuals and founded by this RES Act [2] and the included fixed fed-in-tariffs. Until 2014 more than 1.5 million decentralized generators (DG) have been installed in the German electrical grid [3]. The main share of these DGs is in private hand owned by so called prosumers, which are grid users, on the one hand consuming energy and on the other hand producing electrical energy by RES.

However, the fast growth of DG based on the renewable energy sources causes new challenges related to the grid control. Having millions of DGs in electrical networks providing fluctuating energy by sun and wind power requires different control schemes compared to a network with just a relatively few centralized bulk power stations. Additionally, in the new German RES Acts, two main issues are considered: Firstly, defined annual installation capacities and new pricing models slow down the installation rate of DGs. Secondly, the fixed fed-in tariffs decrease more and more and a market oriented price building process is encouraged [4]. Consequently, prosumers, which build up new RES based DG, cannot longer calculate with concrete revenues due to the fixed fed-in tariffs. To sell the energy they need to participate on the energy markets. Thus, they should be able to deliver their energy under individual requirements and optimizations independent from the generator size.

Consequently, the power system faces more complexity and the requirement of new grid structures and operations are rising. Therefore, the Clustering Power System Approach (CPSA) has been previously introduced as a suitable smart grid concept [5], [6]. But, besides the grid relevant operations, e.g. frequency and voltage control, economic optimization of power supply and demand for the users must be taken into account.

In the previous paper [7] economic optimization of prosumers using genetic algorithms (GA) in combination with the CPSA has been introduced by a case study. It proves that GA provide an adequate method for optimizing energy allocation related to the given sources and the demand of prosumers. With the current paper the case study from [7] is expanded and a market model for an auction based local energy market (LEM) is introduced.

In the second section of this paper, the background of the CPSA and the GA are introduced to give the foundation for the purposed case study. In section three the foundation and the concept of LEM is provided. Section four provides the explanations on the conducted case study and section five contains the discussion of the results. A conclusion will be given in section six.

This research work is supported by the German "*Federal Ministry of Education and Research*" and administrated by the *Projektträger Jülich (PtJ)*, Project: iNET-FA² (03EK3541A).

978-1-5090-4682-9/17/$31.00 ©2017 IEEE

II. THEORETICAL BACKGROUND

In this section the CPSA as the foundation of the paper is elucidated. Further on, a brief introduction to the genetic algorithms is given as the applied optimization technique for the allocation of sources concerning the load dispatch on prosumer level.

A. Clustering Power System Approach

The main idea of the CPSA is the transfer of the transmission system operator (TSO) functions to the medium and low voltage levels operated by the distribution system operators (DSO). In these voltage levels most of the RES based DGs are established. Fig. 1 presents an overview about the entire power system with the application of the CPSA [8]. In this concept cluster networks are defined and being interconnected through power lines. A cluster area can be defined at any level of power systems from a unit in low-voltage level upwards to the upstream high-voltage systems. With this concept, the cluster networks can be seen as control areas, similar to the different transmission systems on TSO level. Consequently, the hierarchical control scheme and functionalities of the transmission systems are adopted in order to coexist operations of TSO and DSO. The key component of cluster operation is the cluster management system (CMS) in which the control schemes, e.g. load-frequency or voltage control, can be implemented.

However, there is no limit concerning the size of a cluster network, i.e. even a household or prosumer can be arranged in his own cluster network as can be seen in Fig. 1. In this paper the focus is given on the prosumer level operating in part of the local area. Since, the prosumers are equipped with a CMS, likewise, operation schemes of the TSO or DSO level can be conducted on prosumer level. In this paper economic load dispatch and energy trade is focused in relation to the CPSA. Therefore, the CMS of the local areas has to be equipped with market operation functions.

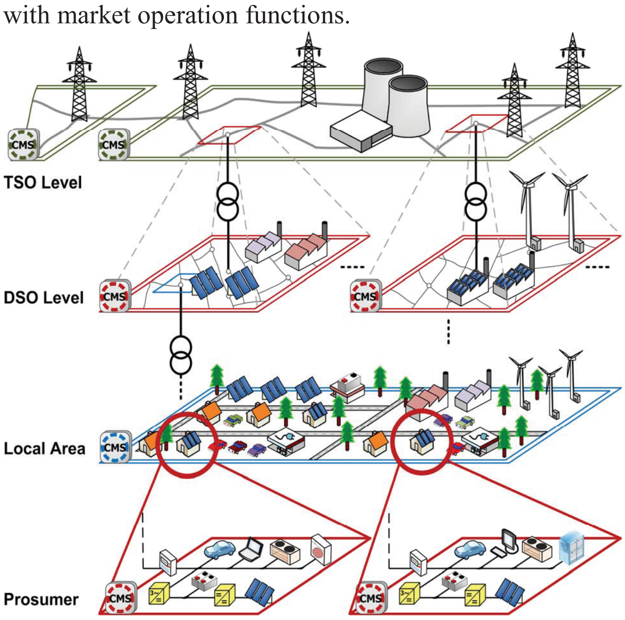

Fig. 1. The entire power system with the application of the CPSA [8].

Additionally, the communication strategy between cluster networks is one important issue in CPSA. On the one hand communication is used in order to handle interoperation among the network clusters in context of system stability, on the other hand it is essential for appropriate operation of the LEM, which has to be established within the CPSA. The communication capability of the cluster networks are enabled by the CMS, using the internet protocol as communication medium. Security requirements will be ensured by using the virtual private network (VPN) technology [9]. Internal and external connections are indicated for the communication. In CPSA the internal communication refers to the devices within a cluster network, i.e. in order to ensure optimal operation of sources, battery and loads. The CMS communicates with these devices, themselves equipped with communication interface and declared as intelligent devices (ID) as can be observed from Fig. 2 below. Information exchange between cluster networks is carried out by web service. Thus, via the CMS the cluster networks, i.e. the prosumer and the local area operator, can interchange information for interoperation adequately in order to ensure appropriate control and market operation. For further reading see [9] and [10].

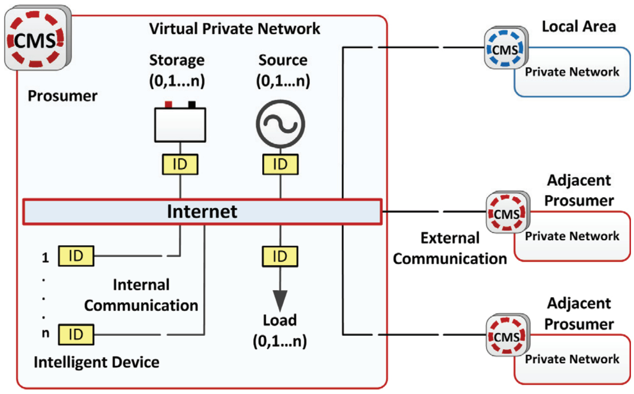

Fig. 2. Communication model, cf. [9].

B. Optimization with Genetic Algorithms

Technical requirements are just one issue on the way to decentralized and renewable power generation, another one is the economic optimization of any grid user. If any owner of a DG, e.g. a prosumer, like to have an optimal operation for their DG related to the energy consumption, energy management tools have to be implemented.

Therefore, a genetic algorithm is applied, which is a metaheuristic optimization algorithm and a subclass of evolutionary algorithm (EA). The EA based optimization techniques are inspired by natural selection and genetics and use natural mechanisms as reproduction, mutation, recombination and selection. They operate as a set of population, containing several individual solutions. The aim is to identify the best-fitted solution to the problems. Therefore, new populations based on the previous ones will be created by the genetic operators' selection, crossover and mutation in an iterative manner [11].

One benefit of GA against other traditional techniques is the GA's ability in doing parallelization, meaning that GA works on a population of candidate solutions in the search space simultaneously. Traditional optimization mostly processes only a single solution simultaneously [12]. GA are well known for its ability to solve difficult optimization problems, with its simplicity, robustness of changing circumstances and flexibility. GA's approach can be applied to the problems where many other traditional heuristic approaches could not do and only produce unsatisfactory results [13].

Until now, EA and GA have been applied for solving optimization problem in several power system areas. In [14] GA have been used for scheduling power plants for an optimal economic dispatch. In [15] GA are applied for an optimal distributed generation allocation in meshed networks. To reduce losses and improve the voltage profile within a grid GA have been applied in [16].

The previous paper [7] describes a case study with three different prosumers being connected to a cluster network. Principally, any prosumer has a delivery contract with a public energy supplier (PES), who has to deliver the energy needed by the appropriate prosumers. Any prosumer has different conditions related to the energy demand, energy production of the RES and the existence of energy storage systems (ESS). Additionally, a demand response (DR) was implemented in a way that the usage of some domestic appliances, e.g. dishwasher, washing machine, etc. could be shifted to times where energy is available by the own RES.

The aim of the GA is the optimization of the energy consumption and production of any single prosumer in order to minimize the energy costs. Therefore, the GA determine optimal operation time for the domestic appliances, the RES, EES and the consumption of energy from the PES of any prosumer within the conditions and restrictions given by any component. Therefore, the GA operate in the corresponding prosumer CMS individually. The objective of the system is to minimize the total electricity generation cost

$$C = \sum_{t=1}^{T} \left(C^{PES}(t) E^{PES}(t) + \sum_{k_S=1}^{K_S} \left(C_{k_S}^{S}(t,P) P_{k_S}^{S}(t) \right) \right) \rightarrow \min, \quad (1)$$

with the energy taken from the PES E^{PES} and the energy price C^{PES} in *€/kWh* at time interval t, the source cost function $C_{k_S}^{S}$ as a function of time t and the source power $P_{k_S}^{S}$ of the DG and the price in *€/kW* for each 15 minutes time interval [7]. For any time period t the equilibrium condition

$$P^{load}(t) \pm P^{bat}(t) - \sum_{k_S=1}^{K_S} \left(P_{k_S}^{S}(t) \right) - P^{PES}(t) \overset{!}{:=} 0 \quad (2)$$

has to be strictly adhered, with the power consumption P^{Load} and the charge and discharge power from the battery P^{bat} at time t, which has positive value in charging case and negative value in discharging case, respectively.

However, the general optimization model as well as a detailed description about the objective function has been introduced in [7]. Results of the optimization performed by the GA within the current case study are provided in section four.

III. Local Energy Markets in CPSA

The operation of CPSA containing communication strategy as well as the GA based optimization for prosumers have already been discussed in detail in the referred literature. This paper focuses on the functionality and the benefit on local energy markets established within the CPSA.

A. Traditional Energy Markets

Beginning with the monopolistic energy supply structure during the 20th century, with the European Electricity Market Directive 96/92/EC [17] the liberalization of energy markets was adopted through the European power economic. Besides the unbundling, one main issue was the non-discriminating network access for third parties allowing a free energy trade and ensuring more competition. Today, the energy market distinguishes between the wholesale energy markets (WEM) and the retail energy market (REM) [18]. Whereas WEM is focused on large amounts on energy dealt between big generating companies and large energy consumers, i.e. energy-intensive industries or subordinate energy suppliers connected to the transmission system, the REM corresponds to distribution level and smaller consumers. In REM the consumer has free option for the retail service. Thus, the distribution market becomes more competitive [18].

However, in WEM and REM the traditional energy suppliers are still dominant and small producers suffer under a barrier during the entry in the markets, e.g. by minimum bids to be offered to the markets. The problems of the traditional energy market structure for distributed generation are pointed out in [18].

B. Local Energy Markets (LEM)

Principally, the idea and theory of LEM is not new and discussed in brought literature. In [19] the opportunity of DG participation on local balancing energy markets is investigated. It is purposed that DG provide balancing energy due to certain price signals.

In [20] an appropriate LEM design to realize market-based control for the integration of PV generation and residential energy storage at household level is examined. The authors point out the benefits of distributed marked based control compared to a central one, i.e. the reduced complexity and amount of information to be proceed by decentralized control.

The authors in [18] discuss the difference between traditional energy markets (TEM) and local energy markets. It points out the problems of TEM structure for distributed generation and highlights the benefits of LEM. The contribution of [18] is the concept, design and operation of an LEM for a power supply based on DG. The LEM design in [18] refers to a local grid controller (LGC) which is responsible for different control tasks, i.e. voltage and frequency control, demand response, DG control as well as market trading and system monitoring. Therefore, certain participants and actors are clustered and connected to the LGC. Thus, a large number of users (producers, consumers, suppliers, network operators, aggregators, etc.) are connected through a bi-directional flow of energy and information. The interface between the market system operator and the LGC, and consequently the producers, consumers, etc., is given by an aggregator. The aggregator participates in the energy trading and provides further services to the distribution grid [18]. With the LEM concept in [18] different trading mechanism, e.g. bilateral contracts, auctions, supermarkets, etc. are intended.

In this paper the operation of auction based trading is focused to be implemented in the CPSA on prosumer level. Principally, these processes correspond to the spot market mechanism to determine the electricity price. Generally, the auction based market processes are as follows: During the trading process the producers, who want to sell their energy, must give their sell offers to the market together with the amount of energy they are ready to deliver. Additionally, the buyers must give their purchase orders with the price they are willing to pay [21].

Both of the sell offers and purchase orders are aggregated to become a curve of sell and buy bids. The intersection of these two curves will result in a market clearing point, which is the electricity spot price. However, the aggregation must follow the rule of merit order. By following the merit order, the aggregation of the sell bids will be sequenced from the lowest price. This aims to lower the entrance price and push more the expensive conventional power down [22]. On the contrary, the sell bids are sequenced from the highest price. In [23] a model for auction based mechanism in LEM has been introduced and tested via simulation. It has been designed to accommodate the needs of non-expert bidders as this is essential on prosumer level. However, the paper points out the benefits for prosumers. On the one hand they profit from lower energy price and on the other hand they will be paid for the energy provided to other prosumers.

C. LEM Operation in CPSA

In CPSA market operation is performed by the CMS automatically. Therefore, it needs to be distinguished between prosumer owned CMS and grid operator owned CMS, see Fig. 3. For prosumer CMS, as explained in section two, TSO and DSO operation are implemented, e.g. frequency and voltage control. Thus, a prosumer is capable to operate in island mode or control its network similar to the interconnected power systems. The same opportunity is given to the CMS of the DSO on the local area. However, in CPSA not all function need to be strictly activated, e.g. prosumer CMS only can activate

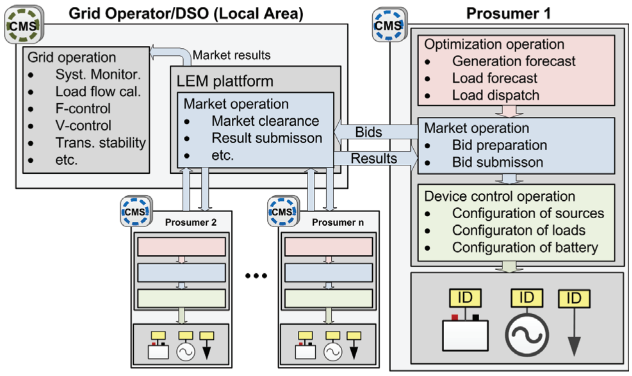

Fig. 3. LEM operation in CPSA

the optimization and market functions without performing frequency or voltage control. This can be done by the super ordinary grid operator CMS in the local area.

However, between prosumer CMS and grid operator CMS a crucial difference is to mention. Whereas the prosumer CMS is permitted to operate grid and market related function in dependence on each other, the operation of grid operator CMS are strictly to separate due to the unbundling requirements, i.e. without any indications of stability problems or limit valuations of equipment (transformer, cable, etc.), the grid operation function must not affect the market operations.

Fig. 3 presents the operation scheme of the LEM operation in CPSA. The prosumer CMS includes optimization, market and device control operation. The CMS of the grid operator in the local area includes grid operation, i.e. system monitoring, load flow calculation, voltage control, etc. These functions are strictly separated from the market function. In normal grid states only information exchange is conducted from the market operation to the grid operation side in order considering the market results for the grid load. The CMS provides the LEM platform to the prosumers and allows information exchange for bid and result submission. Within the LEM platform the market process i.e. the market clearing is processed in order to determine energy price for the exchange power between the prosumers.

IV. Extended Case Study and Local Energy Market Process for Prosumers

In this paper, the case study presented in [7] is extended to a cluster network with 21 smart prosumers/households, representing a small housing complex or a street being brought together in one cluster network (see Fig. 4). The cluster network is controlled by a CMS being installed in the local area. Additionally, each prosumer has its own CMS for internal control functions, i.e. the optimization of energy allocation. Further on, the CMS provides interface to the CMS of the neighboring prosumers (Fig. 2) and the CMS of the cluster network, respectively.

In the case study represented in [7] for power exchange between the prosumers/households, no valid market model was introduced. The focus of the paper was

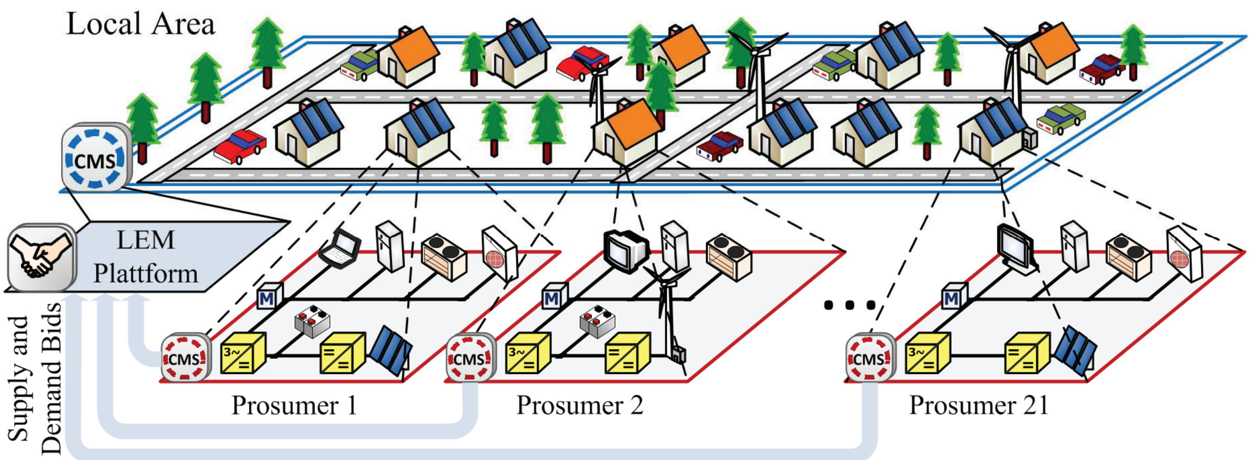

Fig. 4. Schema of the proposed case study.

given to the optimization of the prosumers by applying the GA. Energy Exchange was implemented via a simple concept operating with a kind of prioritization, i.e. after the individual optimization of the first prosumer, it offers the residual production capacity of the DG firstly to the second and third prosumer and vice versa. For transparent and no discriminated market conditions, which are claimed by the ENTSO-E Transmission Codes [24], a valid market design is required.

In this paper a local energy market with an day ahead auction trading operation is proposed. Therefore, the market concept described in section three has to be implemented in the CPSA. In CPSA principally, there must not be any obligations or restrictions to the participation of a specific LEM. To ensure the non-discriminating requirements any prosumer can participate on any LEM. However, generally the CMS of the local area provides market oriented functions and a market platform for the prosumers/households.

For the case study any prosumer has different conditions related to demand, available renewable energy and energy storage system (ESS). To describe the constellation for any prosumer would go beyond this paper. But in altogether 10 prosumers own a photovoltaic (PV) system with a power range of about *2-5* kW_{peak}, three prosumers operate a mini wind energy converter (WEC) with a rated power of *5 kW*. In summary the rated power of the installed RES is about *40 kW*. The maximum load of the 21 prosumers/households is about *28.75 kW* in peak time. The 15 DG owners additionally own an ESS to ensure more flexibility for the fluctuating energy supply of the RES. Others as well optimize their consumption with demand response (DR) functions. Nonetheless, a few households do not own a RES or an ESS, but they will have access to the LEM as well in order to optimize their consumption costs.

However, it should be taken in mind, that a self-contained energy supply is not possible on cluster area and is not been purposed in this case study. Any prosumer still has a provision contract with a public energy supplier and has to pay for its energy consumption. The LEM just provides an additional opportunity for buying additional energy on local area. Energy from the PES is available with a two-tariff mode, where the price from 10 pm – 6 am is less compared to the price at peak time.

A. Initial Optimization for Prosumers using Genetic Algorithms

Applying genetic algorithms, the prosumer related CMSs will manage the energy production and consumption of any prosumer individually. Fig. 5 shows the result of the optimization process after the load and production forecast for two prosumers owning at least a PV system and an ESS. In the time periods where PV power will be available the load can be covered by the PV system (green). In the morning hours from 0 am to 6 am the power demand will be covered by energy from the grid purchased from the PES (yellow), since PV power is not available and the battery has not been charged. The blue parts show the demand which can be covered by power from the battery. The battery either is charged when there is a surplus power by the PV system or if the energy from the PES has lower price due to the two tariff mode, provided that this will reduce the energy consumption costs.

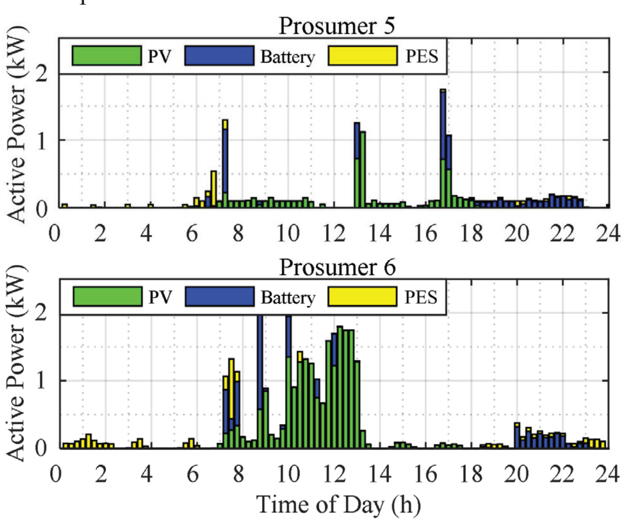

Fig. 5. Use of the resources and load profiles of two prosumers.

B. Offer, Demand and Market Clearing

After all prosumers operated the optimization process individually through their corresponding CMS, the DGs of the prosumers still have remaining power potential, which can be delivered to other prosumers or households. Therefore, they can offer the energy to the day ahead LEM. To gain the most profit any prosumer tries to sell as much energy as possible. Hence, the upper part of Fig. 6 represents the residual capacity of all prosumers after their individual load dispatch. This residual production capacity is offered to the day ahead market.

Fig. 6, upper part, shows that from hour 7 to hour 8 no energy is offered to the market. This is caused by less available power simultaneously with a relatively high forecasted consumption in the morning hours, which can be observed in Fig. 5. Due to high production capacity from the PV systems between hour 12 and hour 18 much power could be offered to the market. In this period there are just some outliers due to high consumption peaks ore negative fluctuations in the RES capacity. Thus, it can be derived that market liquidity is highly dependent on the RES und consequently on the meteorological conditions in the considered cluster network and the consumption behavior of the resided prosumers.

However, many prosumers and households still need to take expensive energy from the PES. But, instead of using the expensive energy from the PES it is aimed, to set a demand to the market, where it is assumed that cheaper energy is available. The resulting overall demand to the market of any participating prosumer is shown in the lower part of Fig. 6. The maximum power demand on the market is about *13.5 kW* occurring at the maximum summarized demand of all households from *28.75 kW* between hour 7 and hour 8.

The bids will be processed by the market operation functions within the CMS of the local area. In the market model applied in the case study the market clearing has to be done for any time period of 15 min individually. Since at any time period the available power as well as the power demand vary, the possibility for block contracts over one hour or more is not taken into account. The capability and the effects of block contracts in the LEM context will be investigated in further research activities.

In accordance to section three, the market operates in the auction based mode. Thus, Fig. 7 shows the merit order lists of the offer and demand and the market clearing of two different periods from 07:00 am – 07:15 pm and from 04:00 pm – 04:15 pm. For a better comparison of the results, the offer is related to energy in *kWh* and the price is related to *€/kWh*, respectively, being the results of the multiplication of the corresponding power value in kW multiplied with 15 min.

The cross point of both curves is declared as market clearing point (MCP). For the first period the overall amount of supply energy offered to the market is about *2.909 kWh*. The overall demand is about *0.716 kWh*. The market clearing price results in *0.129 €/kWh*, whereas the energy amount cleared is about *0.708 kWh*. Hence, a demand bid of about *0.008 k*Wh with a set price of *0.0643 €* is not cleared and the prosumer setting this demand will get no energy from the LEM.

For the second period the offered supply energy is about *3.540 kWh*, whereas the overall demand lies at *0.312 kWh*. The market clearing price results in *0.061 €/kWh*, whereas the energy amount cleared is about *0.321 kWh*. Thus, all demand is satisfied by the LEM. There are two points resulting in a lower market clearing price compared to the first period. Firstly, the overall amount of offered energy raised, whereas the demanded energy has decreased. Secondly, in the second period new bids with very low price drove into the market. It tends to lower the average price per unit of energy and is comparable with the merit order effect in the spot markets of the existing energy markets [22].

After the trading process is closed for the whole day, the prosumers and households, which got energy from the market, aggregates new allocation profiles. Fig 8 shows the new profiles of the depicted prosumers 5 and 6. It can be derived from Fig. 8 that in comparison to Fig. 5 for prosumer 5 parts of the energy, which has to be taken

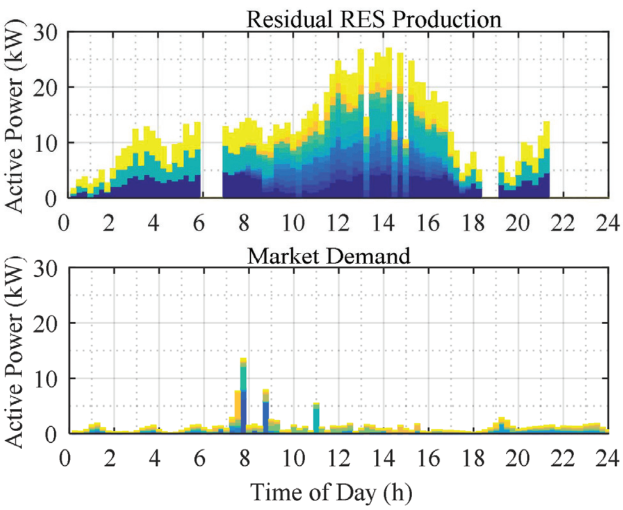

Fig. 6. Residual power potential by RES and market demand by the prosumers.

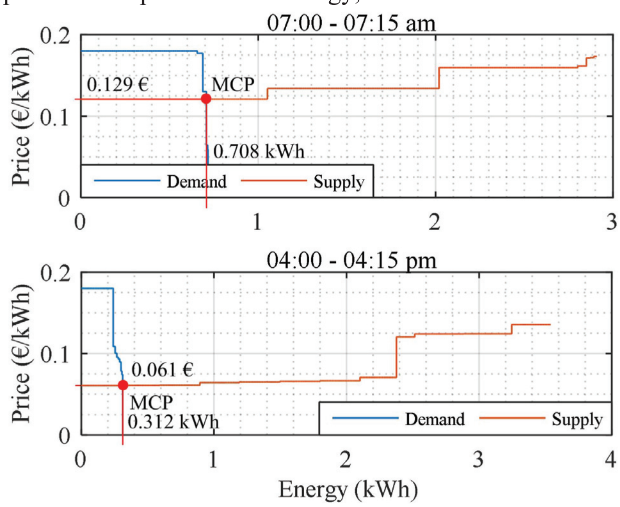

Fig. 7. Merit order of two different periods for energy offer and demand at the local energy market.

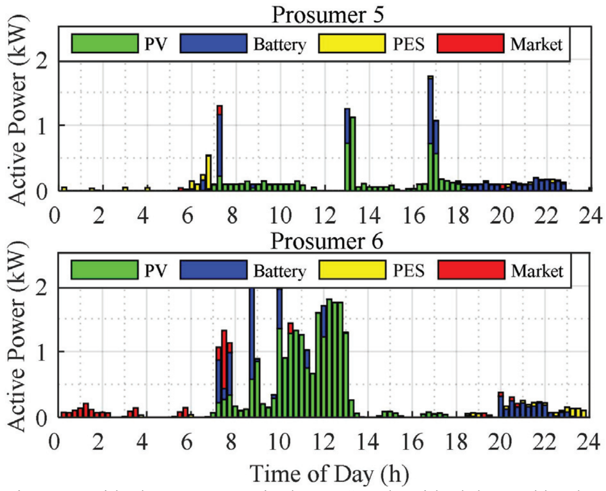

Fig. 8. Residual energy capacity by RES and residual demand by the prosumers.

from the PES due the previous allocation (yellow), is replaced by power with lower price from the LEM (red) after the market process, e.g. between hour 7 and 8 or at hour 20. During hour 6 and 7 the prosumer still has to take energy from the PES, since on the market no energy was available (see Fig. 6, upper part).

For prosumer 6 especially in the morning hours (hour 0 – 12) the energy previously to be delivered by the PES now can be taken from the market. Since this energy is cheaper, compared to the energy from the PES, this reduces the overall costs of the prosumers. Additionally, prosumers delivering energy to the market, gaining further benefits by the sold energy.

V. Results

The optimization process has been used for all 21 prosumers/households individually. Afterwards, the market process has been conducted for the considered day. In this section results of the optimization and market process will be demonstrated in order to show the different results that can occur. To reduce the complexity of the results just a few particular prosumers are chosen. Additionally the results related to the whole cluster network will be depicted to verify the benefits for the whole cluster network. The results of the optimization as well as after the market process will be compared to the case without optimization and market.

Table 1 shows three different results. Initially, in the second row the overall energy consumption E_{total} of the observed prosumers are listed. Below, the results without any optimization are presented. This means that the demand only fulfilled by the energy sources available within the prosumer (PES or/and RES) is analyzed. An ESS or demand response was not considered in this case Since the energy from the own DG is costless just the energy to be taken from the PES $E_{PES,NO}$ and the corresponding costs $C_{PES,NO}$ are given. Below the no optimization case the results using only individual optimization performed by the GA are represented. This means that the ESS usage within the prosumer is activated

TABLE I
Resulting Costs of Power Consumption

Case	Prosumer	5	6	All
	E_{total} (kWh)	3.358	7.917	88,052
No Optimization	$E_{PES,NO}$ (kWh)	1.738	2.629	60,336
	$C_{PES,NO}$ (€)	**0.488**	**0.721**	**16,810**
Individual Optimization	$E_{PES,IO}$ (kWh)	0.428	1.811	42,786
	$C_{PES,IO}$ (€)	0.115	0.443	11,143
Individual Optimization with Local Energy Market	$E_{PES,wLEM}$ (kWh)	0.363	1.036	18,240
	$C_{PES,wLEM}$ (€)	0.097	0.244	4,245
	E_{buy} (kWh)	0.065	0.777	24,546
	C_{buy} (€)	0.007	0.086	2,664
	E_{sell} (kWh)	1.087	0.808	24,546
	C_{sell} (€)	-0.118	-0.069	2,664
	$C_{total,M}$ (€)	**-0.015**	**0.261**	**4,245**

as well as demand response has been taken into account ($E_{PES,IO}$, $C_{PES,IO}$). The last result exhibits the combination of individual optimization and the auction in LEM. Besides the energy to be taken from the PES and its corresponding costs ($E_{PES,wLEM}$, $C_{PES,wLEM}$), the energy to be taken from the market and the costs (E_{buy}, C_{buy}) are listed. In order to determine the overall costs the energy sold at the market and the revenue (E_{sell}, C_{sell}) is represented, additionally. Finally, the total costs ($C_{total,wLEM}$) for energy as the sum of all cost and the benefits are listed in the last row. The results are given for the prosumers 5 and 6. Additionally, the energy consumption and costs for the whole cluster network are depicted in the last column.

The results show that prosumer 5 as well as prosumer 6 could reduce their energy consumption from the PES significantly. After the individual optimization prosumer 5 need to take only about 25 % of the energy from the PES (*0.428 kWh*) compared to the case without optimization (*1.738 kWh*). After market operation *0.065 kWh* have been bought from the LEM with cost of only *0.007 €*. This reduced the energy to be taken from the PES addi-tionally. Furthermore, prosumer 5 has sold *1.087 kWh* to the market with a revenue of about *0.118 €*. Thus, all in all instead of paying *0.488 €* prosumer 5 generates a profit of *0.015 €* due to the GA base optimization and the opportunity of energy trading on the LEM. Similar results can be derived from prosumer 6, which reduces the total energy costs of *0.721 €* down to *0.261 €*. In total for all prosumers/households the energy to be taken from the PES is reduced from *60.336 kWh* down to *18.24 kWh*. In summary, all the results proves the effects of individual optimization process of the prosumers and the additional benefits generated through the LEM.

VI. Conclusion

In future, more and more active players, e.g. prosumers, will participate on the electrical energy supply processes. With this trend, two main issues have to be taken into account: Firstly, the grid control will become more complex and new smart grid concepts are required in order to ensure stable and reliable power supply systems. Therefore, the CPSA has been introduced as an adequate concept for adopting advanced grid control functionality into the DSO-Level. Secondly, energy market related issues arise significantly. A prosumer will not be longer just a passive participant in the grid. They will join the markets and try to optimize their energy consumption and energy supply by their own DG.

This paper shows that the consideration of local energy markets in CPSA in combination with an individual optimization on prosumer level offers high potential to reduce energy costs on prosumer level. The market operation is implemented in the CMS as an auction based trading mechanism requiring appropriate communication capability between and within the network clusters. Subsequent research will need to examine further market relevant issues, as responsibilities of participants and obligations, since contractual topics have not been considered so far. As well other market mechanism, i.e. peer to peer, etc. has to be taken into account in order to develop an appropriate LEM on prosumer level in the CPSA

ACKNOWLEDGMENT

This research work is supported by the German "Federal Ministry of Education and Research" and administrated by the Projektträger Jülich (PtJ), Project: iNET-FA² (03EK3541A).

REFERENCES

[1] Arbeitsgruppe Erneuerbare Energien-Statistik (AGEE-Stat), "Development of renewable energy sources in Germany 2015. [Online], Available: https://www.bmwi.de/Redaktion/DE/Textsammlungen/Energie/arbeitsgruppe-erneuerbare-energien-statistik.html.

[2] German Federal Ministry for Economic Affairs and Energy, "Renewable Energy Sources Act – RES Act 2014", July 2014.

[3] German Federal Network Agency, "Monitoring Report 2015, Bonn, November 2015. [Online], Available: https://www.bundesnetzagentur.de/DE/Sachgebiete/ElektrizitaetundGas/Unternehmen_Institutionen/DatenaustauschundMonitoring/Monitoring/monitoring-node.html.

[4] German Federal Ministry for Economic Affairs and Energy, "Renewable Energy Sources Act – RES Act 2017", Jan. 2017.

[5] E. Ortjohann, P.Wisaranti, M. Lingemann, S. Jaloudi, D. Morton, "Multi-level hierarchical control strategy for smart grids using clustering concept", in *Proc. Int. Conf. Clean Elect. Power ICCEP'11,* Italy, 2011, pp. 648-653.

[6] P. Wirasanti, E. Ortjohann, M. Hoppe, H. Saffour, D. Morton, "Automated Active Distribution Network with Multi-Level Cluster Control Approach", in *Proc. Annual Conf. of the IEEE Industrial Elect. Society IECON'13*, Austria, 2013, pp. 1980-1985.

[7] D. Holtschulte, A.S. Erlangga, E. Ortjohann, S. Leksawat, J. Kortenbruck, T. Premgamone, „Genetic Optimization for Prosumers in Clustering Power System Approach", in *Proc. Int. Conf. Environment and Elect. Engineering EEEIC'16*, Italy, 2016, pp.1-6.

[8] E. Ortjohann, "Intelligente Verteilnetze mit fraktaler Automatisierungs-Architektur (iNET-FA²)", unpublished.

[9] S. Leksawat, A. Schmelter, E. Ortjohann, D. Holtschulte, J. Kortenbruck, D. Morton, "Implementation of Communication Model and Web Services for Cluster-Based Power System Operation in Smart Grid", in *Proc. Innovative Smart Grid Technologies Conf. ISGT ASIA'2015*, Thailand, 2015, pp. 1-6.

[10] S. Leksawat, A. Schmelter, E. Ortjohann, J. Kortenbruck, D. Holtschulte, T. Premgamone, K. Khaola-iead, D. Morton, "Demonstration of Cluster-Based Power System Automation for Future Smart Grids", in *Proc. Int. Conf. Energy Conference ENERGYCON'2015*, Belgium, 2016, pp. 1-6.

[11] S.O. Orero, M.R. Irving, "A Genetic Algorithm for Generator Scheduling in Power Systems", *International Journal of Electrical Power & Energy Systems*, vol. 18, pp. 19-26, Jan. 1996.

[12] A. Al-Hinai., "Dynamic Stability Enhancement using Genetic Algorithm Power System Stabilizer", in *Proc. Int. Conf. Power System Technology POWERCON'2010*, China, 2010, pp. 1-7.

[13] A. Abraham, N. Nedjah, L. de Macedo Mourelle, "Evolutionary computation: from genetic algorithms to genetic programming," in *Genetic Systems Programming*, vol. 13, Berlin, Heidelberg, Germany: Springer, 2006, pp. 1-20.

[14] D.A. Coley, "*An Introduction to Genetic Algorithms for Scientists and Engineers,*" Singapore, World Scientific Publishing Co. Pte. Ltd., 1999.

[15] D. S. Kumar, H. Tianyi, D. Srinivasan, T. Rindl, U. J. Shenoy, "Optimal Distributed Generation Allocation using Evolutionary Algorithms in Meshed Networks", in *Proc. Innovative Smart Grid Technologies Conf. ISGT ASIA'2015*, Thailand, 2015, pp. 1-6.

[16] Y. Alinejad-Beromi, M. Sedighizadeh, M. R. Bayat, M. E. Khodayar, "Using Genetic Algorithm for Distributed Generation Allocation to Reduce Losses and Improve Voltage Profile", in *Proc. Int. Universities Power Engineering Conf. UPEC'2007*, UK, 2007, pp. 954-959.

[17] European Parliament and Council, "Internal Market in Electricity Directive 96/92/EC", Dec. 1996. [Online], Available: https://www.energy-community.org/pls/portal/docs/36275.PDF.

[18] F. Teotia, R. Bhakar, "Local Energy Markets: Conept, Design and Operation", in *Proc. Nat. Power Systems Conf. NPSC'2016*, India, 2016, pp. 1-6.

[19] J. B. Cardell, "Distributed Resource Participation in Local Balancing Energy Markets", in *Proc. Int. Conf. PowerTech PowerTech'2007*, Switzerland, 2007, pp. 510-515.

[20] M. Ampatzis, P. H. Nguyen, W. Kling, "Local Electricity Market Design for the Coordination of Distributed Energy Resources at District Level", in *Proc. Innovative Smart Grid Technologies Conf. ISGT Europe'2014*, Turkey, 2015, pp. 1-6.

[21] Vatenfall AB, "The Common European Energy Market: Electricity, Gas, and Heat". [Online] Available: https://de.scribd.com/document/262963008/Common-European-Energy-Market-2011.

[22] Clean energy Wire, "Setting the power price: the merit order effect", [ONLINE] Available: https://www.cleanenergywire.org/factsheets/setting-power-price-merit-order-effect.

[23] C. Rosen, R. Madlener, "An Auction Mechanism for Local Energy Markets: Results from Theory and Simulation", in *Proc. Int. Conf. Complexity in Engineering COMPENG'2012*, Germany, 2012, pp. 1-4.

[24] ENTSO-E, ENTSO-E Network Codes, [Online] Available: https://www.entsoe.eu/major-projects/network-code-development/Pages/default.aspx.