Abstract: The German research project „E-DeMa“ aims at the development and demonstration of associating up-to-date information and communication technology with the operation of electric distribution power systems towards the “energy market place of the future”. Electronic meters installed at private customers communicate with the central energy market place via a special gateway and broadband data connection. The information exchanged comprises electric metering and measurement data from, as well as dynamic pricing or switching commands to, the customers. One of the work packages of this project investigates to what extent the communication structures, which are primarily implemented for market functions, can also be used for innovative applications and functionality in the area of distribution system operation for both system control and planning purposes in order to make the system more transparent and to impact the loading of the system by use of either dynamic pricing to the customers or by direct control actions to, e.g., micro CHP plants or appliances having relevant data interfaces. The MV/LV transformer stations can be used as data concentration points for the information channels, and they are equipped with data interfaces themselves in order to gain measurements from them, too. In the frame of the „E-DeMa“ project these and further potentialities of innovative distribution system operation are investigated, based on simulations and partly by means of a field test. In particular the latter will reveal the readiness of customers to make use of contracts and dynamic pricing for load management, and thus exhibit to what extent this really can be used for overload relief.

1 1. INTRODUCTION

The E-DeMa project (E-DeMa), funded by the German ministry of economics, aims at the development and demonstration of associating up-to-date information and communication technology with the operation of electric distribution power systems towards the “energy market place of the future”. The customers – both pure electricity consumers as well as small distributed electricity generators –, altogether called “prosumers”, participate at the central electricity market via a special local gateway and broadband data communication, transferring measurement and metering values from the local electronic meters to the market place, and dynamic pricing, switching commands or generator settings to the prosumers, see Figure 1. The administration of information and services on the market place can be bundled by “aggregators”.

One of the work packages of this project deals with the potential use of this information and communication infrastructure – primarily created in the context of the market place – for the implementation of innovative applications in distribution system control. The idea is to make technical information from the prosumers – which arises anyway – available to the distribution system operator for control or planning tasks; thus, efficiency and security of power supply can be improved by the possibility to influence the loading of the system or of parts of it by dynamic pricing or other means.

Area-wide equipage of prosumers with electronic meters and the described information technology would afford a comprehensive survey of the distribution system status, even on low voltage level, which was unimaginable so far. For instance, the voltage profile along a low voltage cable or – in balancing the actual currents of connected prosumers – the loading of cables or cable sections can be observed without the necessity of implementing further measurements. This opportunity, which is highly relevant for system planning, doesn’t require transmission of scads of data; rather selective information transfer at a given point of time – for instance at peak load – or from a pre-selected set of locations is sufficient.

Various control actions impacting the system loading are possible: dynamic pricing for all, or a selected set of, prosumers (for instance such ones connected to system parts jeopardized by overload) which stimulate to adapt consumed or produced electrical power; but, based on an adequate contract offering price advantages, the system operator can set the operating points of distributed small generators or disconnect certain load circuits of prosumers either directly or via their aggregator.
The MV/LV transformer stations can be used as data concentrators for the information channels, and they can also be equipped with data interfaces by themselves, see Fig. 1.

The latter allows for transmitting numerous measurements from the MV system – thus also giving an insight into loading and voltage profiles et cetera –, or of further information such as transformer temperatures, based on which loading dependent transformer maintenance (oil change) could be introduced. If the switches in the MV/LV stations are remotely controlled, flexible arrangement of section-points is possible, not only after occurrence of failures rather than even dependent on system loading with the goal of loss minimization.

Last but not least, additional installation of power quality recorders in MV/LV stations – or even at certain prosumers – would allow for fast and easy location of disturbance sources if the recorders automatically send alerts after triggering via the communication channel existing anyway.

2 APPLICATIONS FOR DISTRIBUTION SYSTEM OPERATORS IN THE E-DEMA PROJECT

In the frame of the E-DeMa project these and further possibilities of innovative distribution system operation are being investigated in simulative manner and partly in a field test. Especially from the latter an insight in the acceptance of contracts and signals for load adaptation is expected, which is hard to assess in advance. In this way in fact it will become evident to what extent the control measures for load deferral lead to alleviation of grid short-age or compensation of high renewables based generation.

In particular, from the distribution system operator’s point of view the following functionalities are relevant:

• influencing power consumption and dispersed generation by means of dynamic pricing and flexibility tariffs;
• clearing of grid shortages and congestions;
• compensation of high renewables based generation;
• fault localization and management;
• control of certain circuits and devices for fault clearance;
• economic system operation, loss minimization.

In the field test the concepts of market place and communication infrastructure will be verified according to their technical feasibility. All relevant mechanisms such as contracting, power control by dynamic pricing or flexibility tariff up to the data provision as a basis for financial balancing will be demonstrated. Rather, the concepts for fault clearance improvement can only be demonstrated in restricted manner since it is expected that the local and temporal limitation of the field test will account for occurrence of very a low number of grid faults only.

The measurements collected during the field test will deliver a comprehensive base of statistical data on the natural behavior of prosumers (i.e. without any inducement) and, in comparison, the reactions on the pricing and flexibility tariffs. Beyond the prototypic validation in the field test, the results must be up-scaled to realistic sizes and numbers of distribution grids with hundred thousands or millions of customers, which implies the performance of extensive simulative calculations. This will also lead to the possibility for assessing the potential of energy and CO₂ emission savings, thus disclosing options for accomplishing the ambitious goals of energy policy. Furthermore, the field test results will indicate if and how the legal environment has to be adapted.

An essential point is the recruitment of customers participating at the field test. In order to achieve meaningful test results, the multitude of customers participating have to be thoroughly informed and prepared in advance. 110 households out of them will be equipped with advanced communication gateways which additionally allow for interaction between the in-house control of certain appliances – washing machines, dish washers and tumble dryers, see (Miele) –, and the aggregator’s system. 20 of these prosumers will also have micro generation. Furthermore, adequate tuning of stimulation mechanisms is a demanding task already in the test period: on one hand their remuneration has to deploy sufficient appeal to the prosumers, on the other hand they should not be too expensive for the distribution system operator if they should constitute effective economic options.

Some principal functionalities relevant to the distribution system operator are described in some more detail in the following.

3 DAY-AHEAD PRICING

The pricing used in the field test are understood as day-ahead price profiles (World Bank, 2005). This means that, latest on the day before at a fixed time, for the 24 hrs of the following day a fixed schedule (hourly, ¼-hourly or for certain tariff times) is announced. The exact modalities of reception (i.e. transmission to a display, publication on a website or a personalized portal or, at longer lead-time, in printed form) have still to be decided.

From the viewpoint of a distribution system operator it appears desirable to have the pricing designed not only time specific but also location specific. For this reason, the distribution system would be partitioned in sectors; for different sectors different (location specific) pricing can be applied at the same time. During the field test all power suppliers will forward the pricing given by the distribution system operator directly to the prosumers. By this concurrent reception identical pricing is ensured to all prosumers in a certain sector, independent of their power supplier. The size of the particular pricing sectors should be defined by the distribution system operator and identified (for the power supplier) via a list of related metering identifiers.

In the frame of the field test the prosumers supplied by one MV/LV transformer or by the MV/LV transformers along one MV feeder are possible pricing sectors. The distribution system operator announces the assignment of metering identifiers to pricing sectors to the relevant power suppliers via the central market place.
Regular prosumers operating usual electric devices only make use of dynamic pricing by conscious and manual modulation of loads. At those prosumers who operate own controllable generation (for instance a micro CHP plant) or controllable appliances (such as a washing machine with data interface), the dynamic pricing directly impacts on the controllable device(s) via the local data gateway which in this case has accordingly extended functionality. In the field test this can lead to activation of a washing machine at 11.15 h if the possible operating time was selected between 8.00 h and 15.00 h by the prosumer.

4 POWER FLEXIBILITY

As a short term intra-day influence mechanism (time horizon from 15 minutes up to some hours) the distribution system operator can make use of the functionality of power flexibility. In this context set-point values are assigned to dispersed generators; furthermore, controllable devices such as washing machines and other household appliances with data interfaces or heat pumps – if present – can be selectively switched on or off.

The contracts for power flexibility can be administered and bundled by an aggregator and have the distribution system operator expect a relatively high respond rate. In the frame of the field test power flexibility with a step-width of 15 minutes will be installed and specified as follows:

- type of dispersed generator or controllable device;
- control range (minimal/maximal power);
- maximal active power flexibility which can be requested in the frame of the contract;
- list of metering identifiers relevant for the contract;
- temporal validity of contract;
- maximal number of requisitions within run time of contract (optional);
- duration of requisition (15 minutes up to some hours);
- dates and begin of requisition;
- tariff structure;
- maximal power gradient (of minor importance at 15 minutes step-width).

Approximately 1-2 minutes before a request the current active power measurement values are polled from the relevant prosumers’ local data interfaces by the distribution system operator. If available, preference lists managed by the aggregator are applied, i.e. power changes are requested according to this list, and only if the first request does not suffice it is reverted back to the next list entry. The ¼-hourly power set-points for the prosumers actually considered are calculated and transmitted to their local data interfaces.

Reference for balancing could be the summarized last ¼-hour active power metering values of relevant prosumers before the request was sent. For contract compliance check it must be possible for the distribution system operator to poll the actual metering values before and during the request period from the central data management system of the market place.

Since the distribution system operator will conclude the power flexibility contracts under consideration of topological coherence, he will get an indication of the impact during the request period by change of the active power measurement value of the relevant MV/LV transformer, which is transmitted to the control center every minute. The identified load change must not necessarily match exactly with the change of summarized ¼-hours metering values: while the power measurement will indicate to the distribution system operator if further measures need to be applied, the sum of metering values is relevant for proof of contract compliance and financial balancing.

5 INTERDEPENDENCY BETWEEN CUSTOMER STIMULATION AND LOAD SHIFTING

Besides a desired – but expectedly moderate – decrement of load, the major effect of stimulation measures will be shifting portions of load from time periods which are unpropitious for the grid to other times hardly to anticipate precisely. This may lead to the effect that a stabilization measure taken at one time causes a de-stabilization of the grid at another time. First simulative calculations proved that this effect strongly depends on the level of the given pricing: generally, a very low price signal would have minor impact, while a very high signal would significantly induce the before mentioned effect. Thus, a well balanced pricing has to be provided, which in fact cannot determined by pure simulation rather than experienced by practical trial in the frame of a field test.

6 APPLICATIONS IN FIELD TEST

The applications implemented for the field test will be sketched in the following; it is presupposed that load flow calculation is available which makes use of information transmitted from the prosumers by the local data inter-faces. The information handled are the ¼-hours metering values, collectively transmitted once a day for the last 24 hours to the central data management of the market place, made anonymous and partly aggregated.

The distribution system operators make their day-ahead scheduling by off-line load flow calculations based on predicted loading of the particular MV/LV transformers, estimates the necessity of measures for power influencing, and decides on those to be applied according to the given potentialities (for instance to convey day-ahead pricing). In the ideal case, the day-ahead scheduling would be sufficiently exact that an intra-day correction is not required any more; but it is expected that, from time to time, additional request of power flexibility is needed which, in the course of the particular day, is then derived from a 2-hours short term prediction; this, of course, has much higher
accuracy than the day-ahead prediction. In account of the short term prediction the distribution system operator could come to the conclusion that limit violations must be expected. In this case it would automatically be evaluated which prosumer(s) could contribute to violation clearance and if appropriate contracts with them are existing; if so, these are proposed to the dispatcher and he could then conduct the requests.

None of the distribution system operators participating in the field test has a short term prediction yet. Therefore, for testing purposes requests for power flexibility have to be induced arbitrarily and will give evidence of the quantitative effect of impact (without real operative reason).

If, in the course of the field test, a thermal limit violation would occur allowing for a respond time of 15 minutes to initiate countermeasures, it seems improbable that this would happen exactly on such feeder where dispersed generation is installed. However, even if this would be the case, it is still improbable that the available power margin of dispersed generators would suffice to overcome the limit violation, since the power of micro combined heat-power units participating in the field test amounts to 20 kW in total only. The full power margin of all these units will be available only rarely, and furthermore the units are connected to different LV circuits.

In this respect the field test will primarily afford a feasibility proof and allow for an evaluation of the impact mechanisms which are necessary for implementation of this kind of control in greater scale. In the course of the field test pretended limit violations are evoked by fictitious reduction of the deposited boundary values; in this way it can be checked out if the fictitious limits can be met by relevant control measures. In any case dispersed generators will receive control commands only at need, otherwise they can feed in arbitrarily.

Regarding the fault localization and re-supply functions it must be expected that these can only be demonstrated in study mode (i.e., with simulated alarm messages) since the probability of fault occurrence in the confined system section allotted to the field test within the limited duration period of the test is rather low.

7 FURTHER APPLICATIONS

Besides those applications which are being practically implemented in the frame of the field test, another set of functionalities is being investigated on the basis of computer simulations with the distribution system modeled in high fidelity:

- additional consideration of controlling heat pumps and charging stations for electric vehicles in order to avoid limit violations;
- optimization of losses by topological switching and load shifting;
- power limiting of prosumers by separately controllable circuits – in the sense of advanced and more flexible ripple control;
- analysis of voltage profiles on both MV and LV voltage levels;
- identification of non-technical losses;
- evaluation of the overall power quality based on power quality recorders distributed in the system;
- reactive power control of dispersed generation.

8 SUMMARY AND OUTLOOK

The data interfaces installed at the “prosumers” in the frame of the German E-DeMa project can provide the distribution system operator with information which, in terms of quantity and quality, widely exceeds the data usually available nowadays; furthermore, the distribution system operator can impact on the customers’ load performance in both indirect (dynamic pricing) or direct (power flexibility) manner. By means of simulations and partly by a field test the corresponding applications are implemented and investigated in which way these functionalities can practically be used in power system control as well as for power system planning purposes.

The benefit of the applications described here should in first order contribute to avoid – or at least postpone – expensive grid extension measures, especially in those cases where the underlying power peaks caused, e.g., by massive dispersed generation or electro-mobility (Einwaechter and Sourkounis, 2010) would occur at short periods of time in the year only.

A fully new problem will occur in connection with balancing if, for instance, the distribution system operator requests system services from prosumers which is not known to the transmission system operator. This will affect real time system control as well as subsequent financial balancing.

In this context also the question occurs if load shedding schedules of transmission system operators for emergency cases have to be re-considered, according to which in particular those distribution systems are disconnected which could actively contribute to overcome the problem by their available system services (e.g., reactive power).

9 REFERENCES

E-DeMa  http://www.e-dema.com/en/
Fig. 1. Structural diagram of E-DeMa field test arrangement.