INTEGRATING DEMAND FLEXIBILITY WITH DG-RES AT THE RESIDENTIAL HOUSEHOLD AND COMMERCIAL CUSTOMER LEVEL IN ELECTRICITY GRIDS

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ABSTRACT

Commercial and operational use of residential and commercial user demand-side flexibility in energy grids will play an important but, as yet, not disclosed role in realizing the required increase in the penetration of DG-RES. An increased embedding potential is needed to satisfy ambitious energy efficiency and carbon dioxide emission targets. Introduction of smart technologies is seen as a facilitator but also encounters technological, operational, market and regulatory challenges. From assessing a number of technologies and field test projects, task 17 of the IEA/DSM program has explored the nature of this demand-side flexibility and the stakeholder context. It was found that a portfolio of services and control strategies for coordinating flexibility in an efficient, safe, reliable, and scalable manner can be found. The boundary conditions, valuation and practical implementation are also discussed.

INTRODUCTION

Within the IEA DSM program, Task 17 was started in 2009 [1] to characterize demand response, distributed generation and storage. Phase 3 of this task was executed from 2014-2016, and analyzed the application of demand response, distributed generation, and energy storage in electrical energy systems and grids in a number of European countries, the US and India. Variable generation of electric energy, like wind or photovoltaic, and energy carrier substitution to electricity for heating and mobility applications, like heat pumps and EV-chargers, are challenging to integrate into existing electric networks and markets. New approaches for local and global network management as well as new market concepts are currently developed. Solutions include increased flexibility of both generation as well as demand-side resources, including additional deployment of electric and heat storage systems. Already now, electric grid assets need to be upgraded or made 'smarter' to serve increased, variable, sometimes multidirectional power flows resulting from use of the many flexibility options in parallel. Special focus was given on the role of flexible demand at households and buildings. Demand response in buildings requires motivation of participants, particularly in economic sense, i.e., properly incentivized by energy policies and adequate information and communications technology (ICT) resources. Contrary to other flexibility options, DR in buildings has low investment costs and is a low operational cost enabler particularly at a relatively early stage of energy system transition with uncertainties ahead.

ASSESSMENT METHODOLOGY

The methodology used in the project is depicted in Figure 1. Firstly, a thorough analysis was made of the roles and interactions of customers. The technical power (kW) and energy (kWh) potential of demand and supply device types have been evaluated with respect to their time interval and frequency of use. ICT requirements for control and coordination were determined on the micro-level. Thereafter, macro-level operation and value creation aspects were analyzed by assessing a number of long-term cost-benefit calculations of the application of

DR-technologies.

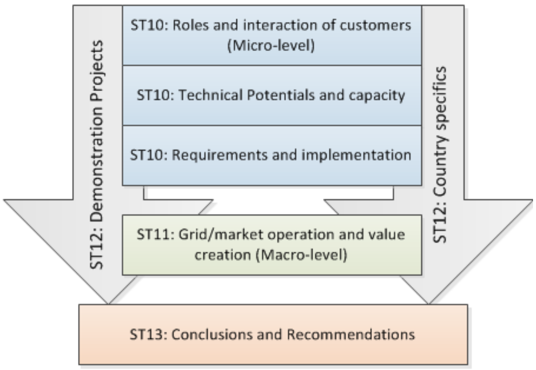

Figure 1. Scheme of the assessment methodology

Based on these activities the task arrived at a number of significant conclusions. Each of these aspects of the investigation are summarized in the following sections.

ROLE AND INTERACTION EVOLUTION

In the energy transition, the consumer role will be more of a *prosumer* and the supplier also will buy electricity at certain moments in time. Another changing role is foreseen for the distribution network operator that also will have to fulfill a role as system operator dealing with local grid operational problems due to local renewables production (e.g. PV) and new HVAC (HP, cogeneration) and EV loads. For DSOs, capacity to deliver flexibility then can treated as an asset to invest in, as in grid components.

In power systems in liberalized market settings, planned power delivery programs are mainly checked according to the network capacity and topology on a day-ahead basis at the transmission system level. With increasing volumes of LV-grid generation and LV-loads, similar checks have to be made on at the distribution grid level also covering more near-to-real-time timespans. Finally, also prosumer communities arise to reach certain renewable targets by mutual electricity trade. With the advent of mobile devices like tablets and smart phones and smart meters producing up to 15 min interval metered kWh and 10 second interval real-time values also for the small consumer segment, electricity retailers already are in the process of rolling out extended information services via apps to customers giving tailored feedback. Also as a result, aggregators arise in the value chain, that build on information and communication services to manage the resulting scale and complexity of optimizing and assigning this flexibility to the actors in an optimal and cost-effective way.

To exchange value between the players in these new settings, to the end user, existing tariff mechanisms do not adequately map their role nor do they yield incentives for change their behavior to generate the required demand response. Tariffs also use macroscopic, averaged factors to account the commercial and grid operation of the electricity system; e.g. synthetic profiles for market allocation and reconciliation and time-independent connection capacity based distribution tariffs. Apart from that, especially on the longer term, customers are very reluctant to becoming an energy manager on a day-to-day basis and having to react upon tariff signals manually. Therefore, demand response automation is an important pre-requisite for successful deployment. Figure 2 illustrates the possible interaction mechanisms between customer demand and supply and electricity system. The picture shows the communication directionality on the X-axis and the decision making level at the Y-axis.

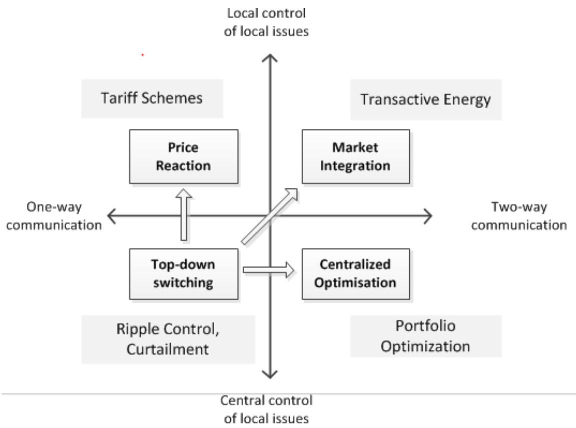

Figure 2. Communication directionality and decision making level

Existing tariff schemes (upper left quadrant; tariffs are broadcasted to customer uni-directionally) were found to only uncover less than 40% of the technical potential of DR-resources within the electricity consuming primary process context. DR-automation lifts this potential to maximally 70%. Tariff incentives then, really have to be very strong. In the studied pilot projects, direct market exposure via transactive schemes [2] with bidirectional communication was found to lead to uncovering a higher percentage of DR at smaller cost.
Innovative, distributed control and coordination approaches that scale easily and address the complexity

of interactions with multitudes of devices, hold promise for reducing integration and maintenance costs; however, their familiarity and maturity level need to increase before large-scale deployments will likely be realized.

Electrical flexibility can be used either implicit or explicit and it is either declared or not-declared by the customer in the market or grid operational context. Greater transparency on the value of flexibility demand for multiple grid services is needed to provide adequate commercial signals for technology deployments. This includes the locational value of flexibility to address electricity infrastructure constraints. Managing the commitment of demand flexibility to address multiple grid services is a challenge that needs to be addressed to realize its full value.

TECHNOLOGY POTENTIALS AND AUTOMATION

Thermostatically controlled loads and heat/cold storage

Thermostatically controlled loads, due to their thermal inertia, have a considerable flexibility potential in end-user DR. With heat or cold storage, temperatures can be kept for extended time-periods without impairing user comfort levels. Using inherent or dedicated heat/cold storage capacity allows uncoupling heat and electricity production. As an energy efficiency measure, electrical water heaters with resistance heating, used throughout in early DSM-programs already are mostly replaced by heat-pumps with a small resistance heater only for a final temperature. Hybrid energy storage solutions have attracted a lot of interest in the last few years. In countries with significant heat or cold demand, energy storage in the form of thermal storage is cheaper than electricity storage and connects the operational coordination of heat or cold production to electricity generating or consuming devices. As shown in Figure 3, taken from the PowerMatchingCity fieldtest [3], in buildings, depending on the building thermal mass, the heat storage capabilities and the duration of the shift can be in the order of 1-6 hours.
Engaging utility and office buildings with automation and communication technology attached to existing building automation systems for HVAC will be easier to cost justify, once these are part of the deal for the users and building managers but also for the investors in commercial buildings. For end customers, the picture is different. In case of heat pump and small cogeneration, financial benefits are directly linked to the energy bill and interfacing of the required ICT can be done easily via the thermostat. In assessed field tests, cheap hot water heat storage, proofed to extend the flexibility in time considerably.

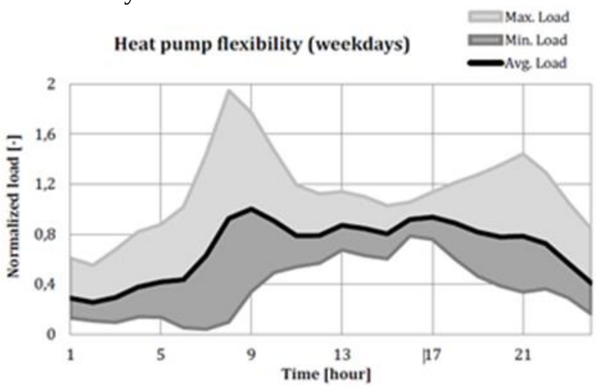

Figure 3. Normalized load flexibility from heat pumps [3].

Compared to HVAC, food storage offers more limited energy and capacity shift capabilities. Commercial industrial cooling and freezing systems have seen a considerable efficiency increase as well. In industrial freezing and cooling, market driven planning of defrost cycles provides an opportunity for providing demand response services. So, here the overall potential is higher. White goods (coolers/freezers), and wet appliances (washers, dryers) have very delicate primary process and quality constraints and also have seen an increase in energy efficiency during the last decades, making the absolute volume of DR less. ICT interfacing is becoming easier and cheaper through IoT(Internet of Things)-based technologies. Wet appliances have a higher potential especially during short-term electrical heating/drying steps. Electricity efficiency of compressors has increased considerably in the last decade bringing the yearly end user electricity consumption of coolers and freezers in households back to 150 kWh per annum.

EV chargers and electricity storage

EV chargers' electricity consumption profiles primarily are driven by car owner driving schedules and battery management requirements. Car owners are driven by range-anxiety striving to restore the EV's SOC (state-of-charge) to full soon after connecting to the charging point. From the car battery management system perspective, the electro-chemical processes at the cathode and anode of the battery require strictly following a charging profile constrained by the boundaries of the charging power at the current SOC. A BMS (battery management system) neither allows frequent stopping or quickly reversing the charging current nor charging outside of the bordering constraints belonging to the current SOC. Already, level 2 fast chargers are installed in homes. The possibility of serving demand response flexibility during certain periods conflicts with the user fast charging requirement. EV charging poses both a challenge and an opportunity. The potential probability, that EV charging leads to exceeding electricity distribution capacity limits is increasing with higher penetrations of EV and schedules with fast charging. The latter also is found to lead to additional flexibility requirements at the higher MV levels. The mobility of the EV means that the local impact can change throughout a day, week, or season. However, the potential for EV charging and discharging to be scheduled or otherwise modulated can make them a valuable flexibility resource. If the need and value of flexibility becomes more transparent, scientific breakthroughs may allow EVs to have greater availability to participate in flexibility services.

VALUATION IN COMMERCIAL AND GRID OPERATION CONTEXT

Real-time portfolio optimization

Electricity flexibility can be used to optimize the portfolio in the hands of the BRP, that aggregates balance responsibility for all their grid connected customers, by shifting load and generation to times where the overall value to the portfolio is higher. Portfolio optimization services require a short time-frame response that might appear to be difficult to achieve for the possibly millions of dispersed DER-systems; on the other hand the response also may be considered statistically leading to at least the desired effect for a subset of the total aggregation. In studied field-tests, distributed control schemes have been shown to be able to coordinate resources to respond to price signals within the frame in the order of 2-4 seconds; however, it may also be worthwhile to revisit frequency regulation limits to understand if relaxing or restructuring the policy can better allow DER to compete on the value of these services. Real-time monitoring, at least on per PTU basis, and measuring and reconciliation of performance of installations are required to allow using aggregated response in this segment. Optimization may pertain to providing:

- Ramp-up/ramp-down capacity to improve the dispatch of large generators in the portfolio. Market trade is based on delivering rectangular blocks with a constant power over a certain period, while actual generators might need more than one PTU to come to that power or to switch to zero.
- Provide passive intra-portfolio balancing services. Flexibility of end user resources can be aggregated to adapt the current position, monitored in real-time, with respect to the program profile issued the day before. Portfolio imbalances, for instance, may result from shifts in a high-volume wind infeed energy profile. The volume of wind generation for the next day can be forecasted reasonably nowadays, but forecasting of the instantaneous power of wind on a per PTU basis still provides a challenge.
- Provide extra-portfolio balancing services. In this case, the current position regarding the program is known and the volume of additional flexibility, that exists can be offered to the TSO. This type of ancillary services is the field for which flexibility, delivered from larger installations is predominantly used. However, the market volumes to be balanced are becoming smaller due to the improvement in the quality of load and generation forecasts. Also the liquidity has been seen to rise quickly when flexibility is more and more used. Apart from large CHPs with heat buffer, flexibility of load is typically used for these services but also larger batteries or other types of hybrid systems with heat storages can be used here.
- Day-ahead and intra-day arbitrage. If the cost of imbalance is low, possibly also the retailer may benefit from higher margins on the electricity sold to the end consumers. Having demand bids counter act bulk supply offers, changes what was a one-sided market to a more self-regulating two-sided market. The aggregator here is to ensure that DER are not overcommitted to multiple grid services.

System operation support

Flexibility can also be used in order to reduce the overall peak load in the system in contingency situations. This for instance happens, once the transmission system or distribution system operator, based on the programs issued by the BRPs, comes to the conclusion, that the programs cannot be accommodated for the next scheduling period. The operator in this case has to reduce the programs and the BRPs as a result of that have to create imbalance in their programs. Depending on the expected contingency, the generation or demand have to adapt their next day profile, leading to a reduction of peaking plants, load shedding schemes or wind curtailment. Demand flexibility used today in critical peak pricing and time of use rate programs to mitigate these system peaks. Other dynamic pricing schemes and transactive energy based systems currently are being tested in the field.

Ancillary services include frequency control via short-term balancing, and voltage control via reactive power compensation at higher voltage levels. Frequency control uses primary, secondary and tertiary reserves, which are paid for by contracted availability fees and actual use rates. The area of spinning reserves represent the field for which in most systems currently power flexibility of the largest generators is predominantly used. As noted before, business models are transient and investments in generation capacity thus are risky. Flexibility of load is typically used for these services but also larger batteries or other types of storages are used here. The growth of DER flexibility will likely diminish the need for spinning reserve and these resources can provide these services more cheaply if they are integrated with applications that serve other purposes. The issue is that an adequate amount of DER is attracted to the ancillary service market and the dependencies with energy markets are understood and managed. This includes the locational value of flexibility to address electricity infrastructure constraints. Peak shaving is a use case more and more economical for energy storages. Often the maximum peak power is taken to determine the distribution/transmission tariff part for the monthly or yearly bill and as a basis for the network connection costs.
Details of the work are captured in 4 IEA published reports [1]:

- A report about new roles and opportunities as well as realized potentials of demand flexibility of consumers for optimal integration of renewables.
- Valuation analysis and analysis of different valuation evaluation methodologies
- A comprehensive list and analysis of existing and successful projects in the participating countries
- Recommendations and conclusions of the analyzed projects and the task.

CONCLUSIONS

Based on these investigation the task arrived at the following conclusions:

- DR potential on a day-by-day basis is in the order of 5-15 % with peaks up to 30% depending on the user motivation and on the flexible devices. Automation of end-user DR in most cases significantly increases the flexibility potential and makes DR have a lasting impression over time.
- Tariff structures in some countries and market design give disincentives for end-user investments or participation in DR. Cost and benefits of DR-solutions heavily depend on the market design and the regulatory context. Better mapping of roles of actors on the latter is required. From a regulatory perspective, allow for market driven usage of flexibility, i.e. load and supply, by setting clear nondiscriminatory rules for using the network. Connection capacity fees to real-time power distribution tariffs.
- New levels for (virtual) aggregation of DR are now emerging in the energy transition. Most notable are self-consumption, the community and at the DSO operational level.
- Set simple rules for optimizing self-consumption and use the flexibility given there for efficient network planning and expansion, i.e. use self-consumption together with control techniques to avoid network expansion.
- Allow actors to make the transition into their new roles. This requires involvement of power transport constraints to be reflected in the aggregators' bidding and operational decisions.
- Social media and ICT in smartphones, PCs and tablets allow the design of attractive energy dashboard products for consumers and producers. Use Internet marketing logics to have consumers to take active part in pilot and demonstration projects in order to gain experiences and show that it works and show the benefits.

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