ComForEn 2021

Using Flexibility Offered by End User Owned Energy Assets

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Abstract – The presented discussion focuses on electric load and production flexibility. Load flexibility could be used to utilise the volatility of distributed renewable sources, increasing the renewable share in the average energy mix. Demand side management can support the balancing, locally within the distribution grid, but also on the energy market across the sources and loads served by an energy supplier or aggregator. We discuss how to identify flexibilities on a per customer level, how to offer flexibilities to potential users, how the quality of offers shall be quantified to achieve a viable fair pricing that a priori covers the inevitable non-fulfilment risk, and sketch how to schedule and possibly aggregate offers. Utilising flexibilities is one piece of the energy transition puzzle, possibly a big one. However, only a plurality and variety of approaches and systems will enable the intended net-zero CO_2 budget, and eventually a truly sustainable renewable (cyclic) energy system.

1. Introduction

Many end-customers voluntarily adopt new technologies that reduce their carbon emissions [1], regulatory and political measures yet to come intend to escalate the adoption rate further. Most prominent are rooftop solar photovoltaic (PV), battery energy storage systems (BESS), electric vehicles (EVs), and electric heat pumps. The path to climate neutral electricity is paved with a plethora of heterogeneous, mostly distributed, still heavily interrelated and customised solutions. Local assets that can be managed actively are referred to as Distributed Energy Resources (DERs) because they commonly reside on customer premises, i.e., behind the meter, and enable some control of the local energy demand and/or production.

Control can be direct, e.g., switching an appliance on/off, adjusting the actual power demand, or by adapting set power limits. These control actions cause an immediate change. While on/off is in principle always possible, it shall be a last resort emergency measure because many appliances may be troubled if such harsh interference occurs frequently. Indirect control that manipulates appliance specific set-points, e.g., the intended temperature, also impact the energy demand, although commonly with some time lag. If adjustments are based on prediction, i.e., performed proactively, the response time can be compensated by setting the control action accordingly earlier. The resultant potential power changes state available flexibility.

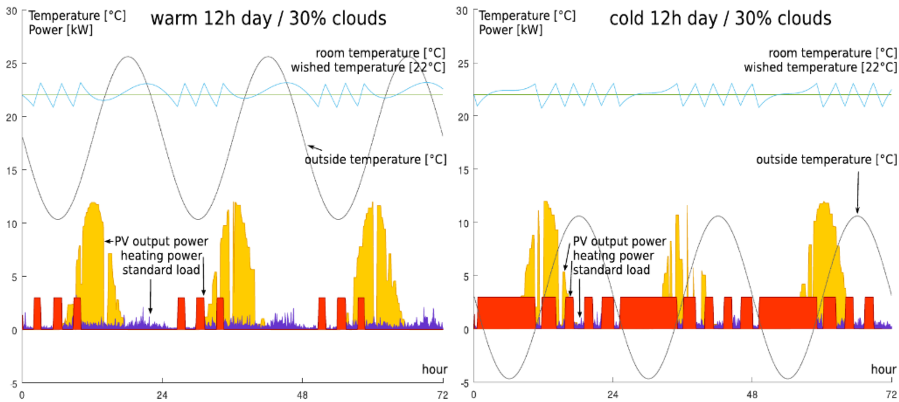

Figure 1: The flexibility offered by customer appliances depends on many factors and varies over time and season. Still, on similar days similar load and production patterns may be identified. These can be used to assess flexibility potentials, the availability and other statistical characteristics of flexibilities [2].

Every appliance has its power flexibility and availability distribution. Both most likely change over the day and across seasons, as shown in Figure 1 for successive days, simulated with equal outside temperature change and randomly distributed cloud cover. The heating intervals slightly move around from day to day, and PV production is interrupted by clouds passing by. Still, we can see recurring patterns, from which we intend to derive timed flexibility offers.

In section 2 we outline the relations of flexibility with the established energy system: How is the energy system organized and how does the energy transition fit in, who may want to buy flexibility, and who can provide flexibility. Section 3 presents an approach to assess the quality of a flexibility offer, addressing both, the providers' and purchasers' aims and needs. In section 4, we sketch how the scheduling of flexibility execution can be pre-planned, and in section 5, how to aggregate flexibilities to achieve high quality offers. Finally, section 6 concludes the discussion and briefly summarises the issues identified.

2. The energy system transition

The transition of the energy system toward a sustainable energy supply is inevitable and has already begun, as indicated in the introduction. The replacement of any fossil fuels is eminent to counteract the manmade climate change. Renewable energy sources (RES) are the most prominent and widely accepted option in contrast to nuclear sources for which neither the waste disposal nor the risk management is yet solved. Photovoltaic electricity generation (PV) and integration of all kinds of DER are essential to achieve the energy transition [1]. However, power from PV is available only when the sun is shining, not comparable to traditional power plants with a rather constant raw power supply or sufficient reservoir to guarantee uninterrupted generation. In addition causes the simultaneity across a region curtailment of PV production around noon. That is neither economic nor ecologically proper, and diminishes the owner's profit causing poor return on investment, a sad example for flexibility usage.
Transition hindrances also result from the energy market, which yet is not designed to handle many volatile not always available RES. Many bulk electricity sources cannot be adjusted sufficiently quickly to compensate the volatility of RES, and legacy power plants may have already sold major shares of the lifetime production to finance their construction. Curtailment or on-demand power provisioning is no option for contractual and economic reasons.

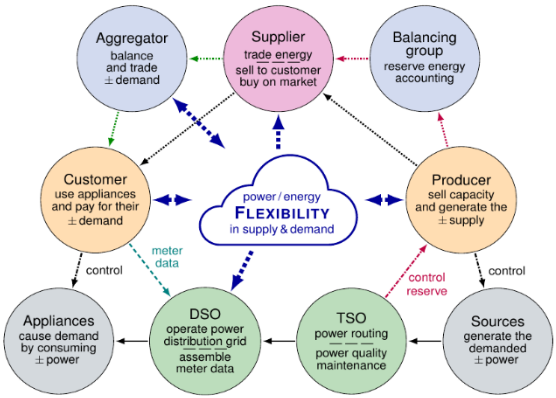

Figure 2: Flexibility in production and consumption could be used by many stakeholders for different purposes with diverging aims (based on [3]).

Figure 2 sketches the established energy system. Electric power conduction is positioned on the bottom and trading the electric energy on the top. On the left, the electricity consumers (appliances) and their users, the customers, are shown, and opposite thereto on the right, are the generators that convert some form of raw energy into electricity, and their operators who sell electric energy to the brokers on the energy market. Active Customers (ACs) and Energy Communities (ECs) as specified by the European Clean Energy Package [4-7] are entitled to trade energy in all markets, similar to the Aggregators shown top left in Figure 2. Regulatory requirements to participate on the energy market shall be fulfilled likewise [5, 7]. Among peers, ACs and the members of ECs can share RES and DER, and may trade energy on a private basis, possibly even independent of the regulated energy market.

Traded energy needs to be transported over the electricity grid, regionally operated by the local distribution grid operator (DSO). Grid codes, also known as network codes, need to be obeyed. ACs and the members of ECs are in general far from self-sufficient in their energy balance and thus, remain clients of their individual energy supplier [6, Article 4]. However, excess power from private generation and the flexibility of loads they control, they may offer as flexibility. Top right in Figure 2 is the Balancing group, which bills the used reserve energy to the energy suppliers dependent on the deviation between energy purchased and actually consumed by their customers [5, Article 6]. Physical power balancing is commonly managed by the Transmission System Operator (TSO), who controls any electricity generation of size connected directly or indirectly to their transmission grid [6, Article 40].

Flexibility can be offered by customers and producers only. It is provided solely by the energy appliances they control. In case they participate in a virtual power plant (VPP) or have some demand side management (DSM) agreement with an aggregator or supplier, they sell their flexibility and hand over the control. These purchasers buy flexibility to reduce their reserve energy demand or to sell it on the intra-day market in case the current price is good. The other purchaser group interested in flexibilities, in particular in localised flexibilities, are the DSOs. They could use it to stabilise local feeders, to perform peak shaving and thereby possibly postpone grid expansion, and to reduce the peak to average gap to utilise their resources more evenly. However, most DSOs are prohibited from energy trading by unbundling regulations.

3. Assessing the quality of flexibility offers

Flexibility is a feature that may be available at times but is never perfectly assured. The output of a PV-inverter can be controlled only when the sun is shining. Deactivating a heating system is only effective if the heating system is currently consuming power. Consequently, a key quality of flexibility offers is the probability that produced or consumed power can actually be altered. The metric is the availability of a certain power-change. The PV-inverter example shows that the availability and the average amount of the available power alteration depend on the time, the season, the weather characteristics, and only finally on the PV system itself.

In Figure 3, we averaged thirty modelled days with identical temperature change and randomly distributed cloud cover across an equilibrium day (6am sunrise, 6pm sunset), similar to those shown in Figure 1. Shown are the in average available power change and the availability of these changes, being the darker shaded areas close to the zero line, scaled from zero to one. Around noon, curtailing PV production is quite probably available on a rather sunny day with only 30% cloud cover. The availability of flexibility from the heating system is far below because two constraints need to be fulfilled simultaneously: the heating system has to be in a usable state, and the current room temperature needs to allow the change. In addition thereto wander the heating intervals, such that the on-to-off ratio also affects the availability.

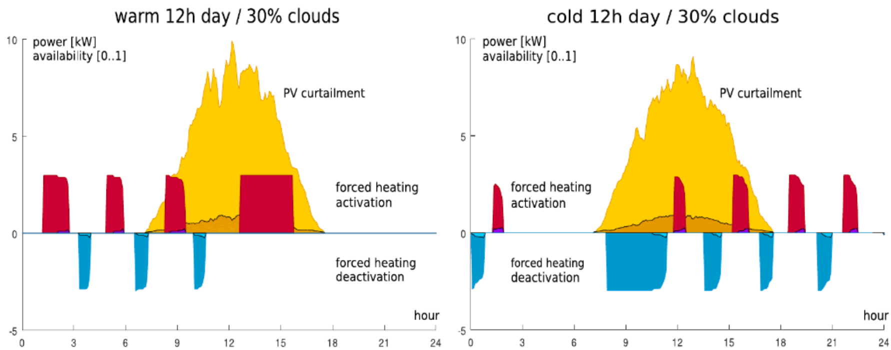

Figure 3: The characteristics of flexibilities result from statistically evaluating sets of days that show a similar pattern [2].

To consider the limited availability, we developed the two dimensional quality rating scheme presented in [2]. The expected availability is covered by one dimension, the other covers the willingness of the asset owner to provide or sell the flexibility. Both are discretised into five bins. The extremes cover special properties and circumstances, and remaining three bins in between cover good, medium, and poor. The more reliable an offer is, the more will a flexibility user pay, and the more compensation a flexibility provider is offered, the more discomfort or control loss will be accepted. Anyhow, the price paid shall a priori cover the possibility not to fulfil an offer. That shall prevent any a posterior reimbursement alike paying for reserve energy and calm any economic fears that could effectively scare off most private customers from offering their individually small but widespread power consumption flexibilities.

4. Optimising the execution of flexibilities

The term Demand Side Management (DSM) refers to managing DERs in general. Diverse approached thereto were proposed and several are readily in operation. First of all, varying energy pricing, either using dynamic price adjustments to trigger on demand load changes or static prices that intend to trigger load shifting away from times at which high load is commonly expected. These schemes belong to the variety where the customers are free to tailor their respond individually. Opposite thereto are switched supply schemes, where the grid operator can cut the supply when needed, typically during high load events. Curtailment of power insertion based on grid codes or some broadcasted signal belongs to the same category, affecting the insertion not the draining of power. Most of these schemes are responsive in that they intend to adjust the load once a critical situation is detected or expected.

In contrast thereto are flexibilities predicted adjustment potentials. Comparable to the stochastic customer response to energy price changes, is the actual availability of a particular flexibility likewise stochastic. Different types of flexibilities that respond more or less reliable can be specified [8]. Assuming the response to different offers is known, we can design pro-active flexibility execution intended to prevent critical states long before these would occur.

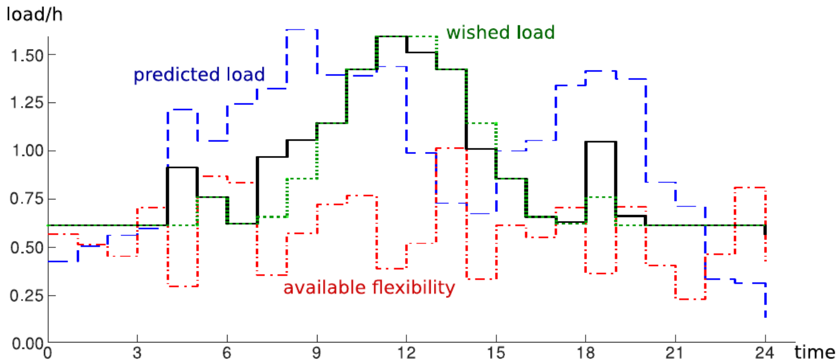

Figure 4: Using local flexibilities (red/dash-dotted) to shift a predicted load schedule (blue/dashed) toward a wished load schedule (green/dotted) resulting in an expected load schedule (black/solid) that benefits both, the flexibility provider and the flexibility user.

Figure 4 shows three load developments over time, which we call schedules. First, we have the planned load schedule on a feeder or transformer (green/solid), which represents the load that the grid operator wishes to achieve by using flexibilities to serve all connected customers best. On the market level that would be the energy a supplier purchased and wishes to sell with minimal deviations. Next, we have the predicted load schedule (blue/dashed) for the feeder/transformer based on the expected customer behavior for a given day considering holidays, events, and the weather. Finally, we have the expected load schedule (black/solid) where flexibilities are used to shift the predicted load toward the planned/wished load. The load changes caused by triggering different flexibilities at different times (red/dash-dotted) are calculated using some multi-dimensional opimisation technique, for example, the SIMPLEX algorithm [https://en.wikipedia.org/wiki/Simplex_algorithm].

5. Aggregation of Flexibilities

Home and Building Energy Management Systems (HEMS and BEMS) provide the means to join different assets into a virtual energy resource, a miniature virtual power plant. Members of Energy Communities can do similar but use the public grid to combine and share their resources. Aggregating different flexibilities can be expected to improve the reliability of a limited power adjustment that can be provided by different subsets of the aggregated sources. For example, if we know that for a certain outside temperature the heating systems of ten similar flexibility provides (households) is in average 30 % on and 70 % off, we can expect that in average three of them could be switched off and seven could be switched on. Assuming a symmetric temperature hysteresis between heating system regular activation and deactivation, we get 50 % probability that the room temperature allows them to provide flexibility. Thus, the probability that three heating systems out of the ten aggregated can be deactivated on demand is 15 %, which equals the individual probability p that a specific heating system may be deactivated to provide its flexibility. The probability that any one of the ten can be deactivated on demand is 80.31 %, using the equation:

$$P(1^+|n) = 1 - (1-p)^n$$

The probability that any one of the ten is activate-able on demand is 98.65 %. Both these probabilities are considerably higher than the individually achievable, i.e., 15 % and 35 % respectively. However, if the flexibility offered shall be 50 % of the total power of all ten heating systems together, we get worse probabilities, i.e., 0.99 % and 24.85 %, based on the binomial probability that exactly k out of n units are available:

$$P(k^+|n) = \sum_{i=k}^{n} \binom{n}{i} [p^i(1-p)^{(n-i)}] = \sum_{i=k}^{n} \frac{n!}{i!\,(n-i)!} p^i(1-p)^{(n-i)}$$

Offering a power adjustment that is in average not available, here 50 % of the total possible where only 15 % or 35 % of the contributing shares are in average executable, is a questionable offer. Even though, some flexibility sources only support switching a fixed amount on/off.

6. Summary and Conclusion

Flexibility is always available where some physical system buffers some form of energy. A room or water tank may store heat energy, compressed air stores pressure, a fly-wheel buffers kinetic energy, and so on. The hysteresis between the maximum and minimum amount stored, the distribution of buffer system states, and the speed at which electric power can be converted constrain the flexibility that is available. To effectively use flexibilities for peak shaving and feeder stabilization, the stochastic nature of flexibilities needs to be considered. Flexibility is not reserve power, but sometimes it can reduce the demand for reserve power. While the optimisation method is only a technical issue, the optimisation target commonly depends on the stakeholder that purchases flexibility. Schemes to calculate the optimal intended load schedule that achieves local balancing and optimised utilisation of local resources still need to be found. For a regionally performed energy transition, the flexibilities offered on a per-feeder or per-transformer level shall rise in parallel to the local RES integration. Thereby shall the impact of inevitable RES volatility be mitigated, the customer awareness for temporary demand and supply mismatches be risen, and private investment in net-zero districts supported.

Acknowledgement & Disclaimer

The work presented has been carried out in the R&D projects cFlex funded in the KLIEN research program "Energieforschung 2018", FFG grant no. 3205608, and the ERA-Net SES RegSys Call 2018 project SONDER, Austrian part under FFG grant no. 3234888, funded in the framework of the ERA-Net Smart Energy Systems' JPP focus initiative Integrated, regional Energy Systems, with support from the European Union's Horizon 2020 research and innovation programme under grant agreement No 775970. The content and views expressed in this material are those of the authors and do not necessarily reflect views or opinion of the transnational oint programming platform (JPP) ERA-Net SES or the funding bodies. Any reference given does not necessarily imply endorsement by ERA-Net SES, FFG, or KLIEN.

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