Local electricity exchange in mini grids: Flexibility to integrate more renewable energy

1. Starting situation

The following discussion is based on the situation in Germany 2015. While numbers may differ, the principles discussed also apply to other environments.
With increasing renewable generation, line capacity and voltage control become the first barriers. The grid was not designed for decentralized generation and bidirectional transport. While important, we do not discuss these barriers here for two reasons:

- Methods to handle them (tap change transformers, reactive power injection, adding medium voltage stations) are well known.
- Desired RE share is well beyond the ~20% where these effects start, so that line capacity issues need to be solved in any case.

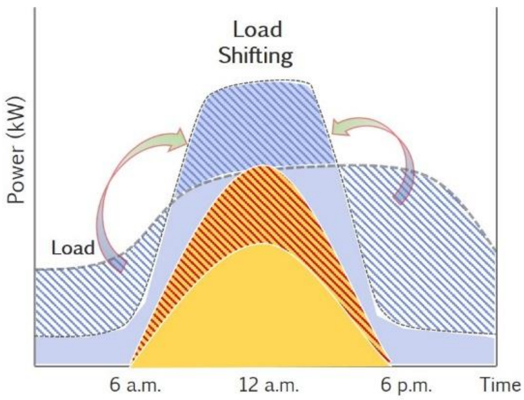
In the following, we consider a grid area (we call it a "mini grid") that may or may not be connected to other grids. Such a mini grid typically has four challenges:

1.1. RE generation reaches peak demand

Solar and wind are volatile. The consequences are shown in a (simplified) example: PV (Photovoltaic) plants deliver ~1100 hrs. of rated output per year (8760 hrs.) in sunny German areas and cover 1/8 of time. With constant load and 100% PV peak demand coverage, PV would deliver 12.5% of average demand. More installed capacity allows higher PV share in mornings, evenings and on cloudy days. Peak production is "shedded" (not utilized). This energy is for free as variable production cost is practically zero.

➔ **Increased load at production peaks uses energy otherwise wasted.**

1.2. Flexible loads can be shifted



Numbers of small flexible loads (<10kW) will grow rapidly when 70% of fossil primary energy used in traffic and heating (30% of primary energy is used for electricity in Germany 2015) are "de-carbonized". Electric vehicles replace fuel powered ones and household heat pumps oil and gas boilers. Both are powered by electricity. Electric cars stand still >95% of time and provide substantial charging time flexibility. Heat pump flexibility can be increased cheaply by thermal storage or connection to a heat grid. A half-day thermal store allows use of PV peak production at midday and reduces load in the evening when PV is not available.

➔ **Flexible loads absorb peak production and reduce backup power need.**

1.3. Combined heat and power (CHP) deliver higher efficiency and backup power

Fossil or biomass fuels will be needed for some time to come. CHP uses them efficiently by simultaneously producing electricity and heat (and cold). Distributed CHP reduces heat transmission loss and improves efficiency, but requires smaller units. While large (industrial) CHP can already be integrated by aggregation, an efficient solution for household CHP is still needed (<10kW to serve individual houses or flats). As with heat pumps, thermal storage and heat grids increase flexibility. CHP can thus shift operation to provide backup power to fill gaps in renewable generation if a business case for flexibility is provided.

- ➔ **Decentral CHP fills gaps in RE production and provides backup power.**

1.4. Co-operative decentralized battery storage

Pioneers install batteries to store solar energy in their homes, motivated by autonomy or technical curiosity. Such applications become more attractive as renewable production becomes cheaper than grid electricity with its overhead. What is attractive for the battery owner unfortunately increases grid strain: Small capacity allows best use of this capital intensive item and improves the business case. Consequently, on sunny days batteries are full around midday, leading to a surge of PV energy injected into the grid. A better option would be battery control to support the grid rather than in-house needs, if a business model for the owner can be found.

- ➔ **Decentral batteries can support the grid if this benefits their owners**

2. Solutions to move forward

Both an extension of the existing and the introduction of a new operating principle are possible to move from the past (few large plants provide flexibility) to the future (many small actors are integrated). An operating mode that implements the paradigm change “demand follows production” is preferable for many reasons.

2.1. Extension of existing operating principle

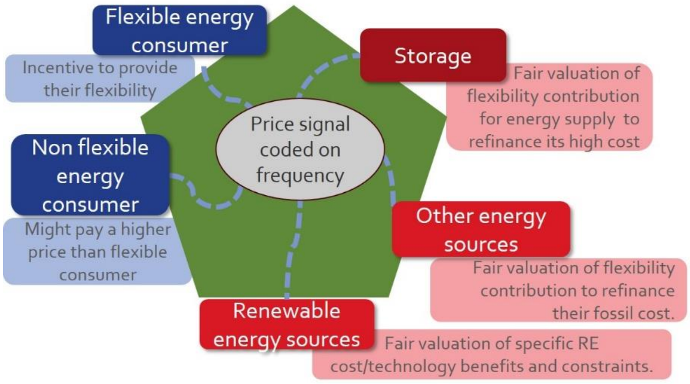
The existing operating principle derives the production schedule from predicted demand, control energy compensates any deviations. With growing share of renewables, the production from fossils is set as the difference between predicted demand and renewable production. If renewable share exceeds load, this may become negative. At the same time, flexibility from fossil production shrinks and must be sought from customers. This is the task of virtual power plants (VPP) or aggregators.

2.2. Introduction of new operating principle

Another alternative is to find a solution for the future together with a migration path from today. One such approach is a real time market (with variable prices for generation and consumption). This is adequate where the number of active players is much larger than before. It also has the important advantage of removing existing flexibility market barriers:

Restrictions on flexibility type (control/exchange markets), size (from several 100 kW upwards), availability and predictability. Note: if decentralized actors react to a generally known price, there is no need to transmit private data to the outside world (data privacy).

2.3. Mini grid exchange activates flexibility



Flexible actors are enabled and motivated by electricity prices that reflect energy scarcity or abundance. If they respond, they support the system and are rewarded by better pricing. While urgently needed, development and deployment of flexible devices are hindered by the absence of a business case until this market design is worked out and implemented. Many smart grid projects do not even address household flexibility as their transaction costs exceed the value of flexibility. Our approach is to implement pilot solutions soon for faster transformation of installed flexibility. Where real time prices activate flexibility, the next step in renewable energy integration can be taken.

3. Easy Smart Grid approach

3.1. Project selection

To benefit most from higher renewable energy share, mini grids should have a good balance of volatile generation and available flexibility, a practical geographic/legal structure and openness to variable prices to implement a local flexibility exchange.

3.2. Price setting

Ideally, electricity price reflects flexibilities of all involved parties. If this cannot be immediately achieved in a mini grid for regulatory or practical reasons, time shifting can be enabled by a variable price component (time variable bonus/ malus). Starting from a centrally controlled system, price will be determined by a grid operator or aggregator e.g. to reflect generation mix. If coupled to a larger grid, a variable price component could reflect in-/outflow of electric energy to/from the mini grid. In any case, a variable price component mobilizes flexibility and can be designed to create no extra income or cost for the operator (net zero effect).

3.3. Price transmission

Prices must be transmitted in a cost effective, reliable and tamper proof way. Higher price update frequency (seconds rather than minutes) improves grid stability (less latency). Easy

Smart Grid proposes a technology for mini grids decoupled from other grids. In a connected pilot, price can be broadcasted to all users with any technology as data rate is low.

3.4. Price reaction

Two types of reaction are needed: flexible actors take decisions using own algorithms and own flexibility, preferences, and price predictions (e.g. from historic and current prices). Meters also receive prices to count priced energy consumption/injection. Note that costly high speed and bidirectional communication is not required (other than with conventional smart meters). Highly aggregated meter readings are transferred to the invoice center once a month or year; other private user data is not transmitted.

3.5. Price prediction

Where historically (renewable) generation prediction was used to schedule fossil plant production, it now helps flexible grid participants to predict prices. In a system dominated by PV and wind, load and weather determine price (predictions on the latter can be supplied by neutral third parties). As such predictions may have an impact on grid operator or aggregator income, it is important to avoid conflict of interest.

4. Project setup and evolution – the Easy Smart Grid way

A mini grid is organized such that RE generation, flexible loads and generation, and battery collaborate to maximize internal electricity exchange and minimize volatility to the outside world. First, a range of a time variable price component is defined. Next, a method to derive this price is defined. We propose to use aggregated in-/outflow of electricity to/from the mini grid. This can be measured at few points (typically medium voltage stations) and has no impact on the outside world. Variable prices can start with the few actors with the strongest need or potential for flexibility. These actors are supported by suitable control technology and analysis before, during and after implementation.

By local trading, price spread and volatility of in/outflow are reduced. More and more actors are integrated (both RE generation and flexibility providers), increasing flexibility and RE share. Then, the mini grid can be taken to a next step: Real time trading and communication using Easy Smart Grid technology. The mini grid is connected to other grids by frequency converters. Within that environment, technology suitable to self-balance isolated or coupled mini grids can be developed, tested, and then rolled out to other mini grids that will benefit from a proven solution that is both efficient and effective.