PROOF-OF-CONCEPT FOR MARKET BASED GRID QUALITY ASSURANCE

Tobias Gawron-Deutsch
Siemens AG Austria
tobias.gawron-deutsch@siemens.com

Stephan Cejka
Siemens AG Austria
stephan.cejka@siemens.com

Alfred Einfalt
Siemens AG Austria
alfred.einfalt@siemens.com

Daniel Lechner
Siemens AG Austria
daniel.dl.lechner@siemens.com

ABSTRACT

The advent of highly volatile components like buildings with PV, batteries, e-cars, and building energy management systems brings on the one hand new challenges in grid quality assurance to the distribution system operator. On the other hand, these buildings can be used for market-based grid control concepts and thus bring new opportunities with them. We describe a novel control concept and provide the results of the first successful proof-of-concept.

INTRODUCTION

The transition to Smart Grids with high penetration of renewables brings new challenges to the energy transmission systems. Single buildings or even whole feeders can change their behavior from consuming to producing energy and back again in short time intervals. New loads like electric vehicles introduce consumption patterns that differ from default load profiles. A building with a PV-generator and a battery system can operate based on own-consumption-optimization. In total this sums up to buildings with customer energy management systems that behave differently and can sell excess energy when it is lucrative or offer flexibilities like load shifting to economic driven virtual power plants (VPP).

As long as the grid operates within its boundaries, no grid quality problems will occur. The traffic light approach differentiates between three states: no problems, medium problems or imminent danger, and grid quality violations. First approaches to distinguish the yellow and the red state were different threshold values for the observed features like voltage. In principle the same actions were taken in both states – restriction of selected consumers/producers as soon as a threshold value has been reached. Thereafter, during non-green states, market based operation is restricted by technical oriented decisions to protect the grid and the connected hardware. This may lead to situations where delivery contracts of a prosumer cannot be fulfilled, not because the prosumer is not able to but because the grid operator has restricted the prosumer to a certain behavior.

Recent discussions about how to ensure grid quality have come forth with a new view on the yellow state for the traffic light approach (e.g. [1]). In the green state no constraints are violated and all participants can act freely. During red state situations, the grid operator should be able to enforce grid oriented behavior. For example, reducing photovoltaic generation could be a measure available for this purpose. Nevertheless, its use should be avoided as it is a direct interfering with internal processes and business models of the generator operator. In the yellow state incentives are used to motivate the connected nodes to act more grid friendly [1].

FLEXIBILITY OPERATOR

In [2] and [3] we have already introduced a possible concept for the new yellow state. It is based upon the assumption that buildings with photovoltaics will be equipped with a building energy management system (BEMS) and perform self consumption optimization. For this purpose they will be generating load forecasts. Furthermore, they are participating through economical virtual power plants on supra-regional energy markets. A local technical virtual power plant – the Flexibility Operator (FlexOp) – monitors the local grid and predicts future grid quality problems based on load forecasts from the buildings. In case of a red state alert the FlexOp can initiate an auction where fitting buildings are invited to place an offer. In most cases these auctioned flexibilities are sufficient to avoid the situation without interfering with internal or external contracts. As backup, red grid state measures as described above can be utilized.

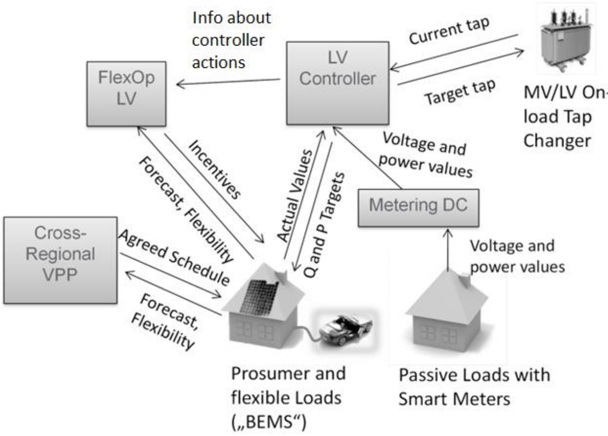

Figure 1 – System Architecture [2]

Figure 1 depicts the basic components and interactions of the proposed approach. The low voltage grid is connected to the medium voltage with an on-load tap changer transformer. Passive loads are equipped with smart meters – some of them are configured to operate as voltage sensors with sufficient update rate. Prosumers and flexible loads use their BEMS to optimize their internal processes and to negotiate energy schedules with a cross-regional VPP. The low voltage controller (or OLTC – online tap-changer controller) is situated next to the transformer and reacts to the current grid state. It collects measurements from various sources (BEMS, smart meters, local measurements) and sets the tap position accordingly. If this is not sufficient, active and reactive power set points can be sent to the connected BEMS – a red grid state occurs. The FlexOp acts pro-actively. For this purpose it collects forecasts (where available) and current measurements. The data is used to generate grid state forecasts regularly. If a future grid quality violation is estimated (=yellow grid state) an auction is initiated. Fitting BEMS are invited to place a bid consisting of a possible flexibility and its price. The interaction between BEMS and VPP is similar to BEMS and FlexOp. The difference is that the VPP acts on economic/market driven interests while the FlexOp is operated by the distribution system operator to stabilize the grid based on technical demands.

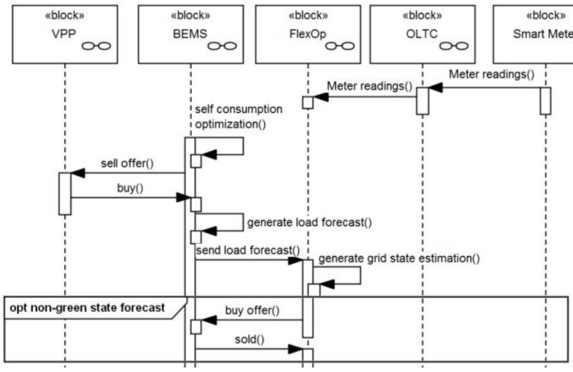

Figure 2 – Sequence Diagram [2]

The interaction sequence of the components is shown in Figure 2. At the beginning of each interval, meter readings are forwarded to the FlexOp via the OLTC. Each BEMS performs a self consumption optimization and – day ahead – trades with a VPP independently from FlexOp [6]. Updated load forecasts are sent to FlexOp as soon as they are available. Based on available data FlexOp calculates grid state estimations and forecasts. In case of non-green forecast results – a problem has been predicted – an auction is initiated. The auction winning BEMS adapts its schedule and will behave accordingly during the predicted time frame.

PROOF-OF-CONCEPT SETUP

The purpose of this proof-of-concept (PoC) is to show that the above sketched concept is working as planned. The interaction between the OLTC, Smart Meter, passive and active buildings has been field tested in e.g. [5]. The PoC has been designed to focus on the core interaction BEMS – FlexOp. To exclude the influence of tap-changing the assumption has been made that the medium voltage level is constantly low. To counter the low medium voltage level, the transformer is always at the highest tap position. Thus, the OLTC is not active during the simulation. Furthermore, grid quality constraints are chosen to be very tight – e.g. voltage is not allowed to drop below 227 V.

The PoC simulation takes place at an arbitrary weekend during summer. Weather is fine and a spotless sky is predicted for Sunday at Saturday noon. The grid itself is located in an rural area and consists of four buildings.

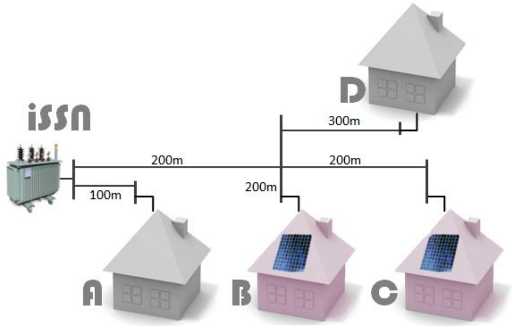

Figure 3 – Minimal Grid

The simulated topology is shown in Figure 3. It consists of a power transformer, two consumer houses (A and D) and two smart buildings (B and C). Each house uses a default H0 curve for Sundays to calculate the current consumption (H0 consumption). All four houses have a peak demand of their uncontrollable loads of 3 kWp (see Table 1). Additional consumption on the BEMS is scheduled from 10 a.m. to 1 p.m. (thermal load). The scheduled production (PV production) of the photovoltaic sites is a sinus curve ranging from 5 a.m. to 8:30 p.m., having the maximum production at 12:45 p.m. Both PVs are modeled with 5 kWp whereas the thermal loads differ slightly (3.5 kW for B and 4 kW for C).

	A	B	C	D
H0 consumption	3 kWp	3 kWp	3 kWp	3 kWp
PV production	-	5 kWp	5 kWp	-
Thermal load	-	3.5 kW	4 kW	-

Table 1 – Building parameters

In the PoC, the simulation starts at midnight and it is assumed that the weather will be sunny on the simulated day. However, at 9 a.m. the weather forecast changes – between 12 noon and 1 p.m. it will be cloudy. During this time span, the photovoltaic production is reduced to 60% of the expected value.

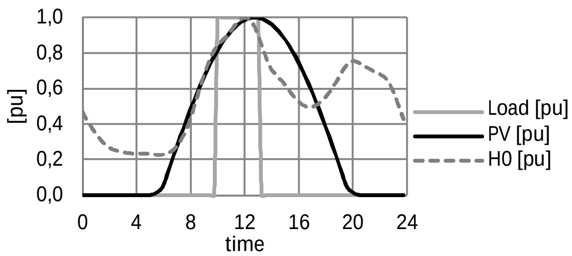

Figure 4 – Load profile (forecast)

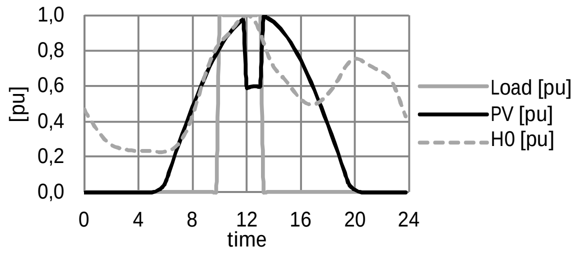

Figure 5 – Load profile (actual)

The according load profiles are shown in Figure 4 and Figure 5. The value on the y-axis is the percentage of the values in the table which is consumed or produced at the time of the x-axis.

PROOF-OF-CONCEPT COMPONENTS

Figure 6 shows the components of the PoC and the communication between them. The possible communication is shown by directed graphs and is achieved by using a XMPP communication based middleware.

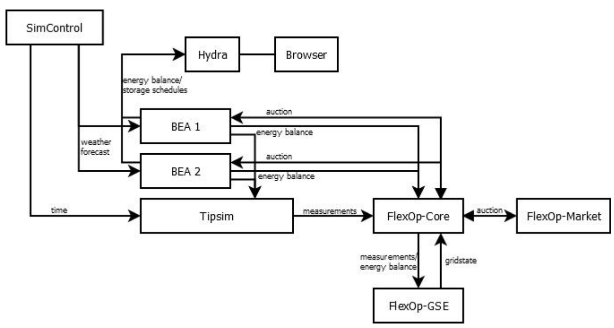

Figure 6 – Software Components for the Simulation

SimControl

The SimControl component is responsible to forward the simulation time for control of the Tipsim simulation and to transmit changed weather forecasts to the BEAs. Each simulation step forwards the time for 15 minutes. A sunny weather forecast is sent at 12 midnight, an update that the weather will be cloudy at 9 a.m. respectively.

BEA

The BEA (building energy agent) components represent smart buildings and their BEMS. Updated energy balances, which contain the estimated consumption/production sum for a time, are sent to Tipsim and the flexibility operator. On the markets request, the BEA can decide to offer their flexibilities to the market for some payment. Flexibility is ordered by the flexibility operator from the auction’s winner. This means that additional power consumption on the BEMS is delayed as shown in Figure 10.

Tipsim

Tipsim provides a simulator for calculating voltages based on the current power consumption and production balance. The topology of the net is taken into account including the length as in Figure 3 and the impedance of a line between two nodes. Energy forecasts for smart buildings are received from the BEA components; for A and D houses a standard H0 profile is used. At every time step current measurements of all nodes are sent to the GSE.

FlexOp-Core

The flexibility operator is the connector between the other components. When the grid state estimator reports a yellow state based on the energy balance forecasts an auction is initiated by the core.

FlexOp-GSE

The GSE (grid state estimator) estimates future conditions of the net based on current measurements and reported energy balance forecasts of the smart buildings. The state of the net is green, yellow or red; but in the PoC only green and yellow states occur. Using the sunny weather forecast no problems encounter, which means that the net is in a green state. At the cloudy weather forecast which is received at 9 a.m., the expected voltage drops under the defined threshold of 227 V between 12 noon and 1 a.m. Therefore, a yellow state is encountered and the flexibility operator needs to come into action for performing countermeasures.

FlexOp-Market

If the grid state turns yellow to signal problems that would arise in the future, an auction is initiated by the core. Flexibilities are requested from the BEAs, which can decide to offer them for a payment. The flexibility is ordered from the auction’s winner, which delays some of its consumption to a later time.

SIMULATION RUN

SimControl starts the simulation at a simulated time of 00:00 on Sunday morning. In the first step, a sunny weather forecast is sent to the BEAs, which respond with their energy balance forecasts. This energy balance forecasts are also sent to the FlexOp-GSE. With each consecutive simulation step, time is forwarded by 15 minutes. After each time step, the current measurements are sent to the FlexOp-GSE. The voltage forecasts are as expected (Figure 7): At the transformer only small deviations from 230 V occur. Building A is connected to the transformer via its own line (100 m) and shows little deviations as well. Buildings B, C and D are connected through a different feeder and have line lengths between 300 m to 500 m. As a consequence, their voltage values are more volatile than the ones for A. Based on the GSE estimations, FlexOp-Core decides at this time (00:15) that no problems will occur and therefore sends a green state.

No auction is needed at this time.

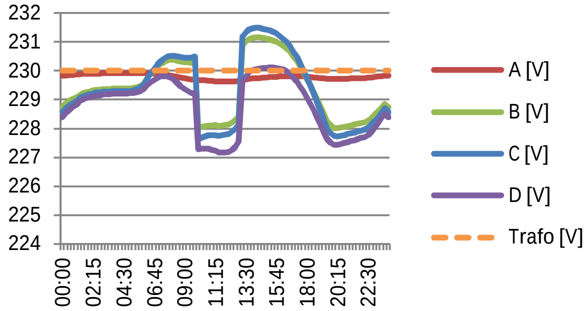

Figure 7 – Grid State Estimation Forecast at 00:15

At simulation time 09:00, the SimControl issues a message to the BEA indicating that the weather forecast has changed. This states that between 12 noon and 1 p.m. clouds will reduce the photovoltaic production by 40%. The BEAs send their new energy balance forecasts to Tipsim and the FlexOp-GSE. Due to internal requirements from their users neither building B nor C decide to postpone heat pump usage at this time. Instead they decide to draw more energy from the grid. At 09:15 the next measurement set is sent to the FlexOp-GSE, which estimates that the voltage drops under 227 V during this time, resulting in a yellow state.

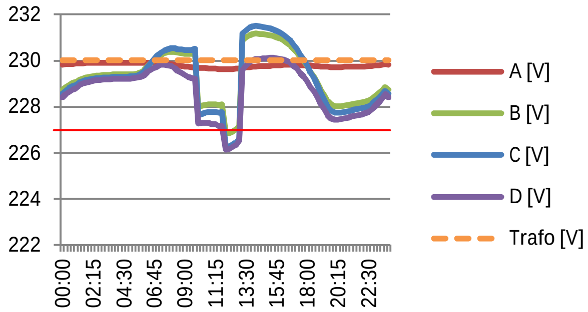

Figure 8 – Grid State Estimation at 09:15

The problem is shown in Figure 8 – the forecast predicts a voltage drop below 227 V after noon for the nodes B, C, and D.

An auction is issued at the FlexOp-Market, requesting flexibilities from the BEAs. Building B offers to shift heat pump activities by one hour from 12-13 to 13-14 at a low price. Building C offers to reduce heat pump activities during 12-13 at a high price. Both proposals would result in reduced consumption and thus reduced voltage drop. Building D would qualify to participate in the action based on its position in the grid as well. Due to the fact that it is not equipped with a BEMS it is neglected by FlexOp.

The result of this auction is that its winner building B shifts the additional consumption scheduled between 12 noon and 1 p.m. to between 1.15 p.m. and 2.15 p.m. After this agreement, the BEMS from building B sends an updated energy balance forecast according to the accepted offer. In result, the grid state estimation shows green states for the whole day from 09:30 on.

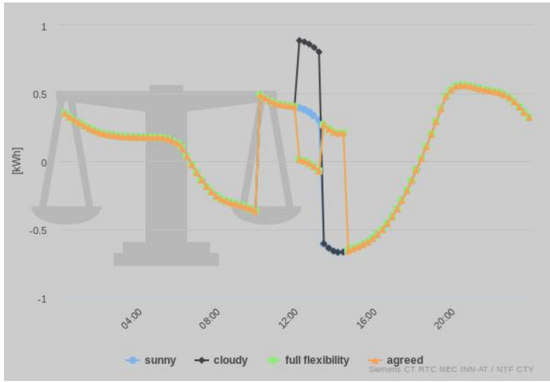

Figure 9 - Load Schedules (Building B)

Figure 9 shows the four different load schedules from building B. The building consumes from or feeds energy back into the grid in the range from roughly +/- 0.5 kWh per time interval (15 minutes slots). "Sunny" is the schedule generated at 00:15. As soon as the weather forecast update arrives, the internal schedule is updated to "cloudy". Building B responses to the auction invitation by offering "full flexibility". After winning the auction, this schedule is transformed into "agreed." If the auction is lost, the building would continue with the schedule "cloudy" which is the case for building C.

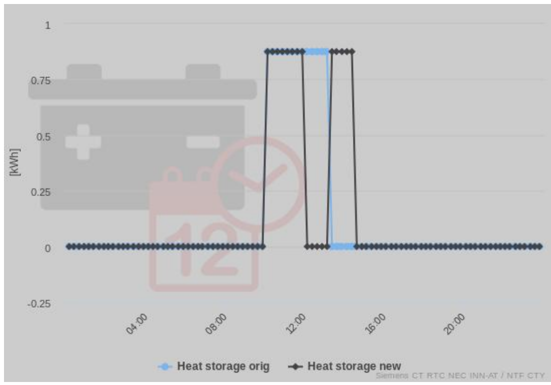

Figure 10 - Heat Storage Schedule (Building B)

The sold heat storage usage shift is depicted in Figure 10. Before the auction, the active schedule was "heat storage orig"; the offered flexibility and the resulting new load schedule is based on "heat storage new."

CONCLUSION AND OUTLOOK

The above described PoC shows clearly that it is possible to use auction based systems to enforce grid stability. Although the setup has been designed to reduce complexity and very narrow voltage bandwidth thresholds are used, the simulation provided a valid test-bed for the interaction between the FlexOp and the connected BEMS. The buildings changed their behavior based on offered incentives in advance. Internal processes like heat storage usage offer flexibilities that may be used for grid stability without interfering with user requirements if sufficient time between prediction and occurance of a problem exists.

As next step it is planned to implement a large scale simulation with hundreds of buildings and several low voltage grids. This will help in understanding how this approach influences grid operation and to identify stability issues. Additionally, the design of the auction and the impact of different kind of incentives need to be examined. If the large scale simulation run is successful a field test is planned.

AKNOWLEDGEMENTS

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