RESULTS OF THE SOLOGRID PILOT PROJECT – DECENTRALIZED LOAD MANAGEMENT TO INCREASE THE EFFICIENCY OF LOCAL ENERGY COMMUNITIES

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ABSTRACT

The expansion of decentralized power generation and the ongoing electrification of the transportation and heating sector is putting additional strain on distribution grids. The electricity grid infrastructure needs to be designed to withstand heavy but rare peak load events, which is expensive and inefficient. GridSense is a decentralized, self-learning load management solution designed to even out the grid-level power consumption and shave the load peaks by controlling primary flexible electric household devices. In the SoloGrid pilot project, the GridSense solution was deployed for a one-year field trial with extensive analysis of measurements and complementary simulations. Both measurements and simulation results indicate that GridSense can support the efficient and safe operation of distribution grids by reducing load peaks and voltage violations. In addition, SoloGrid successfully demonstrates the added value of thorough measurement analyses and innovative ways to integrate measurements in simulations and combinations with generic models.

INTRODUCTION

In this paper, we present the final results of SoloGrid, a pilot project carried out in the Canton of Solothurn, Switzerland [1, 2]. The project scope was to evaluate the effectiveness and working mechanisms of GridSense, a decentralized energy management scheme for prosumer households featuring self-learning algorithms.

The power consumption in electric distribution systems shows considerable fluctuations. The synchronous daily rhythm of residents leads to load peaks in the system, which in turn can lead to voltage violations or overloading of grid components. These peak events occur for a very limited amount of time, yet the whole system needs to be dimensioned to withstand them. This is expensive and inefficient. With the ongoing expansion of decentralized production and the electrification of the heating and transportation sector, the stress on electric distribution systems will increase. Peak loading situations could therefore be even more pronounced if no countermeasures are implemented.

A solution to these problems is to even out the load curve by shifting flexible load consumption in time. GridSense is an innovative system which does that via coordinated control of a large number of distributed, flexible units. A

special feature of GridSense is its decentralized approach: in contrast to most other demand response control systems for household appliances, the control intelligence is distributed among equipped devices and works without communication to a central agent. An important part of the SoloGrid project was the comprehensive result analysis of measurements, measurement-powered simulations, and model-based simulations, which combined the advantages of different analysis approaches. For this purpose, Adaptricity.Sim, a time-series-based simulation platform for active distribution grids, is ideally suited. The platform facilitates the flexible combination of measurement inputs and models for load flow simulations. SoloGrid is a partnership project between Adaptricity, the ETH spin-off company behind Adaptricity.Sim and responsible for measurement analytics and simulations, InnoSense, the developing company of the GridSense solution, AEK Energie, the electric utility in the project region, and Landis+Gyr which provided smart metering solutions.

METHOD

To test the effectiveness of GridSense in supporting grid operation by load management, a set of GridSense units (GSU) was deployed in a Swiss residential neighbourhood called Riedholz, a suburb of the town of Solothurn, which features a weak electric distribution grid. These GSUs then measured and controlled the primary flexible electricity consuming devices (boilers, heat pumps, electric cars, and batteries) in an optimized way to smooth out the total load in the electric distribution system. More details concerning the general setting can be found in previous publications [1, 3].

In Riedholz, devices were previously operated with *ripple control,* confining electric boiler activation to night times. The GridSense system had been in place and active in the pilot region for more than one year (Oct. 2016 – Sept. 2017), yielding measurements of active and reactive 3-phase power as well as voltage in one-minute resolution. During the testing period of GridSense, to ensure the comparability with the previous operation, the distribution grid was alternately operated in three modes: first, *observation mode* (no control systems); second, with activated GridSense system; third, with activated *ripple control*. These measurements allowed us to assess the performance of GridSense at keeping the grid voltages within the standard interval. While measurements provide the most accurate insights for the

given system configuration and the observed boundary conditions, they are also limited to that exact situation. To generalize and extend the scope of the analysis, extensive simulation studies were conducted. Measurements and generic device models can be combined in Adaptricity.Sim to create simulation scenarios that benefit from their respective advantages.

In the first stage, PQ-measurements were used as inputs for a simulation scenario that enabled us to compare the effect of GridSense against the effect of upgrading the grid with a thicker main cable, the classic measure for grid reinforcement. In the second stage, entirely model-based scenarios were created, to provide full flexibility for changes in the underlying grid topology and the system configuration. Among other topics, the effects of variable GSU penetration on the voltage quality as defined in the European norm EN 50160 was analysed with this setup.

RESULTS AND DISCUSSION

Measurements

The measurement results show that GridSense successfully supports a safe grid operation by reducing load peaks and the related occurrence of under-voltage events. In the pilot region, GridSense reduced under-voltages effectively, which is especially visible at heavy under-voltage levels: no voltage value below 0.85 p.u. was measured while GridSense was active (see Fig. 1), unlike during other modes. Also, the frequency of under-voltage events with voltages below 0.9 p.u. was drastically reduced in comparison to the *observation mode*. During activated *ripple control*, the standard load shifting scheme in the pilot region, on the other hand, heavy under-voltage events with voltages below 0.85 p.u. were observed more frequently.

Figure 1. Voltage measurements (in p.u.) at grid connections over one year, from 01.10.16 to 30.09.17. The grid was operated in three different modes: activated GridSense, "observation mode" (periods without any grid level control) and "ripple control" (the previously used approach to control boilers and heat pumps). Over-voltage situations do not occur due to the modest prevalence of photovoltaic units in Riedholz. Voltage limits according to the European norm EN 50160 are indicated in orange and red (0.9 p.u., violation tolerable for a maximum of 5 % of time assessed on a weekly basis, 0.85 p.u., violation not tolerable). The figure is directly taken from SoloGrid's final report [3].
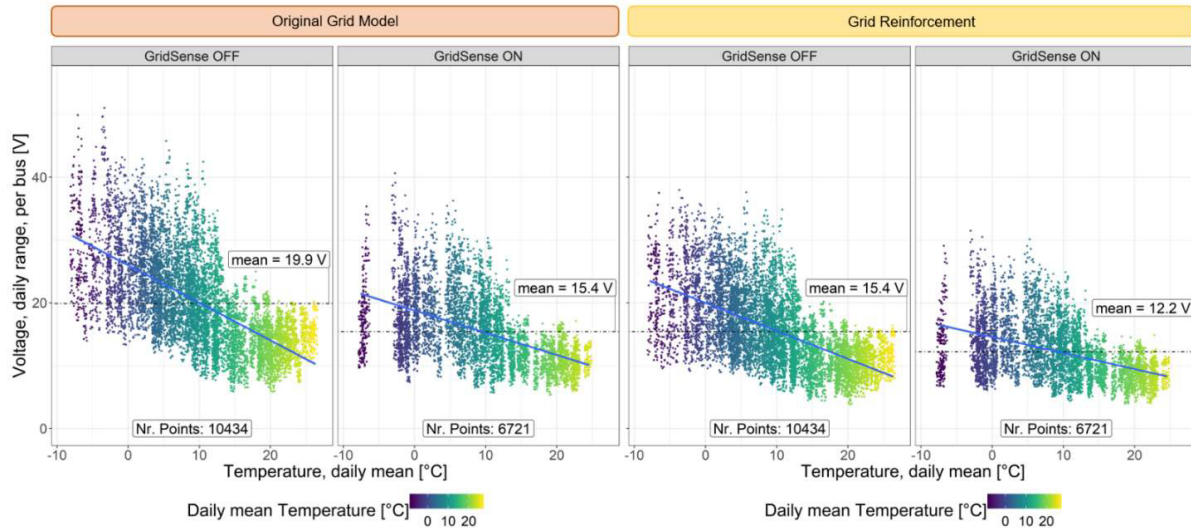
Figure 2. Comparison between GridSense and grid reinforcement on simulated daily voltage ranges, per bus. The daily voltage range is defined as the difference between the highest and lowest 10-minute mean voltage value at a given grid connection point over one day. A big daily voltage range is undesirable as it is evidence of voltage related problems in the grid. One year of power measurements during which GridSense was "ON" and "OFF" were used as inputs for both simulations which provided the bus voltages. Both simulations therefore feature the same periods of GridSense "ON" and "OFF". The only difference between the two simulations lies in the grid model, which was assumed to be reinforced in the simulation scenario shown on the right side, by doubling the cross-section of the main cable. The figure is directly taken from SoloGrid's final report [3].

At the same time, the total number of under-voltage events was also smaller when ripple control was active compared to the observation mode. One potential explanation for this observation is that ripple control, by confining the boiler activation patterns to only a few hours a day, leads to a high synchronicity in their activation. The concentrated activation could then lead to more severe but shorter under-voltage events. For GridSense the picture is clearer: its measurement data, featuring clearly reduced numbers of under-voltage events, indicate that the intelligent dispatch of flexible household devices leads to a smoother daily load profile, which benefits the voltage quality.

Measurement-powered simulations

The measurement-powered simulation analysis was used to compare the effects on voltage of GridSense against an alternative grid-upgrade that would mean replacing the main cable in the Riedholz grid with a cable with doubled cross-section. Our analysis showed that, when looking at the reduction of the daily voltage range, the effect of GridSense is comparable to doubling the cross-section of the main, 250 meter-long distribution cable (see Fig. 2). This suggests that GridSense technology could be a viable potential alternative to conventional grid reinforcements. It is also evident that it is possible to combine the two measures of using GridSense and reinforcing the grid with a thicker cable for an even stronger positive effect on the daily voltage range. In addition, the results show that the daily voltage range is highly dependent on temperature, and that this dependency was reduced when GridSense was active. The reason for this lies most probably in the fact that during colder periods there is more electricity usage by GridSense controllable devices.
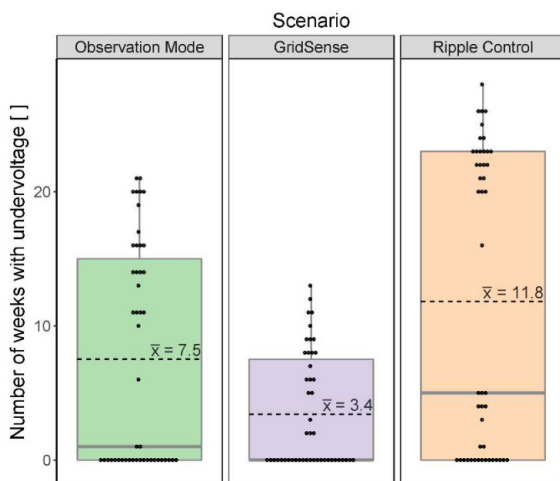

Figure 3. Simulated frequency of under-voltage events, as defined by the norm EN 50160, grouped by control strategy. The boxplots represent the distribution of number of under-voltage events at households over a year. The number of under-voltage events are also shown with individual points, where each point represents one household. The dashed line represents the mean of each scenario. The voltages were provided by year-long model-based simulations with identical boundary conditions and system components. They differ from each other in the way how the flexible electric devices are controlled: "Observation Mode" is a scenario without any control mechanisms besides device-internal ones; "GridSense" is a scenario where GridSense controls 75 % of GridSense-controllable devices; "Ripple Control" is a version of a centralized control strategy for load shifting widely applied in Switzerland. Here, boilers are divided in three equally sized and evenly distributed groups which, on weekdays, only have clearance at night during two 2-hour windows. The time windows are scheduled differently among boiler groups.
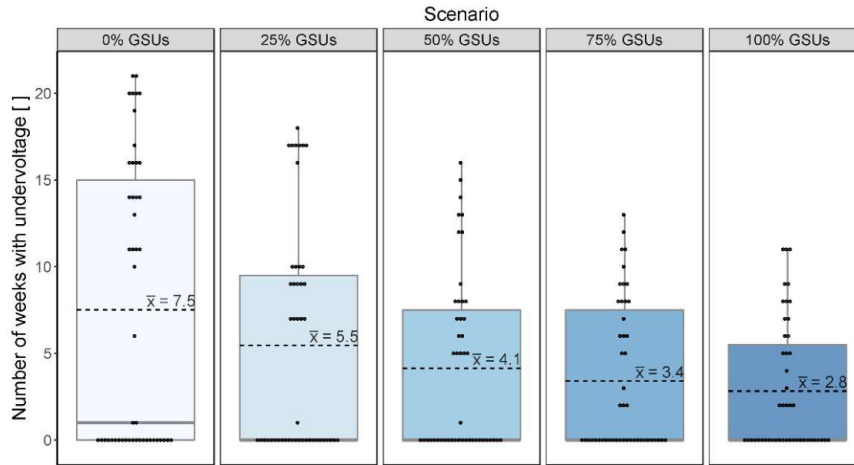
Figure 4. Simulated frequency of under-voltage events by varying penetration of GridSense units. GSU-penetration is defined as the share of potentially GridSense-controllable devices that are actually controlled by GridSense. Each point represents the number of weeks with voltage violations for a specific household. Plot settings are identical to Figure 3. Scenarios "0% GSUs" and "75 % GSUs" are identical to the Figure 3 scenarios "Observation Mode" and "GridSense" respectively.

Model-based simulations

The model-based simulations, i.e. performing power-flow calculations on a grid model of the Riedholz area using device models combined with synthesized household base load profiles, confirmed the main findings of the measurement analysis concerning under-voltage events during different grid control modes. The results presented in Figure 3 support the findings of the measurement analysis: the yearly number of weeks with an under-voltage situation at households' grid connections is reduced with GridSense. They again indicate that the hereby applied ripple control scheme has a negative effect on voltage quality. It is important to note that the simulations were run with absolutely identical boundary conditions and covered the same time period. This eliminates the uncertainty caused by differing boundary conditions that is inevitable with real-world measurement results.

The model-based simulations presented in Figure 4 revealed two main features of GridSense: first, it manages to reduce the number of weeks with under-voltage even starting at low GSU-penetration rates. An important finding is that there seems to be no minimal penetration necessary in order for a positive effect to materialize. Second, with increasing penetration levels the marginal positive effect decreases. For a cost-effective GSU deployment it is valuable to know that a saturation effect was visible at very high penetration levels.

CONCLUSIONS

A multi-faceted analysis showed that GridSense can support the efficient and safe operation of electric distribution systems by intelligently controlling flexible units in a coordinated way. The same analysis revealed that classically operated ripple control can have detrimental effects on the voltage quality in distribution grids. In this regard, a trade-off exists between evening

out the power consumption at a very local level (low-voltage grid) versus a regional level (medium voltage grid) where industrial loads play an important role.

The project also highlighted the added value of a simulation platform like Adaptricity.Sim which facilitates the combination of measurements and load models: measurements enhance the accuracy of results, and model-based simulations enable a thorough testing of foreseeable conditions. In the context of network integration, control concepts, and operations, the software can provide much-needed decision support, by uncovering the complex interactions caused by new, active grid technologies.

Apart from the positive influence on voltage quality, GridSense has additional benefits such as reducing transmission losses by increasing the share of local power consumption, being adjustable to new situations via software updates, and monitoring of grid status to efficiently identify critical areas. On a system level, the effectiveness is likely to increase with the ongoing electrification of the heating and transportation sector which leads to an increase in the number of devices that can be potentially controlled by GridSense.

REFERENCES

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