UTILITY SCALE DOMESTIC SOLAR: THE PROACTIVE TRANSITION OF DISTRIBUTED NETWORK OPERATORS IN SWITZERLAND

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ABSTRACT

Distribution System Operators (DSOs) face new challenges due to the growing installation of solar panels. In Switzerland, DSOs play a reactive role, ensuring that customers are able to install their Photovoltaic panels (PV) while maintaining the quality of service on the network. This article presents an innovative approach that enables the DSOs to play a more proactive role in the transition of the energy system in Switzerland.

With the presented tool, DSOs are able to digitally analyse the network for different scenarios, evaluate for each customer the potential of installing solar panels on their roof and automatically identify the optimal settings for the future PV installations, in order to permit customers to achieve a higher profitability and reduce the required network investment costs.

Even though the presented optimal settings could constrain the overall PV potential in the future, the inclusion of new technologies, such as heat-pumps, batteries or electric-cars, will allow larger installations to reach optimal profitable levels and therefore increase the overall PV generation.

MOTIVATION

Solar Panels on the rooftops to generate electricity are one of the most important pillars of the Swiss Energy Transition. While wind and solar parks still facing difficulties, because of their impact on the Swiss landscape, the installation of PVs on roofs has been increasing exponentially in Switzerland since 2011 [1]. In this framework, almost all rooftop installations are connected to the grid at the Low Voltage (LV) network level. Consequently, high investment costs for network upgrades occur due to the rural topology of the Swiss LV networks, consisting of long lines connecting a low number of customers with high PV potential.

On the other hand, the business model for PV in Switzerland aims at optimizing self-consumption since feed-in tariffs are losing attractiveness due to limits of the financial means set by Swiss authorities.

Therefore, there is a great incentive to identify a common solution that is attractive to both utilities and prosumers in order to reduce network investments while increasing the profitability of private PV installations.

CONCEPT

The Utility Scale Domestic Solar (USCADOS) concept represents a novel approach, providing solutions to the challenges mentioned above. At the core of the USCADOS concept is the proactive role of DSOs in the transition of the Swiss energy system. Currently, DSOs reactively analyze each new PV connection request individually and determine if a network upgrade is required and which method provides the cheapest solution.

This method proposed by the Regulator ensures that customers are allowed to install their desired PV-system and utilities implement the cheapest solution to support it, these reinforcement costs are socialized nationally and are included on the energy bill of all the end-customers [2]. Unfortunately, this method doesn't consider potential future PV-installations, and the cheapest solution for a given customer may not be the best investment if a neighbor plans to install additional PVs on the same LV network at a later date.

On the other hand, the Utilities must ensure the quality of electricity supply for all customers even in the worst situation (maximum solar production, minimal consumption and the highest allowed voltage at the substation level). Consequently, the network will be planned for a worst-case scenario that probably will never happen.

Contrasting to this, in USCADOS the DSO proactively identifies maximum potentials and optimal PV configurations in an entire region and assists customers to reach maximum individual profitability. At the same time, the DSO can minimize network upgrade costs with regional planning and mutual coordination of new systems. The USCADOS concept enables the customer to achieve higher profitability, reduces network-investment costs and allows the installation of a higher number of PV systems per year.

Key elements of the USCADOS Concept

The USCADOS concept is composed of three main algorithm blocks: Network calculation, Customer profitability Calculation and System Optimization.

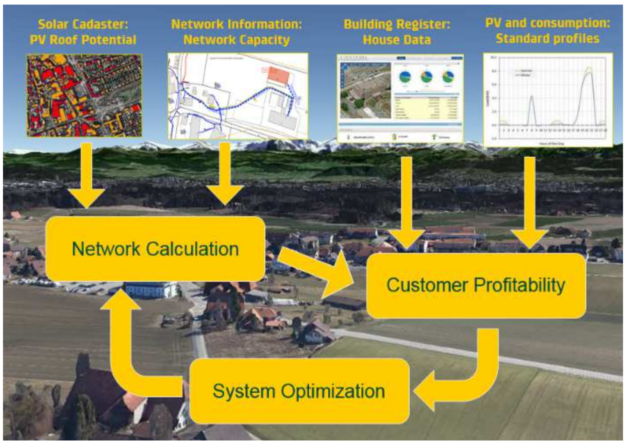

Figure 1: Key elements of the USCADOS Concept

As shown in Fig.1, the process start with the input data being collected and cleaned in order to perform the required analysis.

Data from **solar cadastre** is collected in order to identify which buildings have a high solar potential and how many PVs can be installed on them.

Network data is sorted and stored as LV networks, allowing one to identify which building is connected to each transformer.

Building register data is also collected in order to identify the main characteristics of each building, including:

- Year of construction
- Building type
- Number of apartments
- Apartment information
    - Number of rooms
    - Information of the heating system
    -

This data allows one to sort out the buildings that are not suitable for new PVs (based on year of construction and building type) and enables the development and application of standard customer profiles.

The last data type is a set of standard consumer and PV profiles, based on the solar cadastre and building register; different profiles will be considered for each customer consumption and PV profile for the profitability analysis.

Network Calculations

Once that the input data is prepared, the first step of USCADOS is a network analysis. Where the network will be compared with the potential future PV installations, in order to identify the possible network constraints based on the DACHCZ recommendations [3].

For this analysis, a load flow (LF) algorithm has been developed. This algorithm enables the calculation of the voltage and current on all the network based on the power injections, consequently we can identify the networks that should be reinforced for the following scenarios:

1. Maximum individual injection

In this scenario, the maximum PV injection for each building would be calculated, based on the actual state of the network (network data and installed PV systems updated daily).

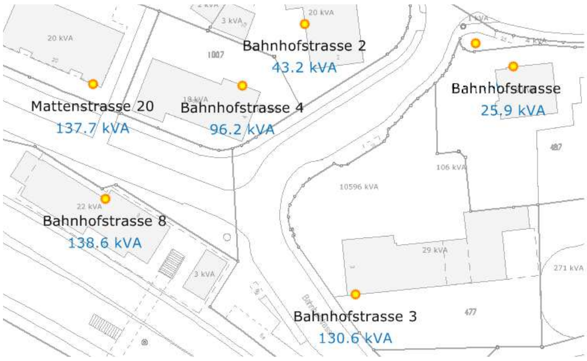

Figure 2: Maximum individual injection

This analysis would allow the user to identify the buildings that have a higher PV potential than maximum individual injection, as shown in Figure 2. This information is valuable for the DSOs, since they can improve their network planning, knowing where constraints could be in the future. These results can be applied later in order to identify the optimal PV system for each customer.

2. Network constraints for maximum PV potential

In this scenario, each LV network is analysed considering the maximum installable PV power for each building with high solar potential. The results as shown in Fig. 3, would allow DSOs to identify which networks could require an upgrade and which ones are sufficient for the installation of all the potential PVs without further investment.

Figure 3: Network constraints for maximum PV potential

This scenario also allows for the evaluation of smart grid solutions, such as voltage regulators or reactive power control. In Fig. 3 the buildings that require a replacement of the cable lines are shown in yellow, but this replacement could be also avoided with an active grid regulation solution.

3. Additional simulations

The network calculations module also allows for the evaluation of any scenario that a DSO could be interested in. Network analysis focused only on the profitable PV installations or based on the optimized design per building could be also implemented.

Customer Profitability

Once the network constraints are identified, the next step is a profitability analysis for each building. The goal of this analysis is the evaluation of a PV system as an investment for each customer. In order to evaluate the profitability, it is necessary to accurately estimate the PV costs, the annual energy that would be injected into the grid and the annual self-consumed energy.

For the PV costs calculations, a function has been developed where a Swiss price catalogue for panels and inverters is merged together with an inference analysis of the installation costs based on the building characteristics. This function has been compared with 25 offers developed by a PV planner in Switzerland, with variations of less than 10%.

For the annual energy flow calculation, two profiles for the PV and the consumer have been developed, based on orientation, inclination, maximum installed power and building type, number of apartments, number of rooms and heat-system type respectively. These two profiles are compared to identify the self-consumption rate per year.

In the next step, the following equations have been implemented, in order to calculate the profitability per building as shown in the Results chapter:

$$\sum_i^{n.years} Ben = \left((1-S_c)PV * PVt_{n.years} + S_cPV * HTt_{n.years}\right) * D_{n.years} - OP_{n.years} \quad \text{[Eq. 1]}$$

$$\frac{\sum_i^{n.years} Ben}{(1+IRR^i)} - Inv = 0 \quad \text{[Eq. 2]}$$

Where *Ben* represents the expected benefits for each year, S_c is the self-consumption rate, *PV* the total solar generation per year, *PVt* the prediction of the PV-tariff for the next 20-25 years, *HTt* the customer high tariff prediction, *D* the expected PV-degradation and *OP* the expected maintenance costs per year.

In the second equation, *Inv* represents the cost of the solar installation and *IRR* the profitability for Net Present Value (NPV) equal to 0.

System Optimization

As shown in the previous equations, the profitability is based mainly on the self-consumption rate, the total solar production and the various tariff options. Therefore there is a high potential for optimization.

1. Potential Optimization of Inverters

Nowadays, solar planners in Switzerland design solar installations with the power of the PV-modules being the same as the inverter power. Following the development and applications of our tool, it has been acknowledged that the correct design of the inverter plays a key role on the profitability of the solar system.

Due to the geographic location of Switzerland, the power generated by PV-panels almost never reaches the nominal power. As shown in Fig. 4 for a standard PV, installing an inverter with a 30% smaller capacity than the nominal power of the PV modules will reduce the annual energy generation in less than 3.8%.

Since the DSO designs the electrical grid, based on the worst case, a smaller inverter could avoid network reinforcement without leading to high amounts of energy loss. On the other hand, the resulting losses wouldn't have an impact on the self-consumption rate since, in periods of high solar irradiation, the production would always be higher than the consumption, and this energy would be injected into the electrical network. An exception to this might be in the case of industry customers with relatively high consumption rates.

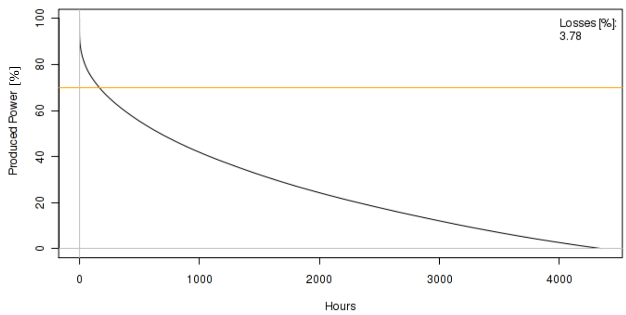

Figure 4: Produced power for standard PV system with south orientation and 30° of inclination in Bern.

For the correct design of the inverters, it is important to consider the orientation and inclination of the solar installation (e.g. an east-west system would never reach higher than 75% of the nominal power) and the consumption behaviour (the inverter should not have an impact on the self-consumption rate).

As the business goes into the self-consumption direction, optimal planning will predominantly lead to larger DC installations rather than larger AC power components and therefore will rise energy production without injecting new peaks into the grid.

In our tool, we have implemented a function that is able to identify the optimal inverter size for each PV installation considered.

2. Potential of module optimization

In Switzerland, the feed-in tariffs for solar systems are being reduced or discontinued. As a result, the PV business must move from a focus on injecting as much energy as possible into the network to one which increases the self-consumption rate. Consequently, an optimum between installation costs, generated energy and self-consumption must be identified.

For this purpose, an optimization function with two variables, the number of panels and inverter size, has been implemented so that profitability is maximized. This function determines the total solar production, investment costs and self-consumption rate, in order to implement the presented equations Eq.1 & Eq.2. The process is iterated on until the maximum profitability is identified, with the optimal number of PV modules and the inverter size specified for each building.

The results presented on the next sections have shown that, with the exception of some industry buildings where the self-consumption rate is close to 100%, the optimal PV installation is always smaller than the maximal available solar potential on the building's roof.
In Table 1, an example of how the system optimization module improves the profitability for customers is shown. This example shows that reducing the installed power three times, not only decreases the price around 55%, but the self-consumption rate increases as well, while the autonomy is less affected. As a result, the profitability becomes positive thanks to the optimized design of the solar system, increasing the interest of customers to install PV systems on their household rooftops.

	Standard solar system	*Optimized solar system*
PV-Module	13 kW	4.3 kW
Inverter	15 kVA	3 kVA
PV Price	28240 CHF	12180 CHF
Self-Consumption	18.5%	45.5 %
Autonomy	28.25%	22.3%
Profitability	- 1 %	0.2%

Table 1: Profitability potential through system optimization, prices in Swiss Francs (1 CHF ≈ 0.93€)

RESULTS

USCADOS has been implemented as a service for various municipalities where the above-mentioned analyses have been implemented. In Figure 5, the profitability for each customer with a high solar potential has been calculated using the Customer Profitability module. It is shown that due to the high installation costs in Switzerland, more than 70% of the customers would have a negative profitability, were they to decide to maximize PV installation by covering their roofs with solar panels.

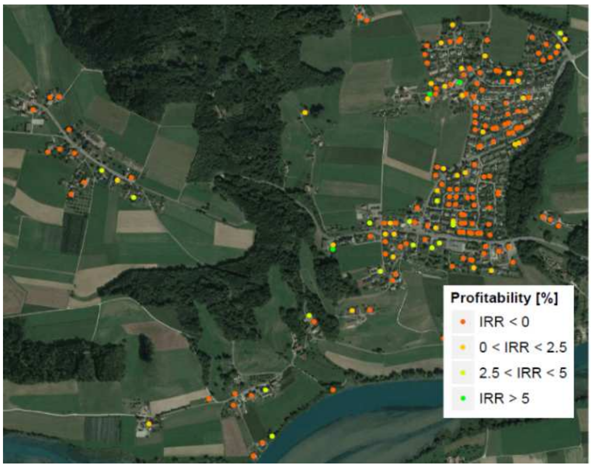

Figure 5: Customer profitability for each building based on 2015 data for buildings with high solar potential

The optimization module has been implemented to evaluate the impact of an improved installation design on customer profitability. The results for the same municipality are shown in Figure 6, where around 30 customers would be able to reach a positive profitability thanks to the optimization calculations.

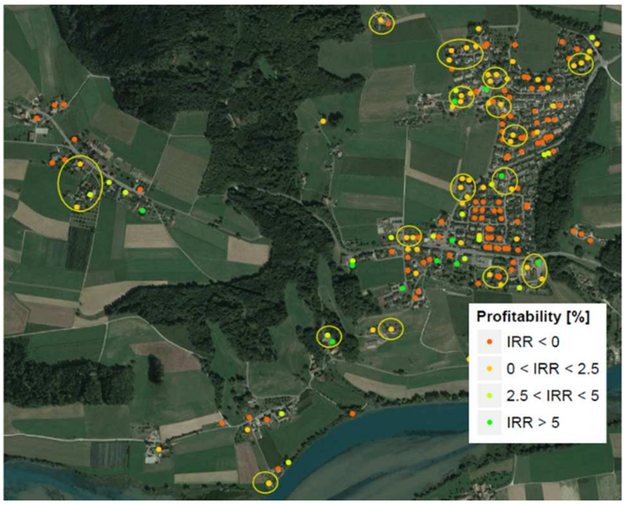

Figure 6: Customer profitability for each building using the optimal PV & Inverter size

In addition, the network analysis also shows that, if the customers would install an optimized PV size instead of the maximum, no network upgrade modifications would be required. This results in a reduction of the network costs and an increase in the self-consumption of the municipality.

On the other hand, the impact of the present concept on the Energy Strategy 2050 should also be considered. Based on the results presented, the total installation of solar panels for the optimized scenario was 65% lower than for the standard scenario.

A reduction of the installed PV power per roof could also limit the total PV generation on the future. Further analysis will be performed in order to evaluate the possible impact.

Potential Applications

The profitability and the optimization algorithms are the foundation for additional applications.

1. Managing heat systems

In Switzerland, around 10% of the total electric consumption are thermal systems, including electro-boilers and heat-pumps. These electro-boilers are programmed to be operated during the low-tariff period in order to reduce electric consumption costs. As a result, these loads can be controlled in order to be used at moments of high solar generation. In USCADOS modelling of potential scenarios have shown that, in such cases, self-consumption and self-autonomy would increase, allowing the installation of a higher number of solar panels on each roof with a positive profitability.

It is expected that the number of installed heat pumps in Switzerland will increase exponentially, at least until 2020 [4]. More research shall go into a better understanding of the heat-pump-consumption profile, in order to evaluate the impact on the self-consumption and profitability, for new PV installations.

2. Batteries

As battery prices keep decreasing, their potential for increased self-consumption and profitability is increasing. The impact of batteries on the self-consumption and profitability was analysed in USCADOS in 2016. Although self-consumption improves, actual battery prices are still not good enough to increase the profitability. However, as PV-tariffs keep decreasing it may be possible to identify solar projects where a battery would increase the profitability for given customers. During 2017, we plan to include a battery package in the System Optimization module, where the optimal battery capacity size will be also calculated for each building.

3. Other flexible loads

New and additional components, such as electric cars, could also help to increase the profitability of solar systems. Charging an electric car is an additional load, but can also act as an electric battery and increase the customer’s self-consumption. In order to evaluate this potential functionality, a further analysis of electric-car behaviour is required.

As shown in the three potential applications mentioned above, the penetration of new, innovative components will allow that optimal self-consumption and autonomy levels are reached with a higher number of solar panels. As a result, by including these new components, the installation of additional PV panels will be supported, which, in turn will increase the total PV generation output.

Development project and field tests

The USCADOS analysis has been implemented in several municipalities, identifying optimal buildings where high profitability was achieved while avoiding network reinforcement. During 2017, up to 50 new PV-systems will be installed thanks to the results of USCADOS calculations. Once the PV-systems are running, a measurement campaign will be launched in order to validate the accuracy of the USCADOS tool.

The team is open for new projects and collaborations with universities, investors, communities, DSOs or energy research institutes.

CONCLUSIONS AND OUTLOOK

The USCADOS concept is a novel, proactive approach which addresses a whole set of challenges that will be faced by DSOs and prosumers in the near future. It permits a higher penetration of PV-systems with a higher profitability, while reducing the required network upgrade costs. On the other hand, the optimized scenario could also constraint the total PV generation in the future. However, the installation of heat-pumps or batteries in the future, will increase the optimal PV power on each roof. Further analysis will be implemented in order to evaluate this impact.

The tool will be extended to include the analysis method into the planning and realization process for middle- and large-scale projects involving a large number of buildings. Developers and investors of such projects will be additional target groups. The team is actively looking for such projects and partners.

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