SIMULATING AND ADDRESSING THE REVENUE LEVELS AND ENERGY FLOWS IN THE DISTRIBUTION GRIDS OF TOMORROW USING A BOTTOM-UP APPROACH

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ABSTRACT

This paper presents simulation results for a future scenario using a bottom-up approach for a distribution grid. The simulation includes usage of electrical vehicles (EVs) and distributed energy generation (DEG). The temporal resolution for the simulation is hourly, and each specific end-consumer is simulated explicitly. The simulation results indicate a significant change of energy flows, which will lead to a significant change of revenue for the distribution grid company (DSO) assuming today's rate plans. The DSO will have to yield their revenue from a more volatile load curve and a reduction of transmitted energy volumes. The increase in peak load (due to the introduction of EV's) is relatively small compared to the reduction (due to DEG) of off-peak. This might lead to the need of re-investments in infrastructure, with increased power flow. The distribution of costs among the end-consumers will be distorted compared to today's cost distribution. In order for the DSO to reach its regulated revenue cap, there is a need for modified tariff design.

INTRODUCTION

The electricity consumption (usage) is changing towards a market with "prosumers" (consumers that produce). The role for end-consumers is changing as they contribute to the balance between load and generation by DEG. When end-consumers start feeding power into the distribution grid, it imposes several challenges for a successful operation of a distribution grid as the initial design was for a one-direction energy flow (central producers and distributed consumers of electricity). This paper has examined which physical changes that will be required for the distribution grid, and also relate it to the subject of changed revenues for the electricity network company and hence the need for modified electricity network tariffs.

BACKGROUND

For this paper a distribution grid in a suburban area was used for the simulation, located in Southern Sweden. The suburban grid is a distribution grid outside the city centre, dominated by stand-alone residential houses and apartment buildings. There are also some commercial real-estate and a few smaller industries. The grid data is from actual metered data during 2012 from a suburban electricity grid, provided by an energy company.

Historical consumption data with an hourly resolution was used for a distribution grid. This data was modified (on a customer-level) in accordance to a scenario with widespread usage of EVs and DEG ("a future scenario").

In total 5,631 independent end-consumers' consumption data were included in the simulations, distributed across 61 secondary substations. The end-consumers and the secondary substations are a part of a radial distribution grid, with power feed from a single primary substation. The total amount of data was around 50 million lines of consumption data. The simulated time period covered one year (2012), however data was missing for about 6 weeks (February and parts of November). The original metered consumption data and the modified data were used to create an original scenario and a future scenario, which could be compared.

DEVELOPMENT OF FUTURE SCENARIO

The future scenario was created by modifying the original data by assuming additional DEG and usage of EVs. The simulated levels of installed capacity of PVs and EVs are based on several long-term national goals originating from the studies North European Power Perspective and Fossil-free vehicle fleet. Based on these studies, the total national (Swedish) fleet of EVs were one million [1] and the annual generation originating from solar power 14.5 TWh. [2]

Based on this, the overall installed capacity of locally distributed PVs was distributed upon a random selection of the end-consumers. All the consumers were assumed to use more electricity than they would generate annually. The simulation of generation from PVs' was based on irradiation data with an hourly temporal resolution from the STRÅNG database from Swedish Meteorological and Hydrological Institute (SMHI, [3]). The dimensioning of the PV-systems were therefore based on the annual consumption and available area for DEG of a certain category and end-consumer. The PV types used in the project and the percentage of customers with PVs (randomly distributed) are shown in Table 1.

Table 1: Types of PVs distributed upon different customer types

Customer type	PV type	Percentage with PV
Private houses	5kW	46%
Apartment buildings	1 kW/apartment	30%
Commercial buildings	5, 30 and 50 kW*	30-45%

**These are distributed so that the annual electricity generation is lower than the yearly electricity usage*

In a similar manner as for the PV-distribution, the usage of EVs was randomized upon appropriate customer groups. The penetration level for EVs for different customer types are shown in Table 2. This was done based on the assumption that EVs are used in a similar manner as today's cars, and that charging is mainly done at home. Additionally, fast charging stations for private cars (to some extent) and taxi cars were added to the distribution grid.

Table 2: Percentage with EV for different customer types

Customer type	Percentage with EV
Private houses	46%
Apartment buildings	30%
Fast Charging	2*

*Two fast charging stations in the area

The charging profiles for the EVs were based on the results from a simulation model developed in a previous study. [4] The parameters that were used for EVs charging at home and EVs fast-charging are shown in Table 3 and Table 4 respectively.

Table 3: Parameters used in the model to simulate load curve for EVs charging at home

Parameter	Value
Charging power	2.3 kW
Battery power	21 kWh
Average speed	46 km/h
Fuel Consumption	0.2 kWh/km

Table 4: Parameters used in the model to simulate load curve for EVs fast charging

Parameter	Value
Charging power	62.5 kW
Battery power	42 kWh
Average speed	46 km/h
Fuel Consumption	0.2 kWh/km

MODELLING AND RESULTS

The total consumption for end-consumer *a* in time step *t* was as shown in calculated as shown in

Equation 1.

Equation 1:

$$C_{tot,a,t} = C_{orig,a,t} + EV_{a,t} - PV_{a,t}$$

As the grid topology was known, the aggregated load for each section in the grid could be calculated once *Ctot,a,t* was calculated for each specific prosumer. The total energy flow per month for the original scenario is shown in Figure 1.

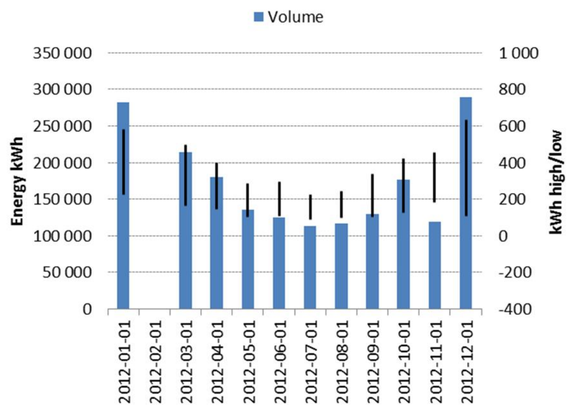

Figure 1: Aggregated energy flow per month in the original scenario. The total volume for each month is shown, as well as the highest and lowest power outtake during one hour (kWh/h).

The total energy flow per month for the future scenario is shown in Figure 2.

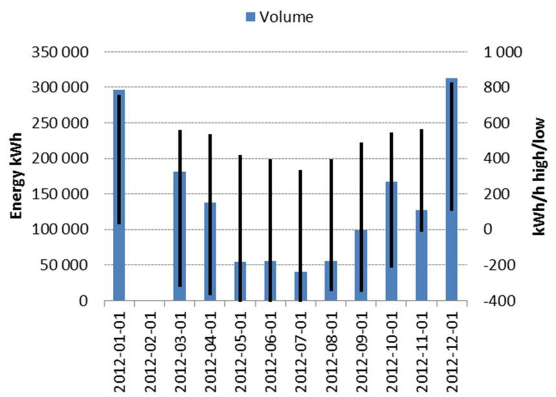

Figure 2: Aggregated energy flow per month in the future scenario. The total volume for each month is shown, as well as the highest and lowest power outtake during one hour (kWh/h).

When comparing Figure 1 and Figure 2, one can see that the spread is larger in Figure 2 than it is in Figure 2; i.e. the load curve is more volatile. The increase in peak-load is relatively small compared to the decrease of off-peak. Hence, the overall transmitted energy over the year is significantly decreased. The aggregated energy flow per month for the original scenario and the future scenario is also shown in Figure 3.

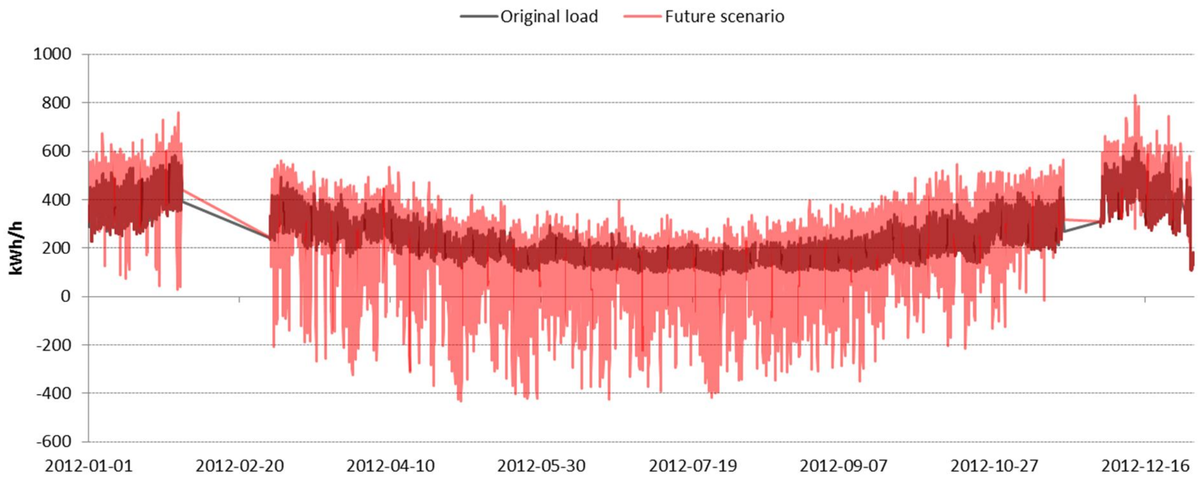

Figure 3: Aggregated energy flow per hour for the original aggregated load and future scenario. Notice that data is missing for February and parts of November.

Consequences for Distribution Net Owners

The results from the future scenario simulations indicate severe changes for DSOs'. These can be divided into:

- Possible need for physical alterations in electricity networks, which requires additional investments
- Possible need for new tariff design, to ensure the same revenue

The results indicate that the two main physical changes that the electricity network has to respond to are:

- Changed direction of net flow
- Increased power peaks

For a single household it is expected that the electricity generation some days exceeds the electricity consumption, for example during a sunny summer day when nobody is home. The excess electricity is fed onto the grid and consumed by surrounding customers. If many customers in the neighborhood are in the same situation the net flow might shift direction. The simulations showed multiple occasions in which the net flow changed direction, all the way up to the primary substation. Given that distribution grids were initially constructed for one-direction energy flow, this might cause problems.

The simulations show that the net flow in the new direction is always lower than the peak load flow in the original direction. Therefore, the change in net flow is not determining the dimensioning of the grid.

As can be seen in for example Figure 3 the usage of EVs increase the peak loads during winter time. The power peak is increased by 15% at overall distribution network-level. At substation-level the power peaks are increased by 40%. Please note that what is referred to as "power peaks" are power peaks in terms of kWh/h, due to the temporal resolution.

The EVs are expected to become very common in certain areas (based on that people often are influenced by their neighbors). Also, there is a possibility that people choose to charge their EVs at similar times (after office hours). This further increase the risk of local power peaks. It is estimated that 30% of the suburban distribution grids in Sweden do not have capacity to handle the power peaks shown in the simulations. [5] Hence, additional investments in grid infrastructure will likely be needed. It is however important to note that the penetration levels of EVs and DEG are quite high and are likely to take a couple decades to be reached. Therefore, a large part of these further investments can be done within original investment plans.

Also, multiple investments can be delayed in time by investing in systems for monitoring and control of the different levels of the electricity network.

As can be seen when comparing Figure 1 and Figure 2, the total amount of transmitted energy is reduced. Given the tariff structures of today, where customers usually pay a large share of the total bill based on transmitted kWh, the DSOs' income will be reduced. Therefore, the companies need to update their tariffs in order to reach their regulated revenue cap. This can be done either be increasing the cost per kWh, by increasing the fixed cost part, by adding a power tariff part (cost per peak kWh/h during a month) or by a combination of these. More and more companies are looking at using power tariffs also for smaller customers. This reduces the weather-dependent income part. It is also considered to give fair cost-bearing distribution among the customers. [4]

Consequences for consumers

The customers which install PV will decrease their electricity usage, whilst other customers which do not install PV will not. The increased use of PVs will increase electricity usage, however to a lower extent than the decrease caused by increased DEG. As an example, the total transmitted energy for different customer groups within the 20A category segment were compared. The 20A customers were divided into groups of original load, customers with EV, customers with PV and customers with both EV and PV. This comparison is shown in Figure 4.

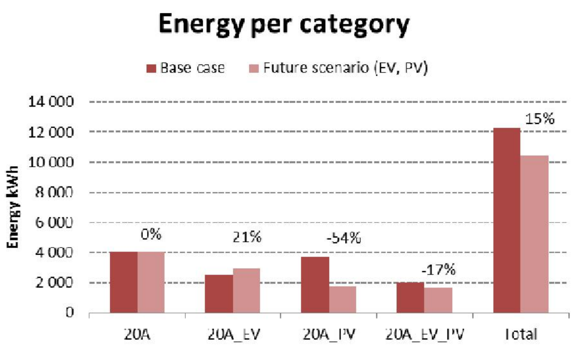

Figure 4: Total transmitted energy for different customer groups within the category 20 A

As can be seen from Figure 4, the energy usage decrease for customers with PV and for customers with both EV and PV. Consequently, the total transmitted energy decline. Since customers installing PVs will reduce their electricity bill, the DSO has to charge other customers more (for the same amount of transmitted electricity) in order to reach the same income. Therefore, there will be a redistribution of cost-burden among different customer groups.

CONCLUSION AND ADDITIONAL OPPORTUNITIES USING BIG DATA ANALYTICS

Big data analytics enables more precise modelling of possible future scenarios. The handling of big data allows modifications of individual customers' load patterns. Using bottom-up approach, power outtake and transferred energy at different desired parts of the grid can be calculated and related to each other. The simulated scenario shows that both customers and DSOs are affected by the additional DEG and usage of EVs.

For electricity distribution companies, there will be a need for further investments in electricity networks, in order to handle situations of changed direction of net flows and increased power peaks. To some extent this can be reduced by additional systems for monitoring and control of the different levels of the electricity network. The DSOs will also need to redesign their tariffs, in order to yield the same revenue levels as before.

For customers there will be a redistribution of cost-burden, where customers without PVs will pay more for the same electricity usage and customers with PVs will pay less than before.

Big data analysis can be used to address many of the challenges that the simulations show might arise. This includes further in-depth analysis of changed net flow directions and peak loads at different levels of the grid (also in other types of grids). Multiple other different parameters can be changed and tested, for example weather, reduced or increased electricity usage within different customer groups, power tariffs, time-differentiated tariffs and much more.

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[5] Results from workshop discussions with representatives from Elforsk's member companies. Elforsk is a non-profit R&D company set up by all major Swedish energy companies and the Swedish TSO.