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Evaluation of Power Flow Prognosis Methods for Congestion Management in Low Voltage Grids

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***Abstract*— For the application of proactive congestion management concepts the enhancement and implementation of power flow forecast methods is essential. The increase of directly marketed renewable generation and the use of flexibility options by market participants may lead to difficulties in predicting the power flow without any knowledge of market actions. Therefore, power flow forecast methods that take data and information from market parties and local building energy management systems into account have to be developed and evaluated. This Paper presents an integrated process for creating power flow forecasts in low voltage grids based on the forecasts of different role-specific system solutions such as building energy management systems and flexibility management systems. Moreover, the use of standard load profiles and Smart Meter measurements for the creation of load profiles is presented. The results of the evaluation of the process and the methods for one low voltage grid in the gridlab Freiamt of Netze BW show the potential of the proposed process and the developed methods for a further congestion management in low voltage grids. Furthermore, possible measures to improve the methods are mentioned.**

Keywords- power flow prognosis; building energy management systems; flexibility management system; grid load management system; SLP; Smart Meter measurements; load profiles; forecast

I. MOTIVATION

The increase in renewable energy-based power plants in Germany to 80 % till 2050 will cause a fundamental change in the power supply structure. The generation capacity shifts to the distribution level and therefore the relevance of distribution systems in ensuring overall system stability will increase. In addition, the challenges in the distribution grids, e.g. feed-in peaks from decentral renewable generation units, require the development of new innovative congestion management concepts. For the application of such concepts the enhancement and implementation of power flow forecast methods in LV grids is essential. The increase of renewable generation and the use of flexibility options such as battery storage units operated by market participants may lead to difficulties in predicting the grid state without any knowledge of market actions in the future. Therefore, power flow forecast methods that take data and information from market participants into account have to be developed and evaluated.

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grid-control

II. RELATED PROJECT AND OBJECTIVE

The research project "grid-control – Advanced decentral grid-control" started in July 2015 to develop and evaluate an overall concept for sustainable distribution grids. The objective is the implementation of role-specific system solutions in an overall concept and the realization of approaches in different working topics, such as congestion management. The integration of the different system solutions in the overall concept creates an added value by using synergy effects.

One part of the overall concept is the realization of the German Grid Traffic Light Concept, as described by the German regulator [2]. The approach makes it possible to combine market-oriented and grid-serving benefits of local flexibilities in the distribution grid. For the realization of the green/ yellow Grid Traffic Light Phase an integrated process between the market parties and the distribution system operator (DSO) is developed, enabling the generation of power flow forecasts in MV/LV grids. Hence, data and information of the market parties including prosumers (supplier and consumer in one) can be considered. Different methods for the prognosis of load profiles and for power flow calculations are implemented and evaluated in a field test.

III. POWER FLOW CALCULATION PROCESS AND SYSTEM SOLUTIONS

The prognosis of the power flow in distribution grids is composed of the prognosis of load (e.g. households, battery storage units) and generation (e.g. PV, wind, biomass). Moreover, it has to be distinguished between the prognosis of inflexible and flexible energy units. Flexible units are able to modify their "generation injection and/or consumption patterns in reaction to an external signal (price signal or activation) in order to provide a service within the energy system" [3], e.g. congestion management. Therefore it may be difficult to predict their infeed/load and to use their flexibility for congestion management without any knowledge of their usage.

A. Input Time Series for Prognosis

In project grid-control, the power flow prognosis is implemented on a quarter-hourly, day-ahead basis. Next to topology information, the input of the power flow calculation are time series for the forecasted generation G and load L for quarter-hour t of day d+1 at the Meter Point MP.

Local Building Energy Management Systems (BEMS) are implemented to create the forecast for buildings/prosumers with flexible units. Next to the forecast for the active power of the inflexible units (e.g. household) the BEMS calculates an initial schedule for the use of the flexible units (e.g. battery storage unit) and a bandwidth for a modification of this schedule (e.g. for market- oriented or grid-serving use). By providing this data to a flexibility aggregator the flexible units are used for market-oriented or grid-serving benefits. Therefor in project grid-control a Flexibility Management System (FMS) is developed for market participants.

Each BEMS is mapped to a virtual Meter Point (vMP). This Meter Point is the aggregated meter point of all generation units and loads that are forecasted by a BEMS, as shown in Figure 1. Moreover, the meter points are mapped to a grid connection point, which can also be seen in the same figure. For example in an apartment building, multiple meter points (and virtual meter points with a BEMS) are possible behind one grid connection point.

The following time series are provided by a BEMS to the FMS of its market participant/aggregator:

- $UL_{vMP,d+1,t} \geq 0$ (Prognosis of inflexible loads incl. initial schedule for flexible units)
- $UG_{vMP,d+1,t} \leq 0$ (Prognosis of inflexible generation units incl. initial schedule for flexible units)
- $Emin_{vMP,d+1,t}$, $Emax_{vMP,d+1,t}$, $Pmin_{vMP,d+1,t}$, $Pmax_{vMP,d+1,t}$ (bandwidth for schedule modifications)

Each FMS collects the time series of its linked BEMS, runs a market-oriented optimization of the schedules for the flexibilities and provides the new schedules to the system of the DSO, the Grid Load Management System (GLMS), shown in Figure 2. The GLMS performs a schedule optimization which outputs the changes of the infeed/load of the flexible units relative to the initial schedule of the BEMS ($FL_{vMP,d+1,t}$ and $FG_{vMP,d+1,t}$).

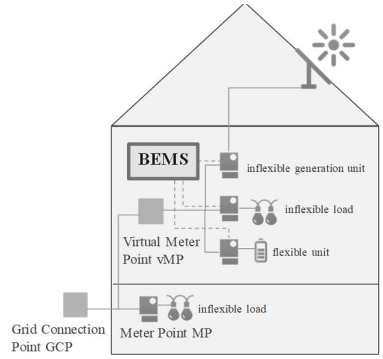

Figure 1: Meter Points and Grid Connection Point

The forecasted and planned total infeed/load (Active Power P) at the virtual Meter Point of a BEMS for day d+1 and quarter hour t can be calculated as

$$P_{vMP,d+1,t} = UL_{vMP,d+1,t} + UG_{vMP,d+1,t} + FL_{vMP,d+1,t} + FG_{vMP,d+1,t} \quad (1)$$

Moreover the FMS calculates load profiles for additional inflexible loads and generation units of other customers (e.g. normal households or PV systems with no possibility to control their infeed). The generation and load forecast for inflexible units of suppliers/market participants with no FMS providing the forecasts (Figure 2, right side) may be done by a service provider or the DSO. In the project grid-control it is assumed that each generation unit and load is mapped to an FMS providing the forecasts to the GLMS. The methods for the prognosis of the different time series are described in detail in section IV.

B. Load Flow Calculation Method

The GLMS is the interface between market and DSO and calculates the power flow in the grid based on the described input time series. For the calculation of the power flow different methods can be applied.

An "advanced" GLMS (Figure 2, bottom right) uses complex power flow calculation tools. Project grid-control focuses on the low-voltage level where the grid topology is mostly a radial structure. Therefore, as a first step a more „simple" GLMS for an estimation of the active power flow is realized (Figure 2, bottom left). With a radial grid topology the grid connection points and their connections can be depicted as a hierarchy/ tree structure. An example is shown in Figure 3. On this basis the active power flow in each connection point can be calculated through an (hierarchical) aggregation of the power infeed/ consumption of the downstream grid connection points. For example, the active power flow at grid connection point 1 in Figure 3 is calculated as

$$P_{1,d+1,t} = \sum_{GCP=2}^{10} P_{GCP,d+1,t} \quad (2)$$

The power aggregation can be realized declarative in a database and no elaborate power flow calculation tools are necessary. In addition, less input data e.g. concerning the grid topology are necessary and no interim results need to be saved. As a further development, planned topology changes can be taken into account by means of a time-based storing of the tree structure.

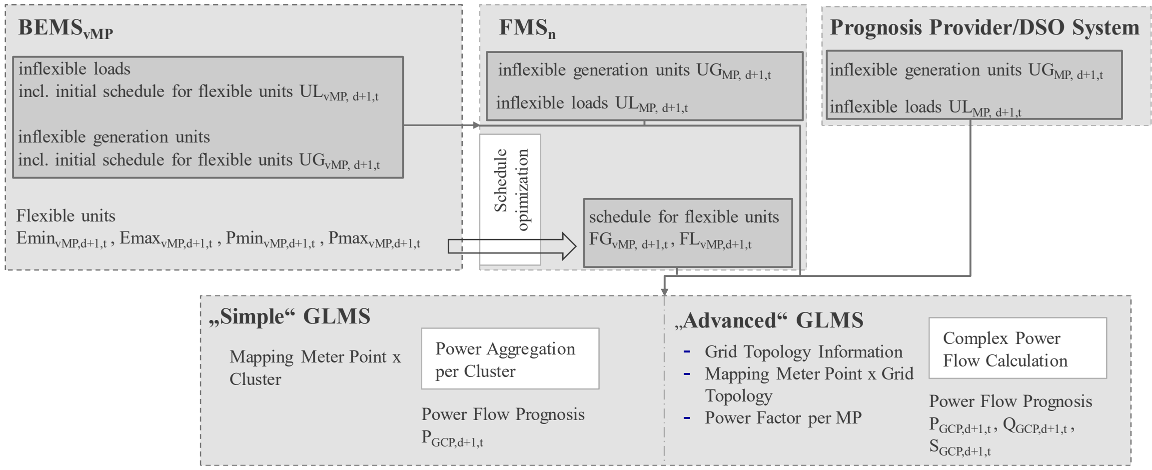

Figure 2: Power Flow Calculation Data & Process

The congestion management approach in project grid-control focuses on the avoidance of congestion at the boundary of certain grid clusters. The cluster levels represent technical restrictions that affect all decentralized energy systems at lower cluster levels and are generally based on the grid structure. In project grid-control, four grid-oriented regional cluster levels are defined, even though the focus is on the low voltage cluster levels

- HV/MV transformer
- MV feeder
- MV/LV transformer
- LV feeder.

The power flow prognosis focuses on the grid connection points of the defined low voltage grid clusters (MV/LV transformer and LV feeder) and the active power (power aggregation per cluster) hereafter. The reactive power, the voltage drop and grid losses should generally be considered in a congestion management concept. By using the presented forecast method this can be done by implementing a buffer.

IV. Prognosis Calculation of the Input Time Series

In this section the prognosis of the following input time series is described in detail:

- Prognosis at prosumer side (BEMS)
- Load profile calculation for inflexible loads
  a) based on Standard Load Profiles (SLP)
  b) based on historical Smart Meter data (SM)

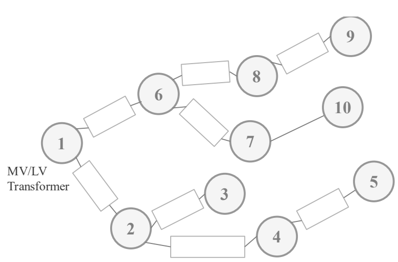

Figure 3: Example Grid Connection Points in a LV Grid Cluster

The two methods for the load profile calculation are both implemented with the aim of a comparison of the forecast quality. The development of prognosis methods for the infeed of generation units e.g. PV is not in focus of the project. Hence, these time series are provided by an external prognosis provider and not described in this paper.

A. *Local Prognosis at Prosumer Side (BEMS)*

Building Energy Management Systems (BEMS) that are located at building or apartment level are used for forecasting buildings/prosumers with flexible units. Since they can gain deep insights into the behavior and schedules of the residents and the operational characteristics of locally installed devices a BEMS may be able to improve the quality of power prognosis in LV grids. Depending on which data is accessible by the energy management system, various different models may be applicable. For example, solely based on historically observed data, the (average) historical consumption gives a possible forecast for consumption [9]. A more sophisticated approach is to either observe devices directly or, if this is not possible, disaggregate the consumption load profile [8] to learn about the users' behavior and use this knowledge to create better consumption forecasts [1].

In project grid-control, only energy management systems on a building level have been tested. These BEMS collect and use the following information:

- *Electricity Consumption*: Historic consumption is the basis for forecasting the initial consumption.
- *Electricity Production*: A forecast for PV production is derived from the historic production.
- *Battery Load, State of Charge and Schedule*: The state of charge and the planned schedule of the battery storage system determine its flexibility, i.e., its capability to influence the building's overall load profile.

Figure 4 depicts the process of creating a load forecast for the building associated to the BEMS. At first, electricity consumption, production and the available flexibility are forecasted. Since, in the project grid-control, the only source of flexibility accessible by the BEMS are battery storage systems, only the flexibility of these resources is considered. The predicted consumption, production and flexibility is then used to maximize self-consumption of the produced energy and finally the resulting overall building forecast is split into two separate forecasts for building electricity consumption and building electricity production.

1) Prognosis of Electricity Consumption: For the prognosis of the electricity consumption, weekdays are clustered into three groups. In the style of standard load profiles it is distinguished between a weekday, Saturday and Sunday. The basic assumption is that the residents behavior will be similar to that observed in the past for a given category of day. A forecast is created by averaging the electricity consumption of a configurable number of past days within the same cluster. In the tests the number was set to two days. For example, if a forecast for a Monday is to be created based on two past days, the forecast equals the average consumption of the prior Friday and Thursday.

2) Prognosis of Electricity Production: The forecast for electricity production by the photovoltaic installation is a simple persistence forecast. Similar to the prognosis of consumption, this is based on the assumption that the past gives a good prediction for the future. The forecasted PV production equals the production observed in the previous 24 hours.

3) Prognosis of Flexibility: Neglecting its environment, the capability of a battery storage system to adapt its load is mainly given by the State of Charge (SoC). Hence it is necessary to forecast the SoC in order to forecast the flexibility. This is done by simple calculating the change in SoC caused by the scheduled load profile. The resulting expected SoC is then transformed into corridors for feasible power and (dis-)charged energy (see [6] for more details).

4) Resulting Consumption and Production Forecasts: Given the forecasted consumption, production and flexibility, the BEMS attempts to maximize self-consumption. The resulting building load profile is separated into a consumption and production forecast ($UL_{vMP,d+1,t}$ and $UG_{vMP,d+1,t}$) with at least one of both being zero for each time step. These two forecasts, combined with a description of the available flexibility ($Emin_{vMP,d+1,t}$, $Emax_{vMP,d+1,t}$, $Pmin_{vMP,d+1,t}$, $Pmax_{vMP,d+1,t}$), are then shared with the FMS of the associated market participant.

B. Load Profile Generation based on SLP

Grid operators and supplier usually use SLP for the accounting of the power delivery to end customers with an annual consumption of less than 100 MWh. Instructions for the use of the SLP are given by the German Association for Energy and Water (BDEW, previously VDEW) [3], [7].

In project grid-control SLP are used to forecast load profiles at individual Meter Points and with that the power flow in the low voltage grid. The accuracy of a SLP for the load forecast at individual grid connection points depends on the number of loads in the downstream grid segment and the dispersion of the behavior of the loads. According to [4] SLP are sufficiently accurate at a minimum of 150 loads in a grid segment. Between a SLP and real measured power consumption of individual households, big deviations are to be expected. Moreover, SLP don't consider new loads, e.g. e-mobility. One aim of the project is therefore to evaluate the accuracy of SLP-based load profiles and to compare them with the Smart Meter based profiles.

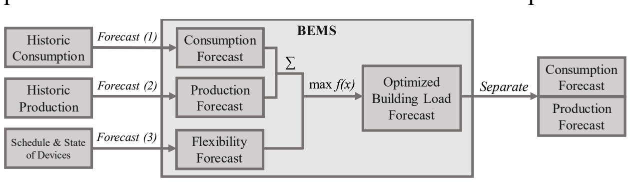

Figure 4: Generation of a Building Load Forecast

There are SLP for three different customer groups, as shown in Table 1. Each group of consumers has a representative profile on a quarter-hourly basis normalized to an annual consumption of 1000 kWh. To cover seasonal differences in the electricity consumption, the year is divided into three seasons (winter, transition, summer) and three characteristic days (working day, Saturday, Sunday/holiday), as shown in Table 2.

Table 1:SLP electricity consumption groups

Group	Customers
Household (H0)	Household (exclusive power2heat systems)
Business (G0)	Office, Surgery, School, Kindergarten, Cafe, Youth club, Bakery
Agriculture (L0)	Agriculture, dairy, animal breeding

Table 2: Static Characteristic Time Zones

Season	Static Characteristic Time Zones
Winter	01.11 – 20.03
Transition	21.03 – 14.05 and 15.09 – 31.10
Summer	15.05 – 14.09

In addition, the H0 load profile is multiplied with an index-linking function (polynomial 4^{th} order) to better integrate leaps between the seasons and to consider, that the consumption is higher on winter days than in summer.

To create a load forecast, a calendar with all working days, Saturdays and Sundays or public holidays in the period under consideration is created. This ensures that the public holidays are correctly taken into calculation every year, because a public holiday has a different typical load curve than a working day. The advantage of this procedure is the possibility to create forecasts for a long forecast period as long as the public holidays are known.

In the next step, a power value from the representative profile is assigned to each quarter of an hour in the forecast period for each customer according to its SLP group, day and season. In the last step, the normalized power value is adjusted to the assumed annual electricity consumption. The conversion of the normalized quarter-hourly values is done with a factor. The factor is multiplied by the normalized quarter-hourly value. The factor is defined by the division of the estimated annual consumption (kWh) through 1000 kWh.

C. Load Profile Generation based on Smart Meter Data

Using historic measured data of real households to generate load profiles for forecasting electricity consumption in low voltage grids might improve the quality of the power flow prognosis in low voltage grids. By using historic meter data, weather influences, personal behavior of the persons in households and different behaviors of family-types or small industry types are added.

For the prognosis in project grid-control historic data from 1500 Smart Meters measured over a time period of one year with an accuracy of 15 minutes in Baden-Württemberg (Germany) are used. Given the fact that the data was measured in a similar geographic region as the region where the prognosis methods are evaluated, the influence of the season can be assumed similar. Moreover, the year of the measurement is known, so that the weekdays and the seasons are known.

To use these data for the prognosis, the historic load profiles are clustered in about 100 profiles according to the yearly electricity consumption using K-Means algorithm. The idea behind that is that every resident (family) with a certain electricity consumption behaves similarly.

For the prognosis of the load profile at a certain Meter Point the following data are considered concerning the forecast period:

- assumed yearly electricity consumption of the customers (family) behind the Meter Point
- date and weekday of the forecast period
- public holidays in the forecast period

Based on this data the load profile of the cluster with the smallest difference to the assumed yearly electricity consumption of the customer and of the same weekday is assigned to his Meter Point as the load forecast. In case of a public or school holiday in the forecasted region, this is taken into account as well.

V. Evaluation

The developed concepts and system solutions are tested and evaluated in a field test in the gridlab (NETZlabor) Freiamt of Netze BW GmbH. The gridlab Freiamt is a rural MV-section (approx. 4,000 inhabitants), where the maximum generation is more than three times higher than the maximum load. These conditions form an environment to test the grid of the future in today's grid operation.

A. Field Test Set-up

The power flow prognosis methods and the developed process are evaluated in one low voltage grid, as shown in Figure 5. Table 3 shows the main facts about the field test setup.

B. Indicators for the forecast quality

The following evaluation of the power flow prognosis is focused on the power flow at the LV busbar of the transformer of the described field test grid section.

To evaluate the forecast quality a selection of typical criteria is used. The first parameter is the "normal" Error (E) in order to distinguish between over- and underestimation.

Table 3: Field Test Grid Segment

low voltage feeders	4
grid connection points	44
meter points (inflexible loads/ inflexible generation)	54 (48/12)
Installed generation capacity	Approx. 200 kWp (12 PV generation units)
BEMS	4
Flexibilities (Battery storage units)	1x 120 kW/ 20 kWh 1x 19 kW/ 19 kWh 2x 4,6 kW/ 9 kWh
PV generation units forecasted by BEMS	Approx. 40 kWp
PV generation units forecasted by external provider	Approx.160 kWp
Transformer rated power	250 kVA

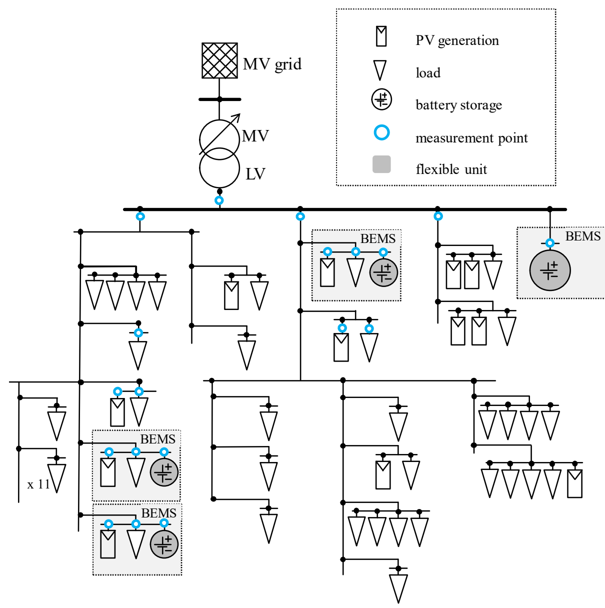

Figure 5: Field Test Setup

The second indicator is the Relative Mean Absolute Error (RMAE). The RMAE refers the Mean Absolute Error to a reference value, in this case the grid capacity of the MV/LV transformer in the field test. For a measurement interval T and with the forecasted values $P_{prog,t}$, the actual values $P_{meas,t}$ and the reference value P_{ref} the parameters are calculated as:

$$E_t = P_{prog,t} - P_{meas,t} \tag{3}$$

$$RMAE_T = \frac{1}{T}\sum_{t=1}^{T}\frac{|P_{prog,t} - P_{meas,t}|}{P_{ref}} \tag{4}$$

For the implementation of a prognosis-based congestion management it is important that the market is not limited more than necessary. Otherwise, the grid capacity is not used efficiently. Moreover, congestions should be forecasted with a certain reliability, so that the DSO does not need to take emergency measures often (e.g. curtailment of PV systems) in the case of an occurring congestion. Hence, the better the power flow prognosis the better the efficiency of the congestion management.

C. Evaluation Results

Firstly, the prognosis of the power flow at the low-voltage busbar of the secondary substation transformer is evaluated. Afterwards, the prognosis and schedules of one BEMS at a certain grid connection point is discussed in detail.

1) Power flow Prognosis at Transformer Busbar

Figure 6 shows the measurements and the forecasts of the power flow at the LV/MV transformer for two exemplary weeks (sunny & less sunny). For this, the one-minute measurements at the transformer busbar are averaged to 15-minute measurements. During the last three days of the displayed week in the upper figure the schedules of the battery storage units are modified market-oriented, so that occasional leaps up to approx. 140 kW are visible (prognosis and measurements).

At first sight, the measurements and the forecasts are quite similar for most of the days, especially for days with high global radiation (such as the first two days in the upper figure). The forecast PV bell curve is visible on all days and on the third sunny day there is a considerable difference in forecast and actual power generation, presumably a very cloudy day. This demonstrates that the prognosis of the PV-infeed has a considerable impact on the forecast quality of the total power flow in the grid. Hence, the evaluation of the developed methods for the creation of load profiles should also be done for grid sections with less or no local generation units. At the moment the methods can only be evaluated for PV dominated low voltage grids. Moreover it is visible, that especially during the winter week (bottom figure) the PV infeed is underestimated. One possible measure to improve the forecast quality is the use of intraday-prognosis updates.

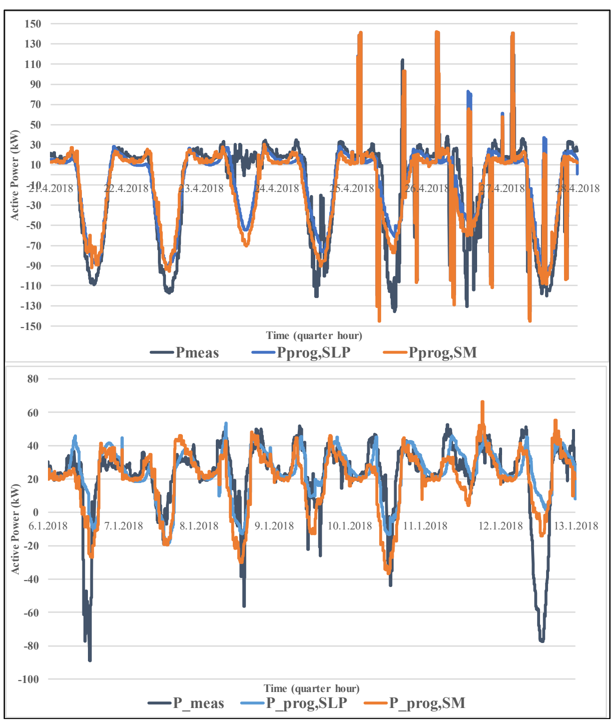

Figure 6: Power flow prognosis (SLP: Standard Load Profile based, SM: Smart Meter based)

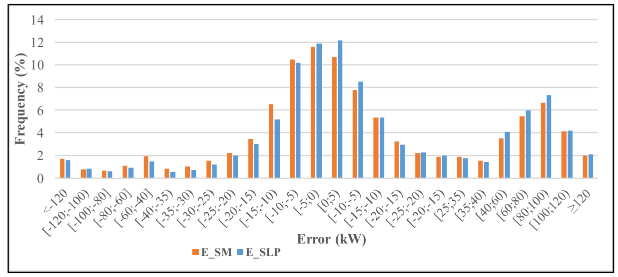

Figure 7: Histogram of the Error (E) of the power flow prognosis

Figure 7 shows a histogram of the calculated Error (E) for the forecasts and measurements for a time period of 11 months (1.10.2017 – 20.8.2018) for both methods for the load profile generation. It has to be mentioned that some Errors refer to the not-maintaining of the final schedules for the flexible units by the BEMS. This may have different reasons, such as a breakdown of a battery storage unit. Moreover a successful maintaining of a schedule regarding the congestion management leads to an Error between the forecast and the actual value. These quarter hours with an active congestion management are only a small number compared to the whole evaluation period. It can be seen, that 40.51 % (SM) and 42.77 % (SLP) of the errors are between -10 kW and 10 kW. Compared to the transformer capacity of 250 kVA the forecast is considerably accurate. The occasional outliers around 120 kW and 50 kW originate most likely from the behavior of the 120 kW battery storage unit. On some occasions the unit did not adhere to the schedule, other times the unit prevented a fictional 50 kW congestion.

With the Smart Meter based load profiles the power flow is under- and overestimated nearly with the same frequency (50.01 % overestimation ($P_{prog,t} > P_{meas,t}$) in total). The SLP based load profiles lead more to an overestimation (53.8 % in total). Hence it is not possible to deduce a buffer for an expected continuous over- / underestimation.

Figure 8 shows the Relative Mean Absolute Error (RMAE) for the measurements and forecasts for the same time period of 11 months (P_{ref} = 250 kW). It can be seen, that for most days the RMAE is less than 10 %. An evaluation based on the Mean Absolute Percentage Error (MAPE) was not considered as it disproportionately weights Errors near 0 kW power flow as being most significant.

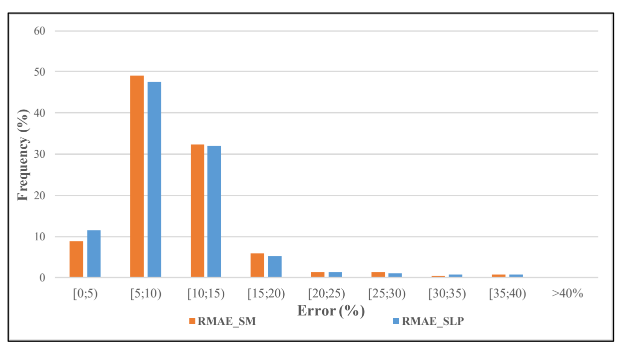

Figure 8: Histogram of the Relative Mean Absolute Error (RMAE) per day

2) Power flow at virtual Meter Point of a BEMS

Figure 9 shows the initial schedule, the market-oriented schedule and the measurements for the virtual Meter Point of a BEMS with a battery storage unit (4.6 kW) and a PV system (5.8 kWp) in the low voltage grid of the field test.

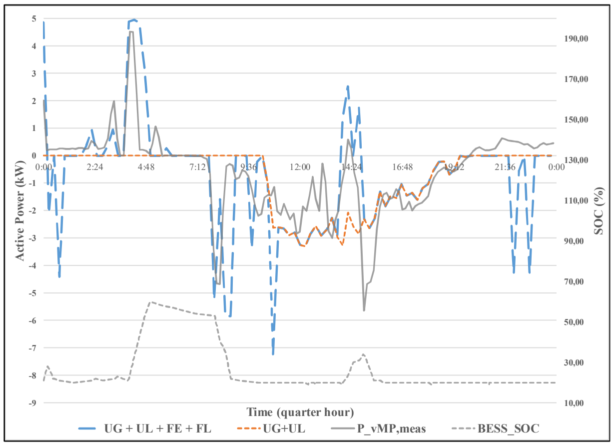

Figure 9: Prognosis, schedule and power flow measurement at vMP of BEMS with 4.6 kW BESS

The initial schedule of the BEMS ($U_G + U_L$, orange line) has the aim to optimize the self-consumption of the building; for instance, until 10:15 a.m. the total load at the vMP is zero as the battery unit charges with the Power from the PV unit. After the BEMS has shared its forecasts for building load and flexibility, the market participant can define a target schedule for the respective day. These modifications can be seen by the leaps of 4.6 kW in the blue curve during some quarter hours. This shows the advantage of the usage of the power forecasts of the BEMS. These leaps (market-oriented use of flexibilities) can only be considered for the power flow forecasts in the grid by using this data of the BEMS.

The actual building load profile that is realized throughout the day is heavily influenced by the BEMS. This can be seen by the grey line ($P_{vMP,meas}$). An intraday optimization tries to follow the target schedule using a greedy heuristic. The heuristic determines the deviation from the target and then scans the flexibility description chronologically, trying to use the flexibility in order to push the deviation to a value of zero. This may lead to a worsening schedule compliance and thus deviation from the forecasted building load profile throughout the day. Hence, one possible measure to improve the building load forecasts of the BEMS is the improvement of the schedule optimization.

The implementation and evaluation of forecasting algorithms for the BEMS was only a subsidiary topic in the project. There is great potential for improving the forecast, e.g. by using additional information like weather forecasts, models for user behavior, stochastic information, and so on. In addition the load profiles of todays lifestyle may look different to the SLP, so that the use of improved SLP probably also improves the quality of the power flow prognosis. Concerning the use of Smart Meter data for the creation of load forecasts, more information about the dataset, such as the temperature in the measured geographical region, may also lead to an improvement.

3) Conclusions concerning Congestion Management Concepts

In principle with the presented power flow prognosis process and methods, the implementation of a proactive congestion management is applicable. With an increasing number of flexible units in the low voltage grid it will be important to use information of market participants for the power flow forecast. The measurements show that swarm effects in the use of flexible units can lead to considerable leaps in power flow and therefore potential congestions. An improvement of the forecast quality through the use of Smart Meter data in comparison to SLP can be neither confirmed nor contradicted in this setup. Further evaluations are planned in upcoming works.

VI. Summary and Outlook

This Paper presents an integrated process for creating power flow forecasts in low voltage grids based on the forecasts of different role-specific system solutions such as building energy management systems and flexibility management systems. Moreover, the use of standard load profiles (SLP) and Smart Meter measurements for the creation of load profiles is presented. The results of the evaluation of the process and the methods for one low voltage grid in the gridlab Freiamt of Netze BW show the potential of the proposed process and the developed methods for a further congestion management in low voltage grids. Furthermore, possible measures to improve the methods are mentioned. These measures, such as intraday forecasts and improved schedule optimization on BEMS-side, will be part of upcoming works.

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References

[1] Barbato, A., A. Capone, M. Rodolfi, und D. Tagliaferri. „Forecasting the usage of household appliances through power meter sensors for demand management in the smart grid.“ 2011 IEEE International Conference on Smart Grid Communications (SmartGridComm). Brussels, Belgium, 2011

[2] Bundesnetzagentur; „Smart Grid“ und „Smart Market“ – Eckpunktepapier der Bundesnetzagentur zu den Aspekten des sich verändernden Energieversorgungssystems“, Bonn 2011

[3] Bundesverband der Energie- und Wasserwirtschaft; Standardlastprofile Strom; Documents at https://www.bdew.de/energie/standardlastprofile-strom/

[4] Engels, K.; Probabilistische Bewertung der Spannungsqualität in Verteilungsnetzen, Dissertation, RTWH Aachen, 2000.

[5] European Distribution System Operators for Smart Grids - Flexibility: The role of DSOs in tomorrow's electricity market, Brussels 2014

[6] Förderer, K., und H. Schmeck. „Demo abstract: a building energy management system in the context of the smart grid traffic light concept.“ Computer Science - Research and Development, February 2018: 269-270.

[7] Fünfgeld, C.; Tiedemann, R.; Anwendung der Räpresentativen VDEW-Lastprofile step by step ; 2000

[8] Hosseinia, Sayed Saeed, Kodjo Agbossoua, Sousso Kelouwanib, und Alben Cardenasa. „Non-intrusive load monitoring through home energy management systems: A comprehensive review.“ Renewable and Sustainable Energy Reviews 79 (November 2017): 1266-1274

[9] Kemmoku, Y.; Orita, S.; Nakagawa, S.; Sakakibara, T.; . „Daily Insonlation forecasting using a muliti-stage neural network “ Solar Energy 66, Nr. 3 (1999): 193-199.