Advantages of Modifying the BDEW Traffic Light Concept for Local Flexibility Markets

Sven Pack, Kevin Kotthaus, Jessica Hermanns, Benedikt Dahlmann, Markus Zdrallek
University of Wuppertal
Wuppertal, Germany
Sven.Pack@uni-wuppertal.de

Sebastian Raczka
SPIE SAG GmbH
Dortmund, Germany
Sebastian.Raczka@spie.com

Fritz Schweiger
E-Werk Schweiger oHG
Oberding, Germany
Fritz@ew-schweiger.de

***Abstract*—The number of flexible loads and renewable energy conversion plants is continually increasing, which also increases the frequency of critical grid situations at low and medium voltage level. The concept of local flexibility markets (LFMs) could be a possible solution to face these future congestions. LFMs could be economically reasonable for the distribution system operator (DSO), compared to the conventional enhancement of the grid. However, the economic advantages are only given if the market is not opened too frequently. Therefore, a key point in this paper will be the specification of the BDEW traffic light phases (TLPs). The influence of reactive power control (RPC) on the market calls is examined in more detail. For demonstrating the advantages of RPC for the LFM, simulations were made on different grid types. The simulations show how the design of the BDEW TLPs influences the LFM.**

reactive power control, local flexibility market, BDEW traffic light concept

I. Introduction

Due to the increasing number of renewable energy conversion plants, the frequency of critical grid situations at low and medium voltage levels increases as well. A high simultaneous photovoltaic feed-in leads to exceedances of the upper voltage limits [1]. These problems could be solved with conventional grid enhancement or with innovative smart grid systems (SGS). In addition to the increase of decentralized feed-in, the number of large decentralized loads like heat pumps or electrical vehicle charging stations are also increasing. An agglomeration of these loads in single strands or parts of the grid could lead to overloads or undercutting of the lower voltage limit. For facing the new challenge SGS must be upgraded with charging management, for instance. This is associated with further investments. In order to avoid these investments, active grid users can be integrated with the help of local flexibility markets (LFMs) to solve the problems [2]. The concept of LFM is based on the BDEW traffic light concept, which tries to solve predicted congestions first by the market mechanism and then by the SGS [3]. Due to the increasing number of problems in the near future, the static sequence of measures according to the BDEW concept should be reconsidered.

In this paper the vague formulation of the BDEW traffic light phase (TLP) is explained in more detail. It will be described in detail which measures are carried out in the individual TLP. The specification of the phases is required in order to avoid unnecessary market openings. This leads to a reduction of the costs for the LFM.

In a previous paper the influence of voltage control in the green TLP with a switching transformer has already been discussed [4]. This paper will deal with the influence of reactive power control (RPC) on the low voltage level. In a simulation with different grid types in a future scenario, the effects of RPC on the cost of acquiring flexibility are determined. The final cost comparison for the retrieval of flexibility with and without DSO measurements provides information about the potential of the specification of the TLPs.

II. The Distribution Grid Traffic Light Concept

A. The Classic BDEW Concept

The BDEW traffic light concept forms the basic framework between the interaction of DSO and LFM. In the context of the concept, LFM were developed as a further opportunity to minimise or avoid the cost of conventional grid enhancement due to the rising share of renewable energy and large decentralized loads. The traffic light concept describes three different phases that define the grid state [3].

In the green phase, the regular grid operation is possible without restrictions and all users can act independently. If a potentially critical grid state is predicted, the green changes to the yellow TLP. This means opening the LFM for the acquisition of local flexibilities. At the LFM, active grid users also known as prosumer, can offer their flexibility, for instance starting a charging process or interrupting it. In case the acquired flexibility is not sufficient, the change to the red phase takes place. The DSO controls the grid operation in order to solve the occurring problem.

B. Specification of the Traffic Light Phases

In the description of the classic BDEW TLPs, the changes of the phases are not clear defined. Due to the high interest in the BDEW traffic light concept, the BDEW published a concretisation of the TLPs [5]. In the concretisation it was described that in the green phase, DSO can also carry out measures. In addition, limits were formulated to indicate the transitions between the TLPs. The technical criteria are shown in Table 1.

TABLE 1. Limits for the TLP change

	Green Phase	Yellow Phase	Red Phase
Voltage (V_n)	± 8 %	-10 % to -8 % +8 % to +10 %	< -10 % > +10 %
Current (I_{max})	0 % to 80 %	80 % to 100 %	> 100 %

The criteria formulated in Table 1 are a proposal from BDEW and are based on EN 50160 [5]. However, it is not only technical restrictions for the change from the yellow to the red phase that should be taken into account. The red phase should be the last stage where all other options were used and do not lead to a solution. Accordingly, the red phase only occurs if the LFM does not find a solution. There are two reasons for this, either the flexibility offered is not sufficient to solve the problem or the costs for the optimized solution are too high. The switch from the green to the yellow phase can also not only be determined by technical limit values. Similar to the change of the red phase, all options in the green phase must be used for the yellow phase. The DSO has several options in the green phase. For instance, the DSO can use switching measures, change control stages at the transformer station and the use of single strand controller or reactive power control. In Fig. 1 the change between the TLPs is shown.

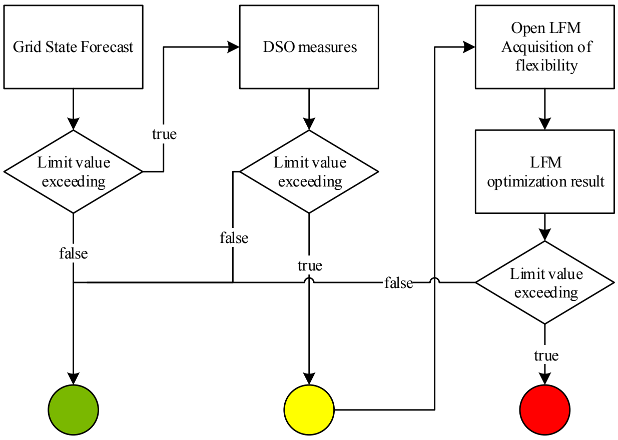

Figure 1. Determination of the TLPs

It should also be mentioned that the DSO is responsible for setting the limit values and can determine them according to its preferences.

III. REACTIVE POWER CONTROL IN LOW VOLTAGE GRIDS

A. Guidelines for Reactive Power Control

In high voltage grids, RPC is an established method for voltage control. Due to the rising share of renewable energies, guidelines for the use of reactive power are also defined for low-voltage grids. Since 2012, Germany had guidelines for the reactive power supply in low voltage grids [6]. The guidelines describe the minimum requirements to be applied to newly installed power plants, especially the cos φ settings are controlled there. The cos φ settings are dependent on the installed power (S_{Emax}) and the type of the power plant. A differentiation is made between type 1 and type 2 power plants. In this publication only type 2 power plants are used, so that their guidelines are described. The cos φ settings described in the guidelines are shown in Table 2. The curves shown must be followed if the feed-in exceeds 0.2 P_{Emax}.

TABLE 2. Type 2 power plants cos φ settings [6]

	$\Sigma S_{Emax} \leq 4.6$ kVA	$\Sigma S_{Emax} > 4.6$ kVA
cos φ settings	$0{,}95_{underexcited}$ to $0{,}95_{overexcited}$	$0{,}9_{underexcited}$ to $0{,}9_{overexcited}$
Type of reactive power control	1. cos φ(P) – curve 2. fixed cos φ	1. Q(V) - curve 2. cos φ(P) - curve 3. fixed cos φ

In addition to the guidelines for power plants, there are also guidelines for charging stations. The guidelines currently only include DC charging stations with the remark that the guidelines should also be extended to AC charging stations [7]. The cos φ settings for DC charging stations with an installed power of S > 12 kVA are identical to the settings described in Table 2 for power plants with S_{Emax} > 4.6 kVA. The guidelines for AC charging stations will be based on the existing ones. In the case of AC charging stations, 11 kW stations will probably also be included in the regulation, due to the reason that 11 kW and 22 kW charging stations will form the standard in the private sector.

B. Voltage Stability with Reactive Power

The guidelines for reactive power control provide the basis for the use of these by the DSO. The DSO is allowed to determine the type of regulation for the respective plants. The cos φ settings have different effects on the grid [8].

The fixed cos φ leads to a permanent reactive power supply into the gird. As a result, the voltage increase due to power plant supply is reduced. However, the reactive power supply induces further stress on assets even if the voltage is within the valid operating range. The effect is similar for charging stations. The fixed cos φ is used to reduce the voltage reduction.

Besides the fixed cos φ setting there are dynamic controls as well. The DSO has the option to define cos φ (P) curves. Such a curve is shown in Fig. 2.

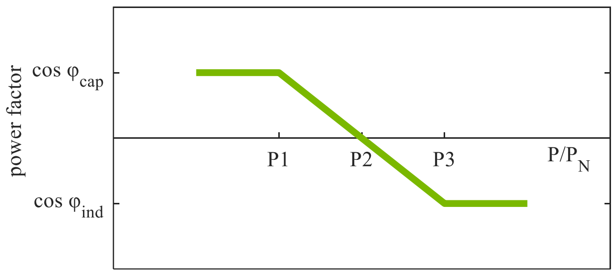

Figure 2. exemplary cos φ(P) curve in the passive sign convention [8]

The reactive power supply is proportional to the feed-in of power plants in the area between P1 and P3. In the range between P1 and P2 there is a capacitive reactive power supply and in the range between P2 and P3 an inductive reactive power supply. P1, P2 and P3 depend on the maximum feed-in of the power plant P_N. So the influence of reactive power on the voltage is also adjusted to the feed-in. According to this control strategy, a high power feed-in will result in exceeding the upper voltage limit. In some grid situations this assumption is correct, but it leads to additional stress due to reactive power even in the cases of no exceeding.

Accordingly, the cos φ(P) control reacts only partially to the grid situation.

For power plants with an installed capacity over 4.6 kVA, the DSO also has the option to determine a Q(V) curve. A general Q(V) curve is shown in Fig. 3.

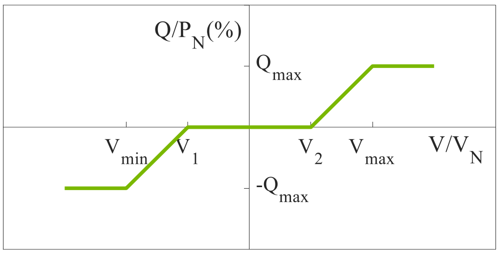

Figure 3. exemplary *Q(V) curve in the passive sign convention [6], [8]*

The Q(V) curve has three different control areas. Between the lower voltage limit V_{min} and V1 the capacitive reactive power decreases proportional. In the second area, the dead band between V1 and V2, no reactive power is supplied. In the last are between V2 and the upper voltage limit V_{max}, the inductive reactive power supply rises. The areas are dependent on the rated voltage V_N. The maximum reactive power Q_{max} is dependent on the determined cos φ. For instance, with a cos φ of 0.9, Q_{max} is around 48 % of the maximum power feed-in P_N. With the Q(V) curve, a more selective control of the reactive power and therefore also of the voltage is achieved. Therefore, this method will be used in the further work of the paper.

IV. SIMULATION OF REACTIVE POWER CONTROL IN RURAL AND URBAN GRIDS

A. Structure of the Simulation

The acceptance and purchase of electrical vehicles will benefit from the possibility to charge at home [9]. Especially detached houses are suitable for the own charging station. Own roof tops are also ideal for the construction of photovoltaic plants. A variety of detached houses can be found in suburban and rural areas. As a result of this combination, a medium-sized urban and rural German low voltage grid is considered in the simulation. The essential characteristics of both simulation grids are shown in Table 3.

TABLE 3. Essential characteristics of the rural and urban simulation grid

	Rural Grid	Urban Grid
Nodes	97	277
cable length	5.66 km	5.25 km
Transformer Size	800 kVA	800 kVA
Number of strands	3	4

The ratio of the number of nodes to the cable length reflects the significant differences between the grids. The urban grid is characterised by many short cable sections and the rural grid by a few long cable sections. The connected flexible loads, photovoltaic systems and households in the simulation grids are based on the reference year 2035. The flexibilities of both grids are shown in Tables 4 and 5.

TABLE 4. Overview of connected flexibilities in the rural grid

	Quantity	Peak Power in kV
Photovoltaic	28	4 to 40
Heat Pump	17	15
Charging Station	15	11 to 22
Household	54	8

TABLE 5. Overview of connected flexibilities in the urban grid

	Quantity	Peak Power in kV
Photovoltaic	28	7 to 30
Heat Pump	24	15
Charging Station	24	11 to 22
Household	59	8

The time series simulation is made with a typical winter, spring, summer and autumn week. They represent seasonal variations and are therefore representative for one year. The time series are normalized and defined for each flexibility. The simulation is made with 15-Minute time steps An extract of the time series for one day is illustrated in Fig. 4.

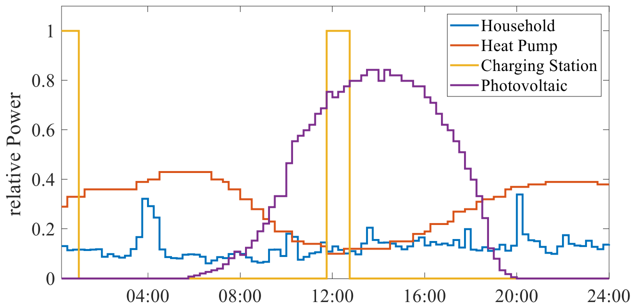

Figure 4. Exemplary day of the time series used for the simulation

A total of 11 different time series have been specified for the flexibilities. The time series for the charging stations were generated synthetically. The time series for the photovoltaic systems, heat pumps and households are based on real measurements.

For the simulation, a market liquidity of 27 % is assumed in the rural grid and 21 % in the urban grid. Fixed price corridors are specified for the offers at the LFM. The offers consist of 2 price components, a fixed and a variable component [10]. A range between 1 € and 10 € is defined for the fixed component and between 12 ct/kWh and 30 ct/kWh for the variable component.

The voltage limits in the simulation are set between 92 % and 108 % and the limit for the thermal limit current is set to 95 %. The cos φ settings in the simulation are based on the guidelines in Table 2 with a Q(V) curve. The voltage values are set as follows:

- V_{min} = 93 %
- V_1 = 97 %
- V_2 = 103 %

- V_{max} = 107 %

The voltage control by the adjustable transformer is based on the voltage of the most critical grid node. The voltage control range of the transformer is ± 3 % with control steps of 1.5 %.

B. Simulation Results

In order to reduce the costs for LFM, it is appropriate to include DSO measures for the decision on market openings, as already shown in Fig 1. Hence, the influence of the DSO measures on the resulting costs must be investigated. For the resulting limit value violations, offers are submitted at the LFM within the resulting price range. The optimal combination of the offers is selected from the sum of the offers with the help of an ac optimal power flow in order to avoid the predicted problem [10]. As a basis for comparison, the simulation is initially made without VNB measures. Then the VNB measures will be integrated successively. First the photovoltaic RPC (PV RPC), then combined with the charging station RPC (CS RPC) and finally the voltage control of the transformer (TVC) with the RPC is considered.

In the simulation three different types of limit value violations are taken into account. A difference is made between pure cable overloads, lower and upper voltage band violations. Violations of the lower and upper voltage bands may also include cable overloads. Overall, there are more limit violations in the rural network due to longer cable sections. Fig. 5 shows an overview of the limit violations.

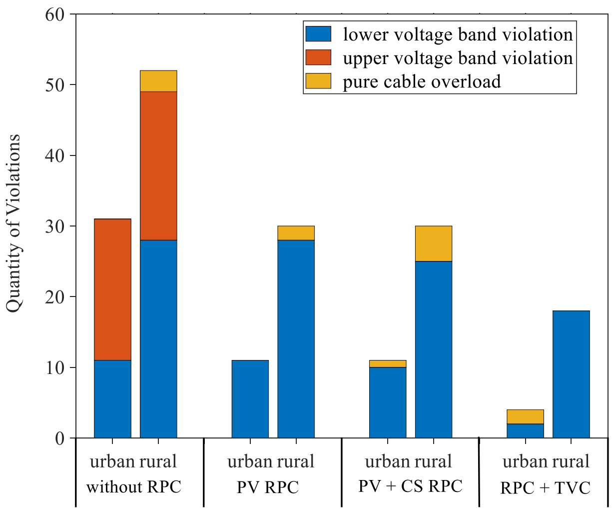

Figure 5. Limit violations in the simulation

A maximum of 2 % of the time steps in the simulation exceed the limit values. The lower voltage limit violations and the pure cable overloads occur due to a low feed-in and a high load in both grids. The upper voltage band violations can all be avoided by the PV RPC. With the further use of CS RPC, a few lower voltage band violations can be avoided as well. Due to the combination of cable overloads and voltage band violations, the number of pure cable overloads increases with the use of PV and CS RPC. The combination of RPC and TVC reduces the overall number of violations significantly. The use of RPC has reduced the total LFM openings by 42 % for the rural grid and 55 % for the urban grid. The combination of RPC and TVC reduces the number of violations by 60 % for the rural grid and 87 % for the urban grid.

The reduction of limit violations also reduces the costs caused by the LFM for the DSO. In Fig. 6 the cost trend based on the control measures is shown.

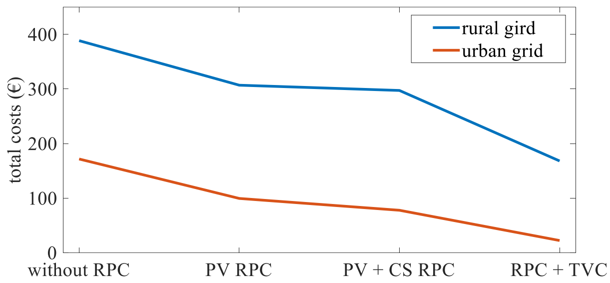

Figure 6. Cost trend based on the various control measures

The cost reduction with PV RPC and the combination of RPC and TVC is obviously due to the reduction of overall violations. The cost reduction between the PV RPC and the combined PV and CS RPC of 21 % in the rural grid and 22 % in the urban grid cannot be linked to it. In this case, the problem to be solved is minimized due to the control measures. On the one hand, this has an effect on the costs and, on the other hand, the probability that an upcoming problem is solved by the LFM is higher. The overall cost saving potential of RPC is 23 % in the rural low voltage grid and 55 % in the suburban grid. With the additional use of TVC the overall costs could be reduced by 57 % for the rural grid and 87 % for the urban grid. In the simulation of both grids two problems could not be solved by the LFM, which would lead to the red TLP. With the use of RPC one red phase in the rural grid could be avoided and with the combination of RPC and TVC no red phase occurred any longer.

V. CONCLUSION AND OUTLOOK

In addition to technical requirements [5], the specifications of the BDEW traffic light concept also includes possibilities for the DSO especially in the green phase. A clear description of the phase change and the individual TLPs is made. The updated German guidelines for new installed power plants and charging points support the use of reactive power by the DSO. The DSO has several opportunities for an effective use of RPC. The effects on the LFM openings and thus also on the costs were investigated in this paper.

The simulation of a rural and suburban German low voltage grids illustrates the effectiveness of RPC for the reduction of voltage problems due to a high feed-in or load. The results in both grids has shown that the use of RPC with photovoltaic systems is very valuable for the reduction of the voltage increase. With RPC all upper voltage band violations were avoided, so that with a well-coordinated control scheme significantly more renewable power plants can be integrated into the grid. Such a statement cannot be made for RPC with charging stations. RPC with charging stations has a positive effect on the grid but LFM openings could not be avoided. However, the problems were successfully solved at lower costs. When using RPC, it is important to note that the cable load is not taken into account in all control methods, which can result in cable overloads. For the further integration of charging stations, the additional use of active voltage control by e.g. a transformer seems useful in the integration. The majority of all occurring limit violations in the simulation could be avoided with the combination of RPC and TVC.

In conclusion, it should be noted that the specific design of the TLPs and the possibilities in the individual phases increase the attractiveness of LFM for the DSO. With a sensible use of DSO measures in the green phase, most occurring limit violations can be avoided. For the other violations, the LFM provides a good solution instead of possibly unnecessary additional grid enhancement. How the effects of the DSO measures on the LFM openings in other grid structures will be, has to be further investigated in order to make more general statements about their potential.

ACKNOWLEDGMENT

The research for this paper was sponsored by the German Federal Ministry for Economic Affairs and Energy – Project Flex2Market (03ET4043A) – The authors take responsibility for the published results.

Federal Ministry
for Economic Affairs
and Energy

REFERENCES

[1] T. Kornrumpf, J. Meese, N. Neusel-Lange and M. Roch, “Economic dispatch of flexibility options for Grid services on distribution level,” in *Power Systems Computation Conference*, Genoa, 2016.

[2] B. Biegel, P. Andersen, J. Stoustrup, K. S. Rasmussen, L. H. Hansen, S. Østberg, P. Cajar and H. Knudsen, “The value of flexibility in the distribution grid,” in *IEEE PES Innovative Smart Grid Technologies*, Istanbul, 2014.

[3] BDEW – German Association of Energy and Water Industries, “https://www.bdew.de,” 10 März 2015. [Online]. Available: https://www.bdew.de/media/documents/Stn_20150310_Smart-Grids-Traffic-Light-Concept_english.pdf. [Accessed 07 Januar 2019].

[4] S. Pack, K. Kotthaus, J. Hermanns, F. Paulat, J. Meese, M. Zdrallek and T. Braje, “Integration of smart grid control strategies in the green phase of the distribution grid traffic light concept,” in *NEIS 2018*, Hamburg, 2018.

[5] BDEW - German Association of Energy and Water Industries, “Konkretisierung des Ampelkonzepts im Verteilungsnetz,” Berlin, 2017.

[6] VDE - Verband der Elektrotechnik Elektronik Informationstechnik e.V., *VDE-AR-N 4105 Generators connected to the low-voltage distribution network - Technical requirements for the connection to and parallel operation with low-voltage distribution network,* VDE-Verlag, 2018.

[7] VDE - Verband der Elektrotechnik Elektronik Informationstechnik e.V., *VDE-AR-N 4100 Technical rules for the connection and operation of customer installations to the lox voltage network (TAR low voltage),* VDE-Verlag, 2019.

[8] E. Demirok, P. Casado González, K. H. B. Frederiksen, D. Sera, P. Rodriguez and R. Teodorescu, “Local Reactive Power Control Methods for Overvoltage Prevention of Distributed Solar Inverters in Low-Voltage Grids,” *IEEE Journal of Photovoltaics,* pp. 174-182, October 2011.

[9] F. Liao, E. Molin and B. van Wee, “Consumer preferences for electric vehicles: a literature review,” *Transport Reviews,* pp. 252-275, 27 August 2016.

[10] K. Kotthaus, J. Hermanns , F. Paulat, S. Pack, J. Meese, M. Zdrallek, N. Neusel-Lange, T. Braje, F. Schweiger and R. Schweiger , “Concrete design of local flexibility markets using the traffic light approach,” in *Cired Workshop 2018*, Ljubljana, 2018.