OPTIMISATION OF HV/MV-TRANSFORMER-VOLTAGE-CONTROL IN DISTRIBUTION NETWORKS WITH A HIGH PROPORTION OF DISTRIBUTED GENERATION

Manfred WERNER, Fabian GRUNDL
LEV Verteilnetz GmbH, Augsburg – Germany
manfred.werner@lew.de

Michael FINKEL, Michael WIEST
University of Applied Sciences Augsburg - Germany
michael.finkel@hs-augsburg.de

ABSTRACT

The power supply from many small decentralised power generation plants (DPG) is increasingly influencing the voltage quality in the distribution networks. The further expansion of the decentralized energy plants is expected to lead to a worsening of the situation. The need to further expand the German distribution network, a need forecast by the BDEW (the German Energy and Water Authority) has given rise to the necessity to look for fast, cheaper and innovative solutions to reduce the negative effects on the power supply of the power generation plants on the MV and LV network levels. Within the framework of a pilot project carried out by the LEW Verteilnetz GmbH, it was examined whether the maintenance of the voltage level in the MV network could be improved with the help of an optimised voltage regulator of the HV/MV transformer, at the same time remaining in the stipulated limits. The LEW Verteilnetz GmbH (LVN) is a regional network operator in Bavaria and a subsidiary of Lechwerke AG based in Augsburg. The network area of Lechwerke includes Bavarian-Swabia as well as parts of Upper Bavaria.

INTRODUCTION

The high rate of connections of photovoltaic and biogas plants in the south of Germany is posing more and more problems for the local distribution grid operator with regard to maintaining the voltage in MV and LV networks. Also at LVN, the feedback capacity in many network areas is considerably higher than consumption. Figure 1 shows the power generation connection trends in the LEW Verteilnetz GmbH network area since the introduction of the EEG (Renewable Energy Sources Act) in the year 2000.

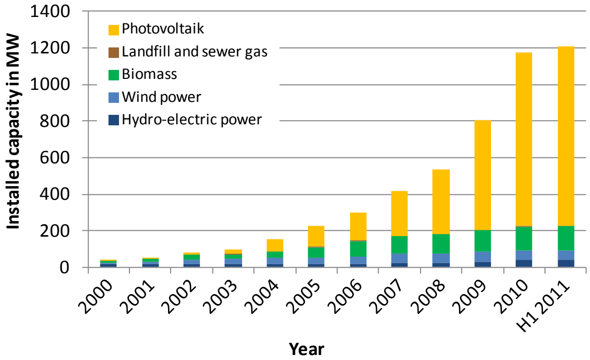

Figure 1. Development of the installed total output of all renewable energy plants in the LVN distribution network.

Above all, there are increasingly more serious voltage increases on sunny Sundays and bank holidays on the MV and LV network levels in rural network areas. However, the thermal stress limits of the operating equipment are seldom reached. As a rule, this problematic situation is counteracted by extensive network expansion and reinforcement measures. According to a study carried out by the BDEW [1], the network expansion requirements in Germany on the MV and LV network level, depending on the scenario in question, lie between 195,000 km and 380,000 km. This expansion will cost approximately 10 to 27 billion Euros up to the year 2020.

A further short-term, feasible and cheap possibility to solve the difficulties with voltage maintenance in the networks, is to optimise the voltage regulators of the HV and MV transformers. The regulation should adapt the voltage level of the MV network levels to the current load flow situation in the network area in order to compensate for the negative effects on the power supply caused by consumers and producers in the MV and LV network.

INITIAL SITUATION AND RESULTING OPTIMISATION APPROACH

In the last few years the distribution networks and hence also the MV network were used purely for the transport of electrical energy to the customer. By applying pure load to the cables and transformers, the task was to compensate for the voltage drop along a cable with the help of a voltage regulator in HV/MV transformers and to keep to the voltage limitations at the customers’ network connection point. In accordance with the voltage drops which occurred in the MV network, the voltage control units were mostly adjusted to a voltage control base set point of between 101 % and 103 % of the nominal voltage. On the basis of this value it sometimes resulted in an additional load-dependent control of secondary voltage in the transformer (electrical compounding).

As a result of the new challenge to now compensate for the voltage increases in the MV network, an optimisation of the control characteristics was to be examined. In order to do this, the entire permitted voltage range according to DIN EN 50160 [2] of ±10 % was divided up. After taking away the control deviation of ±1 % [3] and the static voltage change of 4.5 % in the LV network, only 4.5 % of the nominal value remains for the MV network level. Thus network hubs in the MV networks are critical if they reach a voltage of more than 104.5 % or if the voltage goes below less than 95.5 % of the nominal voltage.

POCEDURE

In order to develop new control concepts, taking into account the stipulated voltage range, a section of the MV network was chosen which was exemplary for the LEW distribution network (Table 1, Figure 2). The criteria for this procedure were, amongst other things, a high density of existing DPG and a network distribution area with both an urban and rural network structure (short cable outlets and long power transmission lines) and network segments which were already known to have voltage problems or where problems were expected to occur.

Table 1. Network data for the pilot network area.

Characteristics		
MS-network	Total number of network stations	249
	Cable length	181,7 km
	Percentage of overhead lines	39%
	Percentage of cables	61%
Loads	Installed capacity	26,5 MW
	Maximum measured load	15,4 MW
	Maximum measured reverse power	-30,4 MW
DPG	Installed capacity	47,8 MW
	Percentage of photovoltaic plants	84 %
	Percentage of biomass/biogas	11 %

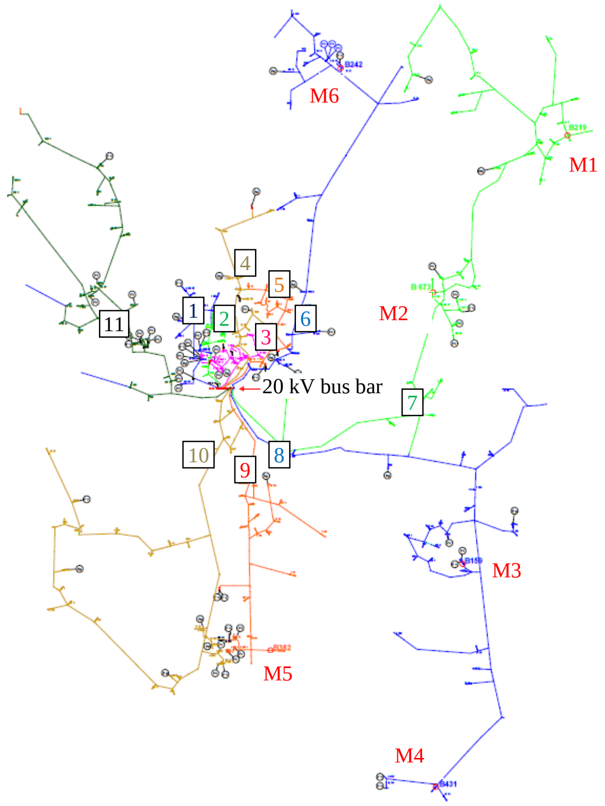

Figure 2. Pilot-network of LVN. In boxes: number of line; M1 to M6: measuring points.

In order to localise the critical intersections, the load flow calculations were carried out for the entire area using PSS®SINCAL. Both worst-case scenarios were implemented – minimal production and maximal load or maximum production and minimal load – in accordance with [4] and thus the critical intersections were localised. Observations with maximum load or maximum supply at the intersections have the advantage that also the places in the network are shown that to some extent could enter the critical voltage areas if a further DPG connection were made or if they had more consumers in the future.

In the calculations a constant voltage of 20 kV was taken as a basis set point on the bus bar. As a result of the simulation, two intersections were discovered at which the voltage limitation of ±4.5 % for MV was exceeded. After determining the theoretical level of the critical network intersections, measurements were taken at a total of six cable outlets in order to verify the results. Figure 3 shows the effect of a high reverse power flow and a voltage regulator (adjusted according to the old criteria) on the network voltage at a 20/0,4 kV network station (Figure 2, M4) at the end of a 14.4 km long transmission line. The bus bar voltage of 20.63 kV is to be attributed to the setting used up to now on the voltage regulator.

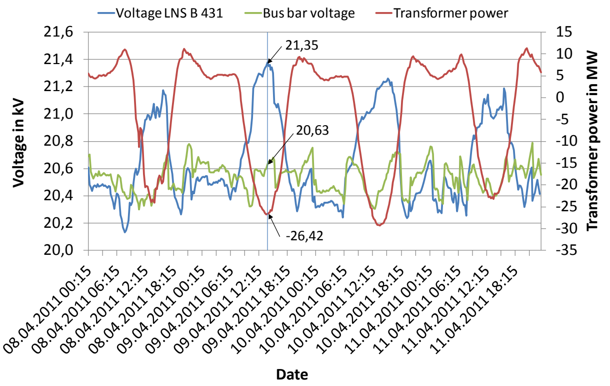

Figure 3. Recorded voltage at the end of a long overhead line (LNS B 431), voltage at the bus bar of the substation and transformer power

At the local 20/0,4 kV network station (LNS) a voltage of 21.35 kV was measured at this time with active power of -26.42 MW in the distribution transformer in the 110/20 kV substation. With regard to the bus bar voltage, this meant an increase in voltage from the bus bar to the local network station of 3.5 %. In comparison to the nominal voltage of 20.0 kV an increase of almost 6.8 % is recorded at the local network station, which minus the voltage tolerance of (±4.5 %) is 2.3 % too high for the MV network. The voltage level at the intersection therefore lies at a critical level.

If the voltage readings V_{MIN} (Table 2) are observed at times where energy is taken from the transformer station, it can be observed that at no point in time do they go below the nominal voltage of 20 kV and thus the negative part (-4.5 %) of the allowed voltage range is not used. However, at five of the six local network stations the allowed voltage limits were exceeded.

In Table 3 the measured maximum and minimum voltage was measured at the same time on the bus bar (V_{BB}). Thus the percentage values indicate the voltage drop and voltage increase on the cables. None of the measurements exceed the ±4.5 % mark. Thus, it can be concluded that through suitable adjustment of the voltage on the bus bar, the voltage at the local network stations can once again be brought down to a safe level.

Table 2. Results of the voltage measurements in the network area.

Line/Mea-suring point	7 M1	7 M2	8 M3	8 M4	9 M5	6 M6
V_{MAX} in kV	21,26	21,12	21,24	21,53	21,10	20,84
V_{MIN} in kV	20,12	20,15	20,22	20,13	20,33	20,16

Table 3. Maximum measured voltage changes at six measuring points in the network area.

Line/Mea-suring point	7 M1	7 M2	8 M3	8 M4	9 M5	6 M6
V_{MAX}/V_{BB} in %	103,2	102,5	104,0	104,1	101,9	101,7
V_{MIN}/V_{BB} in %	98,6	98,8	99,1	98,7	99,9	98,8

NEW INTERPRETATION OF THE SET POINT ADJUSTMENT

A cheap and quick possibility to optimise the voltage regulator used in the pilot network is to redesign the V_f/I_L-curve. After the adjustment, the characteristic curve should not only increase the voltage after the energy is tapped but also, by reversing the load flow, it should decrease the voltage accordingly on the bus bar. Figure 4 serves to illustrate the underlying intention. Here the blue area represents the initial situation of the voltage curve, whereby the green area shows the voltage level, adjusted in relation to the network situation.

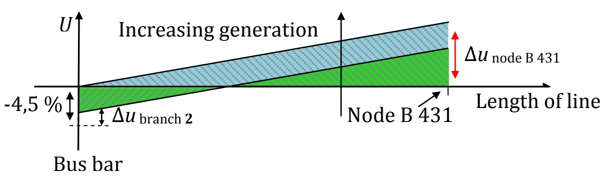

Figure 4. Load flow dependent changes to the set-point curve on the HV/MV-transformer.

Several factors have to be taken into account when configuring a voltage curve suitable for a distribution network. After identifying the critical intersections in the distribution network, the effects of different ratios of the HV/MV transformer on the network voltage could be determined by using a simulated on-load tap-changer in a network calculation program. Both of the load flow scenarios which were set up and simulated beforehand in the pilot network area were the starting point for determining the settings for the new voltage regulators. Taking the ±4.5 %-voltage limitations into account in the LVN MV network, the different levels of the on-load tap-changer could be changed in the calculation program until the desired voltage levels were reached at the critical network intersections.

It has to be taken into consideration that one cannot count on there being a reverse load flow at the same time in all the transmission lines in the distribution network. According to the capacity readings taken, especially the short cable outlets in urban areas with low DPG supply, never reach a level where energy can be fed back into the system. For voltage regulation this means that, owing to the inhomogeneous load flow directions in the distribution network, the voltage on the bus bar can only be decreased when there is a high supply to the extent that the voltage in the lines with low supply does not fall under the voltage limitations. Based on these criteria, this resulted in a lower voltage limit of 19.20 kV (96.0 %) on the bus bar in the transformer substation.

The upper voltage limit on the bus bar was determined in a similar way. For the scenario with a high load and only a low supply, a maximum upper voltage limit on the bus bar of 20.92 kV (104.6 %) was reached. Furthermore, the control deviation or rather the measurement accuracy of the inverters built into the transformer substations should be taken into consideration when determining the voltage limits.

In the course of the numerous distribution network calculations, the basis nominal value for the voltage regulator of 20.2 kV (101 %) proved to be optimal for the distribution network. The steepness of the curve results, essentially, from the maximum loads of the capacity power transformer. In 2010 and 2011 a maximum reverse power flow into the 110-kV-network of almost 31 MW and a maximum supply into the 20-kV-network of 16 MW were measured. In order to reach the established voltage limits on the bus bar a gradient of 5 % was chosen for theses maximum readings. The limits of the voltage regulator were set at values of 98 % and 103 %. The resulting new voltage control set point for the voltage regulator in the pilot network is illustrated in Figure 5.

The curve shown is intentionally put close to the limit of what is technically possible or rather to the permitted voltage range for the MV network, in order to be able to examine further the potential of the existing voltage control unit with the nominal values adapted for the pilot network.

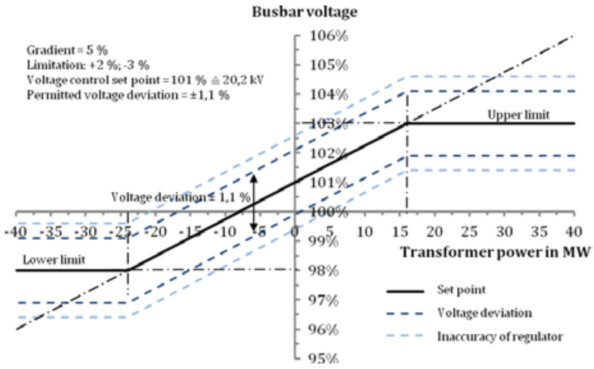

Figure 5. New set point curve of the voltage regulator in the substation with electricity compounding.

TECHNICAL AND ECONOMIC EVALUATION OF RESULTS

As proof of the theoretically calculated capacity of the voltage regulator used in the pilot network area, the new characteristic curve was transferred to the control unit. The changes made to the voltage regulator could be seen clearly in the voltage and power data on the bus bar recorded by the control system (Figure 6). The voltage curve on the bus bar which was adapted to the power flow situation in the network and at the transformer can be clearly seen. The black dotted line marks the day on which the change was made to the control unit in the transformer substation.

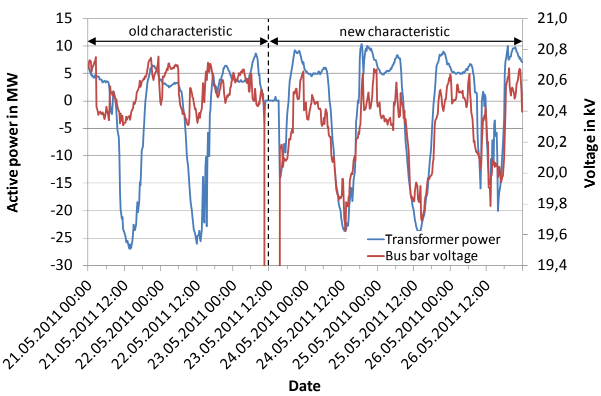

Figure 6. $P(t)$ und $V(t)$ diagram before and after the adjustment to the new V_f/I_L-set point curve in the transformer substation.

Repeated measurements taken at the critical intersections in the distribution network reflect the results of the simulation. On Sunday 19 June, for example, the adjustment to the set point value curve led to a 3.2 % reduction in voltage at the local network station M4 (Figure 2). At this point in time almost 23 MW were fed back from the transformer into the substation. This result confirms the assertion that through suitable adjustment to the voltage on the bus bar, the voltage at the local network station can be brought down to a safe level.

The analysis of the switching operations of the on-load tap-changer resulted in the average number of tap changes per day being increased from six to seven.

Thus it could be proven that the feedback effect of the decentralised production plants installed in the distribution network could be compensated for, to a great extent, through the optimisation of the set-point value curve of the existing voltage regulator, without having to make any compromises with regard to the lifetime of the operating equipment and without having to increase the existing MV network capacity immediately.

The deployment of the examined possibility to optimise the HV/MV voltage regulator cannot replace the network expansion required by the renewable energy laws in the long term, however, it offers this possibility in the short term and with comparably little effort it can guarantee that the permitted voltage range in the MV/LV distribution network is observed.

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